HINSHI–H9003

TNE

YANMAR

APPLICATION MANUAL

INDUSTRIAL DIESEL ENGINE

MODEL TNE series

Certificate No. FM23056

Certificate No. JQA-0099

ISO 9001 Certified

July, 1997

YANMAR DIESEL ENGINE CO.,LTD.

FOREWORD

This manual describes various data required for selecting the appropriate model from Yanmar TNE series industrial engines for optimum matching with the driven machine, taking the following points into consideration:

① *Features of the TNE engine*

② *Performance of the engine and driven machine*

③ *Customer satisfaction in using the engine*

When planning engine installation on the driven machine, please read this manual carefully to ensure proper installation and matching with the driven machine.

Certificate No. FM23056

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ISO 9001 Certified

This products has been developed, designed and manufactured in a plant certified by the JMI, BSI and EQNET to conform to tne quality assurance system standard provided as ISO 9001 (Internationa Standard for Quality Assurance).

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1. TNE Engine Application Standard

The engine operating environment and driven machine conditions must be studied carefully when selecting an engine in order to make the most of the engine performance, extend the service life and improve the machine capacity.

This manual describes the items that must be considered when selecting an engine and determining the specifications to ensure that the engine is not used beyond its capacity.

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1-1 Application Standard

No.	Item	Application standard				Remarks
1	Engine type	Special swirl combustion chamber system engines (IDI engines)	Engines with cylinder bore of 74 mm or less			TNE series
		Direct injection system engines (DI engines)	Engines with cylinder bore of 78 mm or more			
2	Output/rpm	Output/rpm		See section 2-1 in Chapter 2.		Output table
		Output setting conditions	Ambient temperature	298 K (25℃)		Same as in JIS and ISO
			Atmospheric pressure	100 kPa (750 mmHg)		
			Relative humidity	30%		
		Output power correction		See section 4-1 in Chapter 4.		
3	Special operating environment	Actions against sand dust		See section 1-2 in Chapter 1.		
		Actions for outdoor installation				
		Actions against sea air and snow melting agents				
		Actions against cold environment				
		Actions against hot environment				
4	Fuel oil	Fuel oil	Ambient temperature K(℃)	Classification		See section 10-2 in Chapter 10 for the fuel specifications in each country.
		Diesel fuel	≧268 (−5)	Equivalent to JIS Grade 2		
			268 to 253 (−5 to −20)	Equivalent to JIS Grade 3		
			253 to 243 (−20 to −30)	JIS special Grade 3		
		Kerosene	Not allowed			
		Heavy oil	Not allowed			
5	Lubricating oil	See section 11-2 in Chapter 11.				The initial replacement of the lubricating oil and lubricating oil filter shall be done at 50 hours of service.
		Lubricating oil class	Lubricating oil temperature K (℃)	Lubricating oil replacement interval (hr)	Lubricating oil filter replacement interval (hr)	
		Class CC	≦388 (115)	Every 200	Every 400	
			≦393 (120)	Every 150		
		Class CD	≦388 (115)	Every 300		
			≦393 (120)	Every 200		
		Allowable lubricating oil temperature		≦393K (120℃)	See Chapter 9	At the specified maximum ambient temperature.
6	Cooling water	Allowable cooling water temperature at engine outlet		≦378K (105℃)		
		Water quality		Soft water		See section 9-2 in Chapter 9.
		Antifreeze mixing ratio %		Atmospheric temperature K (℃)		See section 9-3 in Chapter 9.
		30		273 to 258 (0 to −15)		
		40		258 to 248 (−15 to −25)		
		50		248 to 233 (−25 to −40)		
7	Power take-off (PTO)	See Chapter 14				
8	Low-temperature startability	See section 1-3 in Chapter 1				
9	Allowable inclination angle	Continuous operation		Longitudinal/lateral	≦25° / ≦25°	See section 11-6 in Chapter 11.
		Instantaneous operation (within 3 minutes)		Longitudinal/lateral	≦30° / ≦30°	
10	Allowable exhaust back pressure	See section 1-4 in Chapter 1.				
11	Allowable depression at engine manifold					

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1-2 Special Operating Environment

The engine performance depends greatly on the operating and environmental conditions. Please consult with Yanmar when unusual operating conditions exist.

(1) Actions against sand dust

Condition	Part	Countermeasure
Wear due to sand dust or liner wear due to entry of sand dust	Air cleaner	The following measures and cleaning are necessary to prevent dust from invading the engine: • Adoption of double element (safety element) • Adoption of evacuator valve • Adoption of dust indicator
	Alternator	Dust-proof type may be required for preventing entry of dust.
	Starting motor	
	Breather air reservoir	Since dust invades from the breather pipe while the engine is stopped, an air reservoir may be installed at the end of the breather pipe.
	Cooling fan	To improve the wear resistance, a fan made of nylon 6 (reinforced with glass fiber) or steel may be required.
	V pulley	To improve the wear resistance, a hardened V-pulley may be required.
	V-belt	To counteract belt wear, a large type V-belt may be required.
	Radiator	Changing the core type and fin material may be required. Heat balance check after the modification is required.

(2) Actions for outdoor installation

Condition	Part	Countermeasure
Rain, snow, etc.	Rain cap (for both intake and exhaust)	Entry of rainwater must be prevented.
	Electrical parts	Since electrical parts correspond to level R2(*) in JIS D 0203, either install them at places not splashed with water or provide covers.
Place for installation	———	Flat, well-ventilated place

(*) Level R2: A water spraying test level for checking the performance of the portion subject to indirect exposure to rainwater or splashing water.

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(3) Actions against sea breeze and snow melting agent

Condition	Part	Countermeasure
Place exposed to salty sea air or snow melting agents	Electrical parts	Since rusting may occur, perform careful maintenance.
	Accelerator lever shaft	
	Stop lever shaft	
	Exhaust manifold set bolts	
	Stop lever return spring	
	Radiator	
Place where salt water may splash onto the engine directly	———	Not allowed

(4) Actions against cold environment

Environmental temperature	Part	Countermeasure	Remarks
243K (–30℃) or above	Battery	Specification must be changed.	See section 1-3 in Chapter 1 for the startability.
	Starting motor		
243K to 233K (–30℃ to –40℃)	Cooling water hose	Special rubber may be required to prevent rubber parts from being damaged by hardening.	
	Intake air hose		
	O-rings		
	Oil seal		
	Fuel hose		
	Fuel feed pump	A solenoid pump is to be adopted.	
	Starting aid	A block heater is to be adopted.	
233K (–40℃) or below		Not allowed	

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(5) Actions against hot environment

Environmental temperature	Part	Countermeasure
313K (40°C) or below	Electrical parts	The temperature inside the engine hood must be kept at 353K (80°C) or below to protect the electrical parts. The air around the electrical parts must not be stagnant.
313K (40°C) or above	Radiator	A large capacity radiator and fan must be adopted to prevent the cooling water and lubricating oil temperatures from rising excessively.
	Cooling fan	
	Oil cooler	Increase the capacity or install as the standard equipment.
	Electrical parts	The temperature inside the engine hood must be kept at 353K (80°C) or below to protect the electrical parts. The air around the electrical parts must not be stagnant.

(6) Others

Condition	Part	Countermeasure
Place where explosive, flammable or toxic gas exists	———	Not allowed

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1-3 Startability

The lowest temperature guaranteed for starting the engine of standard specifications is -15℃ without any load. This low-temperature startability when connected with the driven machine is greatly affected by the machine coupling method, moment of inertia of the driven machine and the capacity of the hydraulic equipment. Since the mounted devices vary with the manufacturer, the low-temperature startability of the engine loaded with the driven machine varies even when the purpose of the driven machine is the same.

The combination of the starting motor, battery and starting aid in each of the succeeding tables is a guideline. Check the engine startability under the actual machine installation state and required starting conditions with the machine manufacturer.

"O" standard in this section is different from the standard specification in estimating the F-F cost. It refers to be standard combination of various units required for satisfying the startability at each temperature shown in the table. In the standard combination, "Δ" option is also provided for the starting aid to enhance the starting performance.

(Remarks) F-F cost means the standard cost when equipped from the fan to the flywheel. Accessories such as the air cleaner, muffler and radiator are not included. Please contact Yanmar for further details.

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1-3-1 2TNE68

(1) Specification

○ : Standard △ : Option

Item / Model	2TNE68 (industrial-use, standard)					2TNE68 (with HO-P)					2TNE68 (direct coupling with oil pump) ○ Gear pump ◎ Variable pump				
Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter: 12V 0.9kW, 119226-77010, starting motor circuit 48A/12A	○	○				○	○								
Starter: 12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○					○				○ ◎	○		
Starter: 12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				○	○				○	○			◎		
Battery: 36B20 (NS40Z) 5-hour rate: 28Ah	○					○									
Battery: 46B24 (NS60) 5-hour rate: 36Ah		○					○					○			
Battery: 55B24 (NX100-S6) 5-hour rate: 36Ah			○	○	○			○				◎	○		
Battery: 80D26 (NX110-5) 5-hour rate: 55Ah									○	○			◎		
Starting Aid: Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○		○ ◎	○ ◎		
Starting Aid: Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△			△ △	△ △		
Block heater	None				○	None				○	None				
Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
Lubricating oil	10W-30			5W-20		10W-30			5W-20		10W-30			5W-20	

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1-3-2 3TNE68, 3TNE74

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	3TNE68 (industrial-use, standard)					3TNE74 (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A	○	○								
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A						○	○			
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○					○		
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				○	○				○	○
Battery	36B20 (NS40Z) 5-hour rate: 28Ah	○									
Battery	46B24 (NS60) 5-hour rate: 36Ah		○				○	○			
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah			○	○	○			○	○	
Battery	80D26 (NX110-5) 5-hour rate: 55Ah										○
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○
Starting Aid	Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△	
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

(2) Specification: With HO-P

○: Standard △: Option

	Item / Model	3TNE68 (With HO-P)					3TNE74 (With HO-P)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A	○	○								
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A						○				
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○				○			
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				○	○			○	○	○
Starter											
Battery	36B20 (NS40Z) 5-hour rate: 28Ah	○									
Battery	46B24 (NS60) 5-hour rate: 36Ah		○				○				
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah			○				○	○		
Battery	80D26 (NX110-5) 5-hour rate: 55Ah				○	○				○	○
Battery											
Battery											
Battery											
Battery											
Starting Aid											
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○
Starting Aid											
Starting Aid	Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△	
Starting Aid	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(3) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

△ Option

	Model		3TNE68 (○ Gear pump ◎ Variable pump)					3TNE74 (○ Gear pump ◎ Variable pump)				
	Destination		Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item	Temperature (°C)	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○ ◎	○				○			
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				◎				◎	○ ◎		
Battery	46B24 (NS60)	5-hour rate: 36Ah		○					○			
	55B24 (NX100-S6)	5-hour rate: 36Ah		◎	○				◎	○		
	80D26 (NX110-5)	5-hour rate: 55Ah			◎					◎		
Starting Aid												
	Glow plug operation: Regular glow plug, 15 to 20 sec.			○ ◎	○ ◎				○ ◎	○ ◎		
	Super quick glow plug, 3 sec.			△ △	△ △				△ △	△ △		
	Block heater		None					None				
	Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil		10W-30			5W-20		10W-30			5W-20	

1-3-3 2TNE68-N

(1) Specification

○ : Standard △ : Option

Item		Model	2TNE68-N (industrial-use, standard)					2TNE68-N (With HO-P)					2TNE68-N (direct coupling with oil pump) (○ Gear pump ◎ Variable pump)				
		Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
		Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A		○	○				○	○								
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A				○					○				○ ◎	○		
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A					○	○				○	○			◎		
Starter																	
Battery	36B20 (NS40Z)	5-hour rate: 28Ah	○					○									
Battery	46B24 (NS60)	5-hour rate: 36Ah		○					○					○			
Battery	55B24 (NX100-S6)	5-hour rate: 36Ah			○	○	○			○				◎	○		
Battery	80D26 (NX110-5)	5-hour rate: 55Ah									○	○			◎		
Battery																	
Battery																	
Battery																	
Battery																	
Starting Aid																	
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.		○	○	○	○	○	○	○	○	○	○		○ ◎	○ ◎		
Starting Aid																	
Starting Aid	Super quick glow plug, 3 sec.		△	△	△	△		△	△	△	△			△ △	△ △		
Block heater			None				○	None				○	None				
Fuel (diesel fuel)			Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
Lubricating oil			10W-30			5W-20		10W-30			5W-20		10W-30			5W-20	

1-3-4 3TNE66-N, 3TNE68-N

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	3TNE66-N (industrial-use, standard)					3TNE68-N (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A	○	○				○	○			
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A										
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○					○		
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				○	○				○	○
Starter											
Battery	36B20 (NS40Z) 5-hour rate: 28Ah	○					○				
Battery	46B24 (NS60) 5-hour rate: 36Ah		○					○			
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah			○	○	○			○	○	○
Battery	80D26 (NX110-5) 5-hour rate: 55Ah										
Battery											
Battery											
Battery											
Battery											
Starting Aid											
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○
Starting Aid											
Starting Aid	Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△	
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

(2) Specification: With HO-P

○: Standard △: Option

	Model	3TNE66-N (With HO-P)					3TNE68-N (With HO-P)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A	○	○				○	○			
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A										
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○					○		
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A				○	○				○	○
Starter											
Battery	36B20 (NS40Z) 5-hour rate: 28Ah	○					○				
Battery	46B24 (NS60) 5-hour rate: 36Ah		○					○			
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah			○					○		
Battery	80D26 (NX110-5) 5-hour rate: 55Ah				○	○				○	○
Battery											
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○
Starting Aid	Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△	
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

(3) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

△: Option

	Model	3TNE66-N (○ Gear pump ◎ Variable pump)					3TNE68-N (○ Gear pump ◎ Variable pump)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item / Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A		○ ◎	○				○ ◎	○		
Starter	12V 1.4kW, 119608-77010, starting motor circuit 53A/17A			◎					◎		
Starter											
Starter											
Starter											
Battery	46B24 (NS60) 5-hour rate: 36Ah		○					○			
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah		◎	○				◎	○		
Battery	80D26 (NX110-5) 5-hour rate: 55Ah			◎					◎		
Battery											
Battery											
Battery											
Battery											
Battery											
Starting Aid											
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.		○ ◎	○ ◎				○ ◎	○ ◎		
Starting Aid											
Starting Aid	Super quick glow plug, 3 sec.		△ △	△ △				△ △	△ △		
	Block heater	None					None				
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

1-3-5 3TNE72-N, 3TNE74-N

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Item \ Model		3TNE72-N (industrial-use, standard)					3TNE74-N (industrial-use, standard)				
	Destination		Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Temperature (°C)		≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A											
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A		○	○				○	○			
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A				○					○		
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A					○	○				○	○
Battery	36B20 (NS40Z)	5-hour rate: 28Ah										
Battery	46B24 (NS60)	5-hour rate: 36Ah	○	○				○	○			
Battery	55B24 (NX100-S6)	5-hour rate: 36Ah			○	○				○	○	
Battery	80D26 (NX110-5)	5-hour rate: 55Ah					○					○
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.		○	○	○	○	○	○	○	○	○	○
Starting Aid	Super quick glow plug, 3 sec.		△	△	△	△		△	△	△	△	
	Block heater		None				○	None				○
	Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil		10W-30			5W-20		10W-30			5W-20	

(2) Specification: With HO-P

○: Standard △: Option

	Model	3TNE72-N (With HO-P)					3TNE74-N (With HO-P)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 0.9kW, 119226-77010, starting motor circuit 48A/12A										
Starter	12V 0.9kW, 119631-77011, starting motor circuit 48A/12A	○					○				
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A		○					○			
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A			○	○	○			○	○	○
Starter											
Battery	36B20 (NS40Z) 5-hour rate: 28Ah										
Battery	46B24 (NS60) 5-hour rate: 36Ah	○					○				
Battery	55B24 (NX100-S6) 5-hour rate: 36Ah		○	○				○	○		
Battery	80D26 (NX110-5) 5-hour rate: 55Ah				○	○				○	○
Battery											
Battery											
Battery											
Battery											
Starting Aid											
Starting Aid	Glow plug operation: Regular glow plug, 15 to 20 sec.	○	○	○	○	○	○	○	○	○	○
Starting Aid											
Starting Aid	Super quick glow plug, 3 sec.	△	△	△	△		△	△	△	△	
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(3) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

△: Option

Item		Model	3TNE72-N (○ Gear pump ◎ Variable pump)					3TNE74-N (○ Gear pump ◎ Variable pump)				
		Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
		Temperature (°C)	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30
Starter	12V 1.0kW, 119255-77010, starting motor circuit 40A/12A			○					○			
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A			◎	○◎				◎	○◎		
Battery	46B24 (NS60)	5-hour rate: 36Ah										
	55B24 (NX100-S6)	5-hour rate: 36Ah		○	○				○	○		
	80D26 (NX110-5)	5-hour rate: 55Ah		◎	◎				◎	◎		
Starting Aid												
	Glow plug operation: Regular glow plug, 15 to 20 sec.			○◎	○◎				○◎	○◎		
	Super quick glow plug, 3 sec.			△△	△△				△△	△△		
	Block heater		None					None				
	Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil		10W-30			5W-20		10W-30			5W-20	

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1-3-6 3TNE78A, 3TNE82A

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	3TNE78A (industrial-use, standard)					3TNE82A (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item / Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.0kW, 124520-77012, starting motor circuit 40A/12A	○					○				
	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A		○	○	○			○	○	○	
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A					○					○
Battery	55D26 (N50Z) 5-hour rate: 48Ah	○									
	65D26 (NS70) 5-hour rate: 52Ah		○	○			○				
	80D26 (NX110-5) 5-hour rate: 55Ah				○			○	○		
	95D31 (NX120-7) 5-hour rate: 64Ah					○				○	
											○
Starting Aid	No air heater operation	○					○				
	Air heater operation: 400 W × 15 sec.		○	○				○	○		
	400 W × 30 sec.				○	○				○	○
	800 W × 30 sec.				△	△				△	△
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(2) Specification: With HO-P

○: Standard △: Option

	Model		3TNE78A (With HO-P)					3TNE82A (With HO-P)				
	Destination		Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.0kW, 124520-77012, starting motor circuit 40A/12A		○					○				
	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A			○	○	○			○	○	○	
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A						○					○
Battery	55D26 (N50Z)	5-hour rate: 48Ah	○					○				
	65D26 (NS70)	5-hour rate: 52Ah		○					○			
	80D26 (NX110-5)	5-hour rate: 55Ah			○	○				○	○	
	95D31 (NX120-7)	5-hour rate: 64Ah					○					○
Starting Aid	No air heater operation		○					○				
	Air heater operation: 400 W × 15 sec.			○					○			
	400 W × 30 sec.				○	○	○			○	○	○
	800 W × 30 sec.					△	△				△	△
	Block heater		None				○	None				○
	Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil		10W-30			5W-20		10W-30			5W-20	

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(3) **Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)**

	Item \ Model		3TNE78A (○ Gear pump ◎ Variable pump)					3TNE82A (○ Gear pump ◎ Variable pump)				
		Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item	Temperature (°C)	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A											
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A			○	○				○	○		
	12V 2.0kW, 129400-77012, starting motor circuit 66A/20A			◎	◎				◎	◎		
Battery	65D26 (NS70)	5-hour rate: 52Ah		○					○			
	80D26 (NX110-5)	5-hour rate: 55Ah		◎	○				◎	○		
	95D31 (NX120-7)	5-hour rate: 64Ah			◎					◎		
Starting Aid												
	Air heater operation: 400 W × 15 sec.			○ ◎					○ ◎			
	400 W × 30 sec.				○ ◎					○ ◎		
	Block heater		None					None				
	Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil		10W-30			5W-20		10W-30			5W-20	

1-3-7 3TNE84(T), 3TNE88

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	3TNE84(T) (industrial-use, standard)					3TNE88 (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item		≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30
Starter	12V 1.0kW, 124520-77012, starting motor circuit 40A/12A	○					○				
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A		○	○	○			○	○	○	
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A					○					○
Starter											
Starter											
Battery	65D26 (NS70) 5-hour rate: 52Ah	○					○				
Battery	75D31 (N70Z) 5-hour rate: 60Ah		○	○	○			○	○		
Battery	95D31 (NX120-7) 5-hour rate: 64Ah					○				○	○
Battery											
Battery											
Battery											
Battery											
Battery											
Starting Aid	No air heater operation	○					○				
Starting Aid	Air heater operation: 400 W × 15 sec.		○	○				○			
Starting Aid	400 W × 30 sec.				○	○			○	○	○
Starting Aid	800 W × 30 sec.				△	△				△	△
Block heater		None				○	None				○
Fuel (diesel fuel)		Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
Lubricating oil		10W-30			5W-20		10W-30			5W-20	

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(2) Specification: With HO-P

○: Standard △: Option

	Model	3TNE84(T) (With HO-P)					3TNE88 (With HO-P)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30	≧-5	-5 to -15	-15 to -20	-20 to -25	≦-30
Starter	12V 1.0kW, 124520-77012, starting motor circuit 40A/12A	○					○				
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A		○	○	○			○	○	○	
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A					○					○
Starter											
Starter											
Battery	75D31 (N70Z) 5-hour rate: 60Ah	○	○	○	○		○	○	○		
Battery	95D31 (NX120-7) 5-hour rate: 64Ah					○				○	○
Battery											
Battery											
Battery											
Battery											
Battery											
Battery											
Starting Aid	No air heater operation	○					○				
Starting Aid	Air heater operation: 400 W × 15 sec.		○					○			
Starting Aid	400 W × 30 sec.			○	○	○			○	○	○
Starting Aid	800 W × 30 sec.				△	△				△	△
Starting Aid	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(3) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

	Model	3TNE84T (○ Gear pump ◎ Variable pump)					3TNE88 (○ Gear pump ◎ Variable pump)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item / Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A										
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A		○					○			
	12V 2.0kW, 129400-77012, starting motor circuit 66A/20A		◎	○◎				◎	○◎		
Battery	75D31 (N70Z) 5-hour rate: 60Ah		○					○			
	95D31 (NX120-7) 5-hour rate: 64Ah		◎	○◎				◎	○◎		
Starting Aid	Air heater operation: 400 W × 15 sec.		○◎					○◎			
	400 W × 30 sec.			○◎					○◎		
	Block heater	None					None				
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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1-3-8 4TNE84(T), 4TNE88

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	4TNE84(T) (industrial-use, standard)					4TNE88 (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A	○					○				
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A		○	○	○			○	○	○	
	12V 2.0kW, 129400-77012, starting motor circuit 66A/20A					○					○
Battery	75D31 (N70Z) 5-hour rate: 60Ah	○					○				
	95D31 (NX120-7) 5-hour rate: 64Ah		○	○	○			○	○		
	130E41 (NX200-10) 5-hour rate: 92Ah					○				○	○
Starting Aid	No air heater operation	○					○				
	Air heater operation: 400 W × 15 sec.		○	○				○	○		
	400 W × 30 sec.				○	○				○	○
	800 W × 30 sec.				△	△				△	△
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(2) Specification: With HO-P

○: Standard △: Option

	Model	4TNE84(T) (With HO-P)					4TNE88 (With HO-P)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.2kW, 129698-77010, starting motor circuit 53A/17A	○					○				
	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A		○	○				○	○		
	12V 2.0kW, 129400-77012, starting motor circuit 66A/20A				○	○				○	○
Battery	75D31 (N70Z) 5-hour rate: 60Ah	○					○				
	95D31 (NX120-7) 5-hour rate: 64Ah		○	○				○			
	130E41 (NX200-10) 5-hour rate: 92Ah				○	○			○	○	○
Starting Aid	No air heater operation	○	○				○				
	Air heater operation: 400 W × 15 sec.			○				○			
	400 W × 30 sec.				○	○			○	○	○
	800 W × 30 sec.					△				△	△
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(3) Specification: With HO-P + secondary balancer

○: Standard △: Option

	Model	4TNE84(T) (With HO-P & balancer)					4TNE88 (With HO-P & balancer)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 1.4kW, 129608-77010, starting motor circuit 53A/17A	○	○				○	○			
	12V 2.0kW, 129400-77012, starting motor circuit 53A/17A			○	○				○	○	
	12V 2.3kW, 129136-77011, starting motor circuit 66A/20A					○					○
Battery	95D31 (NX120-7) 5-hour rate: 64Ah	○	○				○	○			
	130E41 (NX200-10) 5-hour rate: 92Ah			○	○	○			○	○	○
Starting Aid	No air heater operation	○					○				
	Air heater operation: 400 W × 15 sec.		○					○			
	400 W × 30 sec.			○	○	○			○	○	○
	800 W × 30 sec.				△	△				△	△
	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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(4) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

	Model	4TNE84(T) (○ Gear pump ◎ Variable pump)					4TNE88 (○ Gear pump ◎ Variable pump)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
	Item / Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 2.0kW, 129400-77012, starting motor circuit 66A/20A		○ ◎	○				○ ◎	○		
Starter	12V 2.3kW, 129136-77011, starting motor circuit 75A/20A			◎					◎		
Starter											
Starter											
Starter											
Battery	95D31 (NX120-7) 5-hour rate: 64Ah		○	○				○	○		
Battery	130E41 (NX200-10) 5-hour rate: 92Ah		◎	◎				◎	◎		
Battery											
Battery											
Battery											
Battery											
Battery											
Battery											
Starting Aid											
Starting Aid	Air heater operation: 400 W × 15 sec.		○ ◎					○ ◎			
Starting Aid	400 W × 30 sec.			○ ◎					○ ◎		
Starting Aid											
	Block heater	None					None				
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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1-3-9 4TNE94, 4TNE98

(1) Specification: Industrial-use, standard

○: Standard △: Option

	Model	4TNE94 (industrial-use, standard)					4TNE98 (industrial-use, standard)				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	12V 2.3kW, 129900-77010, starting motor circuit 65A/20A	○	○	○	○	○	○	○	○	○	○
Battery	95D31 (NX120-7) 5-hour rate: 64Ah	○	○				○	○			
Battery	130E41 (NX200-10) 5-hour rate: 92Ah			○	○	○			○	○	○
Starting Aid	No air heater operation	○					○				
Starting Aid	Air heater operation: 500 W × 15 sec.		○	○				○	○		
Starting Aid	500 W × 30 sec.				○	○				○	○
Starting Aid	1000 W × 30 sec.				△	△				△	△
Starting Aid	Block heater	None				○	None				○
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

(2) Specification: Direct coupling with oil pump (○ Gear pump ◎ Variable pump)

○: Standard △: Option

	Model	4TNE94					4TNE98				
	Destination	Standard			Cold region	Extremely cold region	Standard			Cold region	Extremely cold region
Item	Temperature (°C)	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30	≧−5	−5 to −15	−15 to −20	−20 to −25	≦−30
Starter	24V 3.5kW, 119131-77010 starting motor circuit 19A/19A	○	○	○	○	○	○	○	○	○	○
Battery	95D31 (NX120-7) × 2 5-hour rate: 64Ah	○	○				○	○			
Battery	130E41 (NX200-10) × 2 5-hour rate: 92Ah			○	○	○			○	○	○
Starting Aid	No air heater operation	○					○				
Starting Aid	Air heater operation: 1200 W × 15 sec.		○	○				○	○		
Starting Aid	1200 W × 30 sec.				○	○				○	○
Starting Aid											○
	Block heater	None				○	None				
	Fuel (diesel fuel)	Grade 2	Grade 3		Special grade 3		Grade 2	Grade 3		Special grade 3	
	Lubricating oil	10W-30			5W-20		10W-30			5W-20	

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1-4 Allowable Depression at Engine Manifold and Exhaust Back Pressures

In the intake and exhaust systems, resistances to intake air flow and exhaust gas flow are generated. The limits shown in the tables below must be observed to assure the engine performance.

The initial upper limit here refer to allowable resistances when the parts in the intake and exhaust systems are new. As the engine is used, the resistances increase due to deposits in the air cleaner and muffler. The upper limits for air cleaner replacement and exhaust system cleaning (including the exhaust tube and muffler) are the limit values for operation.

1-4-1 Allowable depression at engine manifold

Applicable model	Allowable depression at engine manifold ≦ kPa (mmAq)	
	Initial upper limit	Upper limit for air cleaner replacement
All TNE series	2.45 (250)	6.23 (635)

1-4-2 Allowable exhaust back pressure

Applicable model	Allowable exhaust back pressure ≦ kPa (mmAq)	
	Initial upper limit	Upper limit for exhaust system cleaning
2TNE68-N 2TNE68	5.88 (600)	7.06 (720)
3TNE66-N 3TNE68-N 3TNE68 3TNE72-N	9.81 (1000)	11.77 (1200)
3TNE74-N 3TNE74	11.77 (1200)	14.12 (1440)
3TNE78A 3TNE82A	9.81 (1000)	11.77 (1200)
3TNE84 3TNE88 4TNE84 4TNE88	6.37 (650)	7.65 (780)
3TNE84-T 4TNE84-T	4.90 (500)	5.88 (600)
4TNE94 4TNE98	9.81 (1000)	11.77 (1200)

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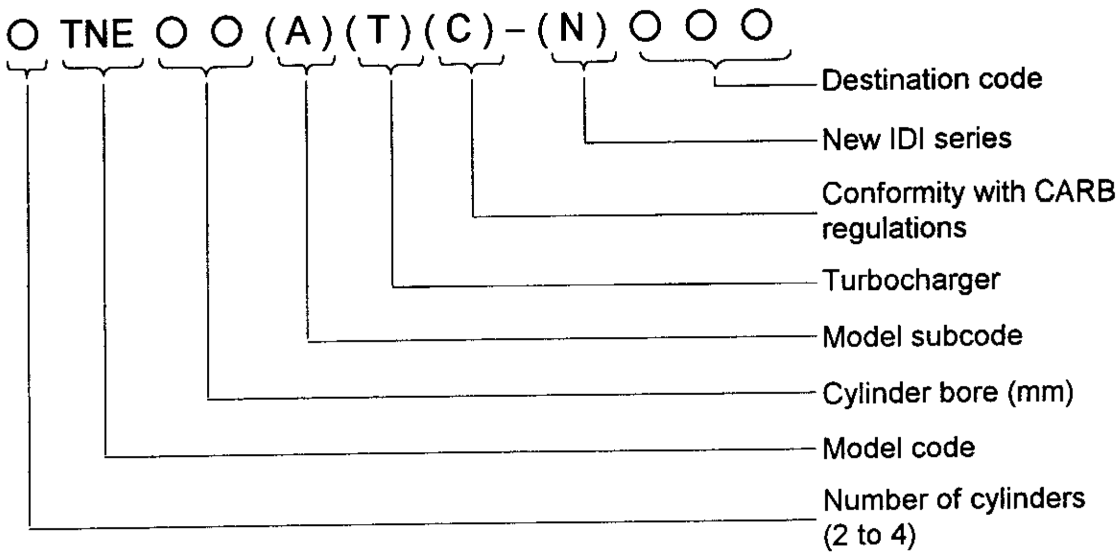
2. Engine Model Selection

2-1 Model Designation



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2-2 Applicable Driven Machine by Engine Classification

* *For the engine classification, see section 3-2 (Specifications) in Chapter 3.*

Classification code	Speed range	Applicable driven machines
CL (Constant, low speed)	1500 or 1800 rpm	Generators (4 poles) and water pumps
VM (Variable, medium speed)	2000 to 3000 rpm	Tractors, loaders, vibrating rollers, combines, carriers, backhoes, forklifts and other general working machines
CH (Constant, high speed)	3000 or 3600 rpm	Generators (2 poles), compressors, water pumps and welders
VH (Variable, high speed)	3000 to 3600 rpm	Compressors and lawn mowers

No.	Model	Classification				Combustion chamber type	
		CL	VM	CH	VH	Special swirl chamber	Direct injection
1	2TNE68	—	O	O	O	O	—
2	3TNE68	—	O	O	O	O	—
3	3TNE74	—	O	O	O	O	—
4	2TNE68-N	—	O	O	O	O	—
5	3TNE66-N	—	O	O	O	O	—
6	3TNE68-N	—	O	O	O	O	—
7	3TNE72-N	—	O	O	O	O	—
8	3TNE74-N	—	O	O	O	O	—
9	3TNE78A	O	O	O	O	—	O
10	3TNE82A	O	O	—	—	—	O
11	3TNE84	O	O	O	O	—	O
12	3TNE88	O	O	—	—	—	O
13	4TNE84	O	O	O	O	—	O
14	4TNE88	O	O	—	—	—	O
15	3TNE84T	O	O	O	O	—	O
16	4TNE84T	O	O	O	O	—	O
17	4TNE94	O	*O	—	—	—	O
18	4TNE98	O	*O	—	—	—	O

* Up to 2500 rpm

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2-3 Rated Output Table

Model			2TNE68	3TNE68	3TNE74			
Aspiration			Natural	Natural	Natural			
Number of cylinders – Bore × Stroke (mm × mm)			2–68 × 72	3–68 × 72	3–74 × 78			
Displacement (cc)			523	784	1006			
Revolution speed (rpm)			Output kW (hp)					
Industrial Use	Rated output	2000	5.7 (7.6)	8.6 (11.5)	11.0 (14.8)			
		2200	6.3 (8.4)	9.4 (12.6)	12.1 (16.2)			
		2400	6.8 (9.1)	10.3 (13.8)	13.2 (17.7)			
		2500	7.1 (9.5)	10.7 (14.3)	13.8 (18.5)			
		2600	7.4 (9.9)	11.2 (15.0)	14.3 (19.2)			
		2800	7.9 (10.6)	12.0 (16.1)	15.4 (20.7)			
		3000	8.5 (11.4)	12.9 (17.3)	16.5 (22.1)			
		3200	8.7 (11.7)	13.1 (17.6)	16.5 (22.1)			
		3400	9.2 (12.3)	13.8 (18.5)	17.1 (22.9)			
		3600	9.6 (12.9)	14.5 (19.4)	17.7 (23.7)			
Generator Use	Rated output	1500	—	—	—			
		1800	—	—	—			
		3000	8.5 (11.4)	12.9 (17.3)	16.5 (22.1)			
		3600	10.0 (13.4)	15.1 (20.2)	19.1 (25.6)			
	Cont. rating	1500	—	—	—			
		1800	—	—	—			
		3000	7.6 (10.2)	11.7 (15.7)	15.1 (20.2)			
		3600	9.0 (12.1)	13.7 (18.4)	17.4 (23.3)			

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Model			2TNE68-N	3TNE66-N	3TNE68-N	3TNE72-N	3TNE74-N	
Aspiration			Natural	Natural	Natural	Natural	Natural	
Number of cylinders – Bore × Stroke (mm × mm)			2–68 × 72	3–66 × 64.2	3–68 × 72	3–72 × 72	3–74 × 78	
Displacement (cc)			523	659	784	879	1006	
Revolution speed (rpm)			Output kW (hp)					
Industrial Use	Rated output	2000	5.7 (7.6)	6.9 (9.3)	8.6 (11.5)	9.3 (12.5)	11.0 (14.8)	
		2200	6.3 (8.4)	7.5 (10.1)	9.4 (12.6)	10.2 (13.7)	12.1 (16.2)	
		2400	6.8 (9.1)	8.2 (11.0)	10.3 (13.8)	11.2 (15.0)	13.2 (17.7)	
		2500	7.1 (9.5)	8.6 (11.5)	10.7 (14.3)	11.6 (15.6)	13.8 (18.5)	
		2600	7.4 (9.9)	9.0 (12.1)	11.2 (15.0)	12.1 (16.2)	14.3 (19.2)	
		2800	7.9 (10.6)	9.6 (12.9)	12.0 (16.1)	13.0 (17.4)	15.4 (20.7)	
		3000	8.5 (11.4)	10.5 (14.1)	12.9 (17.3)	14.0 (18.8)	16.5 (22.1)	
		3200	8.7 (11.7)	11.0 (14.8)	13.1 (17.6)	14.3 (19.2)	16.5 (22.1)	
		3400	9.2 (12.3)	11.5 (15.4)	13.8 (18.5)	14.9 (20.0)	17.1 (22.9)	
		3600	9.6 (12.9)	12.1 (16.2)	14.5 (19.4)	15.4 (20.7)	17.7 (23.7)	
Generator Use	Rated output	1500	—	—	—	—	—	
		1800	—	—	—	—	—	
		3000	8.5 (11.4)	10.5 (14.1)	12.9 (17.3)	14.0 (18.8)	16.5 (22.1)	
		3600	10.0 (13.4)	12.1 (16.2)	15.1 (20.2)	15.4 (20.7)	19.1 (25.6)	
	Cont. rating	1500	—	—	—	—	—	
		1800	—	—	—	—	—	
		3000	7.6 (10.2)	9.5 (12.7)	11.7 (15.7)	12.5 (16.8)	15.1 (20.2)	
		3600	9.0 (12.1)	11.0 (14.8)	13.7 (18.4)	14.0 (18.8)	17.4 (23.3)	

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Model			3TNE78A	3TNE82A	3TNE84	3TNE88	4TNE84	4TNE88
Aspiration			Natural	Natural	Natural	Natural	Natural	Natural
Number of cylinders – Bore × Stroke (mm × mm)			3–78 × 84	3–82 × 84	3–84 × 90	3–88 × 90	4–84 × 90	4–88 × 90
Displacement (cc)			1204	1331	1496	1642	1995	2190
Revolution speed (rpm)			Output kW (hp)					
Industrial Use	Rated output	2000	13.2 (17.7)	14.6 (19.5)	16.4 (22.0)	18.0 (24.1)	21.9 (29.4)	24.1 (32.3)
		2200	14.6 (19.6)	16.0 (21.5)	18.1 (24.3)	19.9 (26.7)	24.1 (32.3)	26.5 (35.5)
		2400	15.9 (21.3)	17.5 (23.5)	19.7 (26.4)	21.6 (29.0)	26.3 (35.3)	28.8 (38.6)
		2500	16.5 (22.1)	18.2 (24.4)	20.5 (27.5)	22.6 (30.3)	27.4 (36.7)	30.1 (40.4)
		2600	17.2 (23.1)	19.0 (25.5)	21.3 (28.6)	23.5 (31.5)	28.5 (38.2)	31.3 (42.0)
		2800	18.5 (24.8)	20.4 (27.4)	23.0 (30.8)	25.2 (33.8)	30.7 (41.2)	33.7 (45.2)
		3000	19.9 (26.7)	21.9 (29.4)	24.6 (33.0)	27.1 (36.3)	32.9 (44.1)	36.0 (48.3)
		3200	20.4 (27.4)	—	25.6 (34.3)	—	33.9 (45.5)	—
		3400	21.6 (29.0)	—	27.0 (36.2)	—	35.8 (48.0)	—
		3600	23.2 (31.1)	—	28.3 (38.0)	—	37.7 (50.6)	—
Generator Use	Rated output	1500	9.9 (13.3)	11.0 (14.8)	12.4 (16.6)	13.5 (18.1)	16.4 (22.0)	18.0 (24.1)
		1800	11.9 (16.0)	13.2 (17.7)	14.8 (19.8)	16.3 (21.9)	19.5 (26.1)	21.6 (29.0)
		3000	19.9 (26.7)	—	24.6 (33.0)	—	32.9 (44.1)	—
		3600	23.2 (31.1)	—	28.7 (38.5)	—	38.2 (51.2)	—
	Cont. rating	1500	9.0 (12.1)	9.9 (13.3)	11.3 (15.2)	12.3 (16.5)	14.9 (20.0)	16.4 (22.0)
		1800	10.8 (14.5)	12.0 (16.1)	13.5 (18.1)	14.8 (19.8)	17.7 (23.7)	19.6 (26.3)
		3000	18.0 (24.1)	—	22.4 (30.0)	—	29.9 (40.1)	—
		3600	21.0 (28.2)	—	26.1 (35.0)	—	34.7 (46.5)	—

Model			3TNE84T	4TNE84T	4TNE94	4TNE98		
Aspiration			Turbocharged	Turbocharged	Natural	Natural		
Number of cylinders – Bore × Stroke (mm × mm)			3–84 × 90	4–84 × 90	4–94 × 100	4–98 × 110		
Displacement (cc)			1496	1995	2776	3319		
Revolution speed (rpm)			Output kW (hp)					
Industrial Use	Rated output	2000	21.0 (28.2)	27.9 (37.4)	35.3 (47.3)	41.9 (56.2)		
		2200	22.8 (30.6)	30.5 (40.9)	38.2 (51.2)	45.6 (61.2)		
		2400	25.0 (33.5)	33.5 (44.9)	41.6 (55.8)	49.3 (66.1)		
		2500	25.7 (34.5)	34.2 (45.9)	43.0 (57.7)	51.1 (68.5)		
		2600	26.8 (35.9)	35.7 (47.9)	—	—		
		2800	29.1 (39.0)	38.6 (51.8)	—	—		
		3000	30.9 (41.4)	41.2 (55.3)	—	—		
		3200	32.0 (42.9)	*42.7 (57.3)	—	—		
		3400	33.1 (44.4)	*44.1 (59.1)	—	—		
		3600	34.2 (45.9)	*45.6 (61.2)	—	—		
Generator Use	Rated output	1500	15.8 (21.2)	21.3 (28.6)	29.1 (39.0)	34.6 (46.4)		
		1800	18.8 (25.2)	26.9 (36.1)	34.6 (46.4)	41.2 (55.3)		
		3000	30.9 (41.4)	41.2 (55.3)	—	—		
		3600	34.2 (45.9)	*45.6 (61.2)	—	—		
	Cont. rating	1500	14.0 (18.8)	19.1 (25.6)	26.1 (35.0)	30.9 (41.4)		
		1800	16.5 (22.1)	24.3 (32.6)	31.3 (42.0)	36.8 (49.3)		
		3000	27.9 (37.4)	37.1 (49.8)	—	—		
		3600	30.5 (40.9)	*40.8 (54.7)	—	—		

(Remarks) Please take contact with Yanmar beforehand for the output range marked *.

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3. Specifications

3-1 Atmospheric Conditions of Engine Output

The engine output varies with the surrounding conditions such as the atmospheric state and installed parts such as the cooling fan. The output representation and handling methods should also be selected according to the application of the driven machine.

These are called the conditions of engine output, and are set or defined as described below.

Out of the conditions of the TNE series engine output, the atmospheric conditions are as follows:

Atmospheric pressure	: 100 kPa (750 mmHg)
Atmospheric temperature	: 298K (25℃)
Relative humidity	: 30%

These are called standard atmospheric conditions, and are the same as those in the ISO. Standards such as the BS and SAE in other countries also conform to the ISO.
Refer to the table below for atmospheric conditions in other countries.

With regard to the engine equipment conditions, the output is indicated in the state of actual use of the engine. In other words, the output is defined in the state with the specified standard cooling fan and radiator, and the silencer and air cleaner satisfying the allowable exhaust back pressure and depression at engine manifold in Nos. 10 and 11 in 1-1, "Application Standard".
The output with full installation of these is called the net output".
The cooling fan described in section 3-2 and the pulley are standard specifications and various options are available separately. The output, however, should be individually determined depending on the combination.

The engine output is roughly classified into that for industrial use and that for generator use, and the handling method varies accordingly.

(1) Output for industrial use

The engine output for industrial use is called the rated output, which applies to the driven machine conforming to the VM or VH specifications in section 2-2 in Chapter 2. Most driven machines conforming to the VM or VH specifications use the maximum output requirement either intermittently or infrequently. The output applied in such a case is the rated output. Therefore, the engine should be selected or the driven machine size should be determined so that the maximum output requirement in the driven machine operation pattern will not exceed the rated engine output.

Some driven machines require the maximum output for a long period because of a fixed revolution range. In such a case, select an engine so that 90% of its rated output equals the continuous maximum output requirement of the driven machine.

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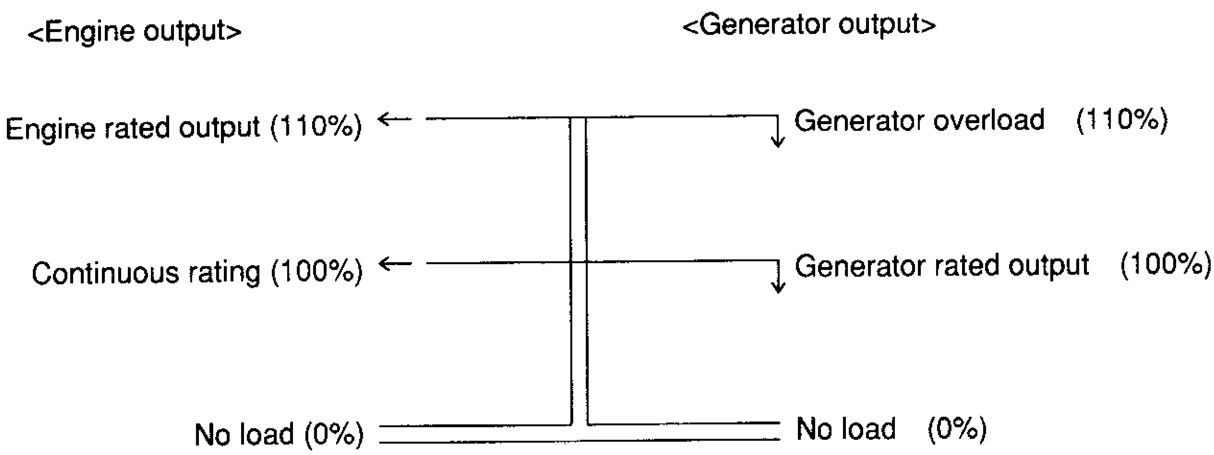
(2) Output for generator use

The output for generator use applies either to the case where the engine is used literally for driving a generator or to the case where the work equipment is driven in place of a motor. The output is classified into the rated output (1-hour rating) and continuous rating.

The generator capacity must be selected so that the engine output it requires (rated output of the generator) is equal to or less than the continuous rating of the engine. The rated output for generator use refers to that which allows 1 hour of operation at 110% of the continuous rating either continuously or intermittently out of 12 hours of continuous operation at the continuous rating of the engine. The corresponding capacity of the generator is called the overload. The generator capacity should be selected so that the overload is equal to or less than the 1 hour rating of the engine output.

These output relationships can be modeled as shown below:



Though the rated output is a term common to the engine and generator, the meaning is completely different. Take care when selecting the engine or determining the generator capacity.

Since this method for determining the generator capacity is for generators for industrial use, select the engine according to the respective standard and specifications in case of generators for disaster prevention or emergencies.

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[Reference: Comparison of atmospheric conditions between JIS and standards in other countries]

No.	Standard No.	Title	Year established	Atmospheric temperature	Atmospheric pressure	Relative humidity	Output type
1	JIS D 0006	Standard form of specifications and testing methods of diesel engines for construction machinery	1994				
2	JIS B 8018	Test Method of Performance of Small Size Diesel Engines for Land Use	1989			30%	
3	ISO 3046/1	Adjustment of net brake power	1986				
4	ISO 3046/2	Power correction method	1987				NET
5	ISO 1585	Road vehicles method (Net power)	1982	298K (25°C)	100 kPa (750 mmHg)		(Fully equipped)
6	ISO 2288	Agricultural tractors and machines	1979			No standard	
7	ISO 4106	Road vehicle, motorcycle	1978				
8	SAE J1349	Engine power test code spark Ignition and diesel	1985				
9	BS 5514 Part 1	Adjustment of net brake power	1987			30%	
10	BS 5514 Part 2	Power correction method	1987				
11	DIN 70020	Automotive engineering power	1984	293K (20°C)		No standard	

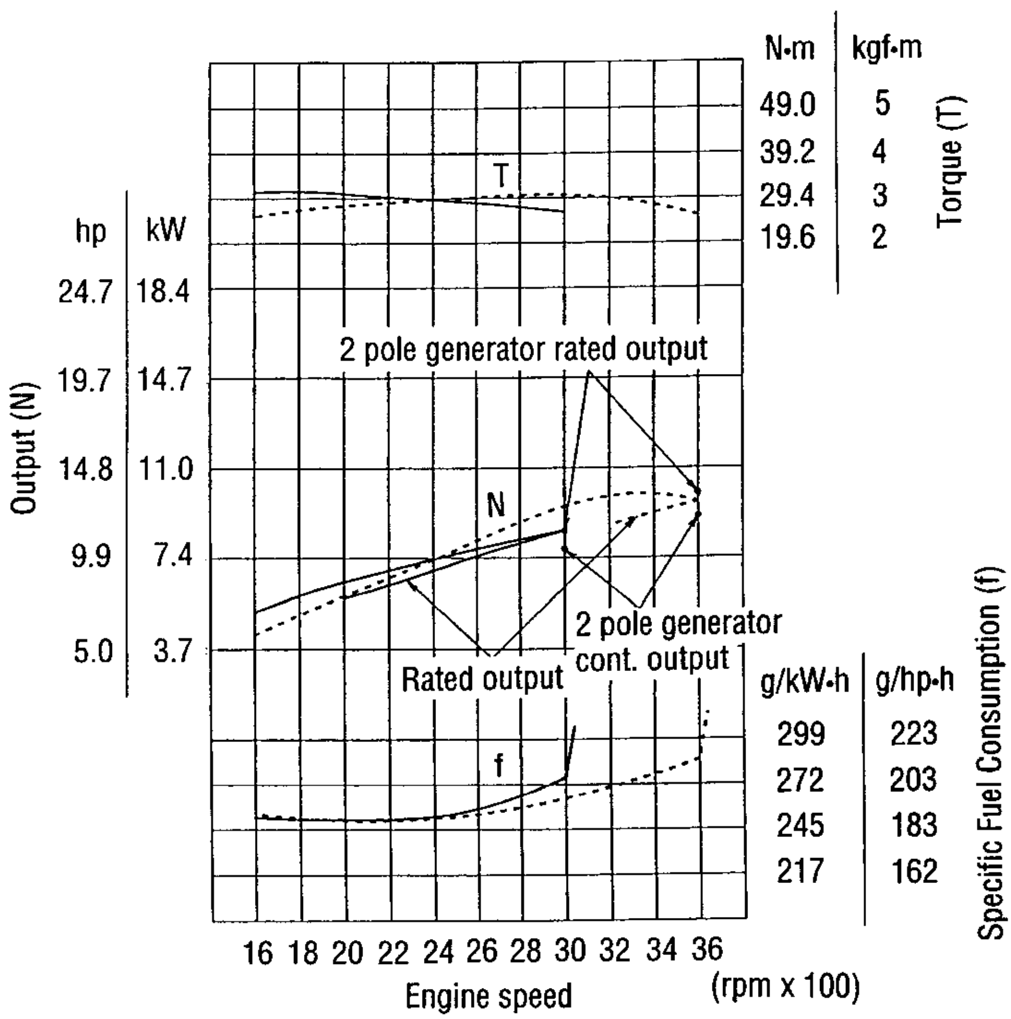
3-2 Specifications, Performance and Dimensions

1. 2TNE68

	Engine model			2TNE68													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders–Bore × Stroke		n–mm × mm	2 – 68 × 72													
4	Displacement		liter	0.523													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										7.6 (10.2)	9.0 (12.1)			
		Rated output	kW (hp)			5.7 (7.6)	6.3 (8.4)	6.8 (9.1)	7.1 (9.5)	7.4 (9.9)	7.9 (10.6)	8.5 (11.4)	8.5 (11.4)	10.0 (13.4)	8.7 (11.7)	9.2 (12.3)	9.6 (12.9)
6	Maximum idling speed		rpm ±50			2180	2375	2590	2685	2780	2995	3195	3175	3805	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)						≦279 (208)		≦299 (223)	≦279 (208)	≦286 (213)	≦292 (218)
8	Exhaust gas temp.		℃			≦480		≦490	≦495	≦500	≦510	≦530		≦580	≦550	≦560	≦580
9	Compression ratio		—	23.0													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 2 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			1.6							2.3				
		Useful	liter			1.0							1.3				
23	Cooling water capacity		liter	0.6													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ290 × 5 (ID mark: L)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ95 / ϕ85													

Note: This table is subject to change for performance improvement.

1. 2TNE68



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2. 3TNE68

No.	Item		Unit	3TNE68													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 68 × 72													
4	Displacement		liter	0.784													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										11.7 (15.7)	13.7 (18.4)			
		Rated output	kW (hp)			8.6 (11.5)	9.4 (12.6)	10.3 (13.8)	10.7 (14.3)	11.2 (15.0)	12.0 (16.1)	12.9 (17.3)	12.9 (17.3)	15.1 (20.2)	13.1 (17.6)	13.8 (18.5)	14.5 (19.4)
6	Maximum idling speed		rpm ±50			2180	2375	2570	2675	2780	2995	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)						≦279 (208)		≦299 (223)	≦279 (208)	≦286 (213)	≦292 (218)
8	Exhaust gas temp.		℃			≦480			≦515			≦540		≦590	≦490	≦540	≦590
9	Compression ratio		—	23.0													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			2.7							3.5				
		Useful	liter			1.2							1.5				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ95 / ϕ85													

Note: This table is subject to change for performance improvement.

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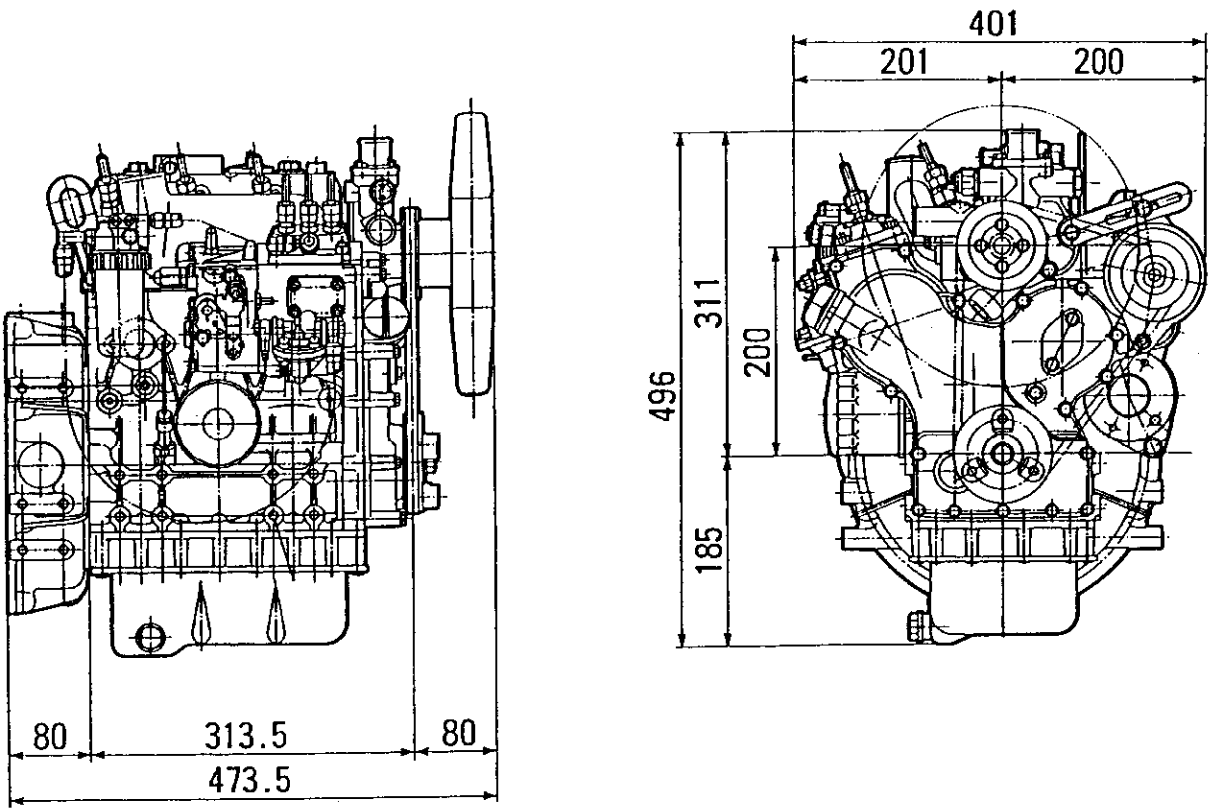
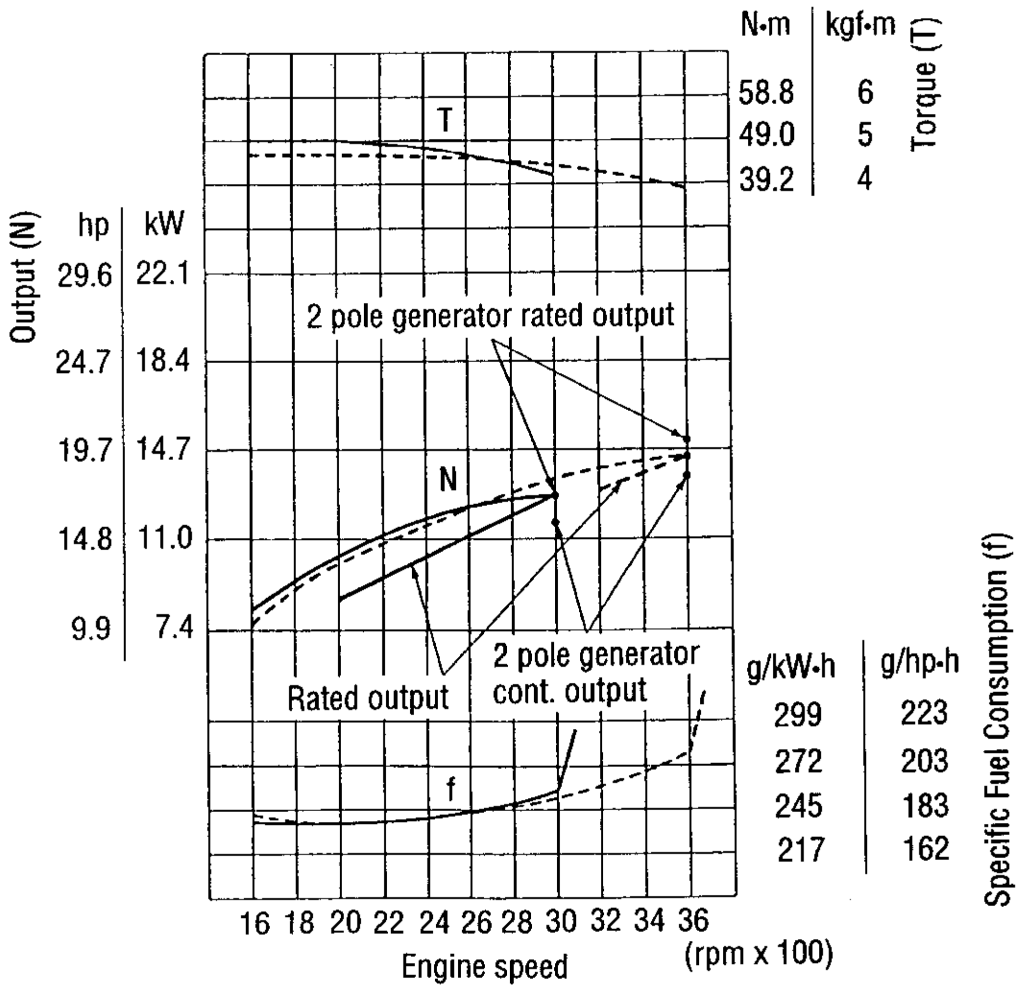
2. 3TNE68

(Unit: mm)





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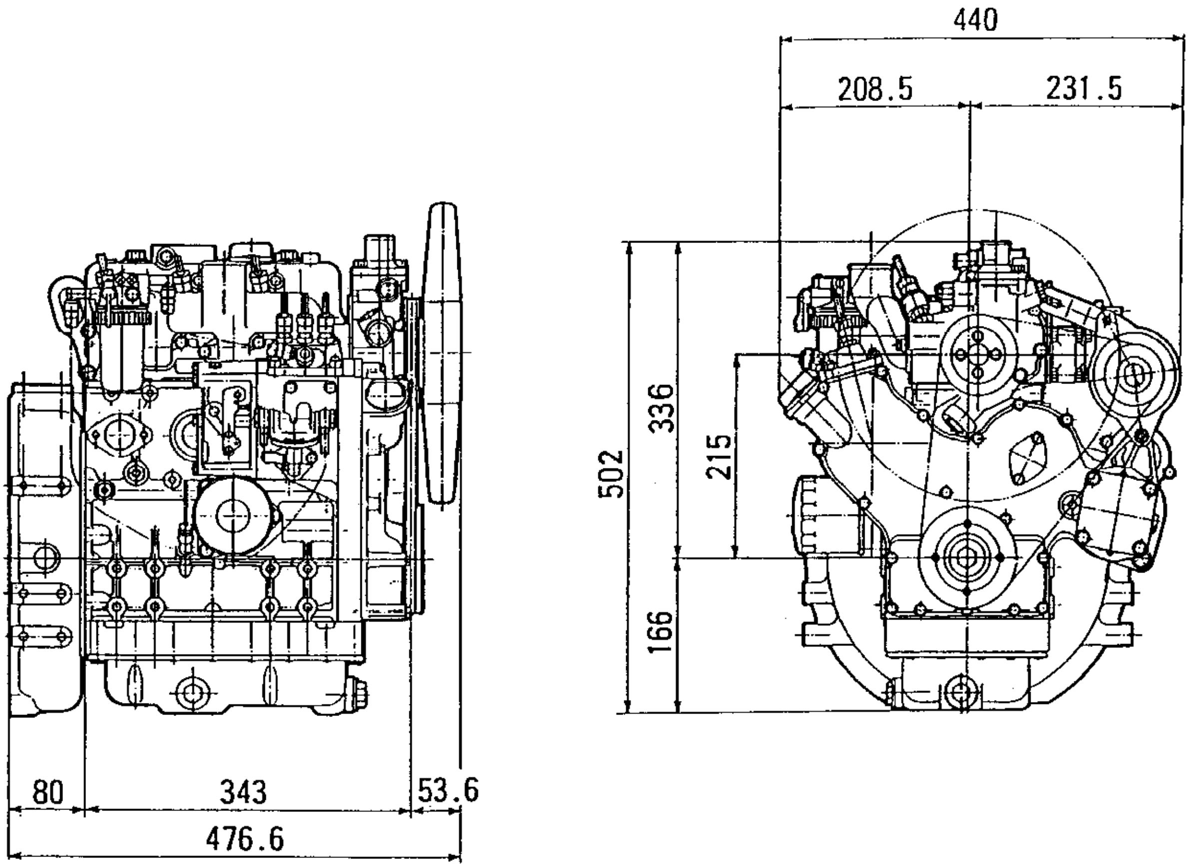
3. 3TNE74

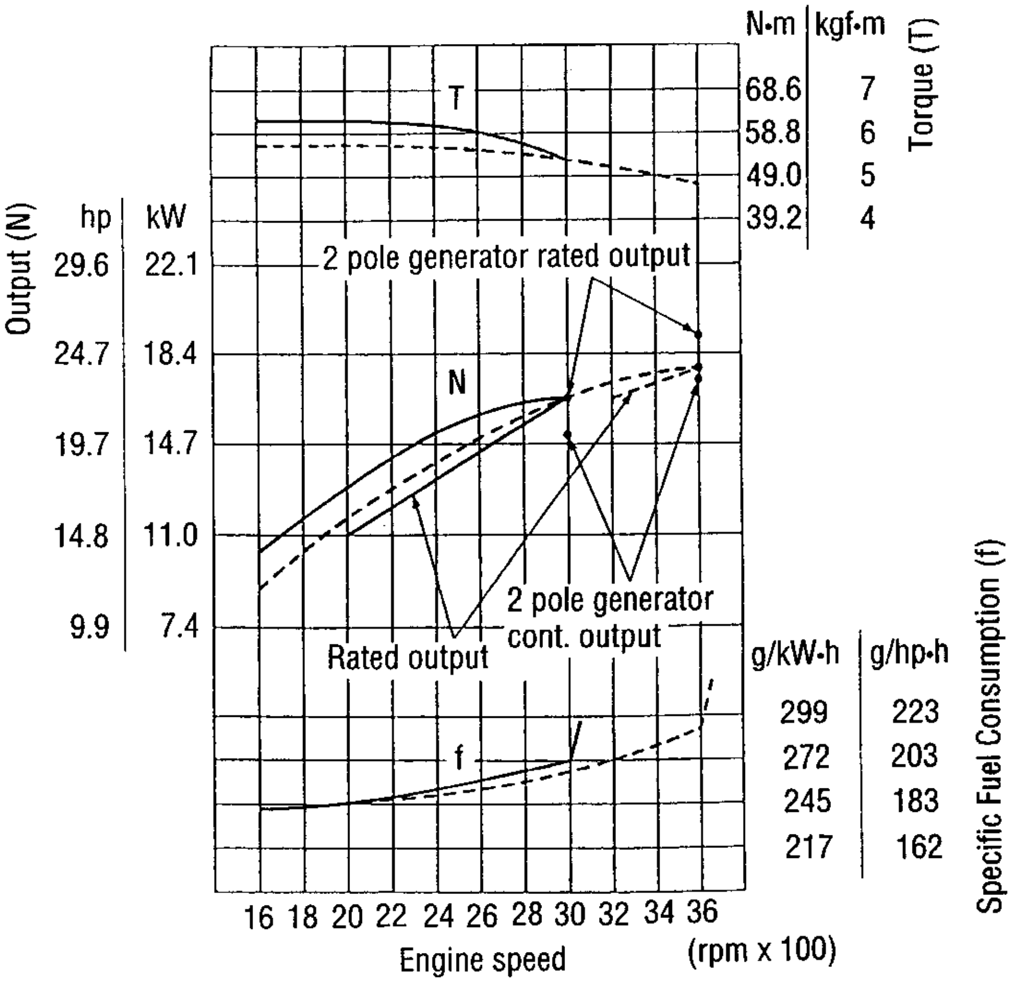
Engine model				3TNE74													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 74 × 78													
4	Displacement		liter	1.006													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										15.1 (20.2)	17.4 (23.3)			
		Rated output	kW (hp)			11.0 (14.8)	12.1 (16.2)	13.2 (17.7)	13.8 (18.5)	14.3 (19.2)	15.4 (20.7)	16.5 (22.1)	16.5 (22.1)	19.1 (25.6)	16.5 (22.1)	17.1 (22.9)	17.7 (23.7)
6	Maximum idling speed		rpm ±50			2180	2390	2590	2695	2795	3010	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)	≦279 (208)		≦286 (213)			≦292 (218)	≦286 (213)	≦299 (223)	≦286 (213)	≦292 (218)	≦306 (228)
8	Exhaust gas temp.		℃			≦480					≦515	≦540		≦595	≦540	≦570	≦590
9	Compression ratio		—	23.1													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter			3.1							4.1				
		Useful	liter			1.5							1.8				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ105 / φ85									φ110 / φ85				

Note: This table is subject to change for performance improvement.

3. 3TNE74

(Unit: mm)





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4. 2TNE68-N

Engine model				2TNE68-N													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	2 – 68 × 72													
4	Displacement		liter	0.523													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										7.6 (10.2)	9.0 (12.1)			
		Rated output	kW (hp)			5.7 (7.6)	6.3 (8.4)	6.8 (9.1)	7.1 (9.5)	7.4 (9.9)	7.9 (10.6)	8.5 (11.4)	8.5 (11.4)	10.0 (13.4)	8.7 (11.7)	9.2 (12.3)	9.6 (12.9)
6	Maximum idling speed		rpm ±50			2180	2375	2590	2685	2780	2995	3195	3175	3805	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)						≦279 (208)		≦299 (223)	≦279 (208)	≦286 (213)	≦292 (218)
8	Exhaust gas temp.		℃			≦480		≦490	≦495	≦500	≦510	≦530		≦580	≦550	≦560	≦580
9	Compression ratio		—	23.0													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 2 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			1.6							2.3				
		Useful	liter			1.0							1.3				
23	Cooling water capacity		liter	0.6													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ260 × 5 (ID mark: TB)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ105 / φ85									φ95 / φ85				

Note: This table is subject to change for performance improvement.

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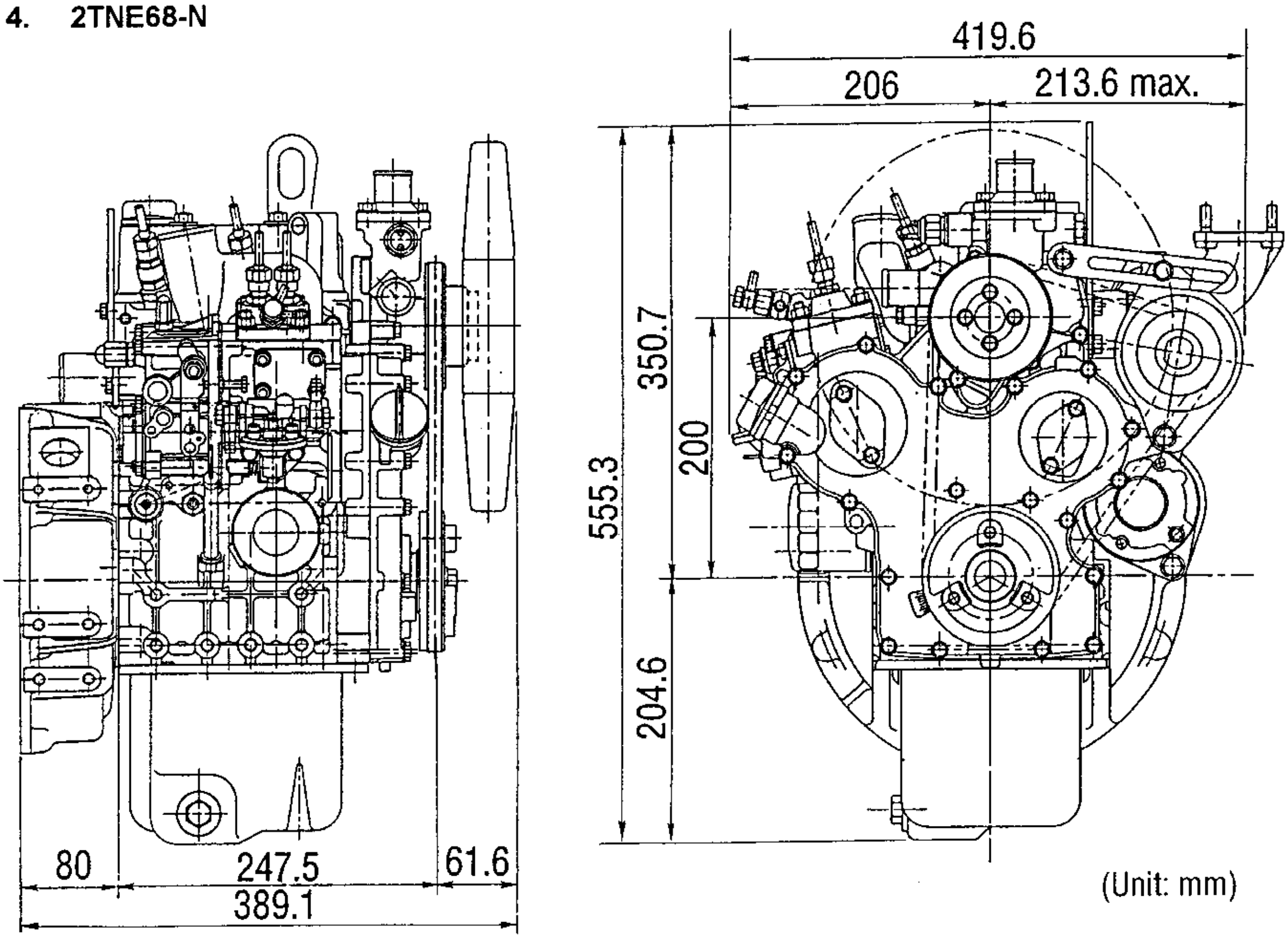
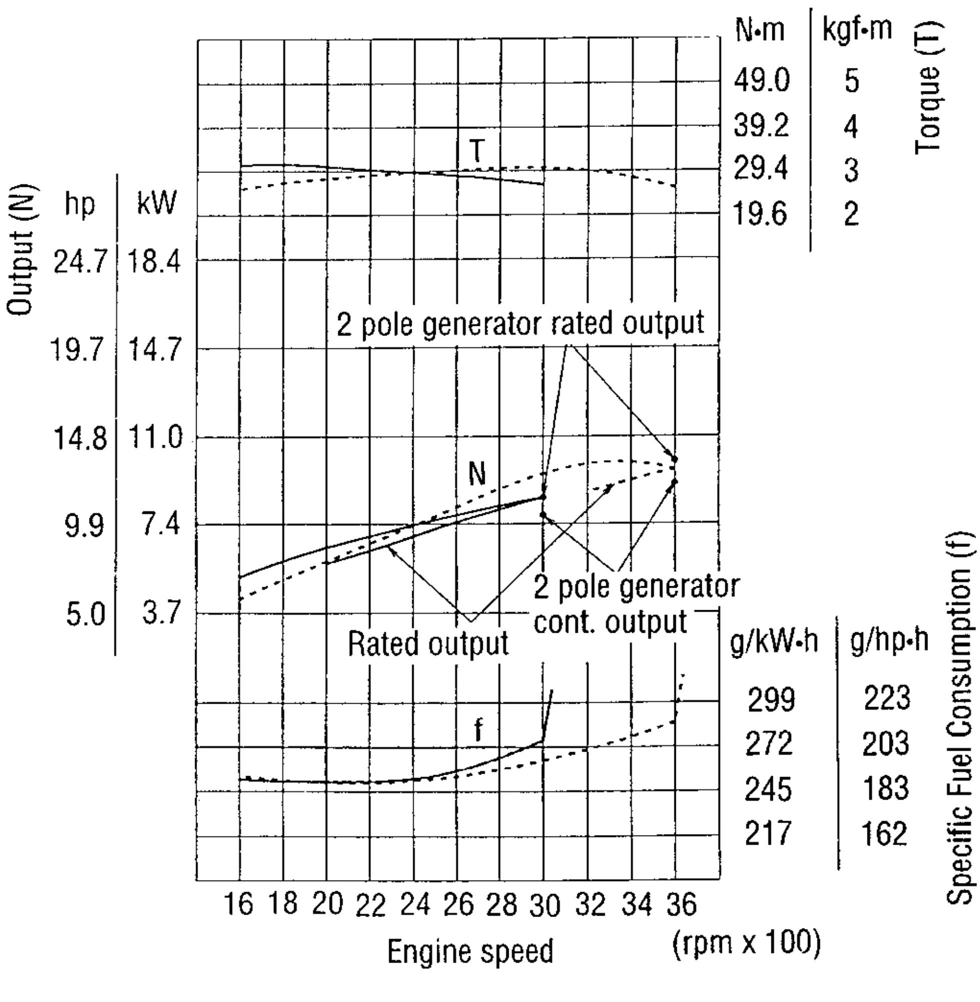
4. 2TNE68-N





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5. 3TNE66-N

Engine model				3TNE66-N													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 66 × 64.2													
4	Displacement		liter	0.659													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)											9.5 (12.7)	11.0 (14.8)		
		Rated output	kW (hp)			6.9 (9.3)	7.5 (10.1)	8.2 (11.0)	8.6 (11.5)	9.0 (12.1)	9.6 (12.9)	10.5 (14.1)	10.5 (14.1)	12.1 (16.2)	11.0 (14.8)	11.5 (15.4)	12.1 (16.2)
6	Maximum idling speed		rpm ±50			2180	2375	2570	2675	2780	2995	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)						≦279 (208)		≦292 (218)	≦286 (213)	≦286 (213)	≦292 (218)
8	Exhaust gas temp.		℃			≦480			≦515			≦540		≦590	≦510	≦540	≦590
9	Compression ratio		—	23.0													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			2.7							3.5				
		Useful	liter			1.2							1.5				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ105 / φ85									φ95 / φ85				

Note: This table is subject to change for performance improvement.

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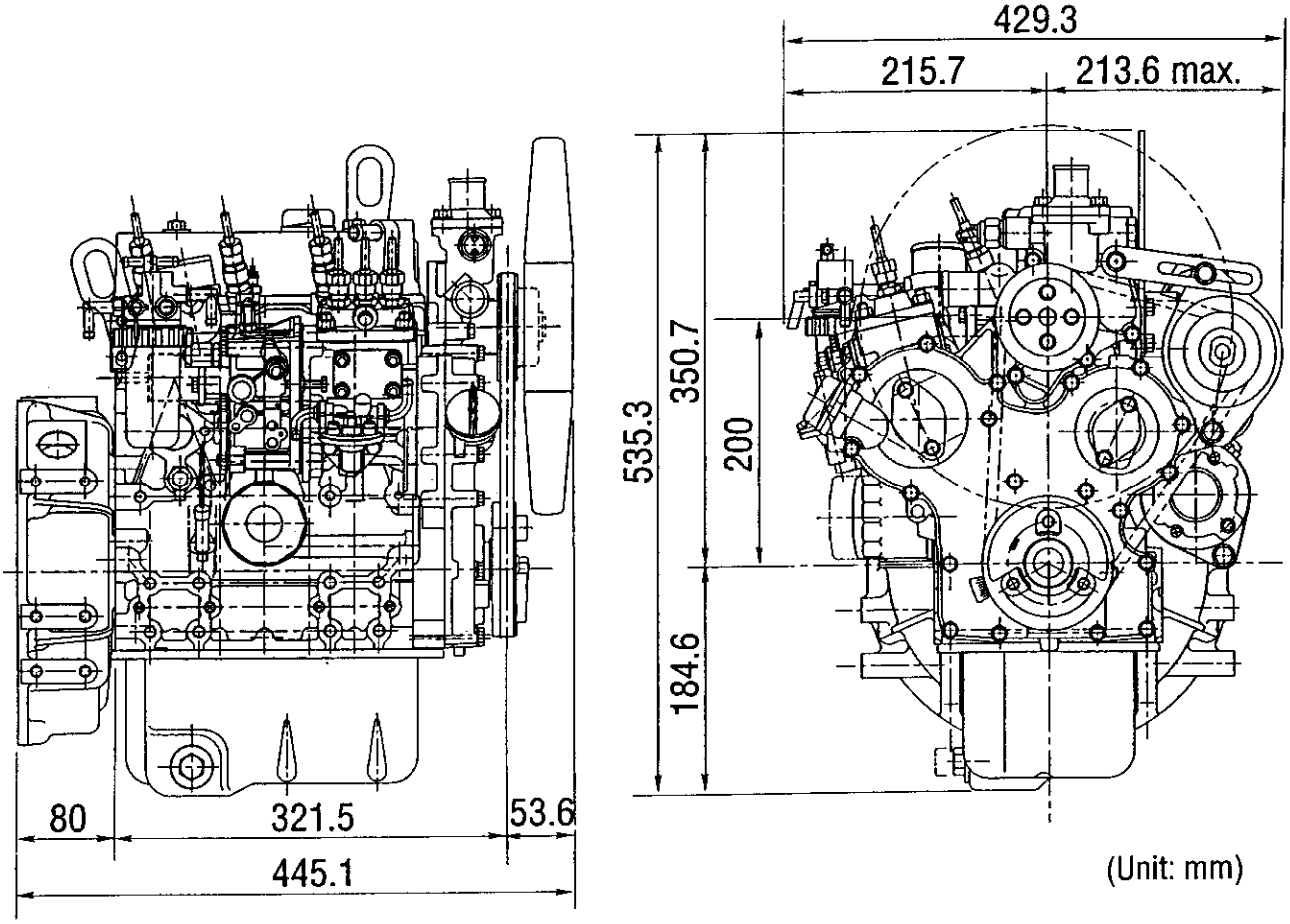
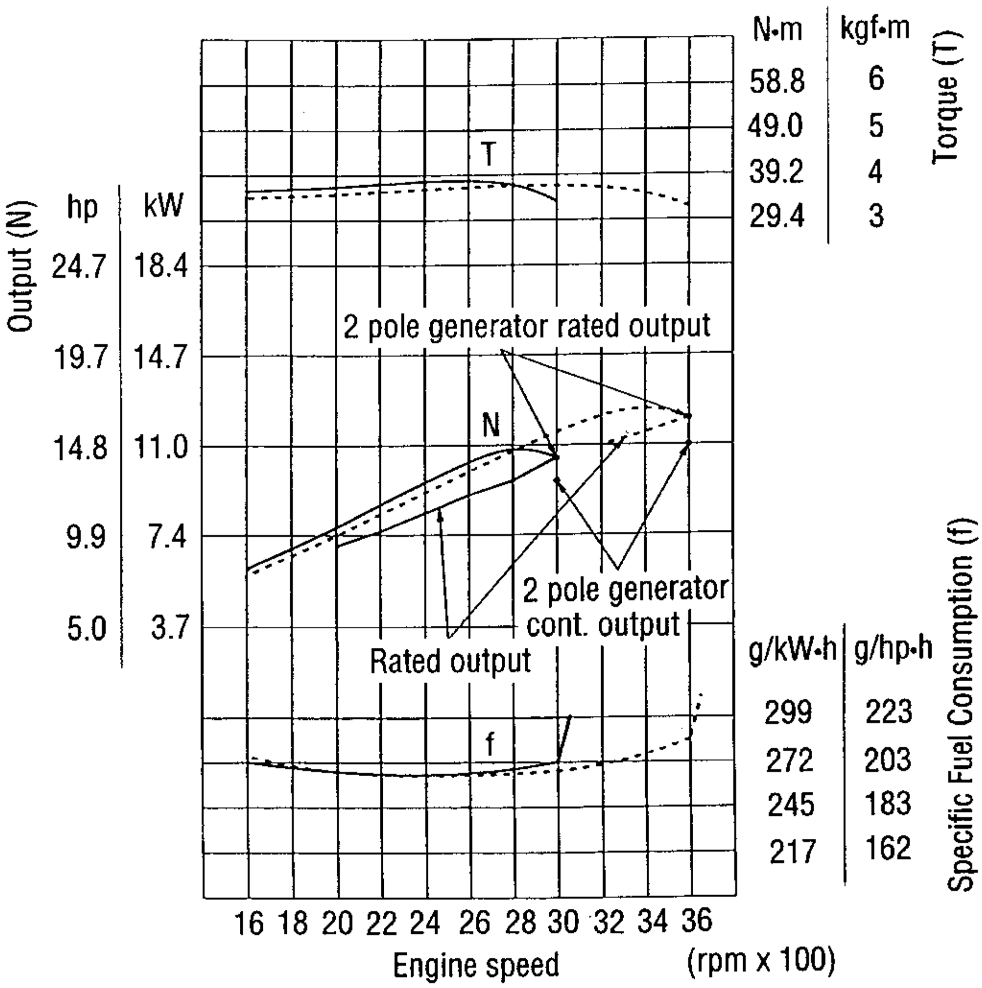
5. 3TNE66-N



(Unit: mm)



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6. 3TNE68-N

Engine model				3TNE68-N													
Engine classification				CL		VM								CH		VH	
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 68 × 72													
4	Displacement		liter	0.784													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										11.7 (15.7)	13.7 (18.4)			
		Rated output	kW (hp)			8.6 (11.5)	9.4 (12.6)	10.3 (13.8)	10.7 (14.3)	11.2 (15.0)	12.0 (16.1)	12.9 (17.3)	12.9 (17.3)	15.1 (20.2)	13.1 (17.6)	13.8 (18.5)	14.5 (19.4)
6	Maximum idling speed		rpm ±50			2180	2375	2570	2675	2780	2995	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)						≦279 (208)		≦299 (223)	≦279 (208)	≦286 (213)	≦292 (218)
8	Exhaust gas temp.		°C			≦480			≦515			≦540		≦590	≦490	≦540	≦590
9	Compression ratio		—	23.5													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			2.7							3.5				
		Useful	liter			1.2							1.5				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ110 / φ85									φ110 / φ95				

Note: This table is subject to change for performance improvement.

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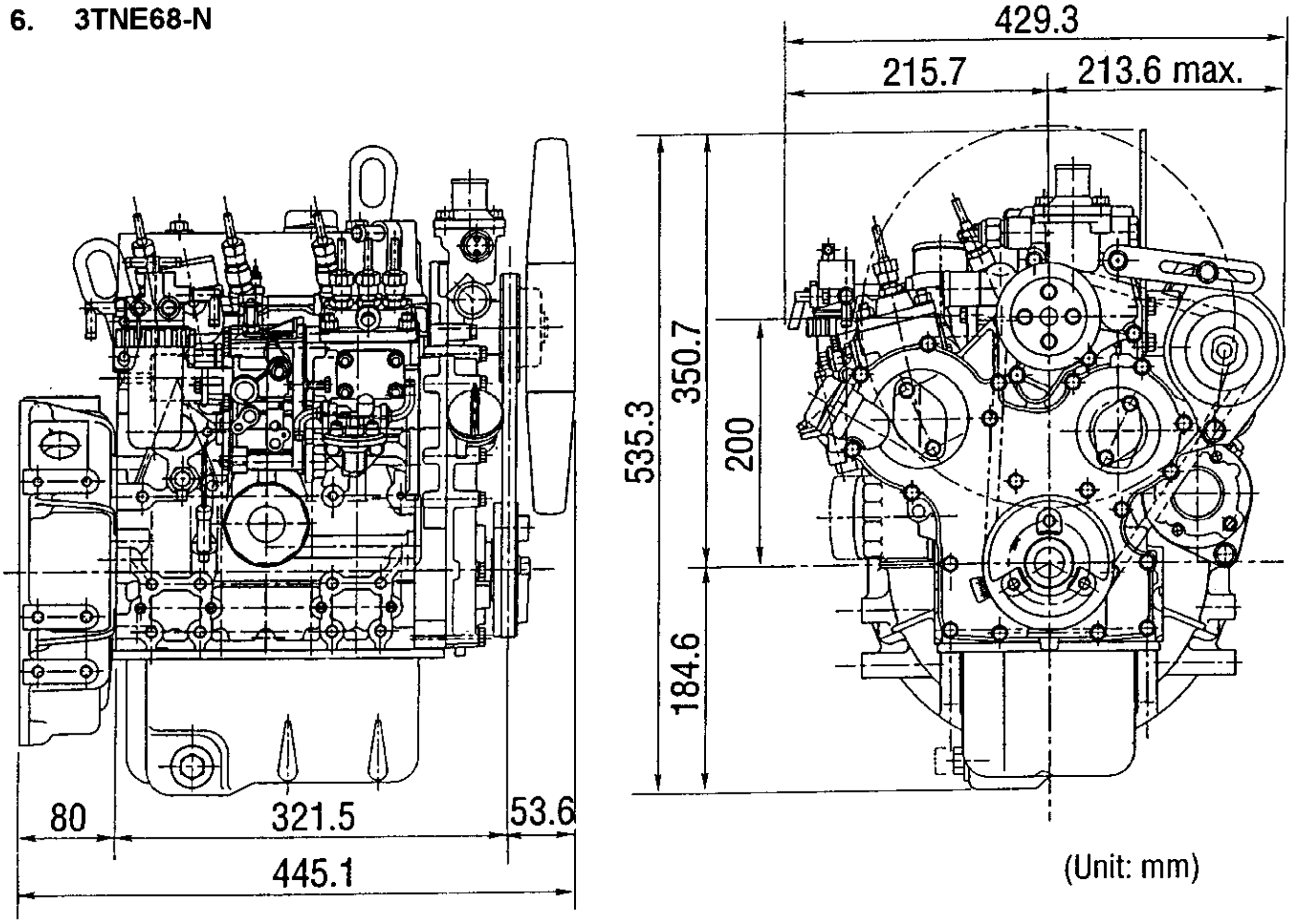
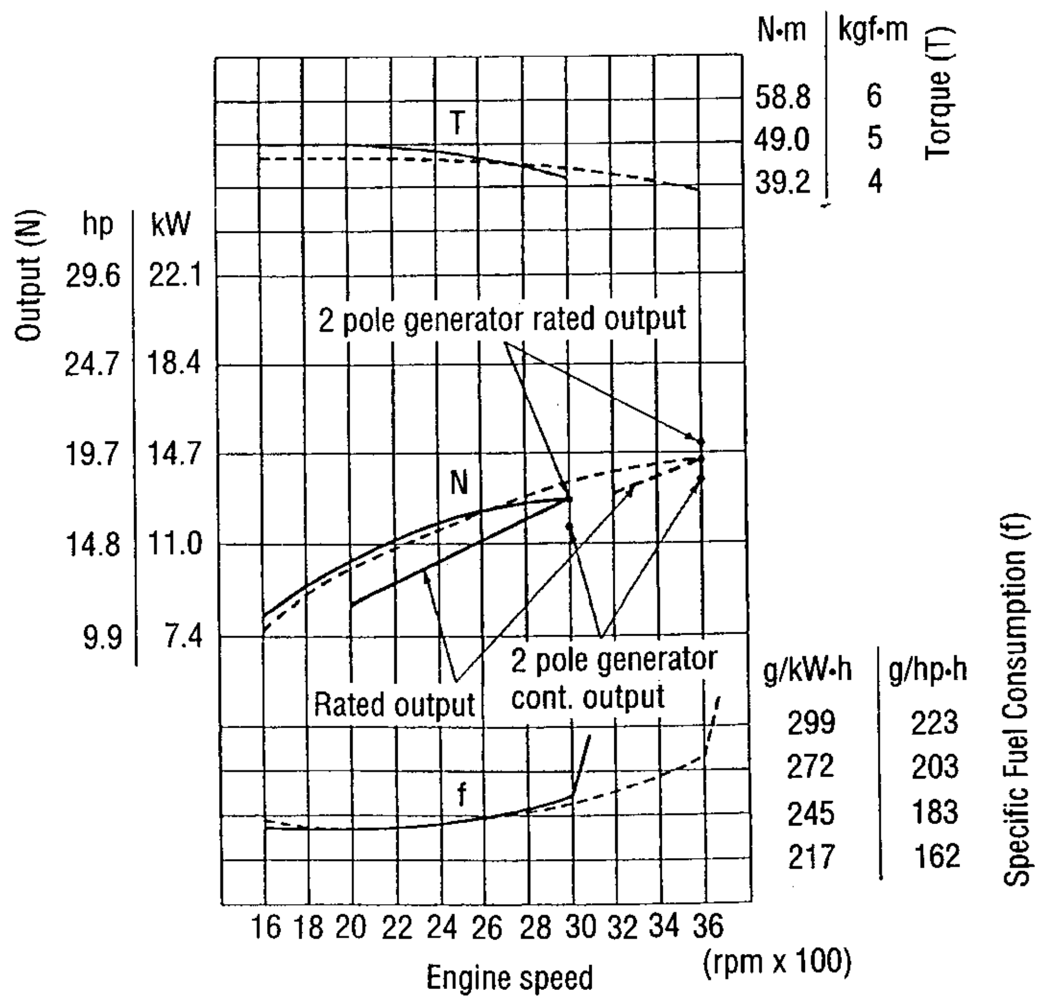
6. 3TNE68-N





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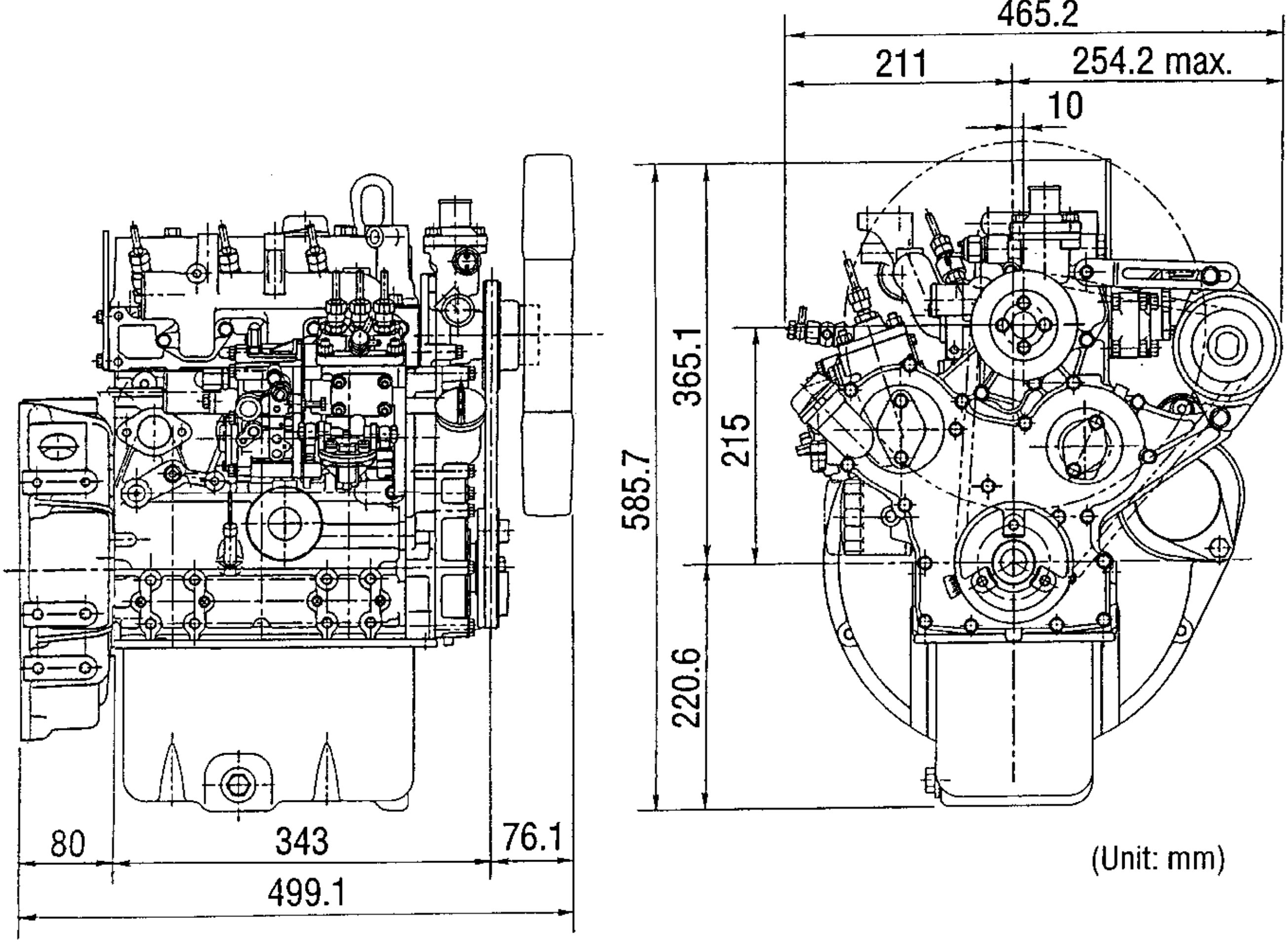
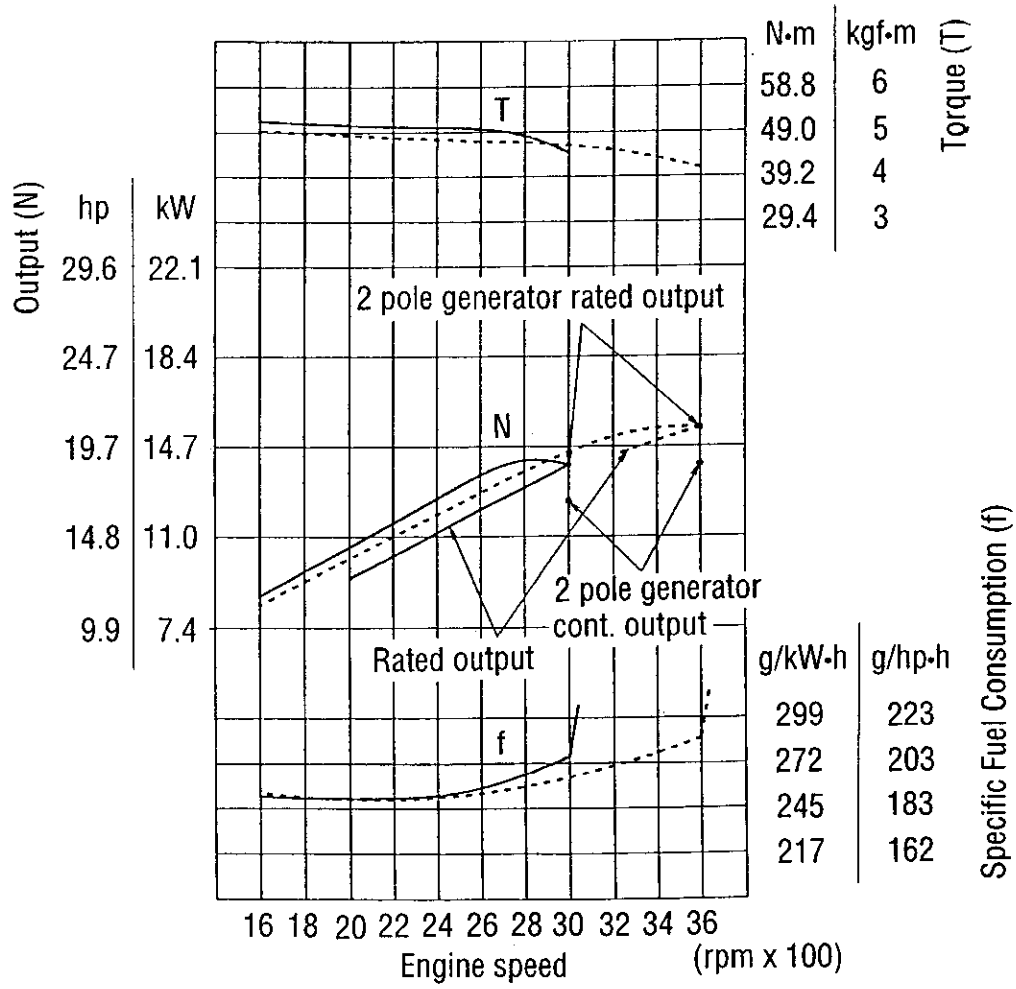
7. 3TNE72-N

No.	Item		Unit														
	Engine model			3TNE72-N													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 72 × 72													
4	Displacement		liter	0.879													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										12.5 (16.8)	14.0 (18.8)			
		Rated output	kW (hp)			9.3 (12.5)	10.2 (13.7)	11.2 (15.0)	11.6 (15.6)	12.1 (16.2)	13.0 (17.4)	14.0 (18.8)	14.0 (18.8)	15.4 (20.7)	14.3 (19.2)	14.9 (20.0)	15.4 (20.7)
6	Maximum idling speed		rpm ±50			2180	2390	2590	2695	2795	3010	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)	≦279 (208)		≦286 (213)			≦292 (218)	≦286 (213)	≦299 (223)	≦286 (213)	≦292 (218)	≦306 (228)
8	Exhaust gas temp.		℃			≦480					≦515	≦540		≦595	≦540	≦570	≦590
9	Compression ratio		—	23.1													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			3.1							4.1				
		Useful	liter			1.5							1.8				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)									Pusher – φ325 × 6 (ID mark: NF)				
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ110 / φ85									φ110 / φ95				

Note: This table is subject to change for performance improvement.

7. 3TNE72-N





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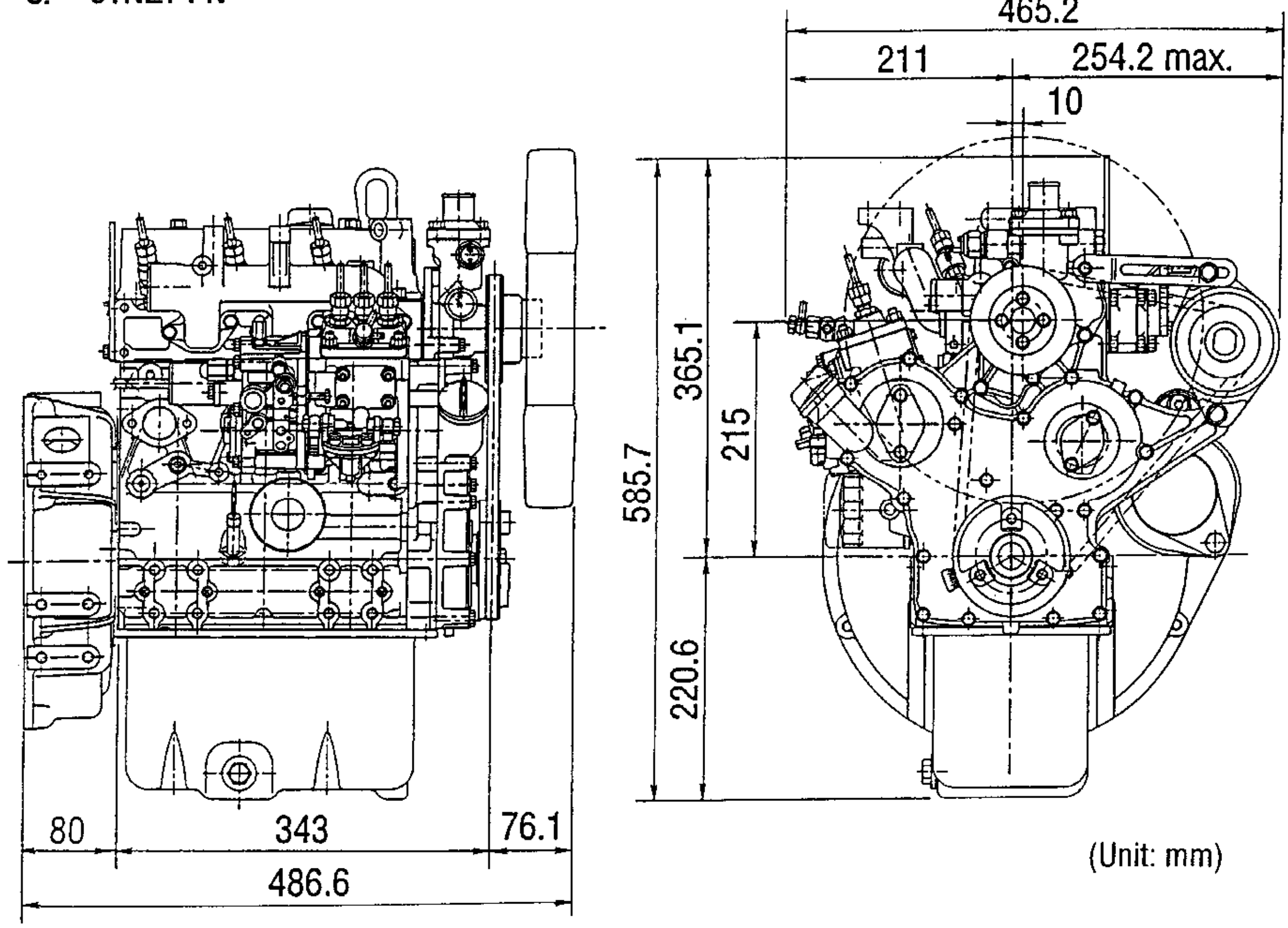
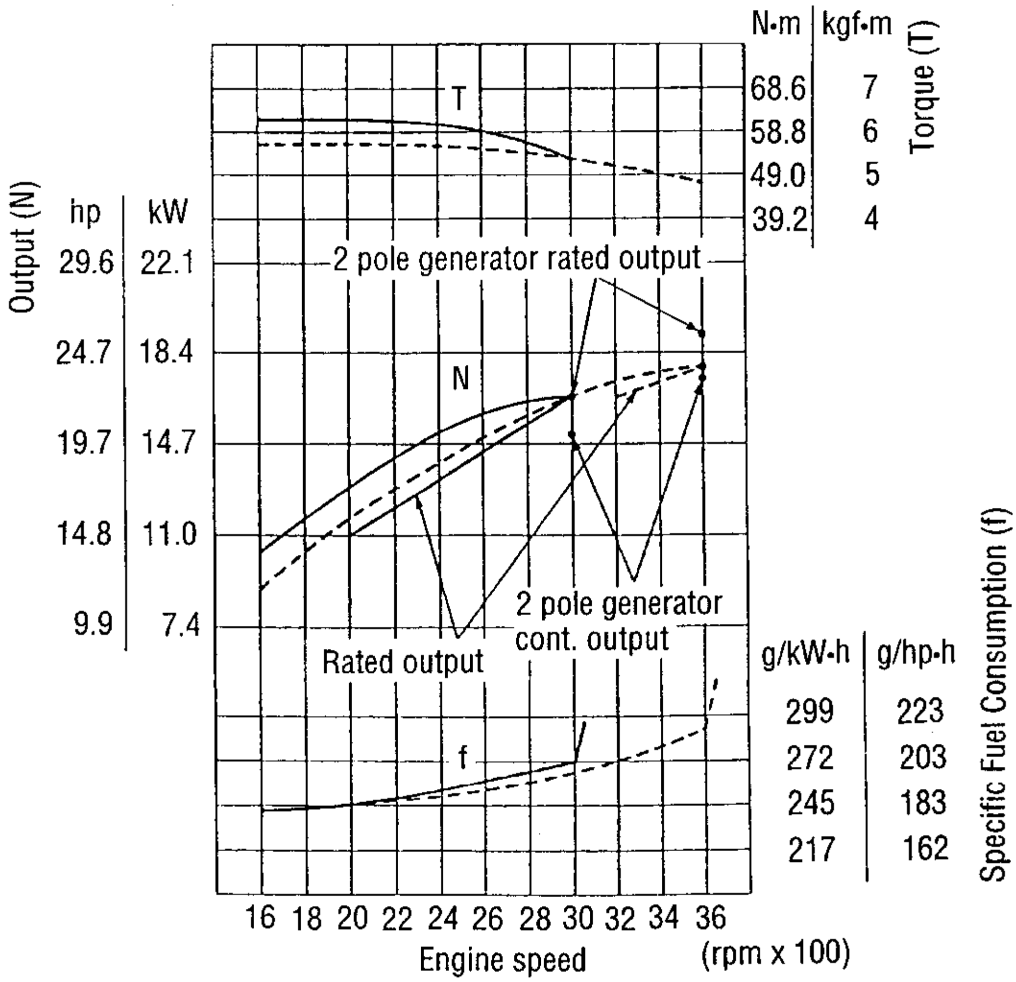
8. 3TNE74-N

Engine model				3TNE74-N													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Indirect injection (IDI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 74 × 78													
4	Displacement		liter	1.006													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)										15.1 (20.2)	17.4 (23.3)			
		Rated output	kW (hp)			11.0 (14.8)	12.1 (16.2)	13.2 (17.7)	13.8 (18.5)	14.3 (19.2)	15.4 (20.7)	16.5 (22.1)	16.5 (22.1)	19.1 (25.6)	16.5 (22.1)	17.1 (22.9)	17.7 (23.7)
6	Maximum idling speed		rpm ±50			2180	2390	2590	2695	2795	3010	3195	3195	3790	3410	3620	3790
7	Specific fuel consumption		g/kWh (g/hph)			≦272 (203)	≦279 (208)		≦286 (213)			≦292 (218)	≦286 (213)	≦299 (223)	≦286 (213)	≦292 (218)	≦306 (228)
8	Exhaust gas temp.		℃			≦480					≦515	≦540		≦595	≦540	≦570	≦590
9	Compression ratio		—	23.1													
10	Fuel injection timing		bTDC (FID)°			14							16				
11	Fuel injection pressure		kPa (kgf/cm²)	11800^{+980}_{0} (120^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/0.9 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Glow plug (10 VDC/10 A × 3 pcs., Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)			245 ± 49 (2.5 ± 0.5)		294 ± 49 (3.0 ± 0.5)				343 ± 49 (3.5 ± 0.5)					
		Idling speed	kPa (kgf/cm²)	≧59 (0.6)													
22	Oil pan capacity	Full	liter			3.1							4.1				
		Useful	liter			1.5							1.8				
23	Cooling water capacity		liter	0.9													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ310 × 5 (ID mark: D)									Pusher – ϕ325 × 6 (ID mark: NF)				
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ110 / ϕ85									ϕ110 / ϕ95				

Note: This table is subject to change for performance improvement.

8. 3TNE74-N


465.2
211
254.2 max.
10
365.1
215
585.7
220.6
80
343
76.1
486.6
(Unit: mm)


N•m
kgf•m
Torque (T)
68.6
7
58.8
6
49.0
5
39.2
4
T
Output (N)
hp
kW
29.6
22.1
24.7
18.4
19.7
14.7
14.8
11.0
9.9
7.4
2 pole generator rated output
N
2 pole generator
cont. output
Rated output
g/kW•h
g/hp•h
299
223
272
203
245
183
217
162
Specific Fuel Consumption (f)
f
16 18 20 22 24 26 28 30 32 34 36
Engine speed
(rpm x 100)

9. 3TNE78A

No.	Engine model		Unit	3TNE78A													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 78 × 84													
4	Displacement		liter	1.204													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)	9.0 (12.1)	10.8 (14.5)								18.0 (24.1)	21.0 (28.2)			
		Rated output	kW (hp)	9.9 (13.3)	11.9 (16.0)	13.2 (17.7)	14.6 (19.6)	15.9 (21.3)	16.5 (22.1)	17.2 (23.1)	18.5 (24.8)	19.9 (26.7)	19.9 (26.7)	23.2 (31.1)	20.4 (27.4)	21.6 (29.0)	23.2 (31.1)
6	Maximum idling speed		rpm ±50	1600	1895	2180	2375	2570	2675	2780	2995	3180	3180	3780	3390	3605	3780
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)		≦258 (192)			
8	Exhaust gas temp.		℃	≦450		≦480	≦500	≦520	≦535	≦545	≦565	≦595	≦540	≦590			
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	10		12		14			16		24		18	20	24
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.2 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	310^{+100}_{-50} ($3.2^{+1.0}_{-0.5}$)		360^{+100}_{-50} ($3.7^{+1.0}_{-0.5}$)						410^{+100}_{-50} ($4.2^{+1.0}_{-0.5}$)					
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter	5.0		3.6							5.0				
		Useful	liter	2.2		1.2							2.2				
23	Cooling water capacity		liter	1.8													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ120 / φ90		φ110 / φ110											

Note: This table is subject to change for performance improvement.

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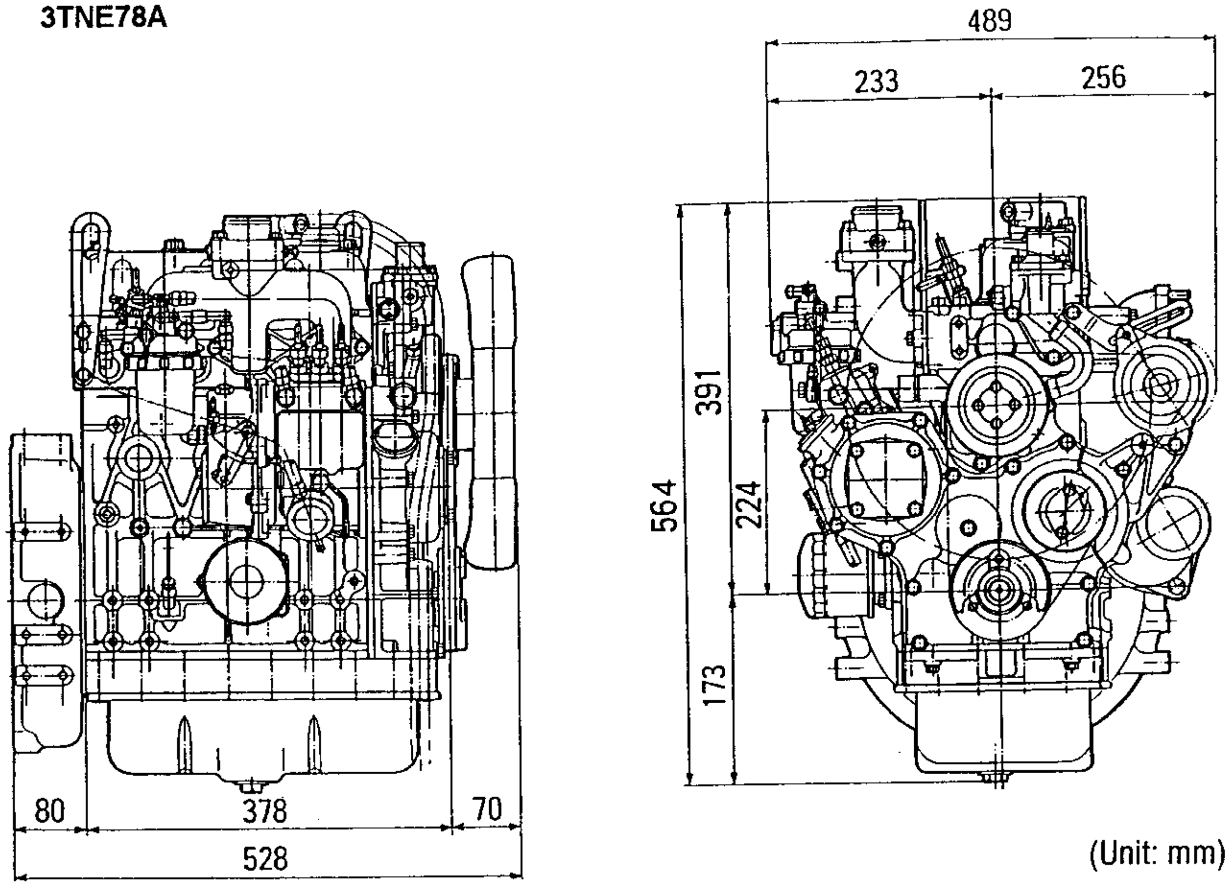
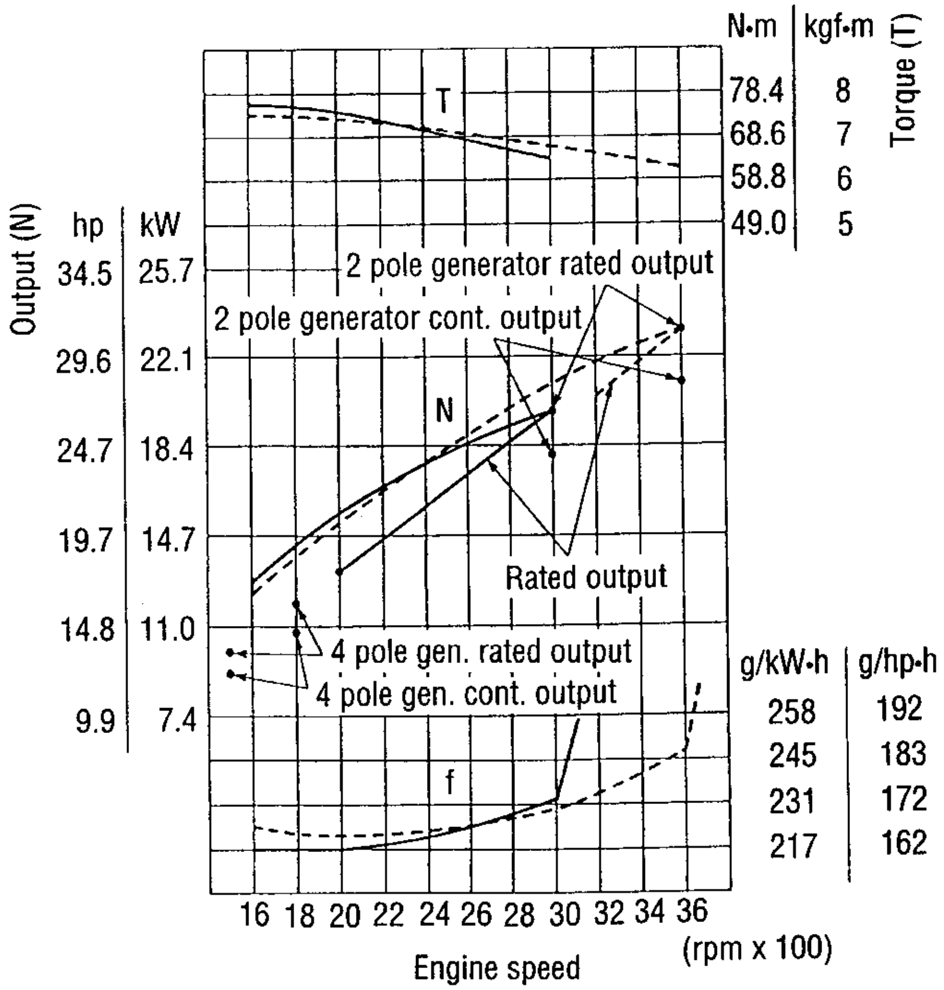
9. 3TNE78A



(Unit: mm)



10. 3TNE82A

	Engine model			3TNE82A													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 82 × 84													
4	Displacement		liter	1.331													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)	9.9 (13.3)	12.0 (16.1)												
		Rated output	kW (hp)	11.0 (14.8)	13.2 (17.7)	14.6 (19.6)	16.0 (21.5)	17.5 (23.5)	18.2 (24.4)	19.0 (25.5)	20.4 (27.4)	21.9 (29.4)					
6	Maximum idling speed		rpm ±50	1600	1895	2180	2375	2570	2675	2780	2995	3180					
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)					
8	Exhaust gas temp.		℃	≦450		≦470	≦490	≦520	≦535	≦545	≦555	≦590					
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	12				14			16						
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.2 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	310^{+100}_{-50} $(3.2^{+1.0}_{-0.5})$		360^{+100}_{-50} $(3.7^{+1.0}_{-0.5})$						←	410^{+100}_{-50} $(4.2^{+1.0}_{-0.5})$				
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter	5.0		3.6											
		Useful	liter	2.2		1.2											
23	Cooling water capacity		liter	1.8													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ310 × 5 (ID mark: D)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ120 / φ90		φ110 / φ110											

Note: This table is subject to change for performance improvement.

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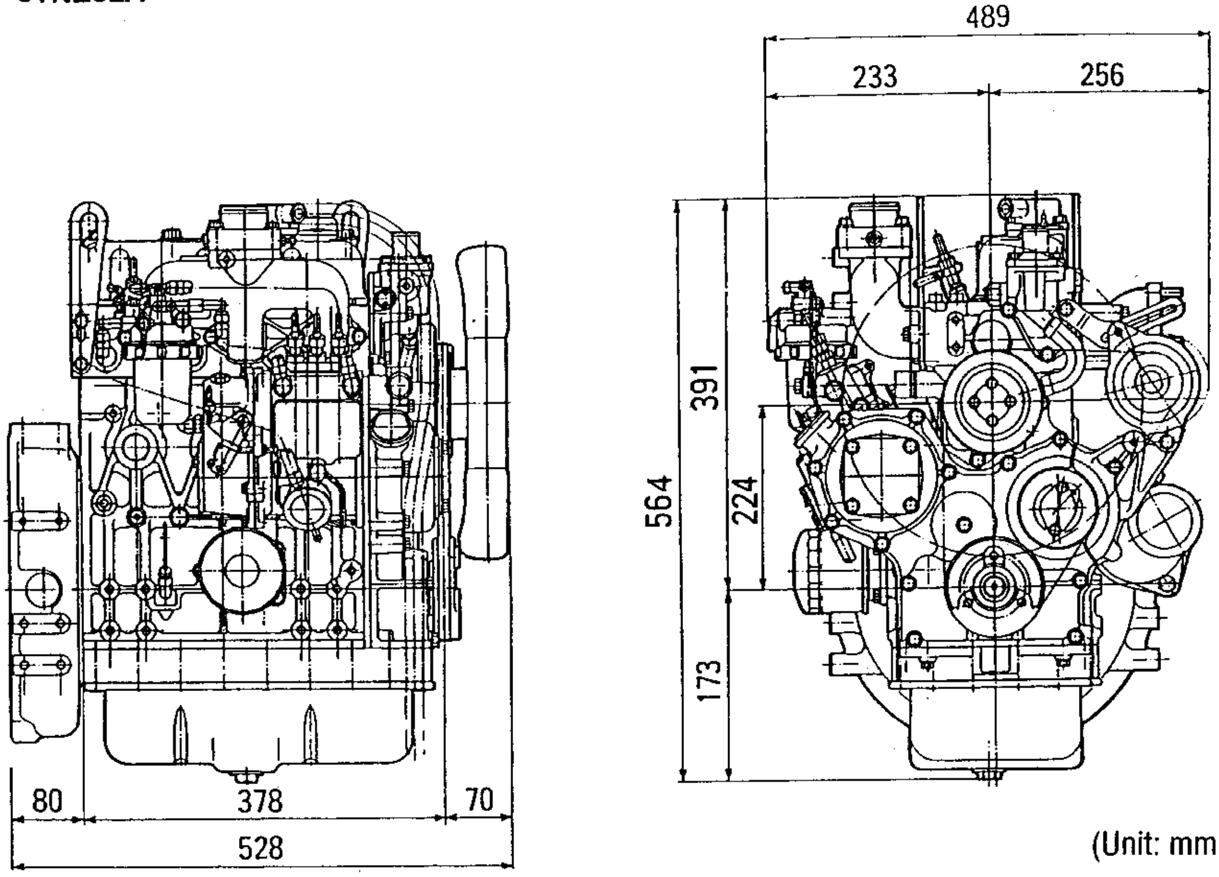
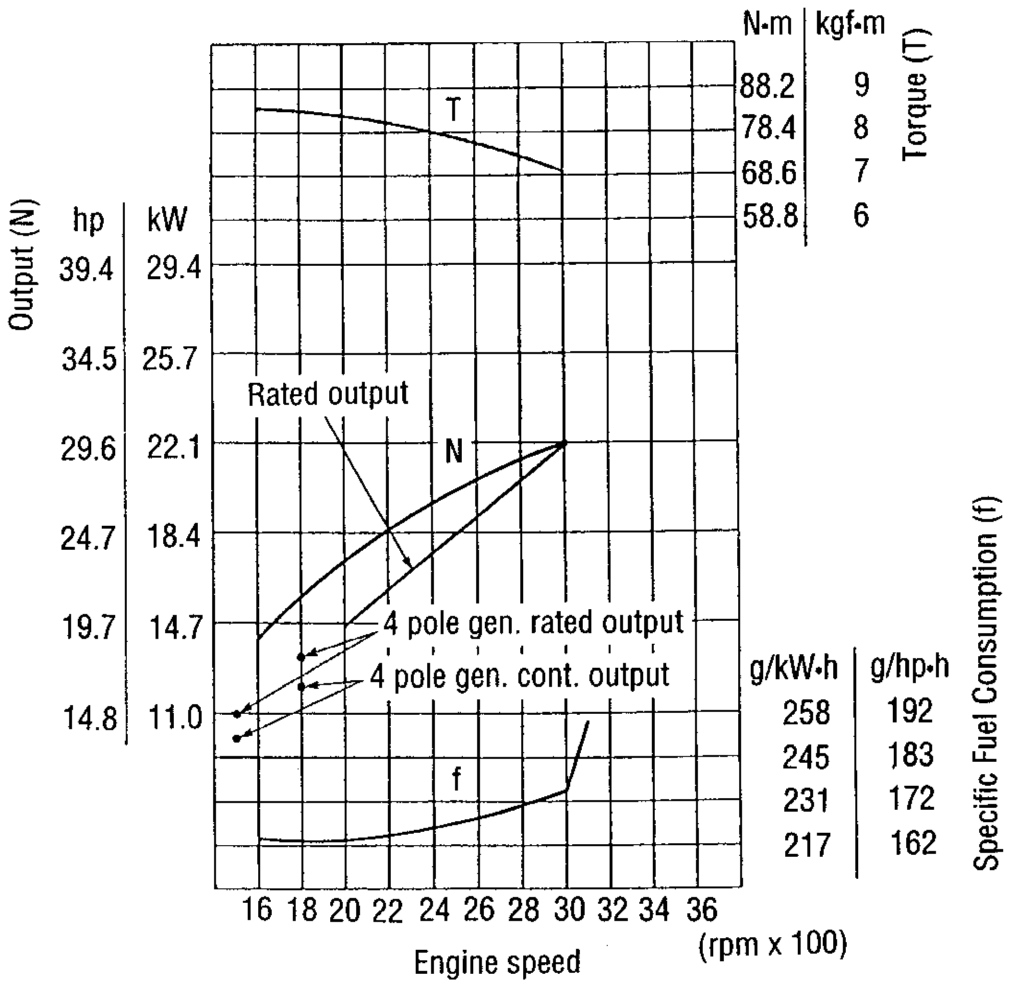
10. 3TNE82A



(Unit: mm)



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11. 3TNE84

<table>
<tr><th colspan="4">Engine model</th><th colspan="14">3TNE84</th></tr>
<tr><th colspan="4">Engine classification</th><th colspan="2">CL</th><th colspan="7">VM</th><th colspan="2">CH</th><th colspan="3">VH</th></tr>
<tr><td>1</td><td colspan="2">Type</td><td>—</td><td colspan="14">Vertical, 4-cycle water-cooled diesel engine</td></tr>
<tr><td>2</td><td colspan="2">Combustion system</td><td>—</td><td colspan="14">Direct injection (DI)</td></tr>
<tr><td>3</td><td colspan="2">No. of cylinders – Bore × Stroke</td><td>n – mm × mm</td><td colspan="14">3 – 84 × 90</td></tr>
<tr><td>4</td><td colspan="2">Displacement</td><td>liter</td><td colspan="14">1.496</td></tr>
<tr><td rowspan="3">5</td><td colspan="2">Rated engine speed</td><td>rpm</td><td>1500</td><td>1800</td><td>2000</td><td>2200</td><td>2400</td><td>2500</td><td>2600</td><td>2800</td><td>3000</td><td>3000</td><td>3600</td><td>3200</td><td>3400</td><td>3600</td></tr>
<tr><td rowspan="2">Output</td><td>Cont. rating</td><td>kW (hp)</td><td>11.3 (15.2)</td><td>13.5 (18.1)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>22.4 (30.0)</td><td>26.1 (35.0)</td><td></td><td></td><td></td></tr>
<tr><td>Rated output</td><td>kW (hp)</td><td>12.4 (16.6)</td><td>14.8 (19.8)</td><td>16.4 (22.0)</td><td>18.1 (24.3)</td><td>19.7 (26.4)</td><td>20.5 (27.5)</td><td>21.3 (28.6)</td><td>23.0 (30.8)</td><td>24.6 (33.0)</td><td>24.6 (33.0)</td><td>28.7 (38.5)</td><td>25.6 (34.3)</td><td>27.0 (36.2)</td><td>28.3 (37.9)</td></tr>
<tr><td>6</td><td colspan="2">Maximum idling speed</td><td>rpm ±50</td><td>1600</td><td>1895</td><td>2180</td><td>2400</td><td>2590</td><td>2700</td><td>2810</td><td>2995</td><td>3210</td><td>3175</td><td>3770</td><td>3395</td><td>3605</td><td>3815</td></tr>
<tr><td>7</td><td colspan="2">Specific fuel consumption</td><td>g/kWh (g/hph)</td><td colspan="5">≦238 (177)</td><td colspan="3">≦245 (183)</td><td>≦252 (188)</td><td>≦245 (183)</td><td colspan="4">≦258 (192)</td></tr>
<tr><td>8</td><td colspan="2">Exhaust gas temp.</td><td>℃</td><td>≦450</td><td>≦470</td><td>≦480</td><td>≦500</td><td>≦520</td><td>≦535</td><td>≦545</td><td>≦565</td><td>≦595</td><td>≦540</td><td colspan="4">≦590</td></tr>
<tr><td>9</td><td colspan="2">Compression ratio</td><td>—</td><td colspan="14">18.0</td></tr>
<tr><td>10</td><td colspan="2">Fuel injection timing</td><td>bTDC (FID)°</td><td colspan="2">10</td><td colspan="2">12</td><td colspan="3">14</td><td colspan="2">16</td><td colspan="2">24</td><td>18</td><td>20</td><td>24</td></tr>
<tr><td>11</td><td colspan="2">Fuel injection pressure</td><td>kPa (kgf/cm²)</td><td colspan="14">19600^{+980}_{0} (200^{+10}_{0})</td></tr>
<tr><td>12</td><td colspan="2">Main shaft side</td><td>—</td><td colspan="14">Flywheel side</td></tr>
<tr><td>13</td><td colspan="2">Rotation direction</td><td>—</td><td colspan="14">Counterclockwise (Viewed from flywheel side)</td></tr>
<tr><td>14</td><td colspan="2">Governor</td><td>—</td><td colspan="14">Mechanical centrifugal governor (All-speed governor)</td></tr>
<tr><td>15</td><td colspan="2">Aspiration</td><td>—</td><td colspan="14">Natural aspiration</td></tr>
<tr><td>16</td><td colspan="2">Cooling system</td><td>—</td><td colspan="14">Force-feed circulation radiator type cooling system</td></tr>
<tr><td>17</td><td colspan="2">Lubricating system</td><td>—</td><td colspan="14">Forced lubrication with trochoid pump</td></tr>
<tr><td>18</td><td colspan="2">Starting system</td><td>—</td><td colspan="14">Electric starting (Starting motor 12 VDC/1.2 kW, Standard spec.)</td></tr>
<tr><td>19</td><td colspan="2">Charging system</td><td>—</td><td colspan="14">Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)</td></tr>
<tr><td>20</td><td colspan="2">Starting aid device</td><td>—</td><td colspan="14">Air heater (12 VDC/400 W, Standard spec.)</td></tr>
<tr><td rowspan="2">21</td><td rowspan="2">Lube oil pressure</td><td>Rated speed</td><td>kPa (kgf/cm²)</td><td colspan="2">340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)</td><td colspan="6">390^{+100}_{-50} ($4.0^{+1.0}_{-0.5}$)</td><td colspan="6">440^{+100}_{-50} ($4.5^{+1.0}_{-0.5}$)</td></tr>
<tr><td>Idling speed</td><td>kPa (kgf/cm²)</td><td colspan="14">—</td></tr>
<tr><td rowspan="2">22</td><td rowspan="2">Oil pan capacity</td><td>Full</td><td>liter</td><td colspan="2">7.2</td><td colspan="7">4.8</td><td colspan="5">7.2</td></tr>
<tr><td>Useful</td><td>liter</td><td colspan="2">3.5</td><td colspan="7">1.9</td><td colspan="5">3.5</td></tr>
<tr><td>23</td><td colspan="2">Cooling water capacity</td><td>liter</td><td colspan="14">2.0</td></tr>
<tr><td>24</td><td colspan="2">Cooling fan type – dia. × No. of blades</td><td>mm</td><td colspan="14">Pusher – φ335 × 6 (ID mark: NF)</td></tr>
<tr><td>25</td><td colspan="2">Crank V pulley dia./ Fan V pulley dia.</td><td>mm/mm</td><td colspan="2">φ120 / φ90</td><td colspan="12">φ110 / φ110</td></tr>
</table>

Note: This table is subject to change for performance improvement.

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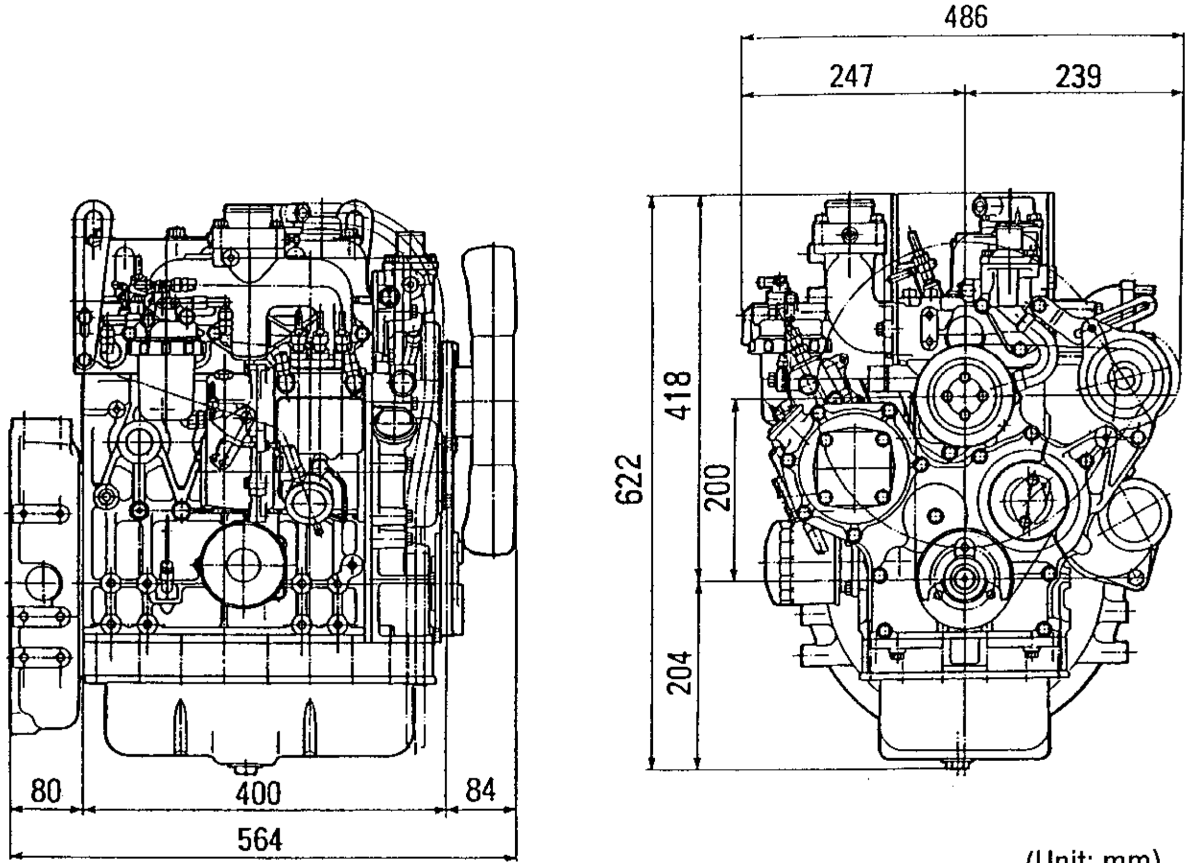
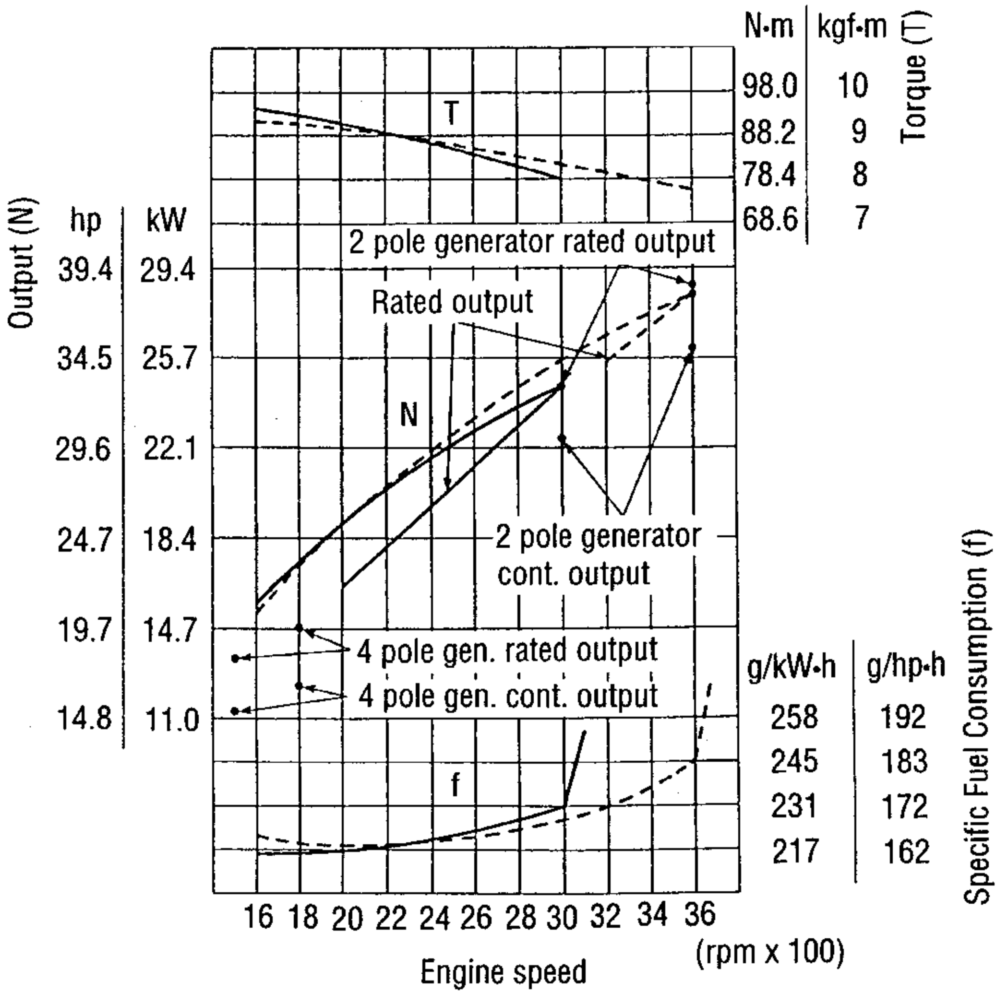
11. 3TNE84



(Unit: mm)



12. 3TNE88

Engine model				3TNE88													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 88 × 90													
4	Displacement		liter	1.642													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)	12.3 (16.5)	14.8 (19.8)												
		Rated output	kW (hp)	13.5 (18.1)	16.3 (21.9)	18.0 (24.1)	19.9 (26.7)	21.6 (29.0)	22.6 (30.3)	23.5 (31.5)	25.2 (33.8)	27.1 (36.3)					
6	Maximum idling speed		rpm ±50	1600	1895	2180	2400	2590	2700	2810	2995	3210					
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)					
8	Exhaust gas temp.		℃	≦450		≦470	≦490	≦500	≦515	≦525	≦555	≦590					
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	10		12		14			16						
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.2 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)		390^{+100}_{-50} ($4.0^{+1.0}_{-0.5}$)							← 440^{+100}_{-50} ($4.5^{+1.0}_{-0.5}$)				
		Idling speed	kPa (kgf/cm²)														
22	Oil pan capacity	Full	liter	7.2		4.8											
		Useful	liter	3.5		1.9											
23	Cooling water capacity		liter	2.0													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ335 × 6 (ID mark: NF)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ120 / φ90		φ110 / φ110											

Note: This table is subject to change for performance improvement.

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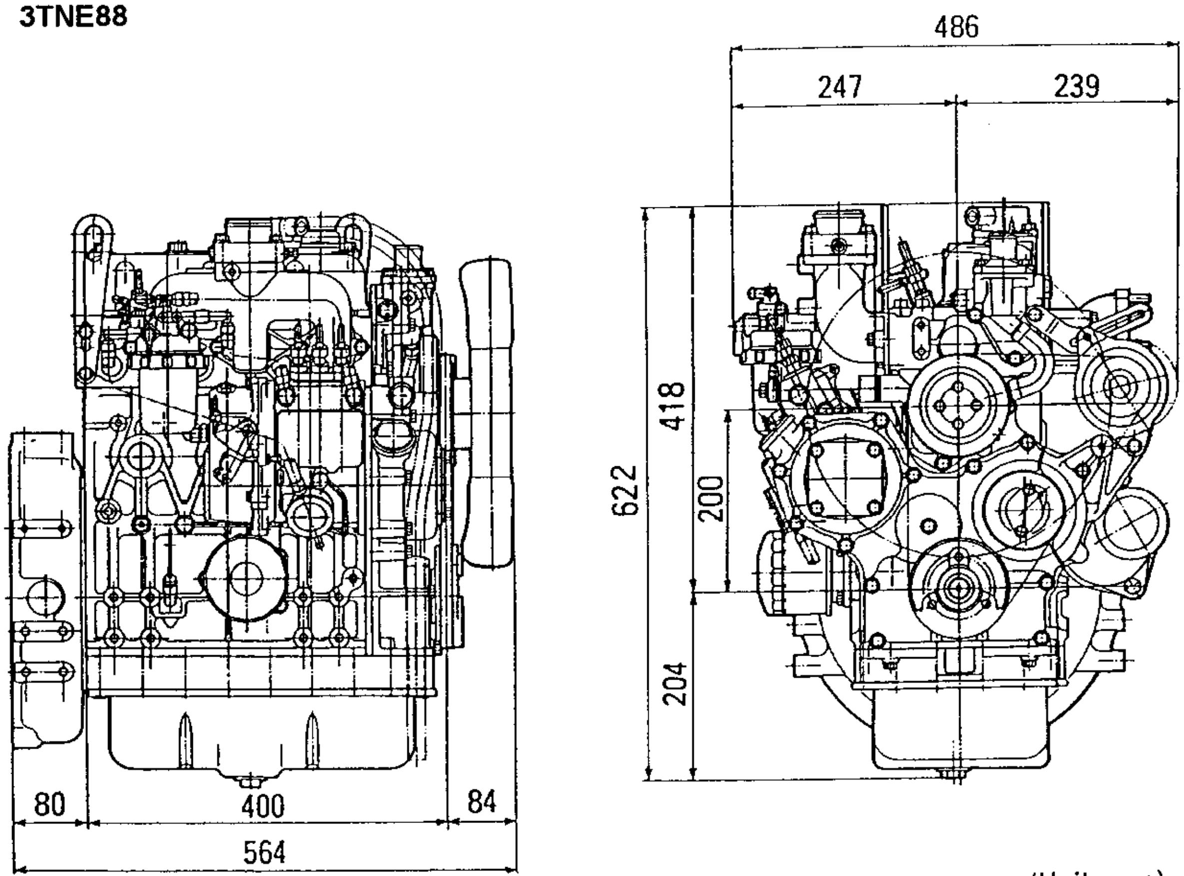
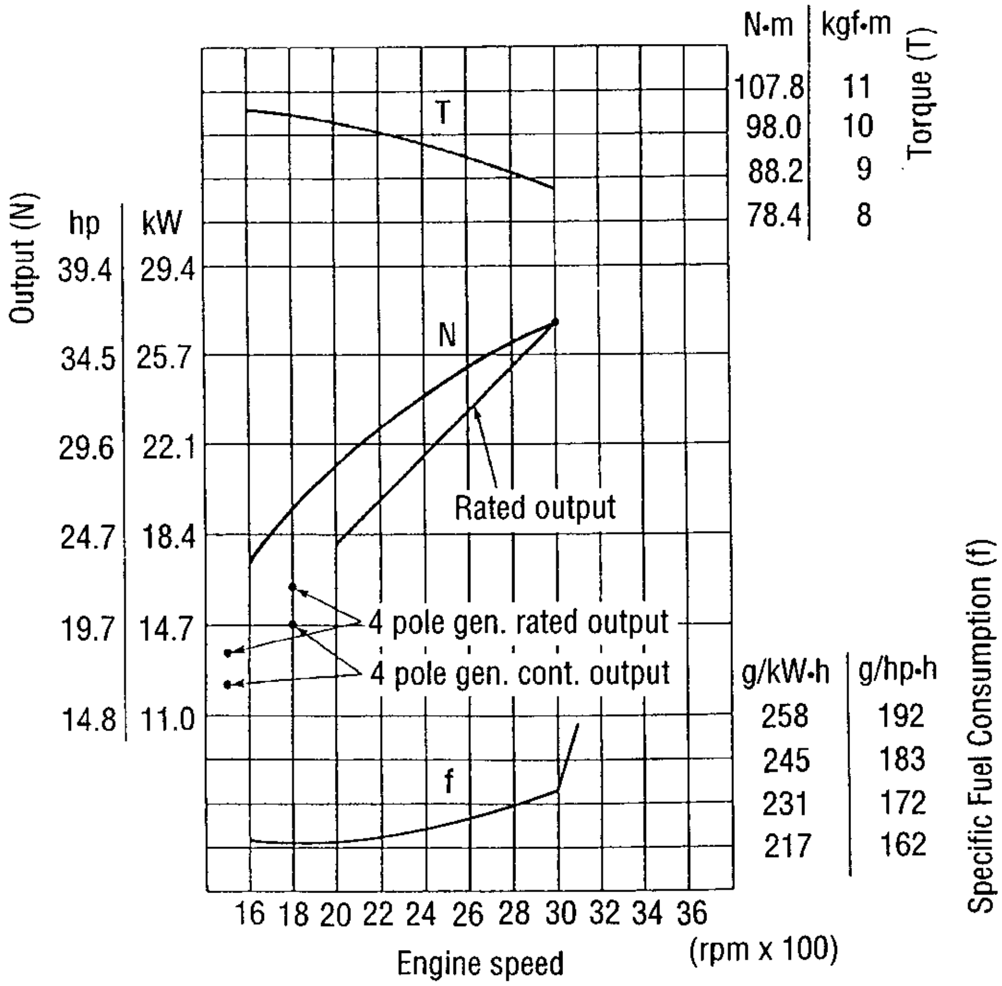
12. 3TNE88



(Unit: mm)



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13. 4TNE84

Engine model				4TNE84													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	4 – 84 × 90													
4	Displacement		liter	1.995													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)	14.9 (20.0)	17.7 (23.7)								29.9 (40.1)	34.7 (46.5)			
		Rated output	kW (hp)	16.4 (22.0)	19.5 (26.1)	21.9 (29.4)	24.1 (32.3)	26.3 (35.3)	27.4 (36.7)	28.5 (38.2)	30.7 (41.2)	32.9 (44.1)	32.9 (44.1)	38.2 (51.2)	33.9 (45.5)	35.8 (48.0)	37.7 (50.6)
6	Maximum idling speed		rpm ±50	1600	1895	2160	2375	2590	2700	2810	2995	3210	3175	3770	3395	3605	3815
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)	≦245 (183)	≦258 (192)			
8	Exhaust gas temp.		℃	≦455		≦490	≦510	≦530	≦545	≦555	≦575	≦600	≦550	≦600			
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	10		12		14			16		24		18	20	24
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.4 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)		370^{+100}_{-50} ($3.8^{+1.0}_{-0.5}$)						410^{+100}_{-50} ($4.2^{+1.0}_{-0.5}$)					
		Idling speed	kPa (kgf/cm²)														
22	Oil pan capacity	Full	liter	8.6		5.8							8.6				
		Useful	liter	4.2		2.3							4.2				
23	Cooling water capacity		liter	2.7													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ370 × 6 (ID mark: EF)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ120 / ϕ90		ϕ110 / ϕ110											

Note: This table is subject to change for performance improvement.

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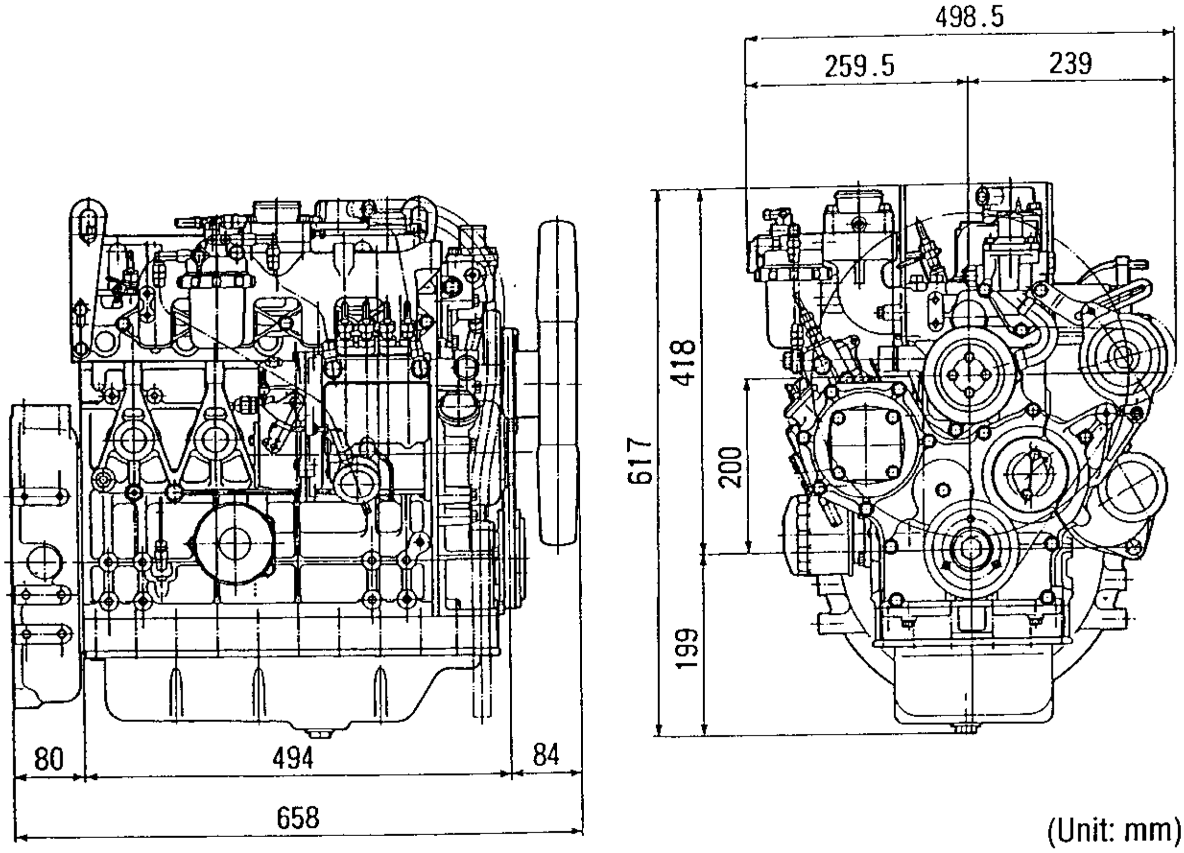
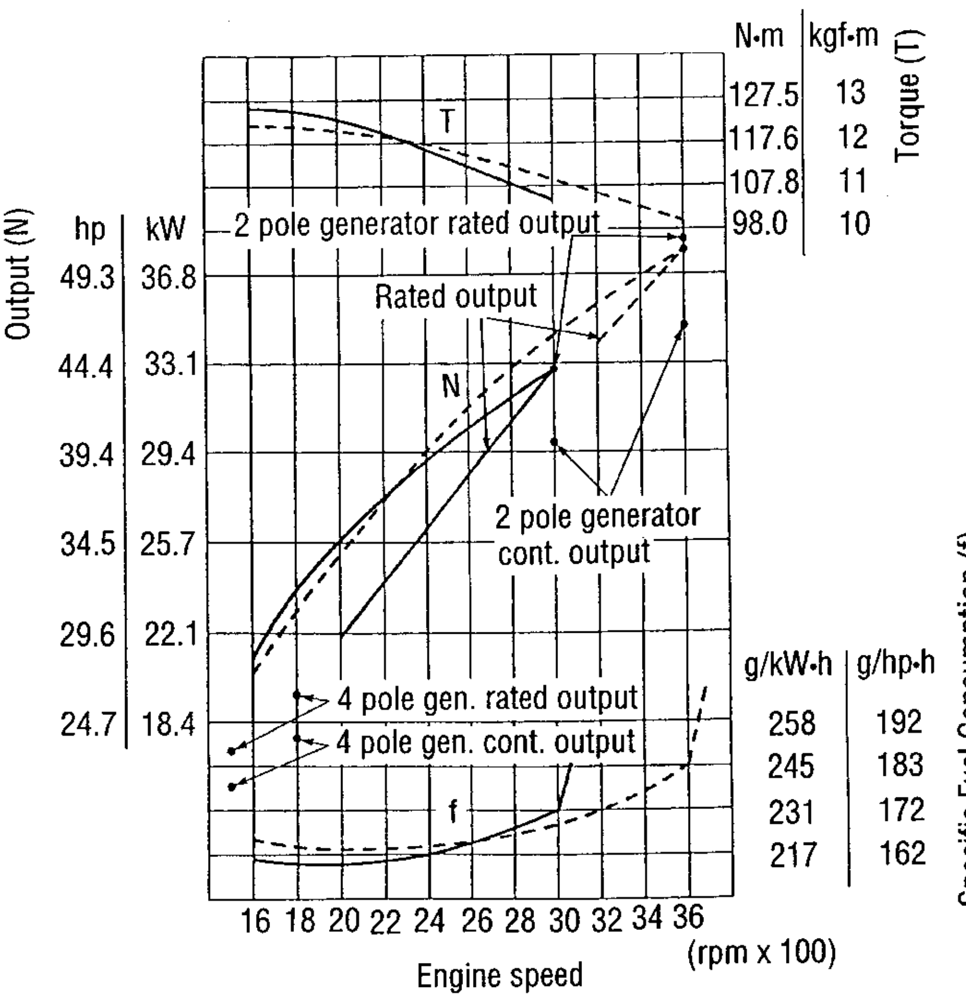
13. 4TNE84



(Unit: mm)



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14. 4TNE88

No.	Item		Unit	4TNE88													
	Engine model			4TNE88													
	Engine classification			CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	4 – 88 × 90													
4	Displacement		liter	2.190													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000					
	Output	Cont. rating	kW (hp)	16.4 (22.0)	19.6 (26.3)												
		Rated output	kW (hp)	18.0 (24.1)	21.6 (29.0)	24.1 (32.3)	26.5 (35.5)	28.8 (38.6)	30.1 (40.4)	31.3 (42.0)	33.7 (45.2)	36.0 (48.3)					
6	Maximum idling speed		rpm ±50	1600	1895	2180	2400	2590	2700	2810	3025	3240					
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)					
8	Exhaust gas temp.		℃	≦460	≦490	≦480	≦500	≦510	≦525	≦535	≦565	≦600					
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	10		12		14			16						
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.4 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)		370^{+100}_{-50} ($3.8^{+1.0}_{-0.5}$)						←	410^{+100}_{-50} ($4.2^{+1.0}_{-0.5}$)				
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter	8.6		5.8											
		Useful	liter	4.2		2.3											
23	Cooling water capacity		liter	2.7													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ370 × 6 (ID mark: EF)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ120 / φ90		φ110 / φ110											

Note: This table is subject to change for performance improvement.

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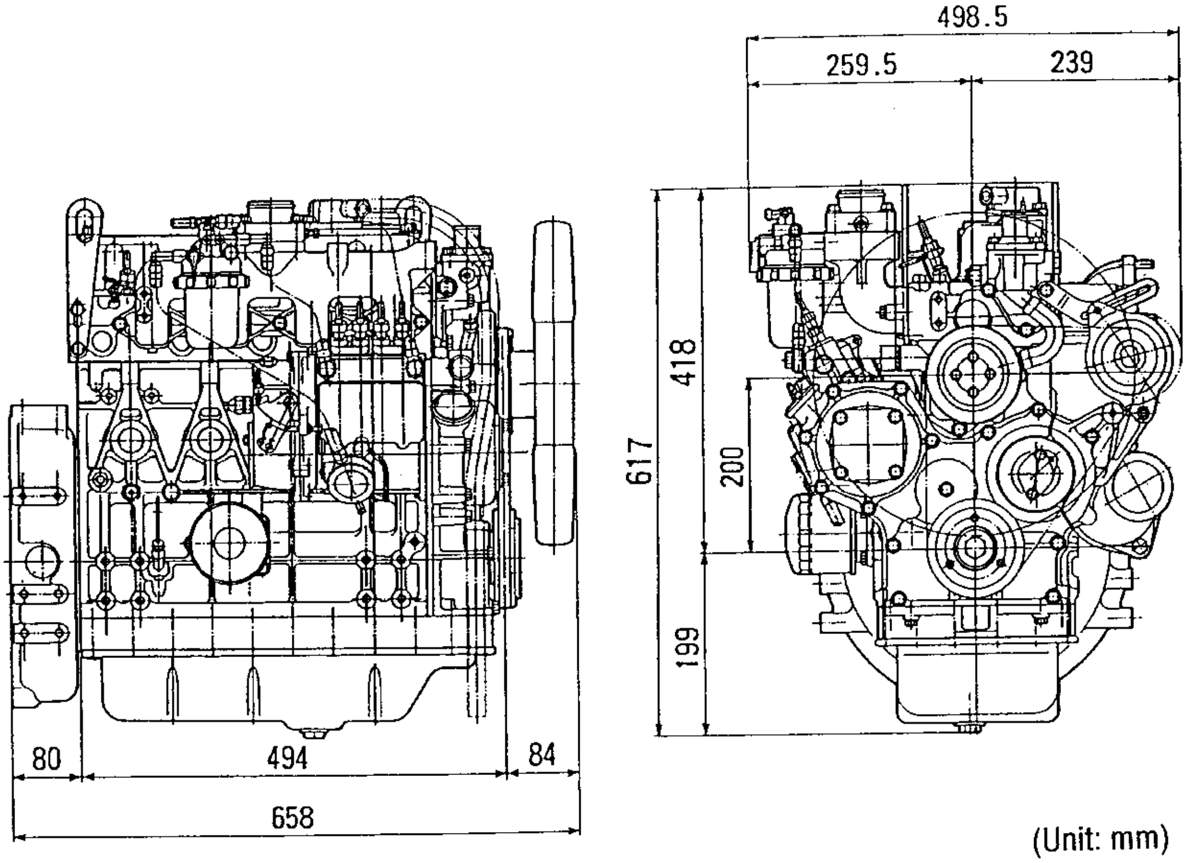
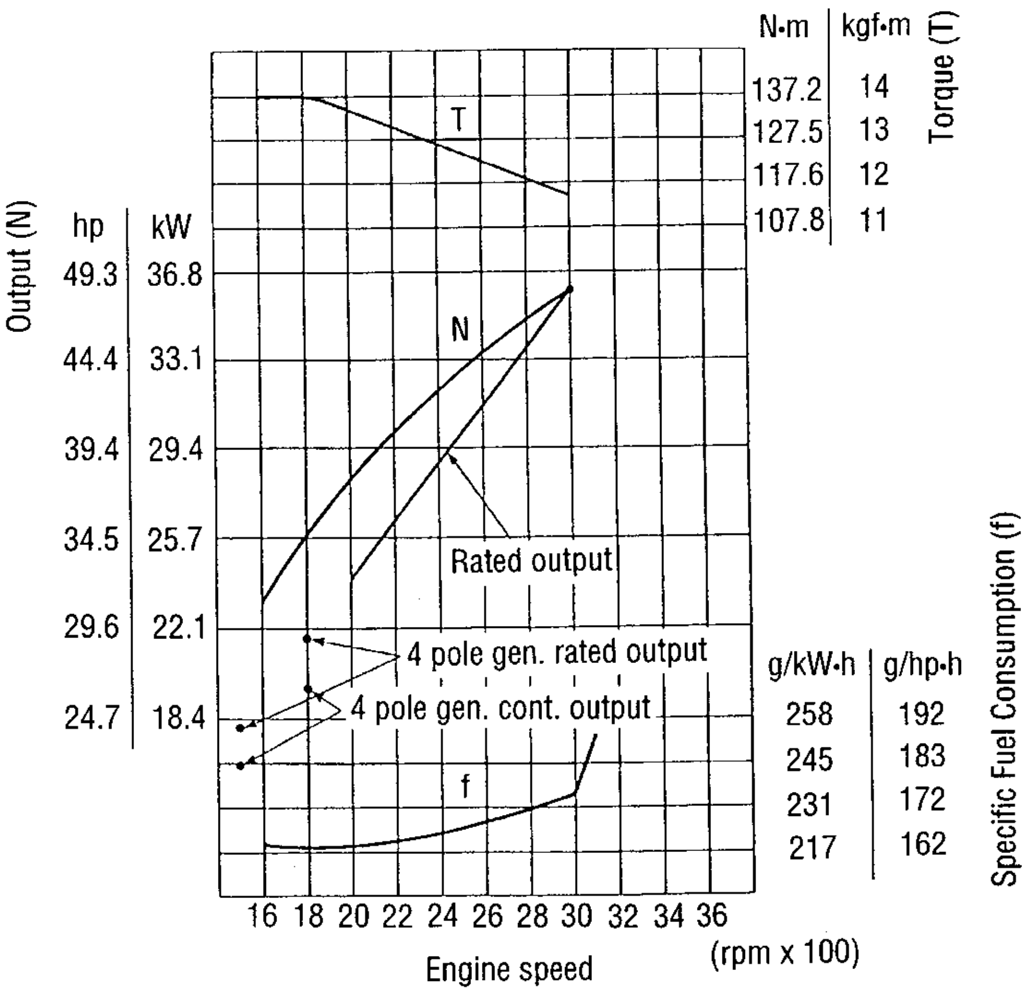
14. 4TNE88



(Unit: mm)



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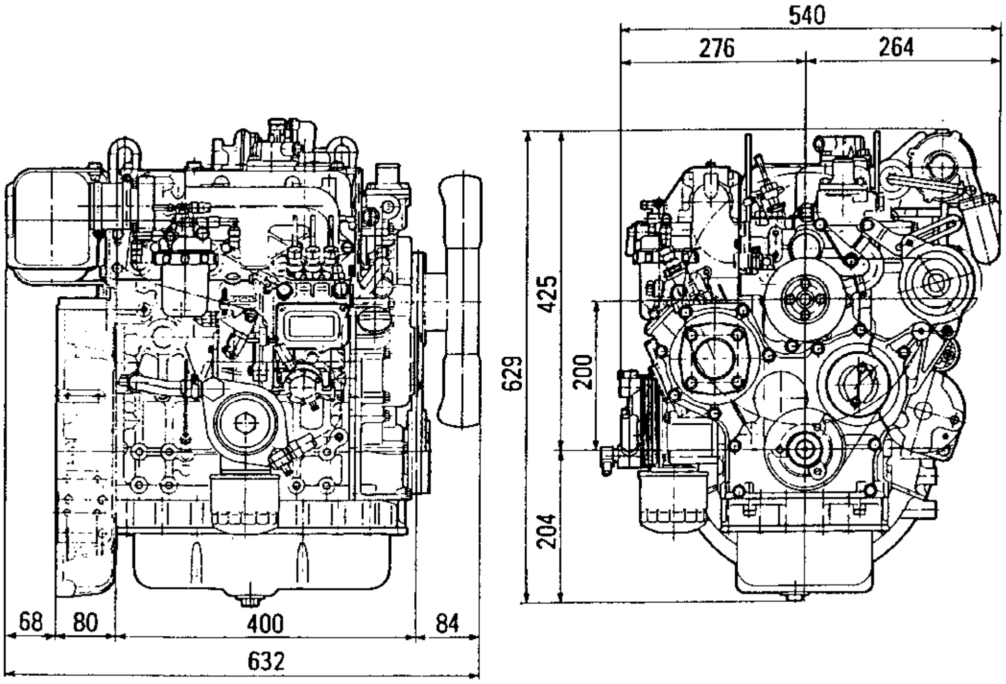
15. 3TNE84T

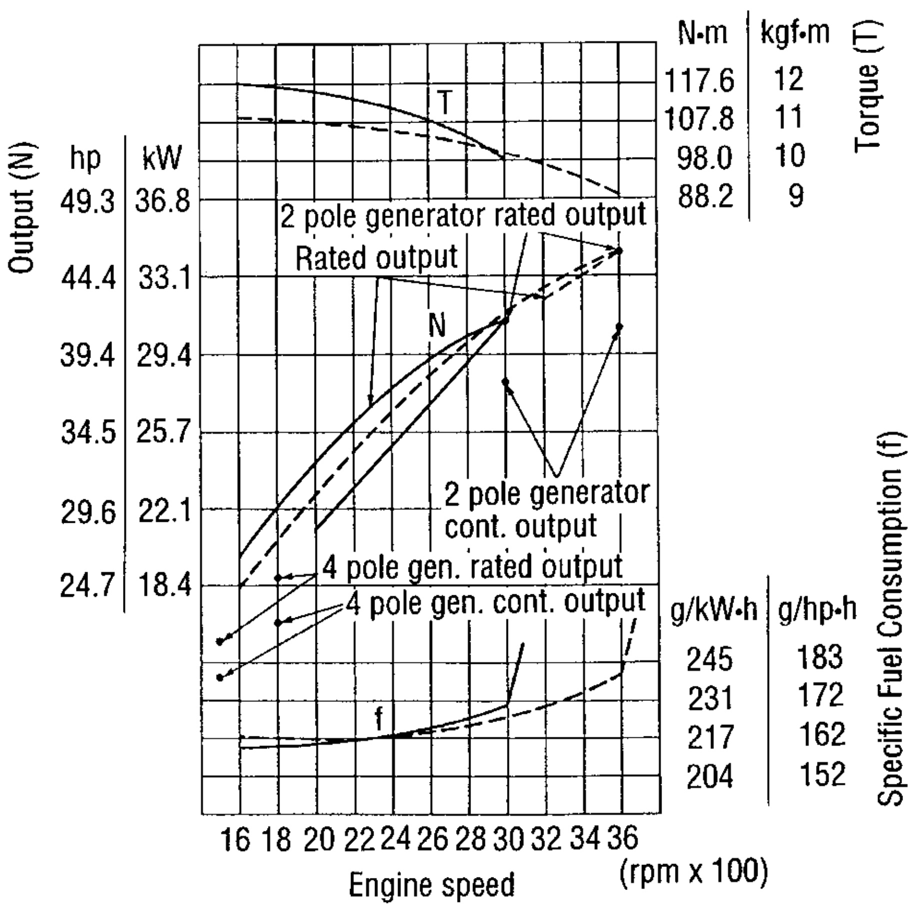
Engine model				3TNE84T													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	3 – 84 × 90													
4	Displacement		liter	1.496													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	3600	3200	3400	3600
	Output	Cont. rating	kW (hp)	14.0 (18.8)	16.5 (22.1)								27.9 (37.4)	30.5 (40.9)			
		Rated output	kW (hp)	15.8 (21.2)	18.8 (25.2)	21.0 (28.2)	22.8 (30.6)	25.0 (33.5)	25.7 (34.5)	26.8 (35.9)	29.1 (39.0)	30.9 (41.4)	30.9 (41.4)	34.2 (45.9)	32.0 (42.9)	33.1 (44.4)	34.2 (45.9)
6	Maximum idling speed		rpm ±50	1600	1895	2200	2420	2615	2725	2835	2050	3270	3175	3770	3425	3640	3850
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)	≦245 (183)	≦258 (192)			
8	Exhaust gas temp.		℃	≦470	≦480	≦530	≦540	≦550	≦560	≦565	≦590	≦610		≦640	≦630		≦640
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	10		12		14			16		19				
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Turbocharged aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.2 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)		410^{+100}_{-50} ($4.2^{+1.0}_{-0.5}$)						440^{+100}_{-50} ($4.5^{+1.0}_{-0.5}$)					
		Idling speed	kPa (kgf/cm²)														
22	Oil pan capacity	Full	liter	7.2		4.8							7.2				
		Useful	liter	3.5		1.9							3.5				
23	Cooling water capacity		liter	2.0													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – φ335 × 6 (ID mark: NF)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	φ120 / φ90		φ110 / φ110											

Note: This table is subject to change for performance improvement.

15. 3TNE84T



(Unit: mm)



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16. 4TNE84T

Engine model				4TNE84T													
Engine classification				CL		VM							CH		VH		
1	Type		—	Vertical, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	4 – 84 × 90													
4	Displacement		liter	1.995													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500	2600	2800	3000	3000	*3600	*3200	*3400	*3600
	Output	Cont. rating	kW (hp)	19.1 (25.6)	24.3 (32.6)								37.1 (49.8)	40.8 (54.7)			
		Rated output	kW (hp)	21.3 (28.6)	26.9 (36.1)	27.9 (37.4)	30.5 (40.9)	33.5 (44.9)	34.2 (45.9)	35.7 (47.9)	38.6 (51.8)	41.2 (55.3)	41.2 (55.3)	45.6 (61.2)	42.7 (57.3)	44.1 (59.1)	45.6 (61.2)
6	Maximum idling speed		rpm ±50	1600	1895	2200	2420	2590	2700	2810	2995	3210	3175	3770	3425	3640	3850
7	Specific fuel consumption		g/kWh (g/hph)	≦238 (177)					≦245 (183)			≦252 (188)	≦245 (183)	≦258 (192)			
8	Exhaust gas temp.		℃	≦480		≦510	≦520	≦530	≦540	≦550	≦570	≦590		≦610	≦600		
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	12				14			16		19				
11	Fuel injection pressure		kPa (kgf/cm²)	19600^{+980}_{0} (200^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Turbocharged aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/1.4 kW, Standard spec.)													
19	Charging system		—	Dynamo (Nominal rating 12 VDC/15 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/400 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340^{+100}_{-50} ($3.5^{+1.0}_{-0.5}$)		410^{+100}_{-50} ($4.2^{+1.0}_{-0.5}$)							440^{+100}_{-50} ($4.5^{+1.0}_{-0.5}$)				
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter	8.6		5.8							8.6				
		Useful	liter	4.2		2.3							4.2				
23	Cooling water capacity		liter	2.7													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ370× 6 (ID mark: EF)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ120 / ϕ90		ϕ110 / ϕ110											

Note: This table is subject to change for performance improvement.
Please take contact with Yanmar beforehand for the output range marked ∗.

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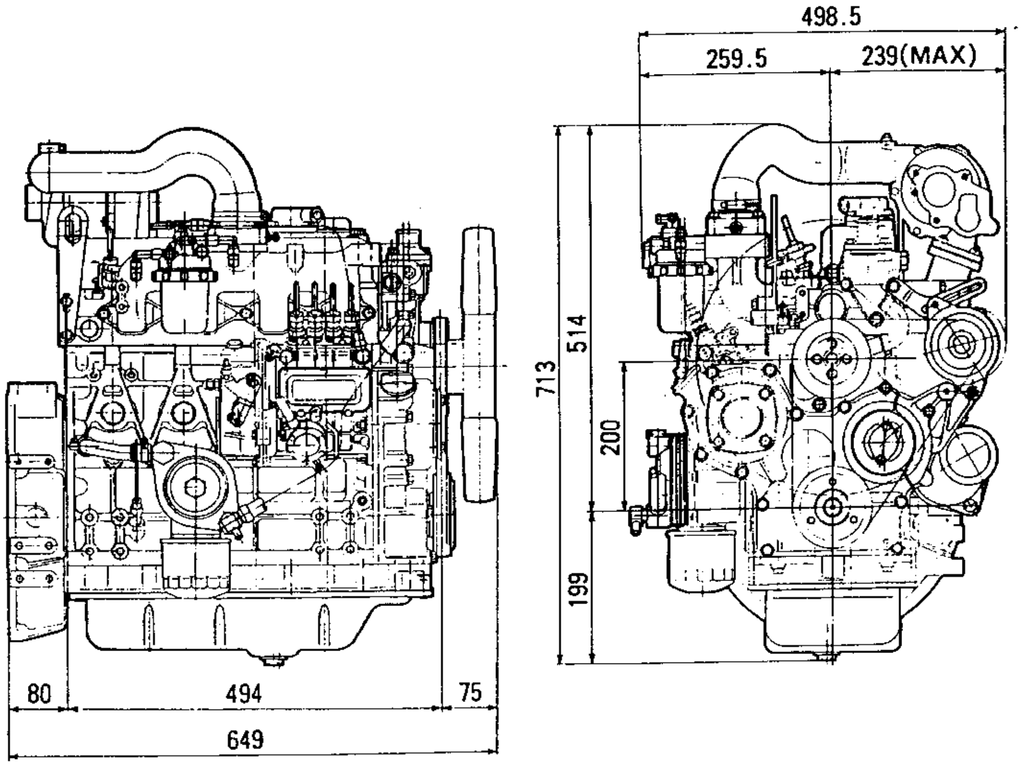
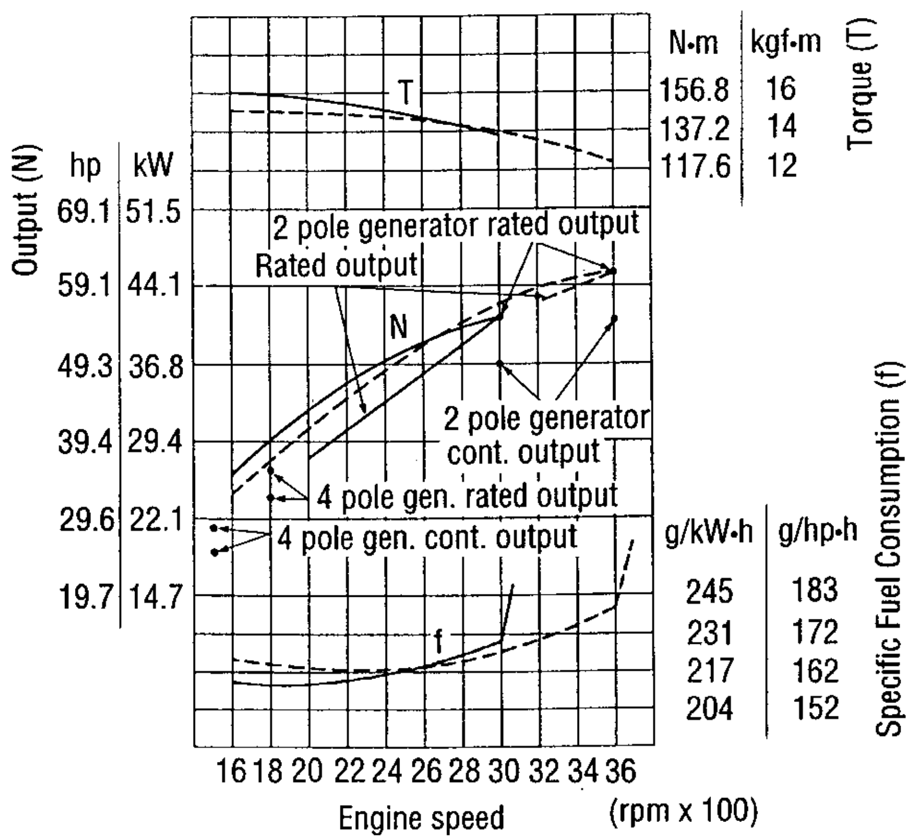
16. 4TNE84T



(Unit: mm)



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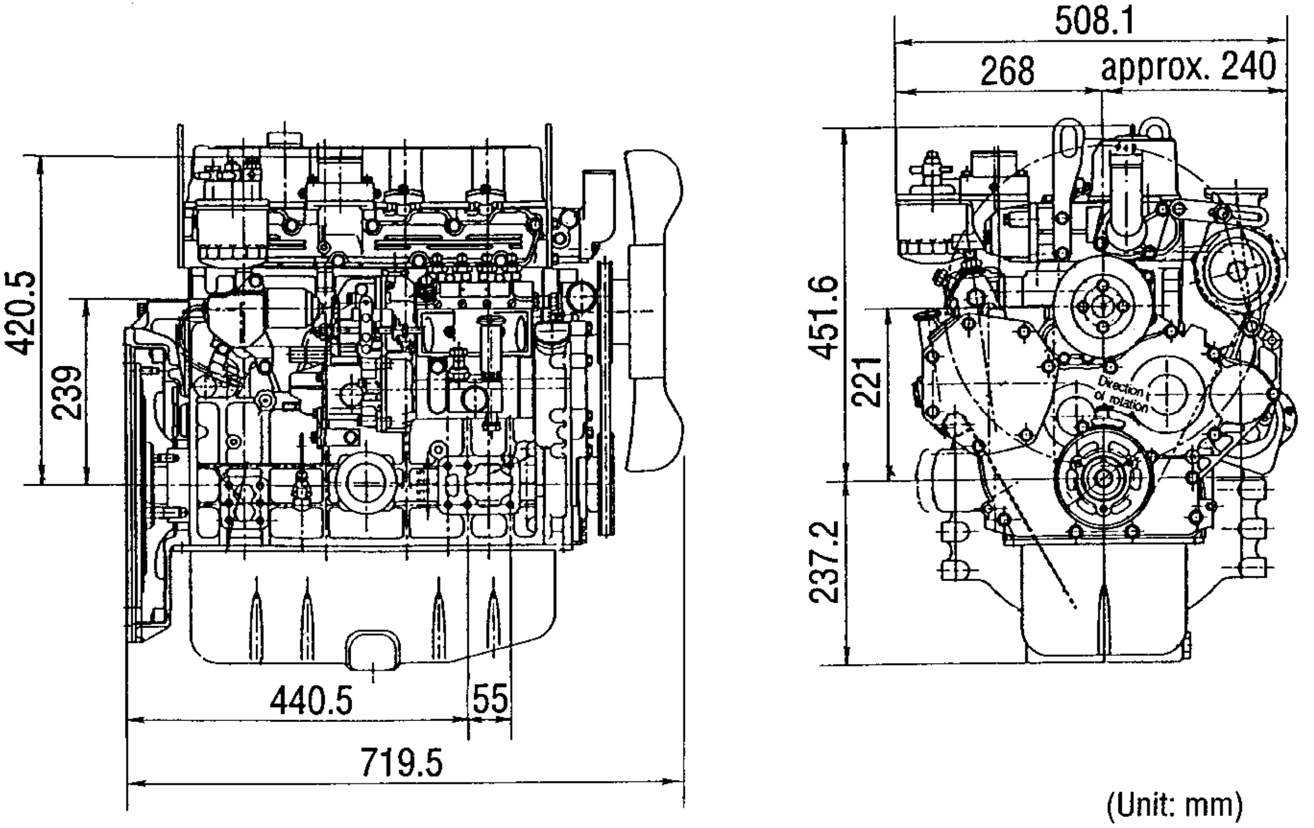
17. 4TNE94

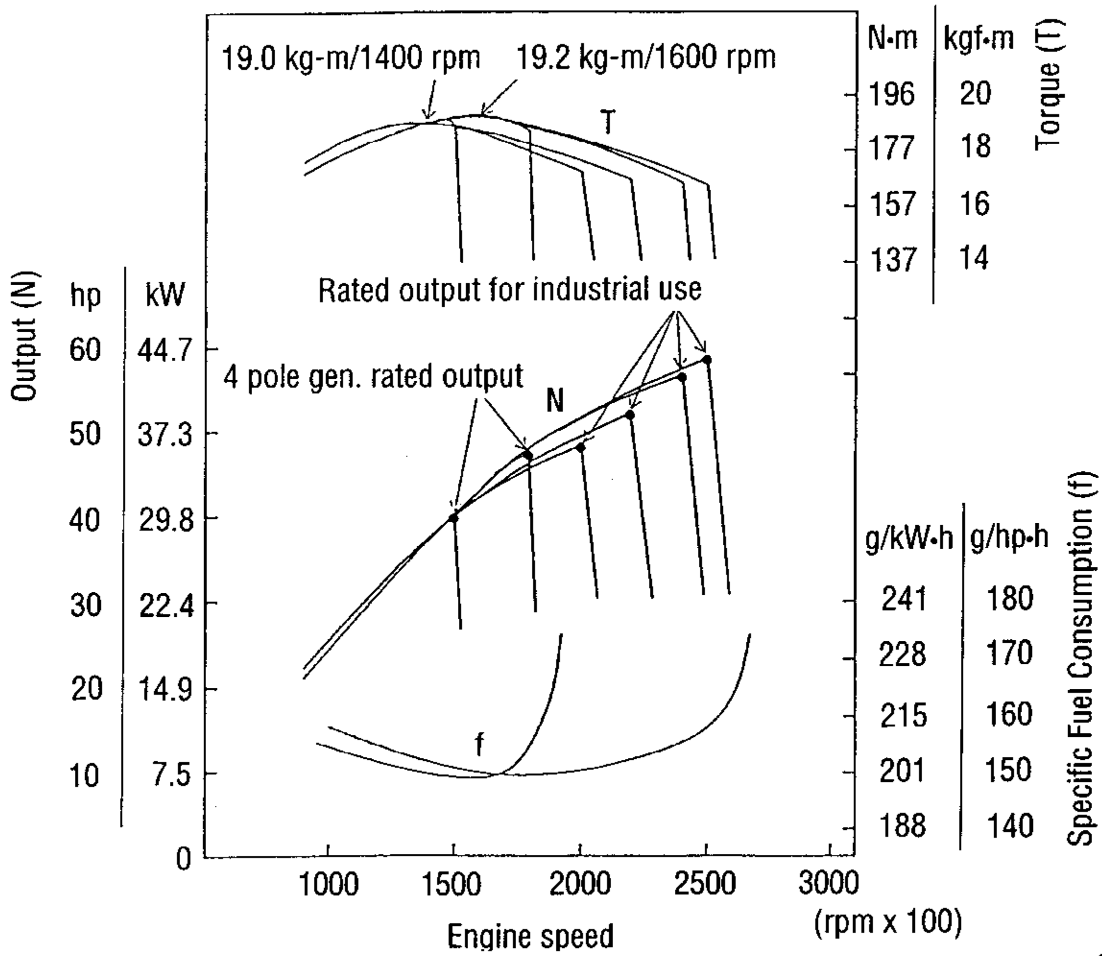
Engine model				4TNE94													
Engine classification				CL		VM				CH				VH			
1	Type		—	Vertical, in-line, 4-cycle water-cooled diesel engine													
2	Combustion system		—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke		n – mm × mm	4 – 94 × 100													
4	Displacement		liter	2.776													
5	Rated engine speed		rpm	1500	1800	2000	2200	2400	2500								
	Output	Cont. rating	kW (hp)	26.1 (35.0)	31.3 (42.0)												
		Rated output	kW (hp)	29.1 (39.0)	34.6 (46.4)	35.3 (47.3)	38.2 (51.2)	41.6 (55.8)	43.0 (57.7)								
6	Maximum idling speed		rpm ±50	1575	1872	2180	2398	2592	2700								
7	Specific fuel consumption		g/kWh (g/hph)	≦224 (167)		≦231 (172)		≦238 (177)									
8	Exhaust gas temp.		℃	≦610		≦580	≦590	≦610									
9	Compression ratio		—	18.0													
10	Fuel injection timing		bTDC (FID)°	11													
11	Fuel injection pressure		kPa (kgf/cm²)	21560^{+980}_{0} (220^{+10}_{0})													
12	Main shaft side		—	Flywheel side													
13	Rotation direction		—	Counterclockwise (Viewed from flywheel side)													
14	Governor		—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration		—	Natural aspiration													
16	Cooling system		—	Force-feed circulation radiator type cooling system													
17	Lubricating system		—	Forced lubrication with trochoid pump													
18	Starting system		—	Electric starting (Starting motor 12 VDC/2.3 kW, Standard spec.)													
19	Charging system		—	Alternator (Nominal rating 12 VDC/40 A, Standard spec.)													
20	Starting aid device		—	Air heater (12 VDC/500 W, Standard spec.)													
21	Lube oil pressure	Rated speed	kPa (kgf/cm²)	340±49 (3.5±0.5)													
		Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity	Full	liter	9.4													
		Useful	liter	4.4													
23	Cooling water capacity		liter	4.2													
24	Cooling fan type – dia. × No. of blades		mm	Pusher – ϕ410 × 6 (ID mark: AI)													
25	Crank V pulley dia./ Fan V pulley dia.		mm/mm	ϕ130 / ϕ130													

Note: This table is subject to change for performance improvement.

17. 4TNE94



(Unit: mm)



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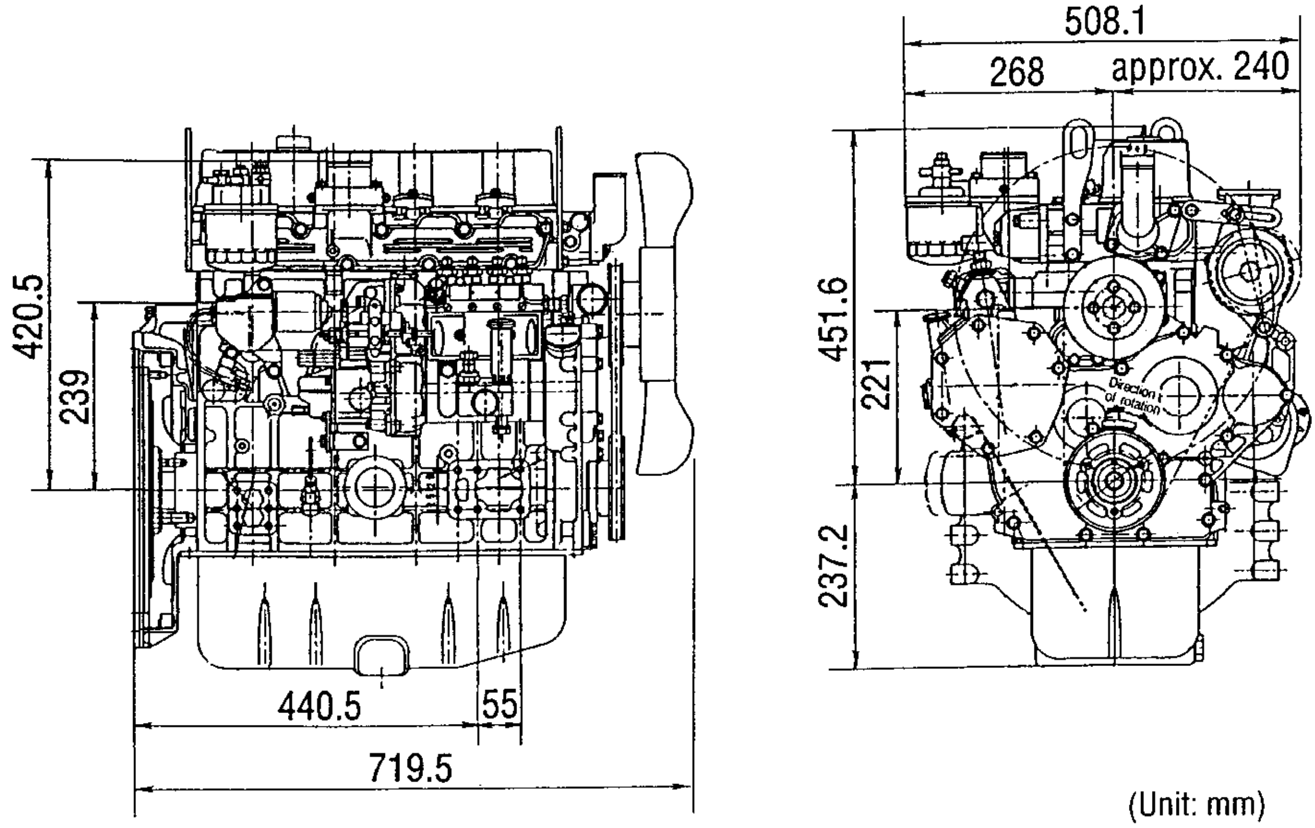
18. 4TNE98

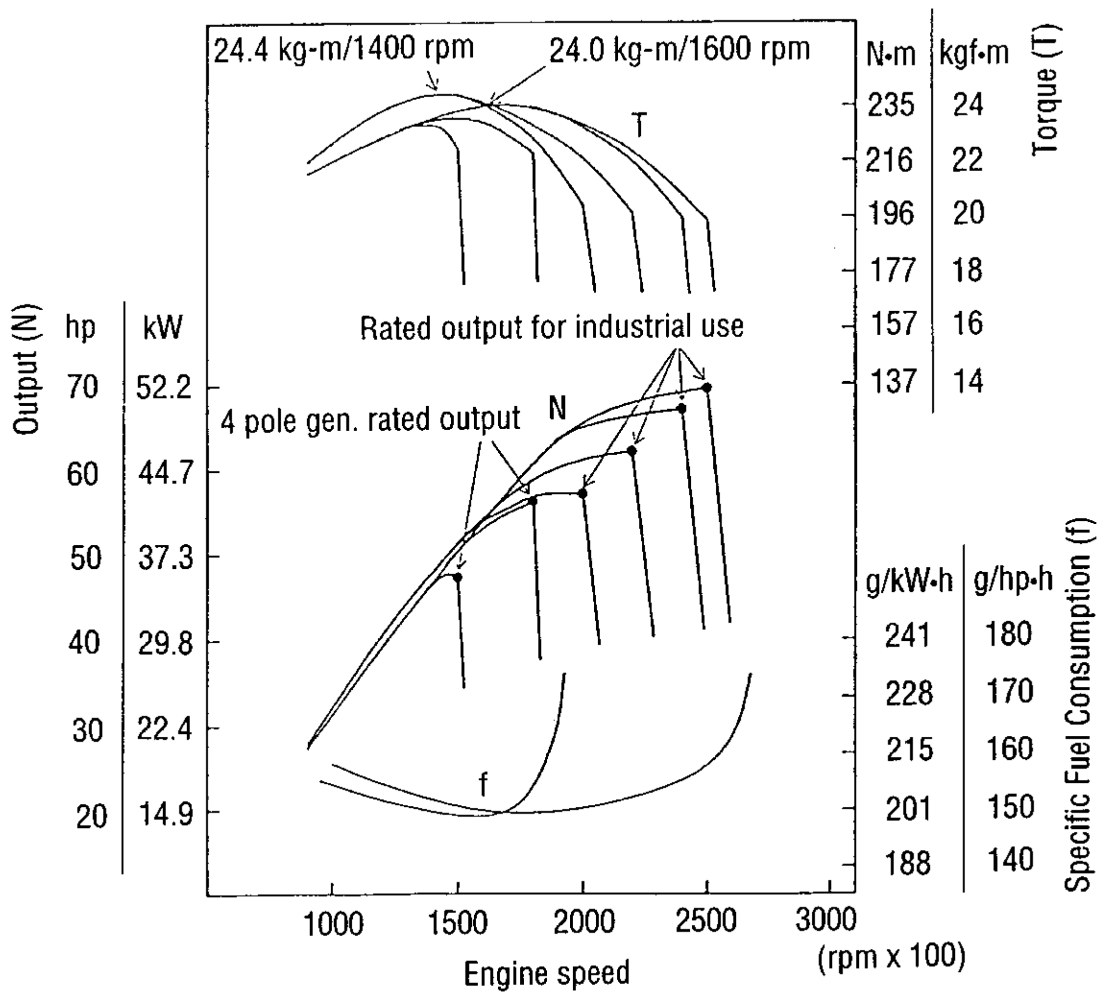
No.	Item	Unit	CL		VM				CH				VH			
	Engine model		4TNE98													
1	Type	—	Vertical, in-line, 4-cycle water-cooled diesel engine													
2	Combustion system	—	Direct injection (DI)													
3	No. of cylinders – Bore × Stroke	n – mm × mm	4 – 98 × 110													
4	Displacement	liter	3.319													
5	Rated engine speed	rpm	1500	1800	2000	2200	2400	2500								
	Output – Cont. rating	kW (hp)	30.9 (41.4)	36.8 (49.3)												
	Output – Rated output	kW (hp)	34.6 (46.4)	41.2 (55.3)	41.9 (56.2)	45.6 (61.2)	49.3 (66.1)	51.1 (68.5)								
6	Maximum idling speed	rpm ±50	1575	1872	2180	2398	2592	2700								
7	Specific fuel consumption	g/kWh (g/hph)	≦224 (167)													
8	Exhaust gas temp.	℃	≦510	≦540	≦550	≦590	≦610	≦630								
9	Compression ratio	—	18.0													
10	Fuel injection timing	bTDC (FID)°	11													
11	Fuel injection pressure	kPa (kgf/cm²)	21560^{+980}_{0} (220^{+10}_{0})													
12	Main shaft side	—	Flywheel side													
13	Rotation direction	—	Counterclockwise (Viewed from flywheel side)													
14	Governor	—	Mechanical centrifugal governor (All-speed governor)													
15	Aspiration	—	Natural aspiration													
16	Cooling system	—	Force-feed circulation radiator type cooling system													
17	Lubricating system	—	Forced lubrication with trochoid pump													
18	Starting system	—	Electric starting (Starting motor 12 VDC/2.3 kW, Standard spec.)													
19	Charging system	—	Alternator (Nominal rating 12 VDC/40 A, Standard spec.)													
20	Starting aid device	—	Air heater (12 VDC/500 W, Standard spec.)													
21	Lube oil pressure – Rated speed	kPa (kgf/cm²)	340±49 (3.5±0.5)													
	Lube oil pressure – Idling speed	kPa (kgf/cm²)	—													
22	Oil pan capacity – Full	liter	9.4													
	Oil pan capacity – Useful	liter	4.4													
23	Cooling water capacity	liter	4.2													
24	Cooling fan type – dia. × No. of blades	mm	Pusher – ϕ410 × 6 (ID mark: AI)													
25	Crank V pulley dia./ Fan V pulley dia.	mm/mm	ϕ130 / ϕ130													

Note: This table is subject to change for performance improvement.

18. 4TNE98



(Unit: mm)



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4. Correcting Observed Power

The engine output basically depends on the oxygen concentration in the air, and the oxygen concentration varies with the atmospheric conditions such as the atmospheric pressure, atmospheric temperature and relative humidity.
When discussing the engine output, it is important to specify the atmospheric conditions. Conversely, the maximum level of engine output at a given atmospheric pressure, atmospheric temperature and relative humidity is also important when considering the engine output. The output correction formula shows the relationship between these atmospheric conditions and the engine output. Also note that the applicable formula varies with the degree of difference between the actual and standard conditions. The concept and formulas are the same in the JIS and ISO.

4-1 Power Corrections

Two power correction formulas are provided as follows for selection according to the actual or specified atmospheric conditions:

(1) Use the power correction formula (A) in section 4-1-1 when the atmospheric conditions are judged to be relatively close to the standard conditions:

Engine inlet air temperature:
283 to 313K (10 to 40℃)

Dry inlet air pressure
(may simply be regarded as atmospheric pressure):
80 to 110 kPa (at 2,000 m or less in altitude)
(600 to 825 mmHg)

Correction factor *k*:
0.9 to 1.1 (See calculation in section 4-1-1(3).)

Standard atmospheric conditions:
298K (25℃)
100 kPa
(750 mmHg)

(2) Use the power calculation formula (B) in section 4-1-2 when the atmospheric conditions are much different from the standard conditions.

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4-1-1 Correction formula (A):

When the actual test conditions are judged to be relatively close to the standard atmospheric conditions.

(1) Obtain atmospheric factor *fa*. This factor is calculated by either of the two formulas shown below for selective use according to whether the turbocharger is provided or not.

(a) For naturally aspirated engine

$$fa = \left(\frac{Pr - \Phi r \cdot Psr}{Px - \Phi x \cdot Psx} \right) \left(\frac{Tx}{Tr} \right)^{0.7}$$

(b) For turbocharged engine

$$fa = \left(\frac{Pr - \Phi r \cdot Psr}{Px - \Phi x \cdot Psx} \right)^{0.7} \left(\frac{Tx}{Tr} \right)^{1.5}$$

Subscript r represents the value under standard conditions, and x the value under actual test conditions.

Pr	:	Standard atmospheric pressure	100	kPa	(750 mmHg)
Φr	:	Relative humidity under standard conditions	0.30		(30%)
Tr	:	Inlet air temperature under standard conditions	298	K	(25℃)
Psr	:	Saturation vapor pressure under standard conditions (Obtain from the table in 4-6.)	3.172	kPa	(23.80 mmHg)
Px	:	Atmospheric pressure under actual test conditions		kPa	(mmHg)
Φx	:	Relative humidity under actual test conditions		%	%
Tx	:	Inlet air temperature under actual test conditions		K	(℃)
Psx	:	Saturation vapor pressure under actual test conditions (Obtain from the table in 4-6.)		kPa	(mmHg)

Pay attention to the unit of each value in actual calculation.
If kPa (kilo Pascal) is used for standard atmospheric pressure Pr, all of Psr, Px and Psx must also be expressed in kPa. Similarly when mmHg is used, all other pressures must be expressed in mmHg.

Always use absolute temperature in K (Kelvin without degrees (°)) for representing the inlet air temperatures Tr and Tx. The relationship between °C on ordinary thermometers and absolute temperature K is as follows:

$$K = 273 + {}^{\circ}C$$

(2) Obtain engine factor *fm*

Engine factor *fm* for each engine should be calculated in a matching test for which high precision is required. In most cases, however, the important point is how the rated output changes under the actual test conditions. Use of *fm* predicted by using the rated output and empirical average specific fuel consumption as shown below will cause no practical problem.

Engine Factor: *fm* at Rated Output of TNE Engines

Model	Rated speed (rpm)													
	For industrial use										For generators			
	2000	2200	2400	2500	2600	2800	3000	3200	3400	3600	1500	1800	3000	3600
2TEN68	0.402	0.414	0.428	0.448	0.467	0.483	0.499				—	—	0.605	0.719
3TNE68	0.481	0.508	0.530	0.549	0.569	0.598	0.637	0.576	0.587	0.636	—	—	0.619	0.725
3TNE74	0.497	0.533	0.551	0.560	0.560	0.587	0.605	0.563	0.577	0.569	—	—	0.667	0.712
2TNE68-N	0.402	0.414	0.428	0.448	0.467	0.483	0.499				—	—	0.605	0.719
3TNE66-N	0.411	0.424	0.456	0.473	0.494	0.511	0.590	0.544	0.578	0.632	—	—	0.573	0.649
3TNE68-N	0.481	0.508	0.530	0.549	0.569	0.598	0.637	0.576	0.587	0.636	—	—	0.619	0.725
3TNE72-N	0.446	0.473	0.494	0.495	0.506	0.526	0.546	0.549	0.572	0.564	—	—	0.607	0.572
3TNE74-N	0.497	0.533	0.551	0.560	0.560	0.587	0.605	0.563	0.577	0.569	—	—	0.667	0.712
3TNE78A	0.313	0.331	0.331	0.353	0.375	0.403	0.403				0.349	0.376	0.358	0.395
3TNE82A	0.305	0.335	0.345	0.355	0.364	0.401	0.411				0.300	0.300	—	—
3TNE84	0.318	0.331	0.347	0.364	0.381	0.411	0.454				0.324	0.338	0.374	0.468
3TNE88	0.319	0.349	0.337	0.359	0.375	0.369	0.429				0.366	0.385	—	—
4TNE84	0.300	0.300	0.300	0.309	0.319	0.347	0.393				0.300	0.300	0.348	0.395
4TNE88	0.300	0.304	0.320	0.331	0.339	0.375	0.427				0.300	0.311	—	—
3TNE84T	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
4TNE84T	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
4TNE94	0.427	0.414	0.448	0.459	—	—	—	—	—	—	0.614	0.599	—	—
4TNE98	0.416	0.409	0.435	0.449	—	—	—	—	—	—	0.605	0.593	—	—

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(3) Obtain correction factor k.

$$k = fa^{fm}$$

Proceed with the calculation if the value of k satisfies the condition $0.9<k<1.1$.

(4) Obtain the corrected output under the actual test conditions.

$$P = P_0 / k$$

Where,

P_0	:	Rated output under standard atmospheric conditions	(kW)
P	:	Output under actual test conditions	(kW)
k	:	Correction factor	

> Example:
>
> The rated output of the 3TNE88 engine under standard atmospheric conditions is 27.1 kW at 3,000 rpm.
> What will be the output under actual test conditions of 98 kPa (approx. 200 m), inlet air temperature of 313K (40℃), atmospheric temperature of 309K (36℃) and relative humidity of 40%?

First determine the power correction formula to be applied according to section 4-1(1) or (2).

Since the engine inlet air temperature and atmospheric pressure are in the ranges of 10 to 40℃ and 80 to 110 kPa, respectively, the correction formula (A) in section 4-1-1 applies.
The atmospheric temperature is not taken into consideration in selecting the power correction formula to be applied.

Pr	:	Standard atmospheric pressure	100	kPa	(750 mmHg)
Φr	:	Relative humidity under standard conditions	0.30		(30%)
Tr	:	Inlet air temperature under standard conditions	298	K	(25℃)
Psr	:	Saturation vapor pressure under standard conditions (Obtain from the table in section 4-6.)	3.172	kPa	(23.80 mmHg)
Px	:	Atmospheric pressure under actual test conditions	98	kPa	
Φx	:	Relative humidity under actual test conditions	0.40		(40%)
Tx	:	Inlet air temperature under actual test conditions	313	K	(40℃)
Psx	:	Saturation vapor pressure under actual test conditions (Obtain from the table in section 4-6.)	7.377	kPa	

(1) Obtain atmospheric factor *fa*. Since 3TNE88 is a naturally aspirated engine,

$$fa = \left(\frac{Pr - \Phi r \cdot Psr}{Px - \Phi x \cdot Psx}\right)\left(\frac{Tx}{Tr}\right)^{0.7}$$

$$= \left(\frac{100 - 0.30 \times 3.172}{98 - 0.40 \times 7.377}\right)\left(\frac{313}{298}\right)^{0.7}$$

$$= \left(\frac{99.3484}{95.4492}\right) \times 1.0350$$

$$= 1.0773$$

(2) Obtain engine factor *fm*.
It is 0.429 for 3TNE88 at 3,000 rpm from the engine factor table.

(3) Obtain correction factor *k*.

$k = fa^{fm} = 1.0773^{0.429} = 1.0325$

Since this value of *k* satisfies the condition $0.9 < k < 1.1$ for application of the example formula, proceed with the calculation.

(4) Obtain the corrected output under the actual test conditions as follows:

$P = P_0 / k = 27.1 / 1.0325$
$= 26.2$ kW

Therefore, the output is down by 0.9 kW or approx. 3.3% in this example.

4-1-2 Correction formula (B)

When the actual test conditions are very different from the standard atmospheric conditions.

(1) First obtain the *K* value expressed as follows for the cases with and without the turbocharger.

(a) For naturally aspirated engine

$$K = \left(\frac{Px - \Phi x \cdot Psx}{Pr - \Phi r \cdot Psr} \right) \left(\frac{Tr}{Tx} \right)^{0.75}$$

(b) For turbocharged engine

$$K = \left(\frac{Px}{Pr} \right)^{0.7} \left(\frac{Tr}{Tx} \right)^{2.0}$$

Subscripts r and x represent the values under standard conditions and actual test conditions, respectively.

Pr	:	Standard atmospheric pressure	100	kPa	(750 mmHg)
Φr	:	Relative humidity under standard conditions	0.30		(30%)
Tr	:	Inlet air temperature under standard conditions	298	K	(25℃)
Psr	:	Saturation vapor pressure under standard conditions (Obtain from the table in section 4-6.)	3.172	kPa	(23.80 mmHg)
Px	:	Atmospheric pressure under actual test conditions		kPa	(mmHg)
Φx	:	Relative humidity under actual test conditions		%	%
Tx	:	Inlet air temperature under actual test conditions		K	(℃)
Psx	:	Saturation vapor pressure under actual test conditions (Obtain from the table in section 4-6.)		kPa	(mmHg)

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(2) Obtain correction factor α as follows:

$$\alpha = K - 0.7\,(1 - K)\,(1/\eta - 1) \qquad \eta = 0.8 \quad \text{(machine efficiency)}$$

$$= K - 0.175\,(1 - K)$$

(3) Obtain the corrected output under the actual test conditions.

$$P = \alpha \cdot P_0$$

Where,

P_0	:	Rated output under standard conditions	kW
P	:	Output under actual test conditions	kW
α	:	Correction factor	

> Example:
>
> The rated output of the 3TNE88 engine under standard conditions is 27.1 kW at 3,000 rpm. What will be the output under actual test conditions of any atmospheric state, 90 kPa (approx. 1000 m), inlet air temperature of 323K (50℃), atmospheric temperature of 313K (40℃) and relative humidity of 80%?

First study which power correction formula is to be applied according to section 4-1(1) or (2).

Since the atmospheric pressure is in the range of 80 to 110 kPa but the engine inlet air temperature is far above the range of 10 to 40℃, the correction formula (B) in section 4-1-2 applies.

The atmospheric temperature is not taken into consideration in studying application of the power correction formula.

Pr	:	Standard atmospheric pressure	100	kPa	(750 mmHg)
Φr	:	Relative humidity under standard conditions	0.30		(30%)
Tr	:	Inlet air temperature under standard conditions	298	K	(25℃)
Psr	:	Saturation vapor pressure under standard conditions (Obtain from the table in section 4-6.)	3.172	kPa	(23.80 mmHg)
Px	:	Atmospheric pressure under actual test conditions	90	kPa	(675 mmHg)
Φx	:	Relative humidity under actual test conditions	0.8		(80%)

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Tx	:	Inlet air temperature under actual test conditions	323 K	(50℃)
Psx	:	Saturation vapor pressure under actual test conditions (Obtain from the table in section 4-6.)	12.338 kPa	(92.56 mmHg)

(1) First obtain the K-value. Since the 3TNE88 is a naturally aspirated engine,

$$K = \left(\frac{Px - \Phi x \cdot Psx}{Pr - \Phi r \cdot Psr}\right)\left(\frac{Tr}{Tx}\right)^{0.75}$$

$$= \left(\frac{90 - 0.80 \times 12.338}{100 - 0.30 \times 3.172}\right)\left(\frac{298}{323}\right)^{0.75}$$

$$= \left(\frac{80.9296}{99.3484}\right) \times 0.9414$$

$$= 0.7669$$

(2) Obtain correction factor α as follows:

$$\alpha = K - 0.175\ (1 - K) = 0.7669 - 0.175\ (1 - 0.7669)$$

$$= 0.7669 - 0.0408 = 0.7261$$

(3) Obtain the corrected output under the actual test conditions as follows:

$$P = \alpha \cdot P_0 = 0.7261 \times 27.1$$
$$= 19.7\ \text{kW}$$

Therefore, the output is down by 7.4 kW or approx. 27.4% in this example.

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4-1-3 Corrections for reducing exhaust smoke density

The power correction explained so far is based on the physical phenomenon that the oxygen concentration in the air decreases under certain atmospheric conditions to cause incomplete combustion and hence a drop in output. In such cases, a decrease in output due to incomplete combustion and resultant worsening of the exhaust smoke density may be inevitable.

To prevent the engine exhaust smoke density from worsening, it is necessary to decrease the fuel to match the decreased oxygen concentration. Decreasing the fuel injection volume means a corresponding decrease in output. It is, therefore, necessary to add power correction for reducing exhaust smoke density to the power correction calculated before, and to keep the required output of the driven machine under the corrected output level.

This study, however, is not for improving the exhaust smoke density at the time of starting or upon sudden change in the load.

The following empirical equation has been obtained in order to reduce the exhaust smoke density:

Power correction for reducing exhaust smoke density = 0.5% per each 100 m in altitude

This % should be added to the calculation result of power correction in section 4-1. Though the factors influencing worsening of exhaust smoke density are not limited to the altitude or the atmospheric pressure, the altitude is used instead of the atmospheric pressure because it has the greatest influence and simplifies the calculation.

Example:
The rated output of the 3TNE88 engine under standard conditions is 27.1 kW at 3,000 rpm. What will be the output under actual test conditions of 90 kPa (approx. 1000 m), inlet air temperature of 323K (50℃), and relative humidity of 80%? What will be the available output without worsening the exhaust smoke density?

The example is the same as that in section 4-1-2. The calculation result was down by 7.4 kW or approx. 27.4% in engine output. This means that the rated output under the standard conditions is 27.1 kW and that the exhaust smoke density is worsened though 19.7 kW is guaranteed under the above conditions.

To suppress worsening of exhaust smoke density, further correction for 1,000 m in altitude is necessary.

Correction for reducing exhaust smoke density
$$= 0.5\% \text{ for each 100 m in altitude} \times 1{,}000 \text{ m}$$
$$= 5\%$$

Therefore, the required output reduction is 27.4% + 5% = 32.4%.

In other words, the 3TNE88 engine can be operated without smoke generation provided the required output for the driven machine or the load does not exceed the following value:

$$27.1 - 27.1 \times 0.324 = 18.2 \text{ kW}$$

4-2 Atmospheric Pressure Calculation for Change in Altitude

$Px = Pr\,(1 - 0.00002257h)^{5.256}$

Where,

Px : Atmospheric pressure in kPa (mmHg) at h (m) above sea level
Pr : Standard atmospheric pressure 100 kPa (750 mmHg) at 0 (m) above sea level
h : Altitude (m)

4-3 Atmospheric Temperature Calculation for Change in Altitude

$Tx = Tr - 0.0065h$

Where,

Tx : Atmospheric temperature (℃) at h (m) above sea level
Tr : Standard atmospheric temperature (25℃) at 0 (m) above sea level
h : Altitude (m)

4-4 Relationships among Altitude, Atmospheric Pressure and Atmospheric Temperature

Altitude (m)	Atmospheric pressure kPa (mmHg)	Atmospheric temperature K (℃)
0	100 (750)	298 (25)
100	98.8 (741)	297.4 (24.4)
200	97.7 (732)	296.7 (23.7)
400	95.4 (716)	295.4 (22.4)
600	93.1 (698)	294.1 (21.1)
800	90.9 (682)	292.8 (19.8)
1000	88.7 (665)	291.5 (18.5)
1200	86.6 (650)	290.2 (17.2)
1400	84.5 (634)	288.9 (15.9)
1600	82.5 (619)	287.6 (14.6)
1800	80.5 (604)	286.3 (13.3)
2000	78.5 (589)	285 (12)
2500	73.7 (553)	281.8 (8.8)
3000	69.3 (520)	278.5 (5.5)
3500	65.0 (488)	275.3 (2.3)
4000	60.9 (457)	272 (−1)

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4-5 How to Obtain Relative Humidity by Dry and Wet-Bulb Thermometer

* *Relative humidity is given by the following table when the wet bulb is not frozen.*

Relative humidity (%)

Dry bulb tempe-rature K (t)	Difference between dry and wet bulb temperatures K–K' (t–t')																				
	(0.0)	(0.5)	(1.0)	(1.5)	(2.0)	(2.5)	(3.0)	(3.5)	(4.0)	(4.5)	(5.0)	(5.5)	(6.0)	(6.5)	(7.0)	(7.5)	(8.0)	(8.5)	(9.0)	(9.5)	(10.0)
313 (40)	100	97	94	91	88	85	82	79	76	73	71	68	66	63	61	58	56	53	51	49	47
308 (35)	100	97	93	90	87	83	80	77	74	71	68	65	63	60	57	55	52	49	47	44	42
303 (30)	100	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50	47	44	41	39	36
298 (25)	100	96	92	88	84	80	76	72	68	65	61	57	54	51	47	44	41	38	34	31	28
293 (20)	100	95	91	86	81	77	73	68	64	60	56	52	48	44	40	36	32	29	25	21	18
288 (15)	100	95	89	84	78	73	68	63	58	53	48	44	39	34	30	25	21	16	12	8	4
283 (10)	100	93	87	81	74	68	62	56	50	44	38	32	27	21	16	10	5				
278 (5)	100	92	84	76	68	60	53	46	38	31	24	16	9	2							
273 (0)	100	90	80	70	60	50	40	31	21	12	3										
268 (–5)	100	87	74	61	48	35	22	9													
263 (–10)	100	82	64	47	29	12															

K : Dry bulb temperature (Kelvin)
K' : Wet bulb temperature (Kelvin)
t : Dry bulb temperature (℃)
t' : Wet bulb temperature (℃)

4-6 Relationship between Atmospheric Temperature and Saturation Vapor Pressure

Atmospheric temperature K (℃)	Saturation vapor pressure kPa (mmHg)	Atmospheric temperature K (℃)	Saturation vapor pressure kPa (mmHg)
293 (20)	2.337 (17.53)	307 (34)	5.319 (39.90)
295 (22)	2.642 (19.82)	309 (36)	5.941 (44.57)
297 (24)	2.983 (22.38)	311 (38)	6.625 (49.70)
298 (25)	3.172 (23.80)	313 (40)	7.377 (55.34)
299 (26)	3.360 (25.21)	315 (42)	8.201 (61.52)
300 (27)	3.560 (26.74)	317 (44)	9.103 (68.29)
301 (28)	3.779 (28.35)	319 (46)	10.088 (75.68)
303 (30)	4.243 (31.83)	321 (48)	11.164 (83.75)
305 (32)	4.755 (35.67)	323 (50)	12.338 (92.56)

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4-7 Characteristics at High Altitude

As described earlier, the engine output drops as the altitude increases or the atmospheric pressure decreases, resulting in worsening of the exhaust smoke density.
Other problems at high altitudes are the engine startability, exhaust white smoke immediately after starting and misfire.

4-7-1 Startability at high altitude

Validation tests show that a decrease in the atmospheric pressure itself at high altitude has no direct influence on the engine startability. Rather, the startability is influenced more by the temperature. The lowering of startability at low temperatures is more pronounced as the altitude increases. The upper limit of altitude is determined, if anything, by the atmospheric temperature.

A rough guideline is shown determine below. Since various driven machines are connected to the engine, it is necessary to study the limit altitude for startability for each type of driven machine.

		Altitude (m)			
		1000	2000	3000	4000
Minimum startable temperature	K	243	248	253	263
	℃	–30	–25	–20	–10

See the startability section in Chapter 1 for the engine specifications for cold starting.

4-7-2 Exhaust white smoke at high altitude

Basically at an ordinary temperature, white smoke generation immediately after starting and the time until its disappearance increase as the altitude increases.

Assuming the warm-up time after starting to be 3 minutes, there is no practical problem up to the temperature of 263K (–10℃) and an altitude of 1,000 m.

At 253K (–20℃) and 3,000 m in altitude, white smoke generation decreases when the warm-up after starting reaches 5 minutes. Though there will be little practical problem if the engine is warmed up sufficiently, the following actions will be necessary for improvement.

Improvement methods for suppressing white smoke generation and for early disappearance:

(a) Use of fuel with high cetane number : 50 to 55 (normally 45)
(b) After-glow or after-heater : Current conduction for 5 minutes or more
(Continued current conduction to the glow plug or heater even after starting)
(c) Advancing fuel injection timing : 2 to 3 degrees advance/3,000 m or more

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4-7-3 Misfire at high altitude

The compression temperature at the time of starting rises to show excellent starting characteristics because of preheating despite the lowering of compression pressure at high altitudes. After starting, however, current conduction to the glow plug or air heater is cut off when the starting motor is set to off to decrease the intake air temperature and the compression temperature. As a result, delay in igniting the fuel injected into the cylinder occurs and causes misfire.

Misfire immediately after starting is likely to occur under the conditions of 263K (–10°C) and 1,000 m in altitude.

Misfire will usually be eliminated within 3 minutes by warming up. The warming-up operation should be continued when the atmospheric temperature is 253K (–20°C) or below and the altitude is 3,000 m or more.

Actions similar to those against white smoke generation in section 4-7-2 are required in order to reduce misfire.

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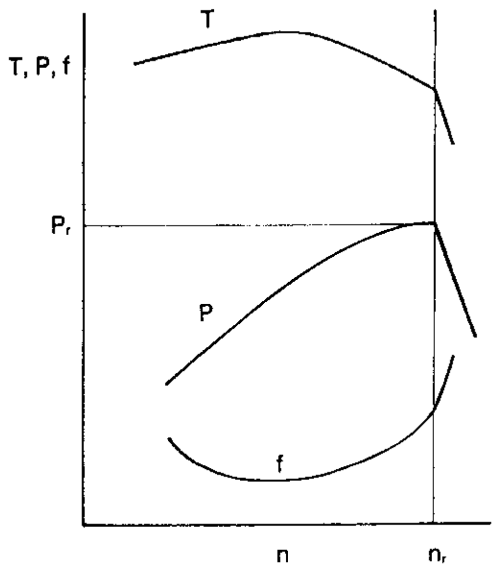
5. Performance

5-1 Performance Curves

Engine performance is generally expressed with three curves: output, specific fuel consumption and torque curves, as shown in the figure below:



T : Torque (N-m or kgf•m)

P : Output (kW)

f : Specific fuel consumption (g/kW•h)

n : Engine speed (rpm)

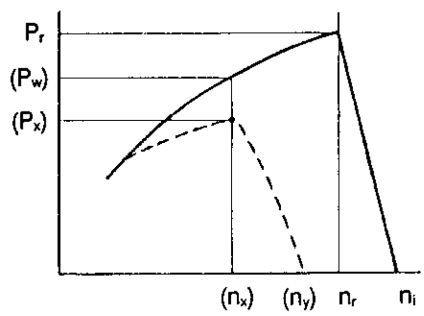
P_r : Rated output (kW)

n_r : Rated speed (rpm)

The engine performance curves represent the performance of an engine at rated speed n_r that produces rated output P_r. The output of the same engine at another speed cannot be read from these curves. Consequently, the performance curves shown in a catalog or this manual show a rated output only at a specific rated speed. If you need performance curves at other rated speeds, please contact Yanmar.

Each of the performance curves has the following meaning.

5-1-1 Output curve P



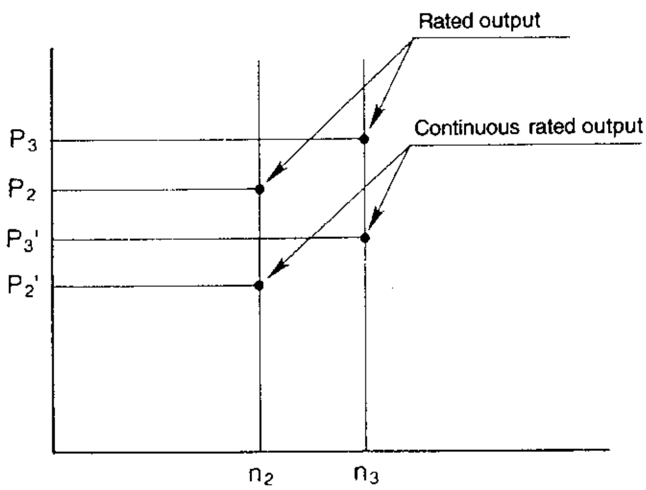
The figure to the left shows a performance curve of an engine set to rated speed n_r and rated output P_r. It shows that the maximum speed is n_i at no load.

For example, in the case of the output curve of a 3TNE84 diesel engine, it shows the no-load maximum speed n_i of 2810 rpm and the rated output P_r of 21.3 kW when the rated speed is set to 2600 rpm.

Care should be taken here that, from the performance curves of n_r and P_r, the rated output may be misunderstood to be (P_w) if the rated speed of this engine is set to (n_x). Supposing that we use this 3TNE84 engine at a rated speed (n_x) of 2400 rpm, for example, what kW will the rated output (P_x) be? From the list of outputs in section 2-3, the rated output will be 19.7 kW as per the performance curve shown in the broken line. The no-load maximum speed (n_y) is 2590 rpm from the specification tables in section 3-2 for 3TNE84.

For the rated output at various rated speeds of engine, refer to the catalog and/or the specifications of this manual.

The output curves show the respective rated output of a 2P (or 4P) generator and continuous output with the arrows. They apply to engines exclusively used for driving generators.



Generators are often driven continuously under load. The output to meet this demand is termed the continuous rated output. The rated output of an applicable generator is determined to be equivalent to or below the continuous rated output of the engine (P'_2, P'_3). Moreover, generators are frequently required to stand a 10% overload of the rated output for one hour. Thus the maximum engine output to stand this requirement will be the rated output (P_2, P_3).

The rated engine speeds of n_2, n_3 correspond to the generator frequencies of 50 Hz and 60 Hz and the generator frequency is fixed to 50 Hz or 60 Hz; therefore the rated speed of the engine will be either fixed or adjusted to n_2 or n_3 for operation.

Consequently, the performance curves for the engine for generator will be the outputs at the rated speeds n_2, n_3 as shown with the arrows.

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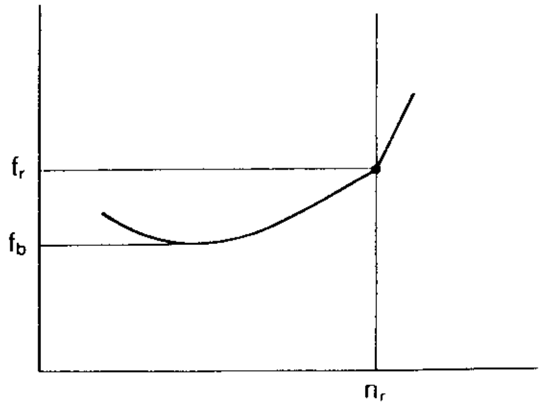
5-1-2 Specific fuel consumption curve f



The specific fuel consumption described in the catalog and/or specification table represents a specific fuel consumption f_r at a rated speed n_r and rated output P_r. In the case of a construction machine, f_b may be called minimum specific fuel consumption.

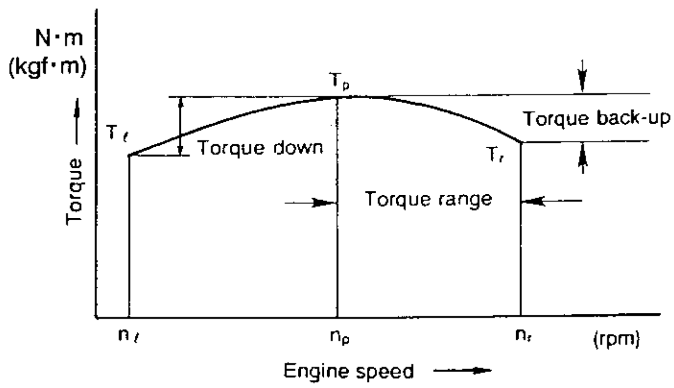
5-1-3 Torque curve

One of the important characteristics of industrial machinery is the torque backup value expressed with the torque curve.

It should preferably be a smooth curve with the peak in the middle. Generally speaking, the tenacity of the engine can be expressed with this torque backup value or torque backing ratio (torque rise) and the size of the torque range.

The greater those values, the better the tenacity of the engine. Ultimately, however, it is necessary to determine the level of torque characteristics in a matching test of the driven machine. In the case of an engine for driving a generator, it has a smaller torque backup ratio (torque rise) than industrial machinery engines in general. The reason is that a generator does not require good tenacity on the part of the engine.

The engine torque curve is shown below.



T_ℓ	:	Torque at low idling speed	N-m(kgf-m)
T_p	:	Maximum torque	N-m(kgf-m)
T_r	:	Rated torque at rated output	N-m(kgf-m)
n_ℓ	:	Low idle	rpm
n_p	:	Revolution at maximum torque (Tp)	rpm
n_r	:	Rated speed	rpm

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∗1. Torque backup value refers to the difference between the maximum torque and the torque at rated output.

$$\text{Torque backup} = \text{Maximum torque } (T_p) - \text{torque at rated output } (T_r)$$

$$\text{Torque backup ratio (torque rise)} = \frac{T_p - T_r}{T_r} \times 100(\%)$$

∗2. Torque down value refers to the difference between the maximum and minimum torque values.

$$\text{Torque down} = T_p - T_\ell$$

$$\text{Torque down ratio} = \frac{T_\ell}{T_p} \times 100(\%)$$

∗3. Torque range refers to the difference ($n_r - n_p$) between the speed (n_p) at maximum torque (T_p) and the rated speed (n_r),

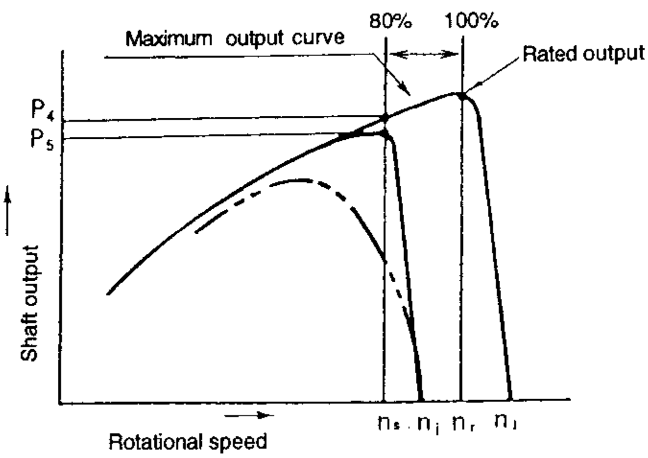
5-2 Partial Recovery Ratio

Partial recovery ratio refers to the recovery of output expressed as a percentage to the maximum output curve at 80% of the rated speed, when an engine set to a rated speed and rated output is loaded from 80% of maximum no-load speed (see the figure).

The 80% referred to above is a definition and does not have any practical significance, but if this characteristic is low, it may cause engine stall when applied to a driven machine whose service range of revolution varies widely. (See the chain double-dashed line in the figure.)

The TNE engine has a partial recovery ratio of 90% or more for standard specifications, but the user must check the work characteristics after installing the driven machine.

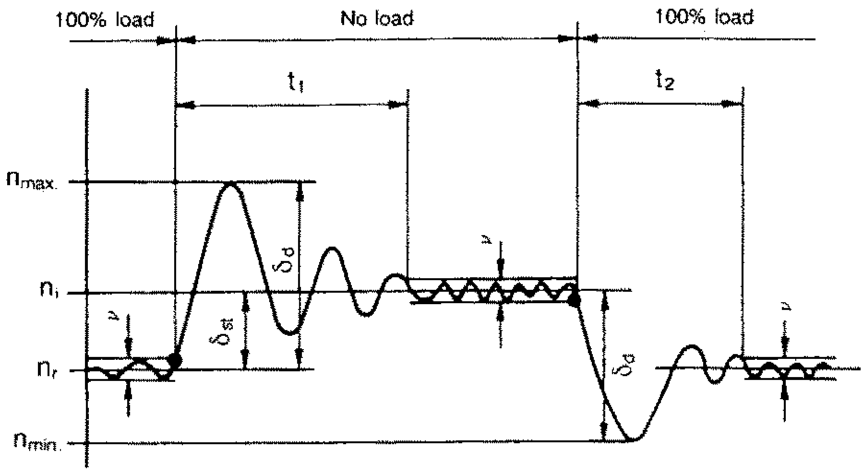
[Partial recovery ratio curve]



n_r : Rated engine speed
n_i : No-load maximum speed
n_s : $n_r \times 0.8$
n_j : $n_i \times 0.8$

$$\text{Partial recovery ratio} = \frac{P_5}{P_4} \times 100(\%)$$

5-3 Governor Performance



$n_{max.}$, $n_{min.}$ } Transient engine speeds under varying load

n_r : Rated speed

n_i : No-load speed

v : Steady-state governed speed band (range of speed variation in steady state expressed as a percentage of the rated speed. The width of variation expressed in rpm is called the speed variation.)

t_1, t_2 : Recovery time (time for steady-state governed speed band from the start of speed variation to the setting to the steady state in transient state, or the time after departure from band v to entry to band v)

δst : Speed droop (deviation in speed after setting governor to rated output and rated speed until transition to no load, expressed by the ratio (%) to the rated speed. Also referred to as permanent speed change ratio.)

$$\delta st = \frac{n_i - n_r}{n_r} \times 100\ (\%)$$

δd : Instantaneous speed difference (ratio (%) of maximum speed change to rated speed when the load is suddenly varied while the engine is running in the governed state. Also referred to as transient speed difference.)

∗1. When 100% load is removed momentarily (in a naturally aspirated engine and turbo-charged engine)

$$\delta d^{+} = \frac{n_{max} - n_r}{n_r} \times 100\ (\%)$$

∗2. When a load is input momentarily (naturally aspirated engine)

$$\delta d^{-} = \frac{n_{min} - n_i}{n_r} \times 100\ (\%)$$

5-3-1 Governor performance specified in JIS B 8002

		Class				
		A_0	A_1	A_2	B_1	B_2
Instantaneous speed difference	(δd^+)	AMC	≦10	≦15	≦18	≦18
	(δd^-)	AMC	≦10	≦15	≦18	≦18
Speed droop	(δst)	AMC	≦5	≦8	≦10	≦15
Recovery time	(t_1, t_2)	AMC	≦8	≦15	—	—

* *AMC means a level determined by agreement between both parties of driven machine delivery.*

Classes (A_0 to B_2) in the above table are classified according to the governor performance specified below:

Class	Governor performance
A_0	Maximum performance requirement
A_1	High performance requirement
A_2	General performance requirement
B_1	General performance applicable to a wide speed range
B_2	Not high performance applicable to a wide speed range

5-3-2 Governor performance of TNE series engines

			Constant speed specification			Variable speed specification			
			IDI	DI		IDI		DI	
			CH	CL	CH	VM	VH	VM	VH
Instantaneous speed difference	(δd^+) (δd^-)	%	≦(8 to 10)	≦(8 to 10)		≦12			
Speed droop	(δst)	%	≦(5 to 6)	≦(4 to 5)		≦(6 to 9)	≦(5 to 8)	≦(6 to 10)	≦(6 to 8)
Recovery time	(t_1, t_2)	sec.	≦6	≦5		≦6			
Steady-state governed speed band	(v)	rpm	≦(22 to 30)	≦15	≦(22 to 30)	≦30		≦(22 to 30)	≦30

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6. Cold Starting Aids

The TNE series engines are equipped with cold starting aids: a glow plug for the IDI system engine and an air heater for the DI system engine. The IDI system engine can start without the glow plug if the minimum ambient temperature is about 278K (5°C). On the other hand, the DI system engine can start without using the air heater provided the ambient temperature is above approximately 268K (–5°C).

Moreover, if an optional block heater is applied, the engine can be started with ease even at excessively low temperature.

For the usage of cold starting aids by ambient temperature, see section 1-3, "Startability" in Chapter 1.

6-1 Glow Plug

The glow plug is a plug with a heating coil that can be installed to the special swirl chamber of the IDI system engine. The glow plug is heated with an electric current from the battery before starting the engine. The combustion chamber is heated by the red-hot glow plug to make starting easier.

The glow plug comes in the standard type and super quick type glow plug each having different length of preheating time.

The TNE series engine is equipped with the standard type glow plug, and the super quick type glow plug can be used optionally. A glow plug is installed for each cylinder.

Nominal voltage	V	12		24
Type name		Standard glow plug	Super quick glow plug	24 VDC glow plug
Part/Code		129795-77800	129155-77801	119660-77800
Standard preheating time	Sec	15	3	10
Rated capacity	V/A	10/ 10.0 ± 1.5		
Identification color		White	Black	Yellow

When using the standard glow plug, it is recommended to equip it with a 15-sec timer (part code: 128300-77920).

When installing the super quick glow plug, no timer is required but a glow register (part code: 129155-77810) will be needed.

When using a 24 VDC glow plug, it is recommended to equip it with a 10-sec timer (part code: 119660-77920).

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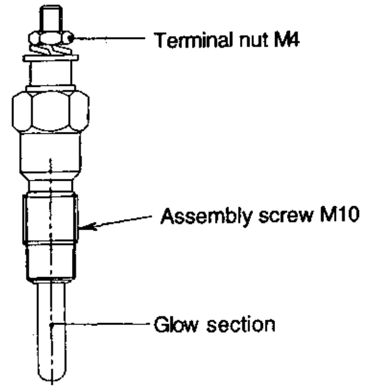
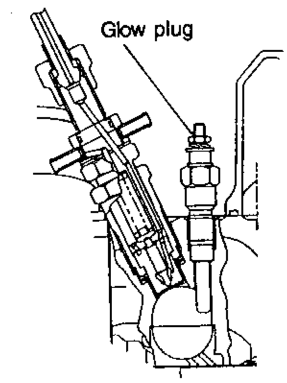
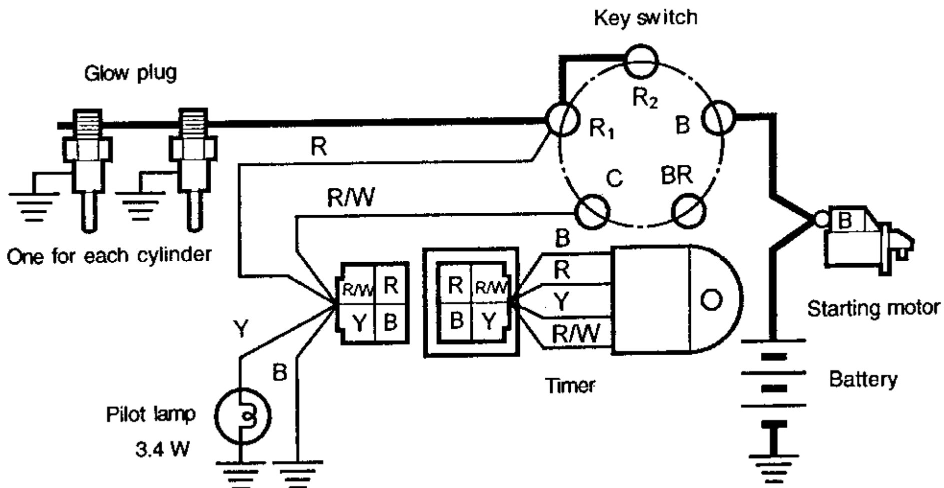
6-1-1 Glow plug structure





6-1-2 Control circuit diagram for standard glow plug



(For the 24 VDC specification, the only difference is 24 V specifications for the battery, glow plug, pilot lamp and timer and the wiring itself is the same as for the standard glow plug.)

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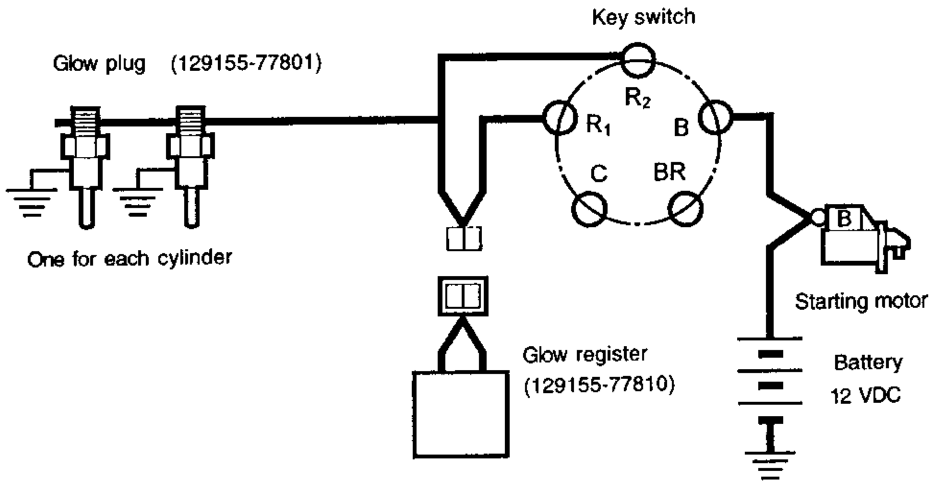
6-1-3 Control circuit diagram for super quick glow plug



6-1-4 Control circuit parts for glow plug

a) Pattern of key switch terminal

The terminal connection patterns of the key switch in the above circuit diagrams (2) and (3) are as follows:

	B	R_1	R_2	BR	C
Preheat	○—	—○—	———	—○	
OFF	○				
ON	○—	———	———	—○	
Start	○—	———	—○—	—○—	—○

The current in the preheating operation in the above circuit diagram of (2) flows from the battery to the glow plug via key switch B, and R_1. The current during starting operation flows from the battery to the glow plug via B, R_2, and external wiring and R_1.

In the case of (3), preheating current flows to the glow plug via B, R_1, then the glow register. However, the current during starting operation flows directly to the glow plug via B and R_2.

The key switch is available in a variety of configurations and terminal connection patterns and their terminal codes differ by the manufacturer.
When installing it, be sure to lay wiring after fully understanding the structure.

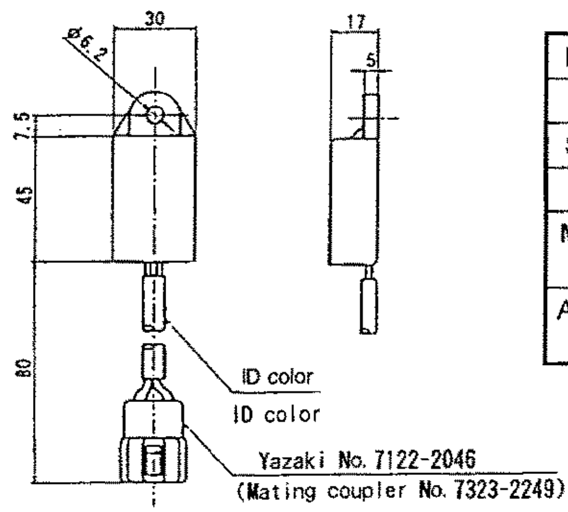
b) Timer and pilot lamp

When the key switch is set to preheating operation, the timer (part code: 128300-77920) starts counting the specified time while the pilot lamp is lit. After about 15 seconds of preheating (may fluctuate slightly depending on the outside temperature), the timer turns off the pilot lamp to indicate that preheating is completed. A color, color other than red is usually used for the lamp.

During cold weather, preheating may last beyond 15 seconds. Note that the glow plug is being energized during the preheating operation even after the lamp is turned off.

Immediately after the completion of preheating, select the key switch to start. The lamp does not light up during the starting operation. This is because that the timer receives voltage from key switch C and turns off the lighting circuit. Likewise, when directly started during the ordinary temperature, the timer receives voltage from the key switch C, hence no pilot lighting.

A 24 VDC timer (part code: 119660-77920) has the same function as described above but the preheat completion time is 10 seconds.



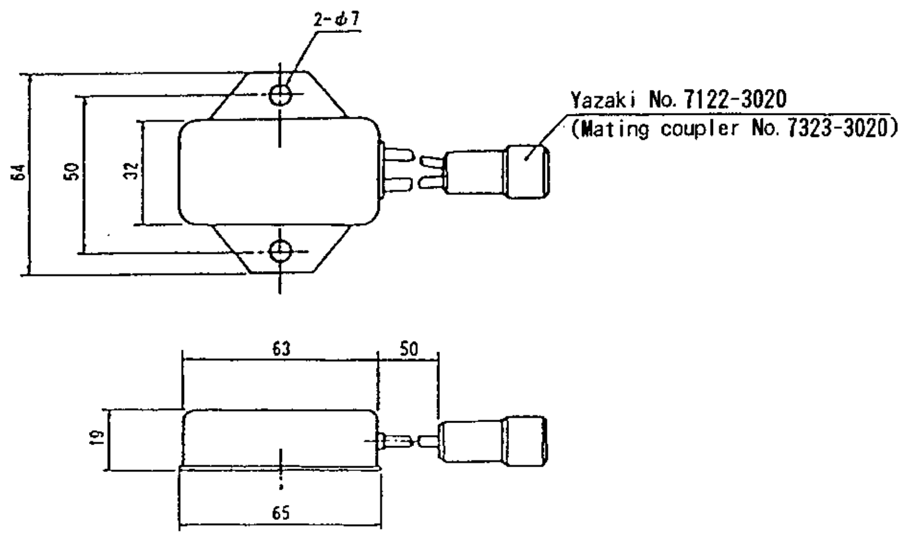
Rated voltage	12 VDC	24 VDC
Part code	128300-77920	119660-77920
Set time (sec)	15	10
ID color	Black	Red
Manufacturer's model	HC0108	HC0113
Applicable pilot lamp	3.4 W	

c) Glow register

A glow register (part code: 129155-77810) is used in combination with a super quick glow plug (part code: 129155-77801). A glow register is not used for the air heater of the DI system engine.

Since the starting motor is on during the starting operation, the battery voltage drop is enormous and the voltage on the super quick glow plug also drops, thus a large current is suppressed. However, during preheating, the battery voltage is directly charged to the glow plug, allowing overcurrent to flow to it which shortens the plug life.

The glow register suppresses the overcurrent appropriately during the preheating operation.



d) Power relay

Study the use of a power relay if the wiring distance between the engine and the key switch becomes too long. The longer the wiring distance, the greater the wiring resistance; this causes the voltage fall and the glow plug performance to deteriorate. As a countermeasure, a power relay is installed between the glow plug and the key switch. For details, see the descriptions on the air heater in section 6-2-4.

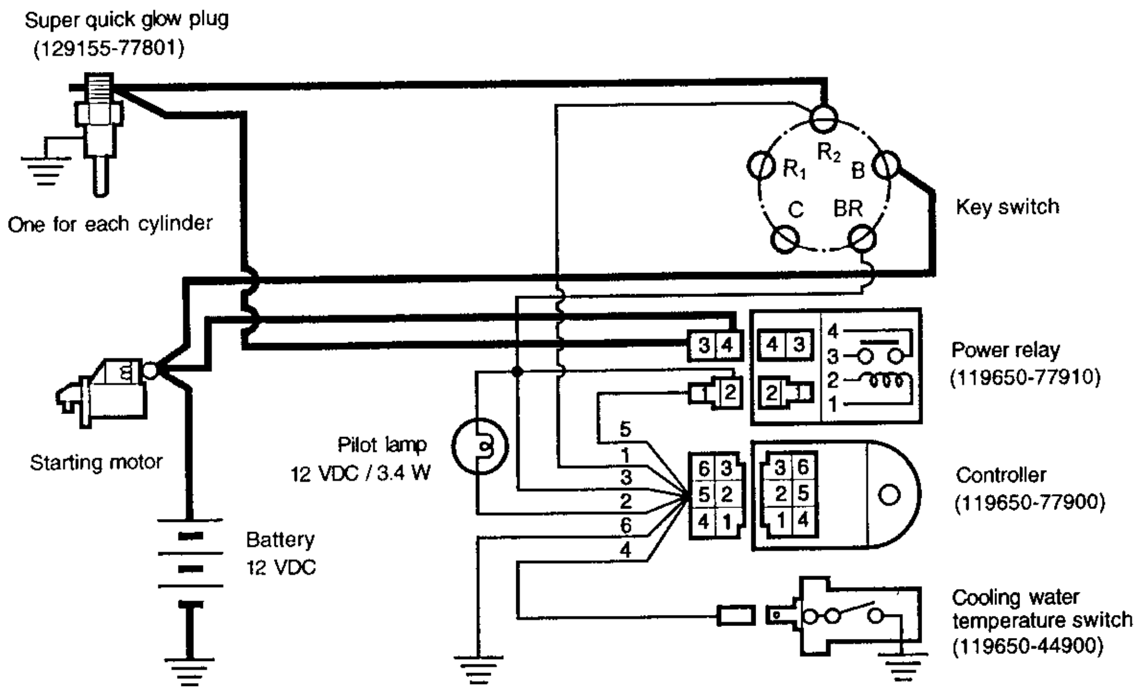
6-1-5 Control circuit diagram for on-glow

When preheating, most of the key switches are turned counterclockwise.
After completing the heating, the key switches are turned off once, and turned on by turning them clockwise and then the starting operation is made. In other words, you have to always switch the keys from left to right.

On-glow control refers to a method of entering the starting operation without the above-mentioned switching action, by energizing the preheating circuit by simultaneously turning the key switches on and preheating the combustion chamber for specified time with the timer.

Upon completion of preheating, the key switches return to the on position. To disable the preheating circuit, an exclusive controller is needed for controlling the on-glow.

The circuit of a currently available on-glow system is shown below. It is a combination of a super quick glow plug, cooling water temperature switch and power relay to control the preheating time with a special controller.



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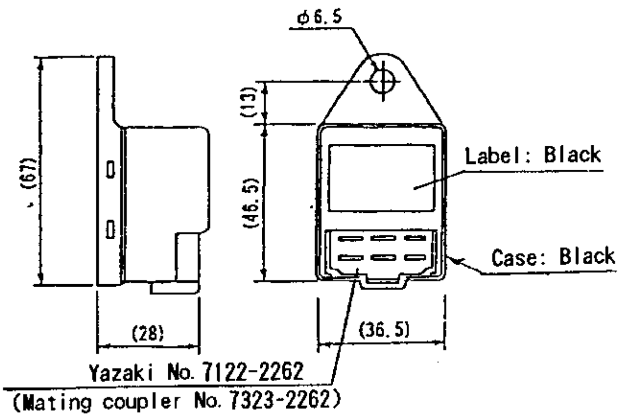
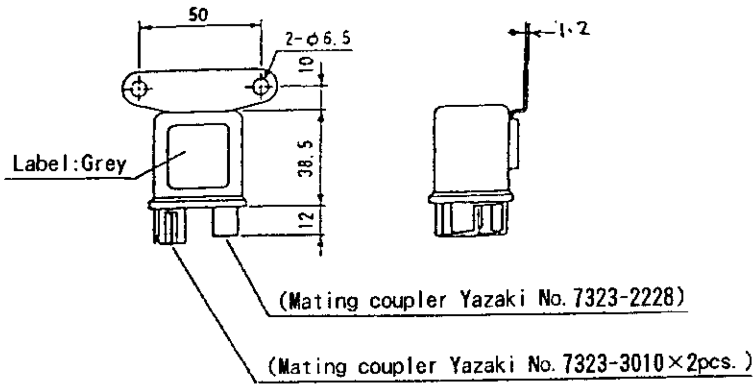
a) Controller



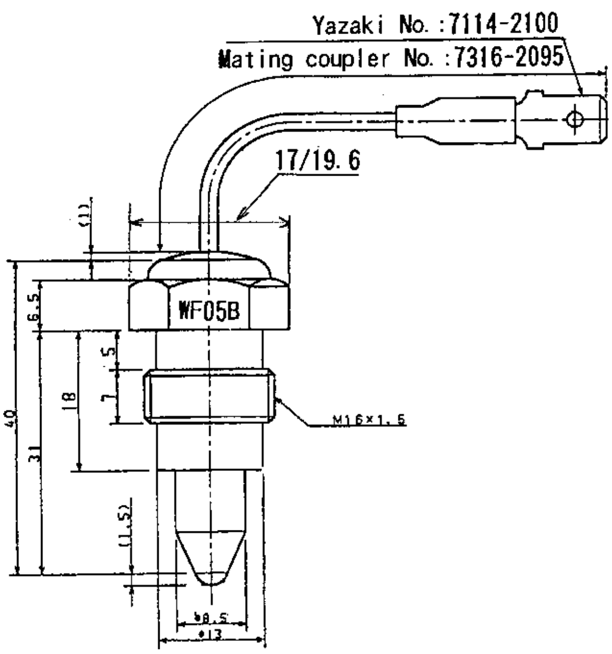
Part Code		119650-77900	
	Voltage V	Cooling water tempera-ture	Lamp and power relay control time (sec)
Glow plug applied voltage	12	5°C and over	$0.7\pm^{0.6}_{0.3}$
	10		$1.0\pm^{0.8}_{0.3}$
	8		$1.6\pm^{1.1}_{0.6}$
	12	Under 5°C	$2.1\pm^{1.2}_{0.3}$
	10		$4.0\pm^{1.6}_{1.4}$
	8		$7.5\pm^{5.0}_{2.5}$

b) Power relay



Part code	119650-77910
Rating	12 VDC / 10 min
Contact capacity	40 A / a-Contact
Exciting current	0.5 A

c) Cooling water temperature switch



Part code	119650-44900
Operating temperature	Open / Close, 5°C 10°C
Contact capacity	0.7A/12VDC (signal use only)

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6-2 Air Heater

The air heater is installed in the intake manifold of the DI system engine to heat the intake air to help the engine start in cold areas.

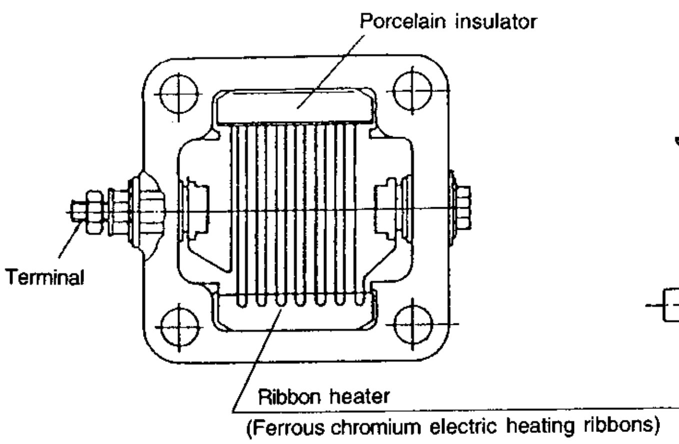
Capacities differ by the engine model but the air heater is provided as standard on the DI system engine. For details on the change of air heater capacity with coldness, combination of 24 V specification and wiring method, refer to the separate "TNE Option Menu."

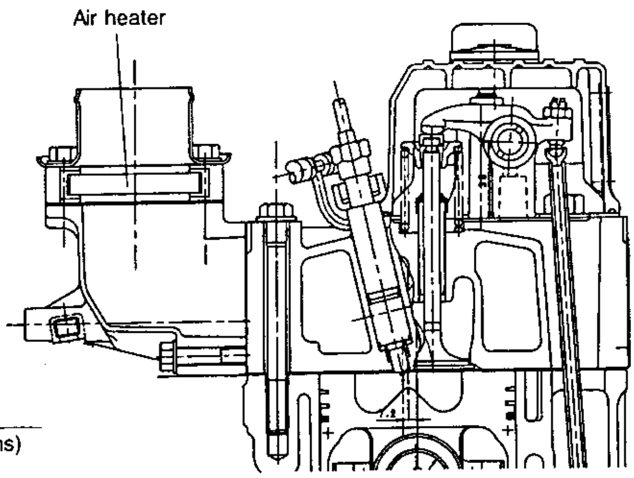
Applicable engine	Rated voltage (V) / Capacity (W)	Standard preheat time (sec)	Standard air heater
3TNE78A, 3TNE82A 3TNE84, 3TNE88 4TNE84, 4TNE88 3TNE84T, 4TNE84T	12 VDC/400 W	15	129120-77501
4TNE94 4TNE98	12 VDC/500 W	15	129915-77050

It is recommended to install a 15-second timer (part code: 128300-77920) on the standard air heater.

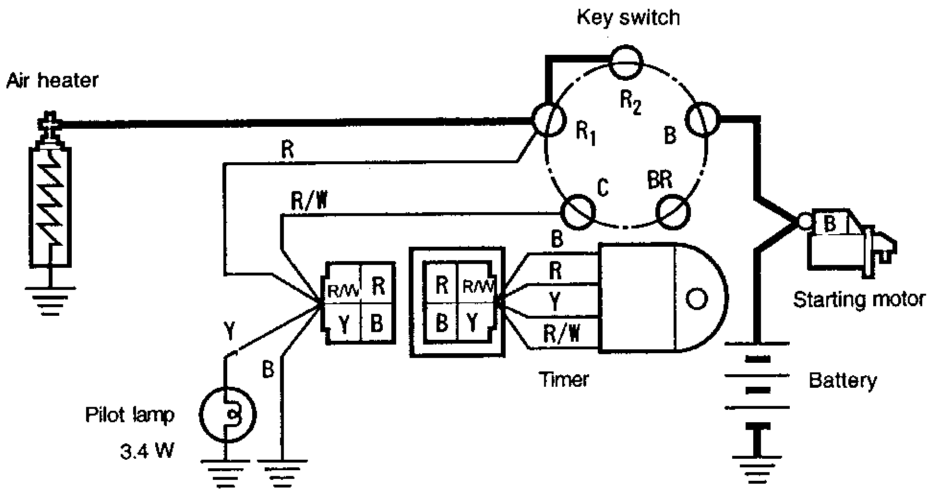
When using a 24 V air heater, installation of a 15-second timer for 24 V (part code: 119129-77920) is recommended.

6-2-1 Air heater structure



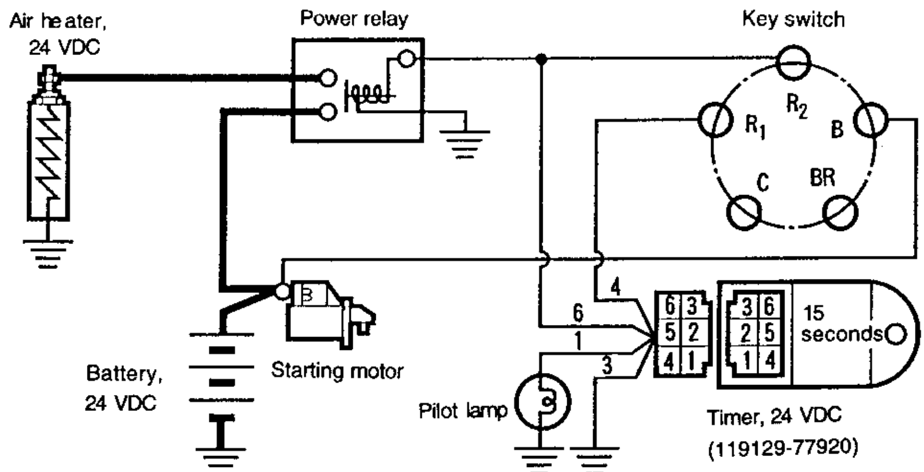


6-2-2 Control circuit diagram for standard air heater



6-2-3 Control circuit diagram for 24 VDC air heater

Since a 15-sec 24 VDC timer has different functions and wiring from those of a 12 VDC timer, care should be taken. Also note that the 24 VDC air heater generally has a large current capacity and that a power relay must be used due to the 15-sec 24 VDC timer structure. Select a power relay having a contact capacity that meets the required current of the air heater.



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6-2-4 Air heater capacity and power relay

The above diagrams show the basic air heater wiring connection. A considerably large current flows in the air heater including the standard type. Depending on the cold area conditions, a larger capacity is produced by combining various types of air heater to improve engine startability.

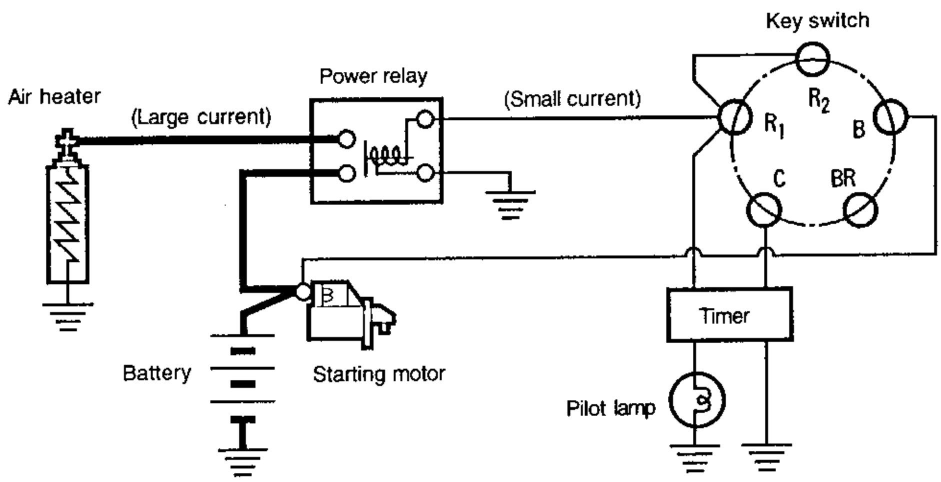
Therefore, it is necessary to check in advance whether the contact capacity of key switch preheating circuit B-R_1 and B-R_2 is sufficient when a large current flows from the air heaters.

If the contact capacity (allowable current) of the key switch preheating circuit is smaller than the required current of the air heater, the current to the air heater will be suppressed and insufficient preheating, damage to the key switch contacts and other problems may occur.

If the contact capacity of the key switch preheating circuit seems to be insufficient, install a power relay.

Application of the power relay is not limited to covering the lack of key switch contact capacity; it is also used to prevent the voltage drop that occurs as the distance between the engine installation point for the driven machine and the key switch location increases, thus increasing the wiring distance.

A typical wiring example is given below. For combinations with various types of air heater capacity, refer to the separate "TNE Option Menu."



The power relay relays the current by being located between the key switch and the air heater. If the wiring is made as illustrated, the exciting current of the power relay only flows to the key switch, eliminating possible damage to the key switch contacts. As it can also reduce the length of the air heater wiring circuit, the voltage drop is minimized to allow the air heater to perform to its full capacity.

Although the closer the power relay is located to the air heater the more advantageous, the location must also meet the power relay conditions for vibration and water resistance.

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When selecting a power relay, check whether the relay's contact capacity has enough margin for the air heater current requirements.

For the various types of power relay and key switches manufactured by Yanmar, refer to the "TNE Option Menu."

6-2-5 Example of control circuit for a driven machine of specific function

The examples of circuits thus far described are circuits commonly used for driven machines where the current flows to the air heater even during the starting operation. As a special exception, startability improves significantly if the current to the air heater is cut off during starting operation as in the case of a driven machine having a large drag torque and severe cold starting condition. The reason lies in the difference of starting effect. That is, it provides better starting effect and raises the cranking torque by increasing the current to the starting motor while cutting the current to the air heater, rather than heating the intake air with the air heater during starting.

However, whether to cut off the current to the air heater or not must be determined by actual vehicle tests under cold conditions. Checking is done by disconnecting the R_2 wiring in the circuit diagram.

6-2-6 Control circuit parts for air heater

a) Pattern of key switch terminal

The key switch pattern used in the circuit diagram for this subsection is the same as that in section 6-1-4 for the glow plug.

Note that key switches are available in various configurations and terminal connecting patterns. Their terminal codes differ by the manufacturer. Fully understand the structure before wiring. Particularly, in the case of the air heater, current requirements become greater and the contact capacity needs to be considered carefully.

b) Timer and pilot lamp

When the key switch is set to preheating operation, the timer (part code: 128300-77920) starts counting the specified time while the pilot lamp is lit. After about 15 seconds of preheating (may fluctuate slightly depending on the outside temperature), the timer turns off the pilot lamp to indicate that preheating is completed.

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A color other than red is usually used for the lamp. During cold weather, preheating may last beyond 15 seconds. During preheating, the air heater remain energized even if the lamp is turned off.

Upon completion of preheating, select the key switch to start. During starting operation, however, no lamp will be lit. The reason is because the timer receives voltage from key switch C during starting operation and turns the off lighting circuit. Likewise, if direct starting is done at ordinary temperature, the timer receives voltage from key switch C and the pilot lamp does not light.

A 24 VDC times (part code: 119129-77920) controls the pilot lamp for 15 seconds the same as the above timer. In addition, this type has a power relay excitation function and a preheating time reduction timer.

The control circuit is the same as 6-2-3, but the 24 VDC timer outputs the exciting current to drive the power relay while the lamp is lit. In other words, the current from the air heater always flows via the power relay. Fifteen seconds later, the lamp turns off and preheating is completed, ready to proceed to the starting operation. At this moment, the key switch R_1 is off and the lamp remains off, but the current from key switch R_2 keeps the power relay on, so the air heater remains energized during the starting operation.

Once the preheating is completed, this timer turns off the light, for example, for up to 10 seconds, to indicate it when the key switch is turned off once and then the preheating operation is started again within several seconds. In other words, this timer reduces the preheating time for the second time around. Since the timer circuit allows no excessive preheating beyond 15 seconds, enter the starting operation as soon as the lamp turns off.

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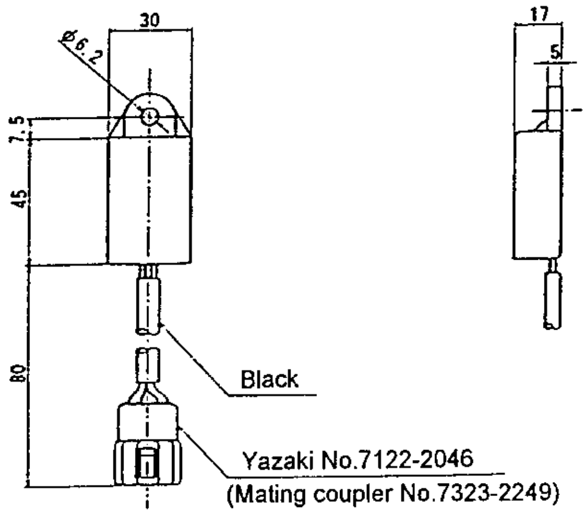
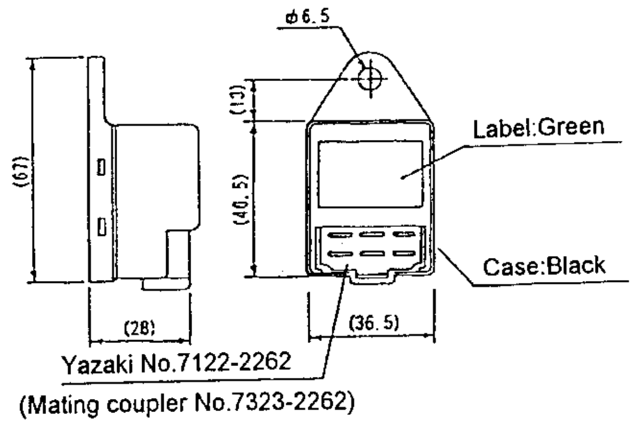
12 VDC 15-sec timer



Rated voltage	12 VDC
Part code	128300-77920
Set time (sec)	15
ID color	Black (tube)
Manufacturer's model	HC0108
Applicable pilot lamp	3.4 W

24 VDC 15-sec timer



Rated voltage	24 VDC
Part code	119129-77920
Set time (sec)	15
ID color	Green (label)
Manufacturer's model	——
Applicable pilot lamp	3.4 W
Exciting output from terminal ⑥	1.0 A (Max.)

6-3 Block Heater

The block heater is installed on the cylinder block on the standard processed special screw mount. The block heater uses the commercial AC power supply instead of the battery.

The block heater heats the cooling water in the cylinder block jacket. It indirectly heats the lubricant, which lowers the viscosity of the fluid to reduce drag torque. It also heats the cylinder head combustion chamber to make the fuel ignition easier and improve cold startability.

As a general guide, connect the block heater to the AC power supply several hours prior to starting the engine although it depends on the ambient temperature condition and the engine size.

The block heater is quite effective in starting engines in cold climate of 248K (–25°C) or below or for a driven machine having a large drag torque. Its only drawback is mobility as it has to be connected to an AC power supply.

Block heaters are standard equipment for engines for disaster prevention or for those mounted on emergency generators to ensure starting in case of an emergency. If the ambient temperature is high, the cooling water will reach boiling point if the block heater is connected to the power supply permanently. Since disaster preventive or emergency generator equipment are usually left in unmanned, it is necessary to prevent this danger by turning the block heater power supply on or off with an automatic control circuit to keep the cooling water temperature inside the cylinder block at a constant level.

Since alternating current is supplied at various voltages, the block heater can be set to meet the requirements of various voltages. The following table indicates parts frequently used for industrial engines:

Part name	Part code	Remarks
Block heater	171015-77900	Rated capacity: 115 VAC/400 W
Connecting code	171015-77910	Approx. 300 mm long
Bracket	119621-11950	For IDI system engines only. For more details, see the "Option Menu."

<Cautions>

- *Do not connect the block heater to the power supply without cooling water.*
- *Never use it at ordinary temperature as the cooling water will boil.*
- *In both of the above cases, the block heater will be burnt.*
- *When the engine starts, turn the commercial power supply off, then disconnect the cord from the engine.*

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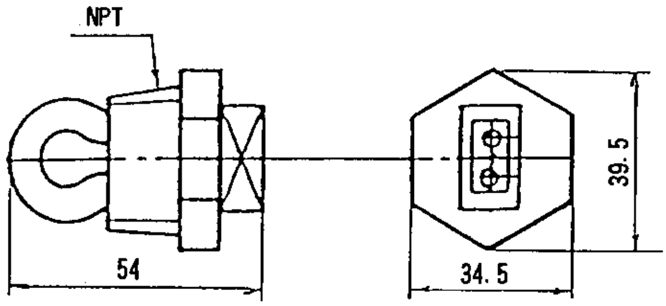
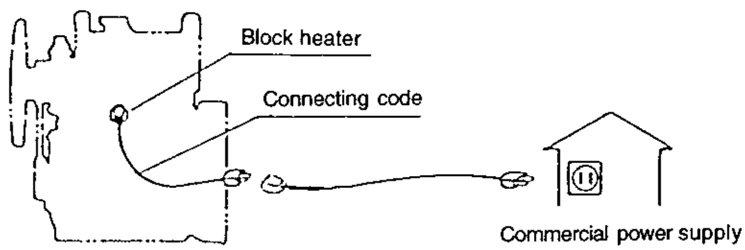
(1) Block heater configuration



(2) Block heater connection diagram



7. Air Intake System

The amount of air supplied to the combustion chamber in the intake stroke of the engine is directly related to the combustion performance of the engine. The intake system must be carefully considered as the air amount greatly affects such basic engine performance as the engine output, specific fuel consumption, exhaust system and engine service life.

7-1 Air Capacity Required for Combustion

The minimum amount of air theoretically required for complete combustion of approx. 1 kg of fuel is approx. 14.6 kg (about 12.5 m^3/standard atmospheric condition). However, this is not enough to ensure complete combustion, for which extra air is required. The ratio of the extra amount of air needed to the theoretical minimum amount of air for complete combustion is called the excess air ratio. In the case of a diesel engine, the excess air ratio at the full load is 1.5 to 2.0. In other words, the engine requires 1.5 to 2.0 times the theoretical minimum amount of air. However, it is not true that the greater the excess air ratio, the better. The excess air ratio is obtained to ensure optimal combustion in the vicinity of the rated output of the engine. Consequently, for a smaller load, less fuel is injected, which increases the air excess ratio, but this causes a drop in combustion temperature and problems in the exhaust system, so low-load operation for an extended period of time must be avoided.

7-1-1 Calculation of the air capacity

Air capacity includes two types of air flow: the air flow actually needed for combustion and the apparent intake air flow for checking the air cleaner capacity. Different calculation formulas are used according to the purpose. A calculation formula is described in section 7-5-1(1) as given in the technical manual of NEGA (Nippon Engine Generator Association). This calculation formula is adopted for documents and materials for driven machine engines for governmental offices.

(1) Air capacity required for combustion

There are a number of ways to determine the air capacity necessary for fuel combustion in the engine. The simplest calculation method is based on the engine displacement as follows:

$$Q_1 = \eta_V \cdot V_S \cdot N \cdot C \cdot 10^{-3}$$

Where,

Q_1	:	Required air capacity	m^3/min
η_V	:	Volumetric efficiency:	
		Naturally aspirated engine	0.85 to 0.9
		Turbocharged engine	1.3
V_S	:	Engine displacement	ℓ
N	:	Speed of engine	rpm
C	:	Constant, 4-cycle engine: 1/2	

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Volumetric efficiency η_V differs slightly depending on the range of service speed of the engine, but since this is not a research manual, η_V can be constant without practical problem. Supposing η_V is 0.9 for the naturally aspirated engine and 1.3 for the turbocharged engine and the revolution N is a variable, then the required air capacity for combustion in the respective engines is given by the following calculation formula:

N: Engine speed (rpm)

No.	Engine model	Engine displacement: liter	Required air capacity Q_1 for combustion: m^3/min
1	2TNE68(–N)	0.523	$2.35 \times 10^{-4}N$
2	3TNE66–N	0.659	$2.96 \times 10^{-4}N$
3	3TNE68(–N)	0.784	$3.53 \times 10^{-4}N$
4	3TNE72–N	0.879	$3.96 \times 10^{-4}N$
5	3TNE74(–N)	1.006	$4.53 \times 10^{-4}N$
6	3TNE78A	1.204	$5.42 \times 10^{-4}N$
7	3TNE82A	1.331	$5.99 \times 10^{-4}N$
8	3TNE84	1.496	$6.73 \times 10^{-4}N$
9	3TNE88	1.642	$7.39 \times 10^{-4}N$
10	4TNE84	1.995	$8.98 \times 10^{-4}N$
11	4TNE88	2.190	$9.85 \times 10^{-4}N$
12	3TNE84T	1.496	$9.72 \times 10^{-4}N$
13	4TNE84T	1.995	$1.30 \times 10^{-3}N$
14	4TNE94	2.776	$1.25 \times 10^{-3}N$
15	4TNE98	3.319	$1.49 \times 10^{-3}N$

Example: How many cubic meters of air capacity will be required per minute for burning fuel in a 3TNE84 diesel engine at 21.3 kW/2600 rpm?

From the above table, the calculation formula for the air capacity required for burning fuel in the 3TNE84 diesel engine is

$$Q_1 = 6.73 \times 10^{-4}N$$

Therefore, the required air capacity can be obtained by substituting N with 2600 rpm.

$$Q_1 = 6.73 \times 10^{-4} \times 2600$$
$$= 1.75\ (m^3/min)$$

(2) Apparent air capacity

Apparent air capacity is applied when selecting the air cleaner capacity. The mean air capacity that passes through the air cleaner is the air capacity of item (1) required for combustion. However, since the engine intakes air only once every two revolutions, the air flows with considerable pulsation. To retain the same intake load level to the air cleaner even when the air flow increases because of pulsation, it is necessary to determine in advance a slightly larger air capacity for the air cleaner than the mean air capacity. This is called apparent air capacity. Since the smaller the cylinder number, the greater the pulsation, the coefficient to the mean air capacity becomes greater.

Use the following formula to calculate the apparent amount of air in the engine. This formula applies to both naturally aspirated engines and turbocharged engines.

$$Q_2 = Q_1 \times K$$

Where,

Q_2 : Apparent air capacity — m^3/min

Q_1 : Required air capacity for combustion — m^3/min

K : Coefficient depending on cylinder number

2 cylinders: 2.0

3 cylinders: 1.7

4 cylinders: 1.0

7-1-2 Air cleaner selection table

The intake air capacity of an engine is approximately proportional to the engine speed as mentioned. Yanmar uses the following table when selecting the air cleaner for respective types. We may recommend one size larger air cleaner depending on the intended use of the driven machine and the service environment.

Engine model		Applicable air cleaner size (nominal)
IDI	2TNE68(–N) 3TNE66–N 3TNE68(–N) 3TNE72–N 3TNE74(–N)	4 inch
DI	3TNE78A, 82A 3TNE84, 88 4TNE84, 88 3/4TNE84T	5 inch
	4TNE94, 98	6 inch

Refer to the separate "TNE Option Menu" for details.

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7-2 Air Cleaner

In the preceding subsection, the air capacity required for combustion was calculated. The purpose of the calculation was mainly to determine the air capacity for assuring the engine output performance.

In order for the engine to operate to the full capacity, the intake air capacity should be sufficient, and the air has to be clean. Any dust mixed in the intake air has an adverse effect on the life of the main moving parts such as the piston, piston ring, cylinder block and the intake/exhaust valves. The air cleaner removes dust in advance. The air cleaner used for TNE system engine is called a cyclone paper element type, and the element is a paper filter.

The air cleaner size is expressed by nominating its body diameter in inches. Three types of air cleaners, 4, 5, and 6 inches, are used for the TNE system engine. In addition, air cleaners of various configurations with different air intake/exhaust port positions are optionally available to suit various driven machines and mounting positions. For details, refer to the separate "TNE Option Menu."

In recent years, the air cleaner body material has been changed from steel to resin. This manual describes the plastic air cleaner only, but the principles of operation are the same for both plastic and conventional steel structures.

Although air cleaners are an essential part for general-purpose engines, in the case of an engine for emergency purposes, which is installed indoors and the operating time is quite limited, it is almost completely unaffected by dust at all, hence no cleaner is generally provided. In such a case, the air inlet must be covered with metal wire mesh or equivalent material, however.

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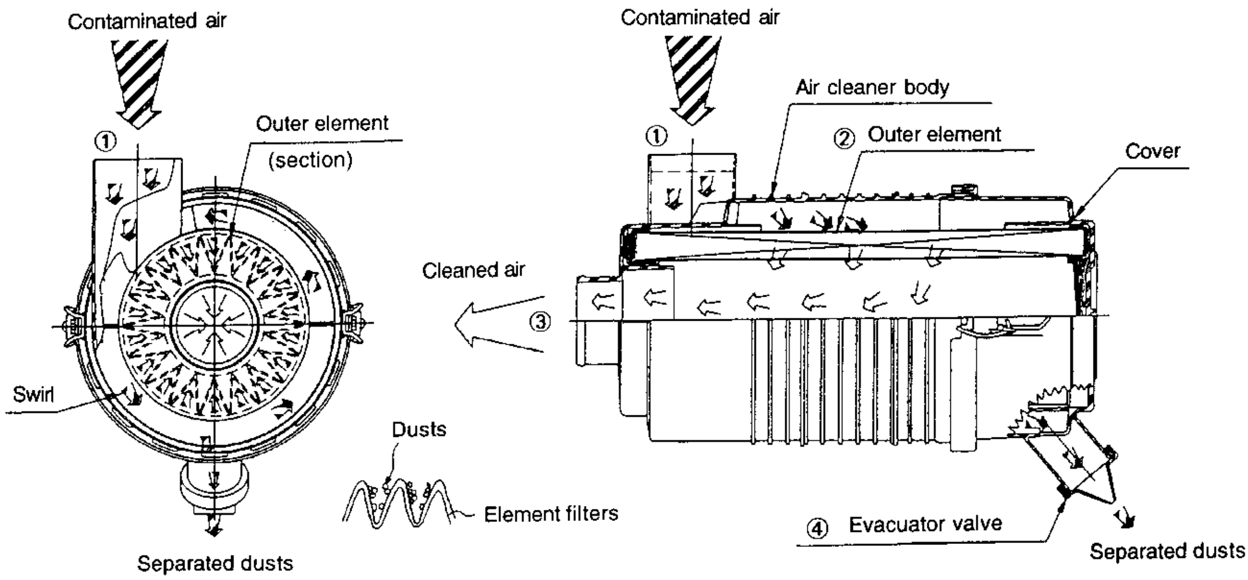
7-2-1 Dust removing principle of air cleaner

The dust in air is cleaned as follows.

Air that contains dust is sucked in the direction of the tangent from the air inlet ① on the cleaner body close to the circumference, is forced to swirl along the guides (vanes) on the inside of the main body, and the larger particles of dust are separated by centrifugal force. The outer element ② removes more than 99.9% of dust and allows the cleaned air to enter the engine from the outlet ③.

The dust and water separated by centrifugal force are transferred to the rear cover while swirling along the inner wall of the body and enter the evacuator valve ④. The valve opens/closes according to the pulsation of inlet air and automatically ejects the dust from inside the valve.



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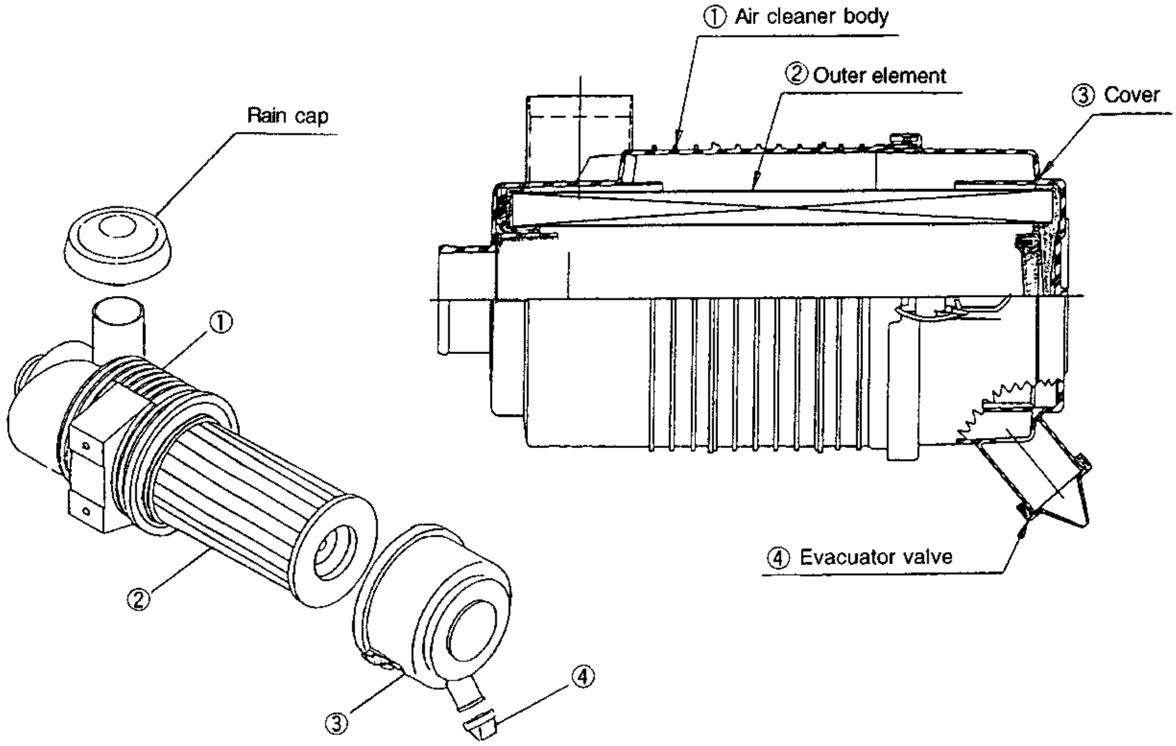
7-2-2 Structure of air cleaner

(1) Structure of single element type

This is the most general type of structure, and is the type used unless otherwise specified. This air cleaner consists of four main components: the main body, air cleaner element, cover and evacuator. The figure also shows the rain cap that must be installed if the cleaner is likely to let in rainwater.



(2) Structure of double element type

Yanmar calls an air cleaner having both the outer and inner elements the "double element" type. This does not mean that it has twice the filtering area as the single element type. If the nominal size of an air cleaner is the same, both the single element and double element have the same filtering area. The filtering area of the inner element is at best only about 4% of the outer element, so it does not help extend the maintenance period of the air cleaner.

The purpose of the maintenance check of the air cleaner is to clean and replace the air cleaner element. When removing the element, dust deposited on the surface of the filters tends to come off and enter the exit joint of the air cleaner body. This dust is then sucked in next time the cleaner is operated, damaging the piston and other important parts. The inner element is designed to prevent this by covering the air outlet inside the body. Therefore, this element is also called a safety element, and an air cleaner having the inner element is referred to as an air cleaner with a safety element.

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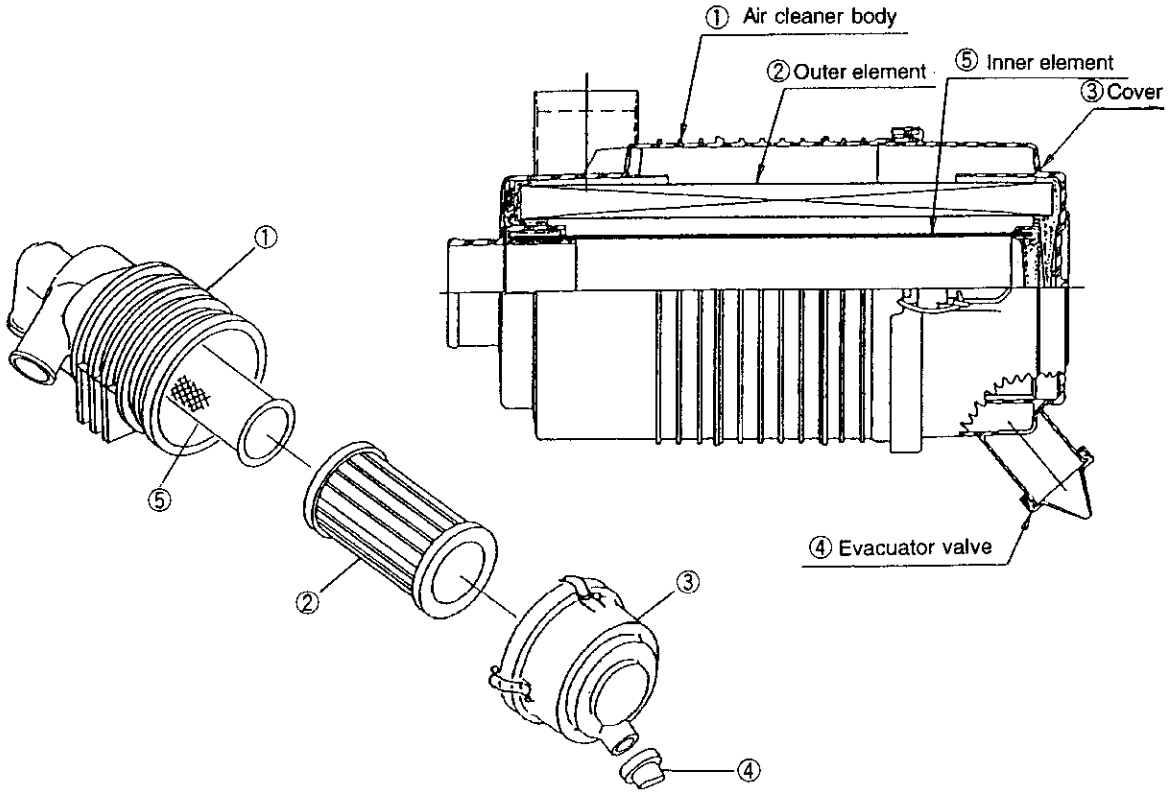
While it is best to equip all engines with the double element type cleaner, use of the double element type cleaner is limited due to cost. From experience, the double element type cleaner is necessary for machines handling sands, particularly volcanic ashes. To determine whether to use this type, manufacturers of driven machines need to have good marketing experience and the parties concerned should discuss the operating conditions in advance. If the nominal size of the body is the same, then an inner element can be installed at a later date.



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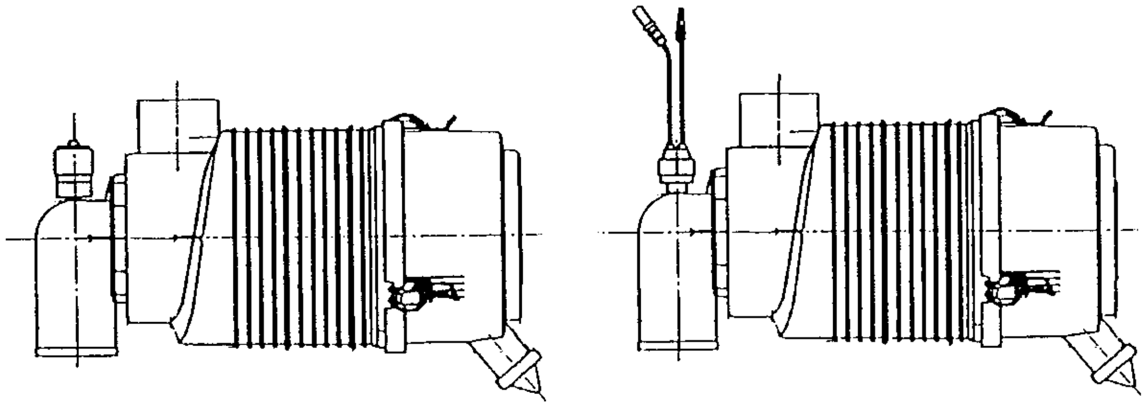
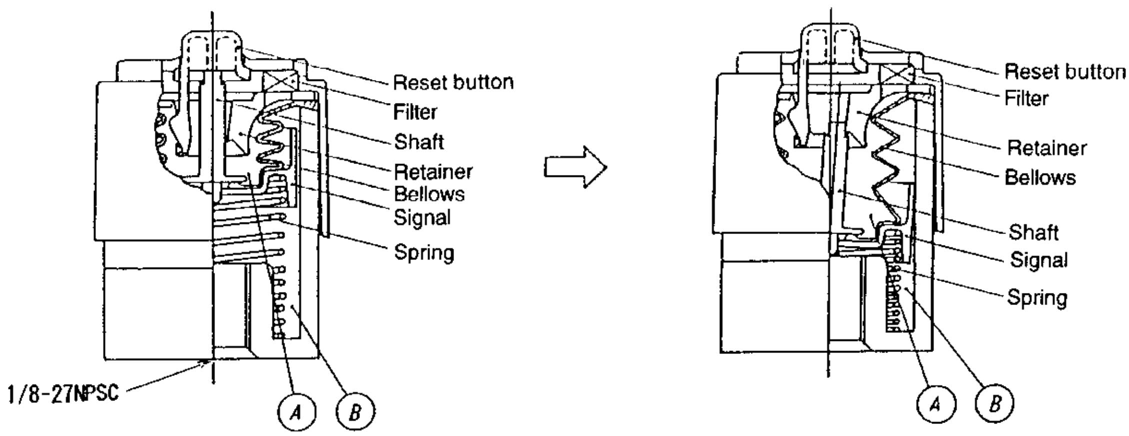
(3) **Dust indicator**

The dust indicator is mounted on the exit joint of the air cleaner to indicate the degree of clogging, and is available in a mechanical or electric type. Both types are tripped to operate when the clogged state reaches a back pressure of 6.23 kPa (635 mmAq) at the engine manifold. The mechanical type indicates a red color while the contact of the electric type is turned on to light up a lamp to show that the air cleaner element needs to be replaced or cleaned.



Mechanical dust indicator — Electrical dust indicator

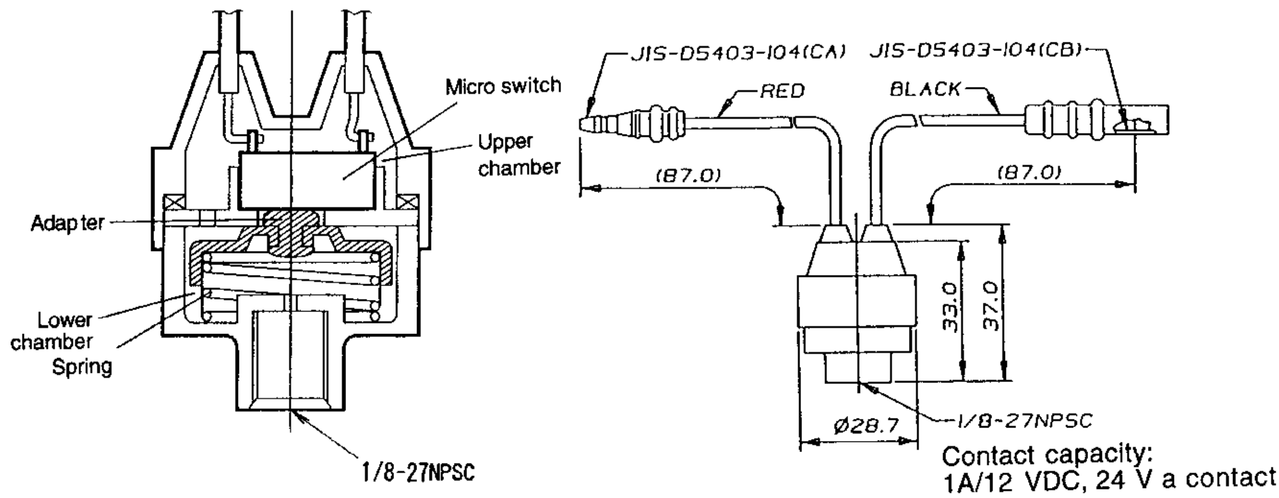
a) Mechanical dust indicator: Part code: 126650-12680



This unit detects the clogged state of the air cleaner element and mechanically indicates the timing for cleaning and replacement.

It is divided into two chambers Ⓐ and Ⓑ by the bellows. Chamber Ⓐ is connected to the atmosphere and Chamber Ⓑ to the intake manifold. With the clogging of the element, negative pressure in Chamber Ⓑ increases. The bellows presses down the indicator integrated to the shaft against the force of the spring. When it reaches the operating pressure, the hook at the end of the shaft catches the retainer claw to retain the indicator-down state. At this time, the indicator (in red) is seen through the transparent body, allowing the clogged state of the element to be checked. Pressing the reset button after checking releases the shaft from the retainer claw and the red indicator is reset.

b) Electrical dust indicator: Part code: 119140-12680



This unit electrically detects the clogged state of the air cleaner element and indicates the timing for cleaning and replacement with a pilot lamp, etc.

This unit operates on a contact system that turns the microswitch on and off by converting changes in the negative pressure of the air cleaner to the vertical movement of a built-in adapter. The principle of operation is that at a low negative pressure, the adapter presses the microswitch with a spring and the circuit is off. As the negative pressure increases with the clogging, the differential pressure between the upper and lower chambers separated by a diaphragm increases, and when it reaches the working pressure, it overpowers the spring force and lifts the adapter, turning the microswitch circuit on. When the negative pressure decreases, the adapter is pushed upward and turns the microswitch off.

7-2-3 Installation of air cleaner

Maintenance of the air cleaner greatly affects the engine's service life. Therefore, the air cleaner has to be installed in a position that facilitates maintenance work. Since the air cleaner requires a space for drawing the element out for replacement, the air cleaner layout must be considered carefully when designing a driven machine.

In addition, when installing an air cleaner on the engine body, select the bracket rigidity to keep vibration acceleration within 78 m/sec^2 (8G) for an air cleaner made of steel or 88 m/sec^2 (9G) for an air cleaner made of plastic. If the air cleaner is installed on the engine, resonance with the engine vibration isolator must be avoided for installation of a driven machine. Check the vibration and durability upon installation. If the vibration acceleration exceeds the target value, consider changing the position of the air cleaner.

Determine the position for installation in consideration of the ambient air temperature flow so that the air cleaner body temperature is kept at 80°C or below.

7-3 Piping of the Air Intake System

When laying the piping for the air intake system, it is important to determine the piping layout or air cleaner position so as to feed cool air, in addition to preventing vibration of the air intake pipe and avoiding contact with other components. If the intake air temperature is judged high according to section 12-5-2, "Heat balance assessment" of Chapter 12, the air intake position must be reconsidered. Select the position so that no water, snow or dust can enter from the intake port.

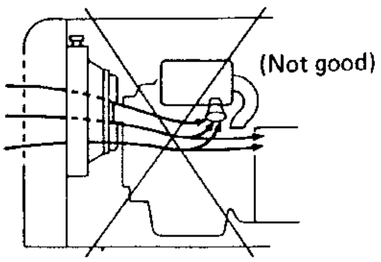


Diagram A

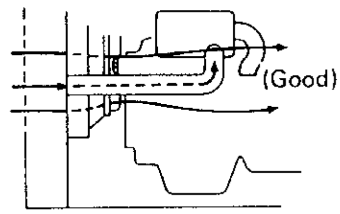


Diagram B

When using rubber hose for the air intake pipe, use materials of the following characteristics or better.

[Reference: Genuine rubber hose]

		Naturally aspirated engine	Turbocharged engine
Heat resistance		393K (120°C) or higher	
Pressure resistance	Negative pressure	13 kPa {0.13 kgf/cm^2} or higher (air cleaner to air intake manifold)	29 kPa {0.3 kgf/cm^2} or higher (air cleaner to turbocharger)
	Positive pressure	—	196 kPa {2 kgf/cm^2} or higher (turbocharger to air intake manifold)
Materials		Ethylenepropylene rubber	

* *Do not use vinyl hose. It may be easily deformed under heat or intake negative pressure. Moreover, vinyl hose becomes hard and brittle at low temperature.*

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7-4 Depression at Engine Manifold

Factors contributing to the increase or decrease of depression at the engine manifold (intake resistance) include the following items:

a) Intake air capacity to the engine
b) Air cleaner capacity
c) Length and diameter of the intake piping
d) Number of bends of intake piping and their angles

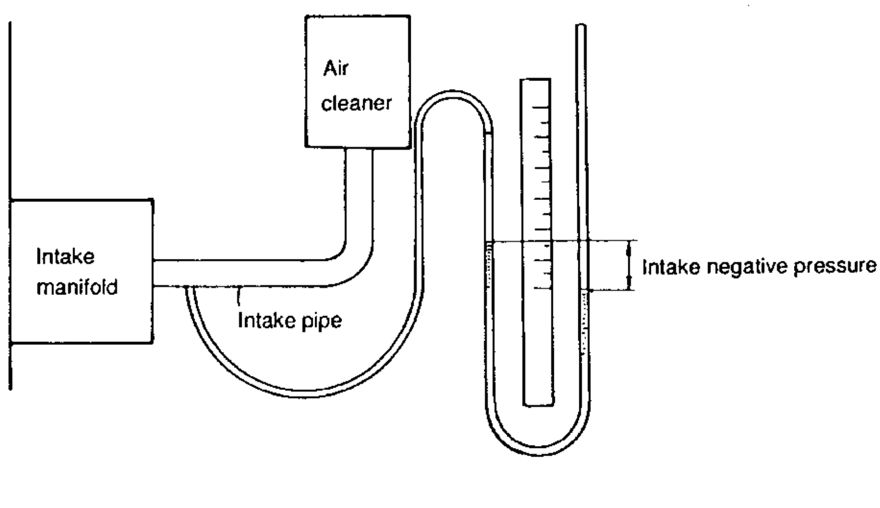
If the depression at the engine manifold is large based on the above factors, it becomes impossible to obtain the necessary air capacity for combustion, adversely affecting the engine's combustion performance. If the depression at the engine manifold exceeds the allowable value, effects appear in the engine performance that may be concerned with quality assurance such as increase in fuel consumption, exhaust temperature rise, drop of output, degradation of emission content, and hence a shorter engine life, etc.

Reduction and improvement of depression at the engine manifold cannot be achieved solely with the engine itself. To determine the appropriateness of depression at the engine manifold, it is necessary to conduct a negative pressure test after installing all the parts and components of the intake system. If the test result exceeds the allowable value, either one of the above b), c) or d) must be re-studied.

7-4-1 Measuring of depression at engine manifold

The depression at the engine manifold is measured at the general entrance to the engine intake manifold. Generally a pipe is attached near the intake manifold on the intake piping that connects the air cleaner to the intake manifold to sample the negative pressure. Negative pressure is usually led to a manometer via a piece of vinyl pipe. Since deposited water in the vinyl pipe prevents correct measurement, care should be taken.

The measuring device is typically configured as follows:



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7-4-2 Allowable depression at engine manifold

If the measurement of depression at engine manifold exceeds the allowable value that can assure the engine performance, the intake system must be reviewed before starting production of the driven machine. For the values of allowable depression at engine manifold, see the descriptions in section 1-4 "Allowable depression at manifold and exhaust back pressure" of chapter 1.

The allowable depression at engine manifold consists of the initial upper limit and the upper limit for air cleaner replacement. Apply the initial upper limit value to the development stage of the driven machine and the upper limit for air cleaner replacement to the maintenance check stage.

7-5 Ventilation Capacity of Generator Room

The ventilation capacity of a building or room to accommodate a diesel generator is determined based on the feeding of combustion air to the diesel engine, suppression of the rise of room temperature, health and hygipacity necessary for engine combustion.

7-5-1 Calculation of air and ventilation capacity

(1) Air capacity required for engine combustion: Q_1

$$Q_1 = \frac{14.6 \times b \times Pe \times \gamma \times 10^{-3}}{60 \times \rho}$$

Where,

Q_1	:	Air capacity required for engine combustion	m^3/min
14.6	:	Air capacity required for burning 1 kg of diesel fuel	kg/kg
b	:	Specific fuel consumption	g/kWh (g/hph, g/PSh)
Pe	:	Engine output	kW (hp, PS)
γ	:	Excess air ratio	Naturally aspirated engine: 2.0, Turbocharged engine: 2.5
ρ	:	Air density : 1.165	kg/m^3 (at 303K (30℃))

(2) Ventilation capacity for suppressing the room temperature rise due to radiation from the engine and generator to 10K (10℃)

$$Q_2 = \frac{Hu \times b \times Pe \times k \times 10^{-3}}{C_P \times \Delta t \times \rho \times 60} = 6.114 \times b \times P_e \times k \times 10^{-2} \ m^3/min$$

Where,

Q_2	:	Ventilation capacity for suppressing the room temperature rise to 10K (10℃)		m^3/min
Hu	:	Lower calorific value of diesel fuel	4.3116×10^4	kJ/kg (10300 kcal/kg)
b	:	Specific fuel consumption		g/kWh (g/hph, g/PSh)
Pe	:	Engine output		kW (hp, PS)
k	:	Heat loss from the engine and generator surfaces (see table below):		
C_P	:	Specific heat at constant pressure (at 303 K, 101.3 kPa) (at 30℃, 760 mmHg)		1.00884 kJ/kgK 0.241 kcal/kg℃)

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Δt	:	Difference between the room temperature after rising and the outside temperature	10K	(10°C)
ρ	:	Air density:	1.165 kg/m³	(at 303 K (30°C)
k	:	Heat loss from the engine and generator surfaces (with full insulation around the exhaust pipe)		

Engine Model	k	Engine Model	k	Engine Model	k	Engine Model	k
IDI series	0.100	3TNE78A 3TNE82A	0.080	3TNE84 3TNE88 4TNE84 4TNE88	0.075	3TNE84T 4TNE84T 4TNE94 4TNE98	0.070

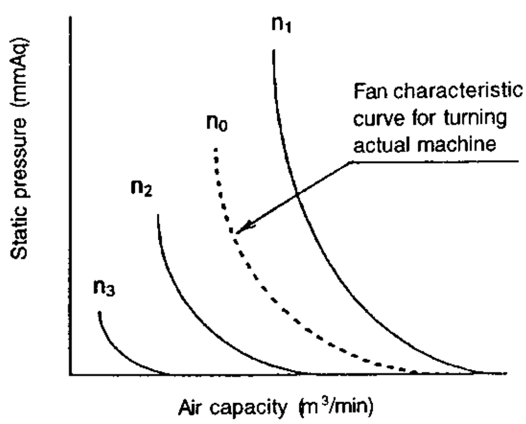
(3) Radiator cooling air capacity: Q_3

Since there are too many interrelated parameters, it is difficult to calculate the radiator cooling air capacity Q_3 with a formula. In other words, calculation is not simply a matter of entering certain data and figures. Therefore, should you need to find a radiator cooling air capacity, contact Yanmar and specify the model name of your engine.

For reference, the air capacity is obtained according to the following procedures, and you will need to analyze the fan characteristic curve and the radiator characteristic curve.

a) Fan characteristic curve

The fan characteristic curve graphically represents the result of measurement of air capacity conducted by turning the fan in a wind tunnel at a constant speed n and choking the tunnel exit to vary the resistance (static pressure). The smaller the static pressure, the greater the air capacity curve, and vice versa.

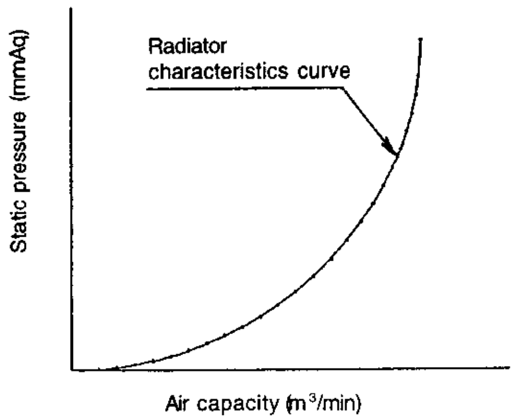


This characteristic curve will be indicated by the fan manufacturer by using several curves for different fan rotation speeds, which do not necessarily match the number of revolutions of the actual fan.

Characteristic curves are therefore created every time a new machine is shipped by estimating them for actual fan speeds empirically or calculating them by estimation by considering the fluid characteristics of the fan.

b) Radiator characteristic curve

Similarly, characteristic curves are obtained from the radiator manufacturers but, different from the case of the fan, no characteristic curves on the service radiator itself are available. The radiator manufacturer's characteristic curve shows the relationship between the air flow rate and resistance (static pressure) determined by the radiator core configuration.

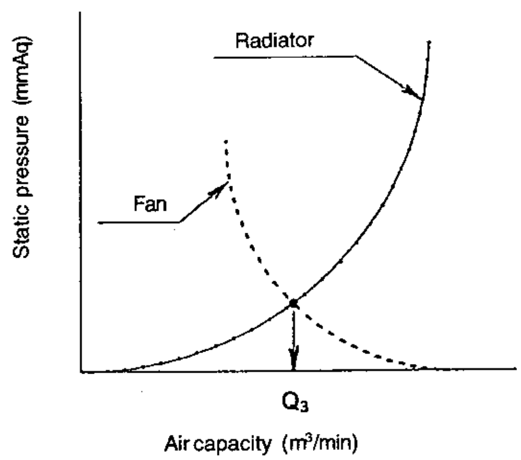


To convert this curve to the relationship with the flow rate, the core configuration of the radiator to be used will be examined. The air flow rate-static pressure characteristic curve is created by multiplying the velocity of the flow-static pressure characteristic curve of that core configuration by the total area of the core of the radiator to be used.

This would become a single characteristic curve when the radiator is finalized. In short, it indicates that the greater the air volume making contact with the radiator, the greater the static pressure becomes.

c) Determination of radiator cooling air capacity Q_3

After creating the characteristic curves of the fan and radiator on the same basis, these two curves are overlaid. The intersection formed is the equilibrium point for the characteristics of the fan and radiator and the air capacity reading for this point is the radiator cooling air capacity Q_3 of this engine.



Now calculate the radiator capacity using this air capacity. If the air capacity is too low, increase the fan speed or diameter, redraw the characteristic curves and repeat the process from the beginning.

Determine the fan diameter, number of rotations and the radiator as described. The air capacity from the final combination of these parameters will be the radiator cooling air capacity Q_3.

When calculating the radiator capacity, it is necessary to consider the air temperature in contact with the radiator depending on whether the fan is of the suction (puller) or discharge (pusher) type.

For the suction type, then the outside temperature is used for the calculation, but in the case of a discharge type fan, the air temperature has to be calculated as pre-heated by the surface radiation from the engine and the driven machine. The radiator capacity is usually calculated by estimating such temperature rise as 10℃ and the excess or shortage of air capacity is examined.

Generally, the discharge type fan is used for a generator engine. This means that the radiator cooling air capacity Q_3 contains a separate portion of air capacity Q_2 for suppressing the room temperature rise to within 10℃. Therefore, it is not necessary to consider Q_2 in the case of a radiator cooling type.

TNE system diesel engines have various combinations of cooling-related parts according to the purpose of the driven machine. Therefore, radiator cooling air capacity differs by driven machine.

7-5-2 Concept of ventilation

The ventilator capacity differs by the type of ventilator, pusher or discharge. The concept of ventilation also differs by whether the diesel generator has the radiator cooling system or discharging cooling system.

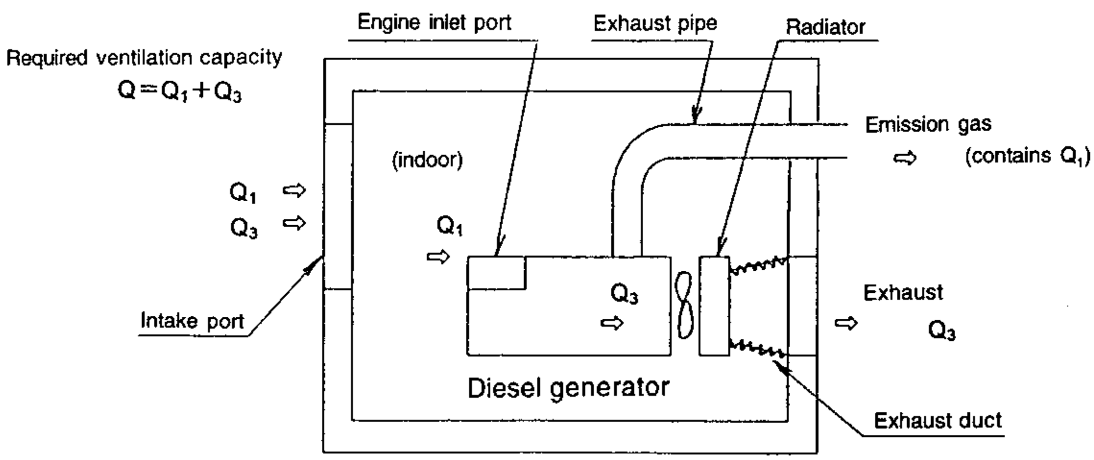
The individual ventilation capacity calculation formulas handle their calculation result different way irrespective of the ventilation method, for which care must be taken.

(1) Radiator cooling system

The cooling fans on the diesel generators of radiator cooling systems mostly use the discharge fan. In this case, it is not necessary to install a ventilator by providing an exhaust air duct. The intake side must have an intake port large enough to feed the required ventilation capacity Q.

In the case of the radiator cooling system, it is not necessary to consider providing room ventilation Q_2 to suppress the room temperature rise since the radiator cooling air capacity Q_3 already contains capacity for suppressing the rise of room temperature.

Therefore the following ventilation relationship is used:



Where, Q : Required ventilation capacity
Q_1 : Air capacity required for engine combustion
Q_3 : Radiator cooling air capacity

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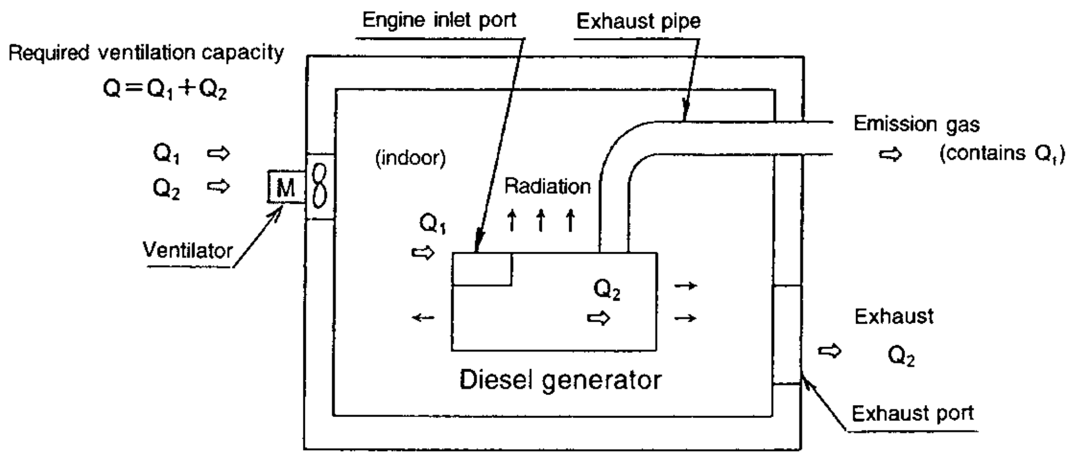
(2) Discharging cooling system

The diesel generator of the discharging cooling system directly brings in engine cooling water from outside and discharges it after cooling the engine. It is, therefore unnecessary to provide ventilation for cooling the engine.

Note, however, that the capacity of the ventilation fan to ensure the total of air volume Q_2 for suppressing room temperature rise resulting from heat radiation from the generator including the engine and air volume Q_1 required for engine combustion depends on where the fan is to be installed.

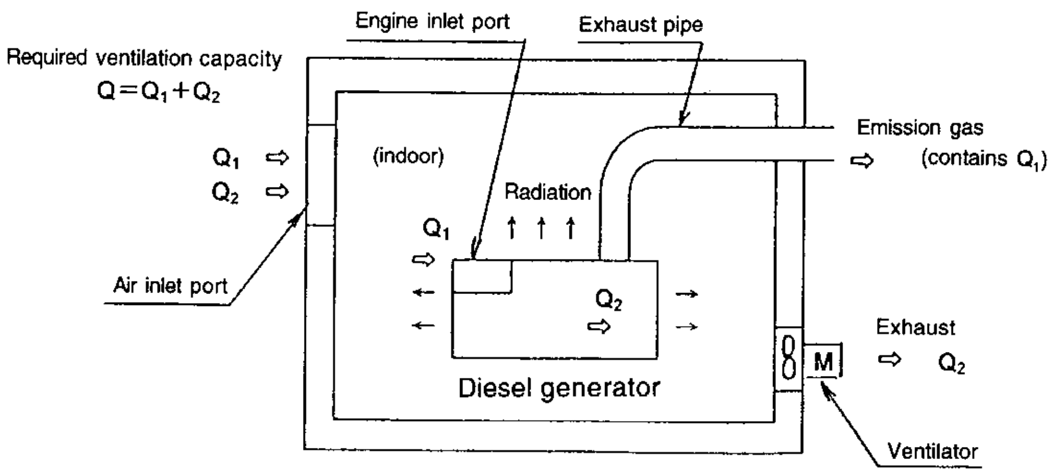
The ventilation layout, therefore, should be designed as shown below.

(a) When the ventilation fan is to be installed on the air inlet side, provide an air outlet port to discharge air volume Q_2 for suppressing the room temperature rise on the exhaust side.



Where, Q : Required ventilation capacity
Q_1 : Required air capacity for engine combustion
Q_2 : Ventilation capacity for suppressing the room temperature rise

(b) When the ventilation fan is to be provided on the discharge side, provided an air intake port to supply air volume Q on the inlet side.



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8. Exhaust System

The purpose of the exhaust system of an engine is primarily to lead high temperature emission gas generated during fuel combustion to a safe location and release it to the open air. A secondary purpose is to reduce the exhaust noise to an allowable level using a muffler, etc.

Piping for guiding exhaust gas and the muffler for suppressing noise all prevent smooth flow of emission and adversely affect the engine combustion performance due to so-called exhaust back pressure (exhaust resistance). When the exhaust back pressure exceeds an allowable value, the fuel consumption increases, the exhaust temperature rises, output drops, the emission content worsens, and smoke density becomes worse, all affecting engine life and other performances that are related to the quality assurance of the engine. In addition, since the exhaust system is subject to high temperatures, safety, measures have to be taken.

These measures for safety and exhaust back pressure cannot be effectively addressed with the engine design itself; they should be examined in advance at the stage of designing a driven machine and testing the prototype, and the acceptability of quality should be comprehensively checked.

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8-1 Exhaust Back Pressure

Factors contributing to the increase or decrease of exhaust back pressure (exhaust resistance) include the following:

a) Exhaust gas quantity
b) Muffler capacity and type
c) Length and diameter of exhaust pipe
d) Number of bends of exhaust pipe and their angles

Using these items as the factors, the back pressure can be calculated in advance at the design stage. For the calculation method, see section 8-4 "Exhaust Gas Volume and Exhaust Back Pressure." The calculation formula, however, is for general application and discrete engine characteristics are not considered. Therefore, the back pressure should be checked finally through prototype tests. This section describes how to measure the back pressure of the driven machine and allowable value. If the calculation result exceeds the allowable value, the above items b), c), and d) must be re-checked.

8-1-1 Measurement of exhaust back pressure

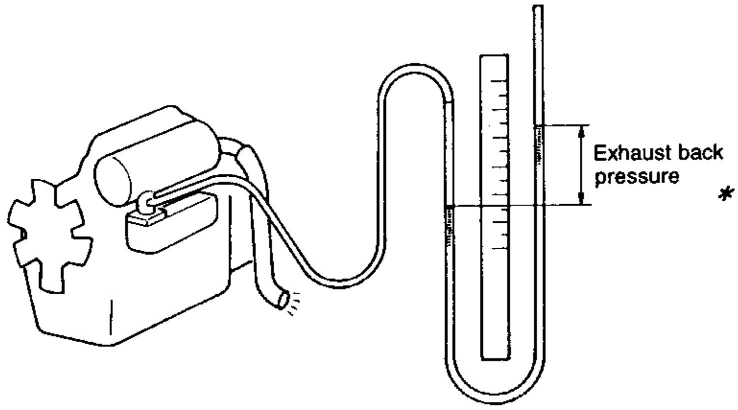
Exhaust back pressure is measured at the general outlet of the engine exhaust manifold. Generally, the back pressure is sampled by installing a pipe joint near the joint flange on the side of the manifold of the exhaust muffler or exhaust pipe.

The pressure is normally led to a manometer via a vinyl pipe. Since the pipe joint is directly exposed to the heat from the exhaust gas, the vinyl pipe may be damaged if the length of the pipe joint is too short. To avoid this, use 8 mm diameter copper pipe for the joint. In this case an extension pipe of about 1 meter will be needed for radiation of the heat.

To avoid vibration on the side of the engine as much as possible, it is necessary to wind the extension pipe into a spiral form. A drain tank should be provided to deposit drain generated in the extension pipe during the test.

When measuring the exhaust back pressure, create a state equivalent to the maximum load of the driven machine by fully equipping the engine with the exhaust system parts and components of the driven machine.

The measuring device will be generally configured as follows:



* *Measure the exhaust back pressure by installing a manometer.*

8-1-2 Allowable exhaust back pressure

When the measured exhaust back pressure exceeds the allowable exhaust back pressure at which the engine performance is assured, the exhaust system must be reviewed before starting to produce the driven machine. For the value of allowable exhaust back pressure, see section 1-4 "Allowable depression at engine manifold and exhaust back pressure" in Chapter 1.

The allowable exhaust back pressure value consists of the initial upper limit value and the upper limit value for exhaust system cleaning. At the development stage of a driven machine, the initial upper limit value should be applied, and the upper limit value for exhaust system cleaning to the maintenance check stage.

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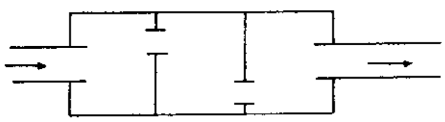
8-2 Exhaust Muffler

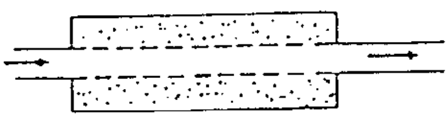
The purpose of the exhaust muffler in the exhaust system is to reduce the exhaust noise to an allowable level.
The exhaust muffler is called a muffler or silencer, but the meaning is the same.

The structure and appearance may differ by purpose, but normally the following three types of model structures are used when describing the principle of sound energy attenuation inside the exhaust muffler:

a) Expansion type
Guides the exhaust gas to the silencer and allows it to be expanded and diffused, thus attenuating the noise energy.



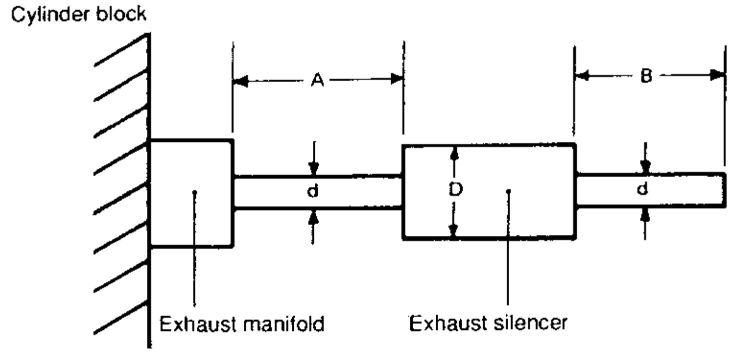
b) Resonance type
Divides the silencing chamber into several cells with the shielding plates and attenuates the sound energy by a sort of resonance with the combination of the cells.



c) Absorption type
Absorbs the sound energy with sound absorbing material such as glass wool, etc. which covers the outside of the exhaust tube with multiple holes. This type is also called a non-resistance type.

Silencers whose structures are based on the principle of sound attenuation are frequently used for engines for installed type machines, particularly for generators.
For engines for industrial application in general, mufflers having a complex structure are used by effectively combining the three principles for the purpose of miniaturization.

To reduce exhaust noise, it is necessary to examine the exhaust pipes to and from the muffer, that is, the diameter and the length of the tail pipe in addition to the installation of the exhaust muffler.



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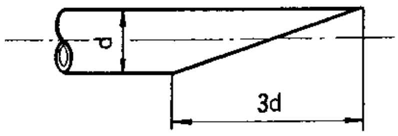
For a standard setting, select 1/3 to 1/5 of the diameter (D) of the exhaust muffler for the diameter (d) of the tail pipe. The greater the ratio, the greater the silencing effect but care should be taken to ensure that the exhaust resistance does not increase too much accordingly. The balance of the length of exhaust pipe (A) between the exhaust manifold and the exhaust silencer with the length of tail pipe (B) also help reduce the exhaust noise, but the length for the maximum silencing effect is to be determined as part of the noise reduction measure test.

Arrange the exhaust pipe and the tail pipe as straight as possible. Even if bending is necessary, adopt as great a corner radius (R) as possible for the maximum noise reduction effect.
For the best effect, machine the end of the tail pipe diagonally rather than at right angles.
The standard length of the cut section of the tail pipe is approximately three times the tail pipe diameter (d).



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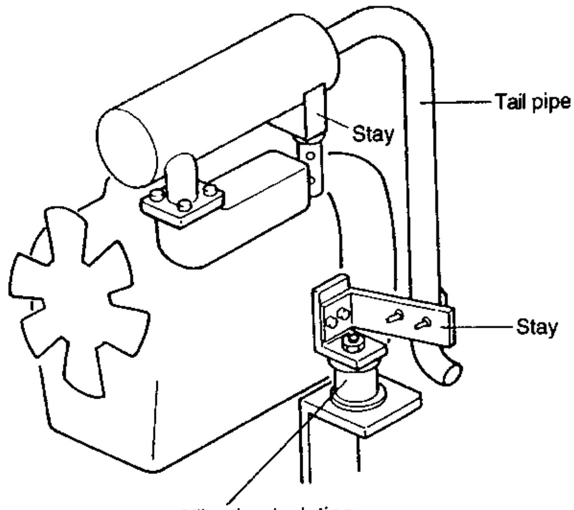
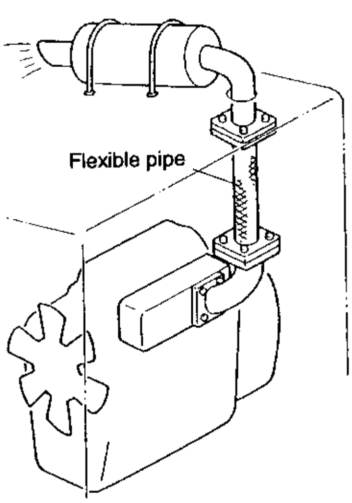
8-3 Precautions for Exhaust System Fitting

Fitting of the exhaust system requires a careful examination not only from performance viewpoints but also safety aspects. Carefully check the installation for the following points as the system is directly related to fire and human accidents.

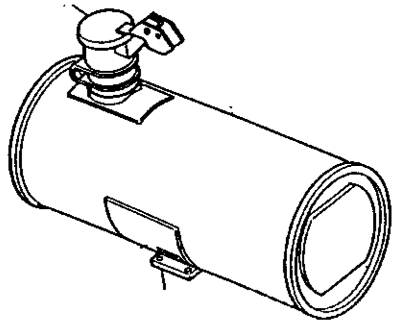
8-3-1 Installation of exhaust muffler



The exhaust muffler must be installed on the driven machine side with as little vibration as possible. When installing the muffler on the engine side, fix it and the tail pipe with highly rigid stays. Base the stays on the engine main body.



When installing the exhaust muffler apart from the engine, insert a flexible pipe between the engine and exhaust muffler In the case of a turbocharged engine, do not connect the flexible joint directly to the turbocharger but by way of an exhaust interconnecting pipe.



Deposits of water inside the exhaust muffler corrode the muffler. Install the muffler so that rainwater cannot enter the exhaust outlet or tail pipe. Special care should be taken when installing the muffler outdoors or the machine is driven outdoors.

Arrange the exhaust muffler to prevent contact with the hand and/or foot. Take measures to prevent fire or burns.

8-3-2 Piping of exhaust pipe

The most important thing in laying the piping for the exhaust system is safety. Fit the exhaust system to ensure that the parts and components of the fuel system, lubrication system, and various electrical parts are not in contact with or in the vicinity of the piping of the exhaust system. Instruct the driven machine assembly lines accordingly. Where there is a risk of contact of the human body with high temperature sections, consider during the design stage providing shielding plates or heat insulating material for protection.

In the case of a piping structure that allows rainwater or drain to accumulate, provide a small hole (or drain plug) at the lowest position of the piping system to let the rainwater and drain escape.

Consider the position and direction of the exhaust gas outlet of the tail pipe to prevent the heated exhaust gas from mixing with the cooling air of the radiator. Such mixing will directly cause overheating by the heated exhaust, allowing carbon particles to be deposited on the radiator core and leading to rapid clogging after servicing. Should the engine room temperature rise excessively, insulate the exhaust system with heat insulator material. To decide whether this is necessary.
See "Matching Test Procedure" in Chapter 12.

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8-4 Exhaust Gas Volume and Exhaust Back Pressure

Depending on the engine mounting position or location of installation of the driven machine, the exhaust piping of the engine may be extended.

However, extending the exhaust pipe length or putting bends in the pipe at random will increase the pipe line resistance when the exhaust gas flows through the pipe, raising the exhaust back pressure. This may cause the engine output to drop, the exhaust temperature to rise and other problems.

Therefore, it is necessary to estimate the back pressure by calculation when reviewing the exhaust pipe system, and then consider the length, diameter and bends of the exhaust pipe so as to maintain the initial exhaust back pressure at the target level or less.

This calculation formula, particularly the method of calculating exhaust gas volume, includes excess air ratio, intake volumetric efficiency and other individual constant engine characteristics. Therefore, this formula must not be used to examine the test engine.

Of course, when examining general-purpose engines, this calculation method may be used without problem.

8-4-1 Exhaust gas volume

(1) Combustion gas volume
First obtain the volume of combustion gas when liquid fuel reacts with the oxygen in the air to become a gaseous body of 1 atm at 273K (0℃).

a) Naturally aspirated engine

$$Vd = 21.53 \times b \times Pe \times 10^{-3}/3600 \quad m^3/sec$$

b) Normal turbocharged engine

$$Vd = 23.76 \times b \times Pe \times 10^{-3}/3600 \quad m^3/sec$$

c) High turbocharged engine (with intercooler)

$$Vd = 26.00 \times b \times Pe \times 10^{-3}/3600 \quad m^3/sec$$

Where,

Vd :	Combustion gas volume	m^3/sec	(273K (0℃), 1 atm)
b :	Specific fuel consumption	g/kWh	(g/hph, g/PSh)
Pe :	Engine output	kW	(hp, PS)

(2) Exhaust gas volume

Actually, heat is generated with chemical change, so the gas expanded by the exhaust temperature is the exhaust gas volume.

$$V = Vd \bullet \frac{Tex}{273} = Vd \bullet \frac{273 + t}{273} \quad m^3/sec$$

Where,

V : Exhaust gas volume m^3/sec

Vd : Combustion gas volume m^3/sec (273K (0℃), 1 atm)

Tex : Exhaust gas temperature K
K = 273 + t

t : Exhaust gas temperature ℃

Notes:

Exhaust gas volume V, which is the biggest factor in the calculation of exhaust back pressure, is an expanded volume of the combustion gas volume Vd under the exhaust gas temperature t℃.
Since Vd in the equation of item (1) above is calculated larger than the actual volume, the exhaust gas volume V becomes greater than the actual volume.

To obtain the exhaust gas volume V in the back pressure calculation of general-purpose machines for other than governmental use, use Q_1 as described in section 7-1-1(1), "Air capacity required for combustion" in Chapter 7 for a more realistic result.

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8-4-2 Exhaust back pressure

(1) Specific weight of exhaust gas

$$\gamma = \gamma_0 \bullet \frac{273}{K} \bullet \frac{P_1}{P_0}$$

Where,

γ : Specific weight of exhaust gas — kg/m^2

γ_0 : Specific weight of exhaust gas (273K (0℃), 1 atm) — $1.29\ kg/m^2$

$$= 1.29 \times \frac{273}{273 + t}$$

K : Exhaust gas temperature — K
$K = 273 + t$

t : Exhaust gas temperature — ℃

P_0 : Standard atmospheric pressure

P_1 : Atmospheric pressure at the service location

$P_1/P_0 \fallingdotseq 1$

(2) Exhaust gas speed

$$v = \frac{V}{a}$$

$$= \frac{4 \bullet V}{\pi \bullet d^2}$$

Where,

v : Exhaust gas speed — m/sec

V : Exhaust gas volume — m^3/sec

a : Section area of exhaust pipe — m^2

d : Inside diameter of exhaust pipe — m

(3) Pipe line resistance

Pipe line resistance is calculated by adding the straight pipe resistance, pipe joint resistance muffler resistance and pipe-end discharge resistance.

For a summary of the coefficients and data to be used for calculation, see section 8-4-4.

a) Straight pipe resistance: $\triangle P_1$

$$\triangle P_1 = 2\mu \bullet \frac{\gamma \bullet v^2}{g \bullet d} \bullet L \qquad \text{mmAq}$$

b) Pipe joint resistance: ΔP_2

$$\Delta P_2 = 2\mu \cdot \frac{\gamma \cdot v^2}{g \cdot d} \cdot (d \cdot A \cdot n) \qquad \text{mmAq}$$

Where,

μ	: Pipe friction coefficient	
γ	: specific weight of exhaust gas	kg/m^3
v	: Exhaust gas speed	m/sec
g	: Acceleration of gravity	9.8 m/sec^2
d	: Inside diameter of exhaust pipe	m
L	: Total length of straight portion of exhaust pipe	m
A	: Resistance-equivalent length of joint	m
n	: Number of joints	

c) Muffler resistance: ΔP_3

(Examples)
Expansion type silencer : 60 mmAq
Non-resistance type silencer: 20 mmAq

d) Pipe-end discharge resistance: ΔP_4

40 mmAq

8-4-3 Total back pressure of exhaust system: P

$$P = \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 \qquad \text{mmAq}$$

If the total back pressure of the exhaust system exceeds the initial allowable exhaust back pressure described in section 1-4, "Allowable depression at engine manifold and exhaust back pressure" in Chapter 1, re-examine the length of exhaust pipe, the number of joints, and the inside diameter of the exhaust pipe and calculate the total back pressure again.

8-4-4 Materials for calculating exhaust back pressure

Table 1 Relationship between pipe friction coefficient μ of exhaust gas and inside diameter d of the exhaust pipe

Nominal size	d (m)	a (m^2)	μ	Nominal size	d (m)	a (m^2)	μ
SGP 25A	27.6×10^{-3}	0.598×10^{-3}	0.01242	SGP 80A	80.7×10^{-3}	5.115×10^{-3}	0.00594
SGP 40A	41.6×10^{-3}	1.359×10^{-3}	0.00999	SGP 100A	105.3×10^{-3}	8.709×10^{-3}	0.00513
SGP 50A	52.9×10^{-3}	2.198×10^{-3}	0.00756	SGP 125A	130.8×10^{-3}	13.44×10^{-3}	0.00464
SGP 65A	67.9×10^{-3}	3.621×10^{-3}	0.00675	SGP 150A	155.2×10^{-3}	18.92×10^{-3}	0.00432

SGP: Carbon Steel Pipe for ordinary piping.

Table 2 Resistance-equivalent length of joints

Joints	SGP nominal size	A	Joints	SGP nominal size	A
90° elbow	10A to 65A	30	90° bend	R/d=3 to 5	10 to 20
90° elbow	80A to 150A	40	Long elbow	25A to 80A	15 to 20
90° elbow	175A to 200A	50	45° elbow	25A to 80A	15 to 20

R: Radius of bending

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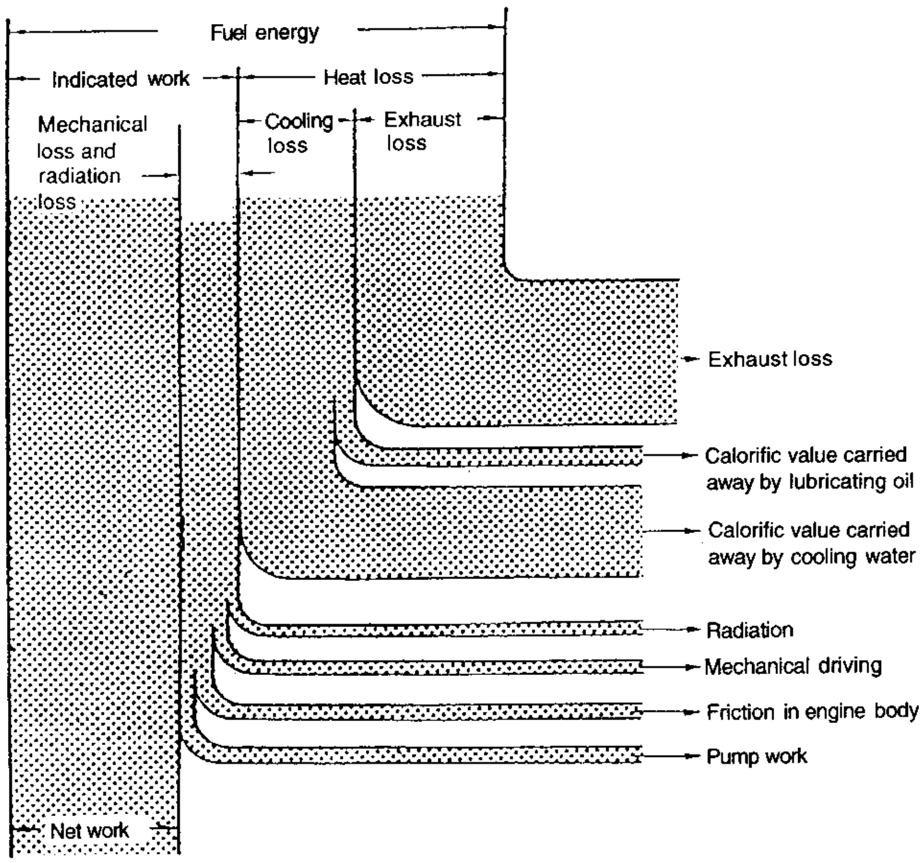
9. Cooling System

Out of the heat generated by combustion of the fuel, 30 to 40% can be taken out as power. Some 25 to 30% is carried away by the cooling water and 30 to 35% is released as a loss into the open air by exhaust or heat radiation from various parts. The comparison of the generated heat and the breakdown of the consumption is called the heat balance. It varies with the presence or absence of a turbocharger and the combustion system. The figure below shows an example of heat balance for a naturally aspirated engine.

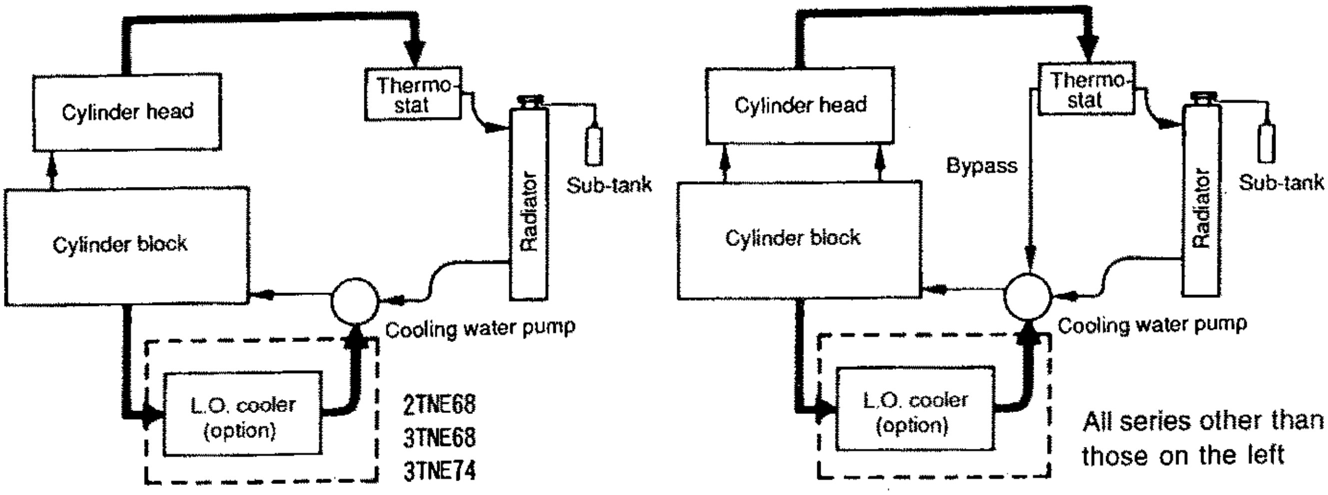


As compared with the DI system engine, the special swirl chamber system engine involves an additional cooling loss of 8 to 10%. This is because of the greater surface area of the combustion chamber including the special swirl chamber to be cooled and a loss work for gas intake and exhaust to and from the special swirl chamber.

In a turbocharged engine, part of the heat released as the exhaust is recovered by the turbine to drive the blower for supplying compressed intake air to the engine.

As seen from the figure above, the cooling loss and exhaust loss account for a great portion of the loss. Reduction of these losses is important in improving the thermal efficiency. Reduction of the cooling loss is especially important as it incurs further cooling fan drive loss for releasing the heat released to the cooling water again into the open air through the radiator.

9-1 Cooling System Diagram



The above figure shows the cooling water system diagram for the TNE series engines. The water cooled through the radiator is fed by the cooling water pump into the engine water jacket to cool the inside of the engine, the cylinder outer walls and cylinder head, and returns to the radiator via the thermostat. In the radiator, the cooling water is cooled to the appropriate temperature for recirculation in the engine by the cooling fan driven by the engine.

9-2 Engine Cooling Water

The heat generated by combustion in the combustion chamber heats the neighboring parts. If the cooling state is incomplete, the cylinder head, combustion chamber, pistons and exhaust valves around the combustion chamber are influenced excessively by the heat and the materials used lose their strength, leading to failures and shortening of the service life.

Incomplete cooling also affects the lubricating oil supplied to each moving contact portion of the engine, causing lowered lubrication effect and oil deterioration that may result in problems such as abnormal wear and seizure.

If the coolant temperature is too low, on the contrary, the thermal efficiency is lowered, causing poor combustion and rusting of cylinder bores by the corrosive products resulting from reactions between carbon monoxide and sulfur dioxide generated in the combustion process and the condensate water in the gas. The cooling water rate and temperature are, therefore, very important.

9-2-1 Required characteristics of engine cooling water

1. Shall be soft water.
2. Shall not freeze.
3. Quick heat transfer shall be assured.
4. Shall be chemically stable.
5. Shall suppress rusting or corrosion.
6. Shall be electrically non-conductive.
7. Shall be a fluid in the whole operating temperature range.

9-2-2 Cooling water quality

The cooling water supplied to the diesel engine may generate corrosion or scale in the cooling water system depending on its quality. To prevent problems in the cooling water system, always use high quality soft water within the recommended standards.

[Recommended water quality standards and major troubles from poor water quality]

No.	Item	Recommended value	Description	Major trouble	
				Corrosion	Scale
1	pH 298K {25℃}	6.5 to 8.5	Expresses the hydrogen ion concentration in an aqueous solution. It is used as the measure for judgement of neutrality (pH=7), acidity (pH<7) or alkalinity (pH>7). Acidity increases corrosion and alkalinity increases scale generation. Generally, pH of natural water is between 6 and 8.	○	○
2	Electrical conductivity 298K {25℃}	<400 μ℧/cm	Indicates micro-moh per cm. High electrical conductivity means high contents of electrolytic ions and solids in the water, which increase corrosion and scale generation in water.	○	○
3	Total hardness ($CaCO_3$)	<100 ppm	Indicates the quantity of Ca ions and M_2 ions in the water by the corresponding calcium carbonate in ppm. High total hardness increases scale generation.	–	○
4	M alkalinity ($MaCO_3$)	<150 ppm	Indicates whole alkaline contents in the forms of hydroxides, carbonates and bicarbonates in water by the corresponding calcium carbonate in ppm. High M alkalinity means dissolution of alkaline contents, which increases scale generation.	–	○
5	Chlorine ion content (Cl^-)	<100 ppm	Indicates chlorine ion content in water. High chlorine ion content in water increases corrosiveness.	○	–
6	Sulfate ion content (SO_4^{2-})	<100 ppm	Indicates the sulfate ion content in water. High sulfate ion content in water causes copper corrosion. If Ca ion content is also high, $CaSO_4$ is generated by the reaction with Ca^{2+}, which increases scale generation.	○	–
7	Total iron (Fe)	<1.0 ppm	Indicates the iron content in water. When 0.3 ppm is exceeded, coloring by precipitation occurs. High iron content causes scale generation.	–	○
8	Silica (SiO_2)	<50 ppm	Indicates silicic acid content in water. Hard scale is generated by combination with Ca and M_2. This is not a serious problem if the water hardness is low.	–	○
9	Evaporation residue	<400 ppm	Quantity of non-soluble substances obtained by evaporation. Much suspended solids increases electrical conductivity, which increases corrosion.	–	○

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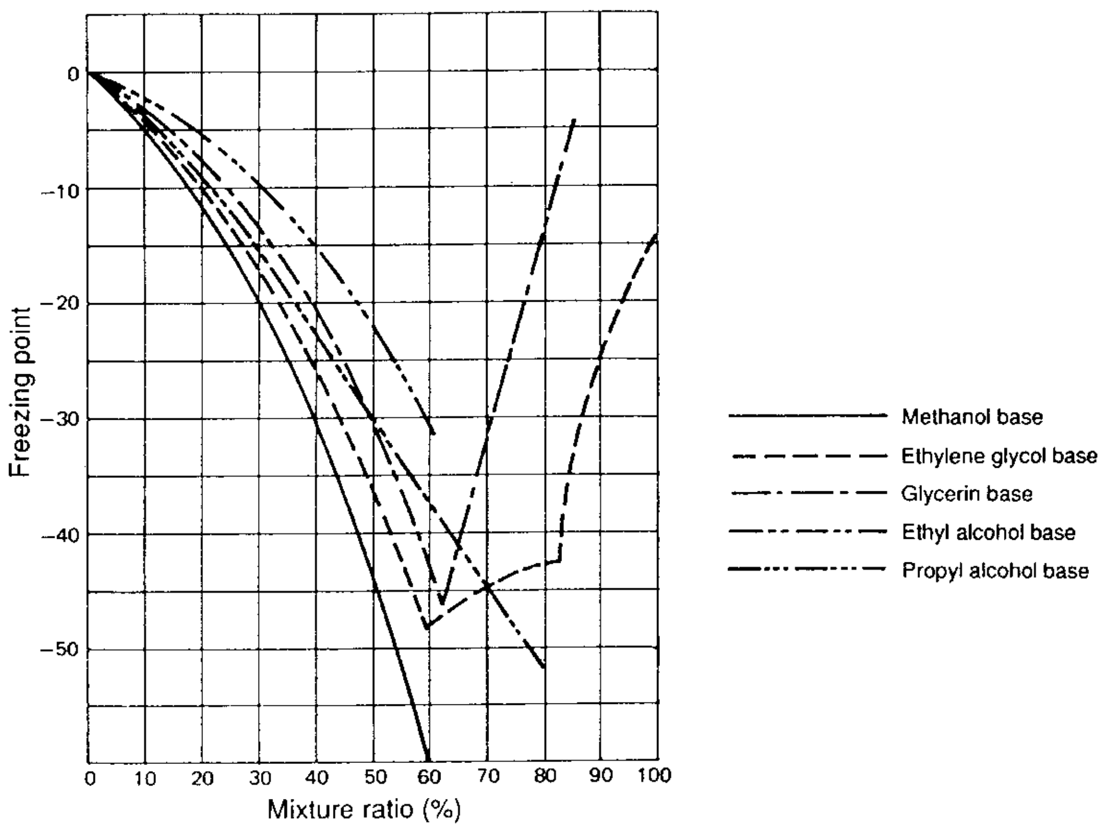
9-3 Antifreeze, Rust Preventive and Descaling Agents

9-3-1 Antifreeze

Antifreeze is mixed in cooling water to prevent the engine water jacket and radiator from being damaged by freezing of cooling water. Antifreeze prevents not only freezing but also corrosion. Antifreeze is available in types for use in the cold season only and throughout the year.

[Reference: Mixing ratio of antifreeze for various freezing points]



(1) Precautions for use

1. Thoroughly drain water from the cooling system before filling antifreeze.
2. Note that antifreeze changes the heat balance to a certain degree as shown in the table below.

Antifreeze	Rise in cooling water temperature
30%	1 K {1°C}
50%	2 K {2°C}

3. After filling antifreeze, warm up the engine for several minutes to ensure sufficient mixing of antifreeze.
4. When using antifreeze, carefully read the materials and catalog issued by the manufacturer.

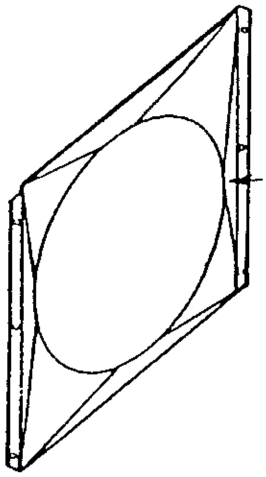
9-3-2 Rust preventive and descaling agent

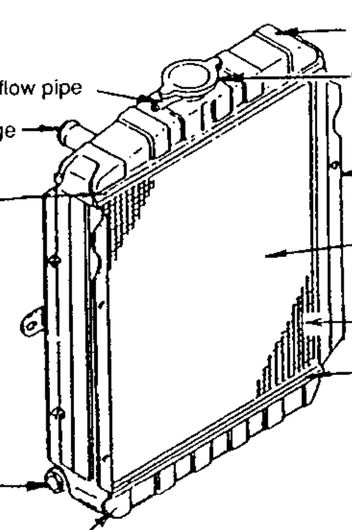
When hard water or water containing mud, sand or dirt is used, scale deposits in the cooling system and obstructs the water flow, causing overheating from worsened cooling effect and corrosion. It is recommended to use a rust preventive and descaling agent. When using a rust preventive and descaling agent, read the precautions in the materials and catalog issued by the manufacturer.

9-4 Radiator

A diesel engine requires cooling to maintain the cylinders, cylinder head, pistons and lubricating oil at each moving contact portion at appropriate temperature levels. The radiator circulates the cooling water and radiates the heat from the cooling water for this purpose.

[Structure of radiator]



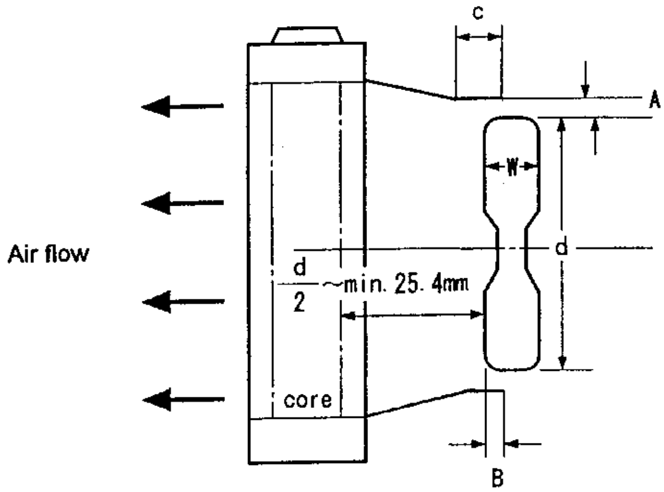


9-4-1 Radiator position

The relative positioning of the radiator and fan greatly influences the cooling efficiency. If the radiator is too close to the fan, the portion near the fan shaft is not cooled sufficiently. If too far, the air blown by the fan does not reach the radiator core. The air flow is different between the pusher type fan and suction type fan. If the radiator is provided with a fan shroud, at least 25 mm distance must be kept between the core surface and fan.

Refer to the following figure for the relative positions of the fan and fan shroud. The figure shown here, however, is a general example. Determine the final positions of the radiator and fan to obtain the best heat balance with the engine mounted on the driven machine.

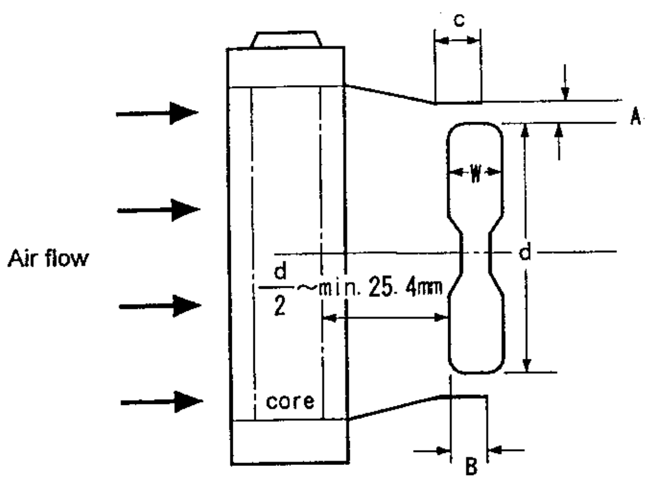
(1) Pusher fan



Symbol	Meaning	Description
* A	Clearance at end of fan blade	Aperture (between end of fan blade and shroud): 10 to 15 mm
B	Fan lap width	Lap at 1/3 or more of projected fan blade width (W)
C	Shroud ring width	Approx. 1/2 of projected fan blade width (W)
W	Projected width of fan blade	
d	Fan diameter	

* Roughly 10 mm for stationary equipment and 15 mm for on board equipment

(2) Suction fan



Symbol	Meaning	Description
*A	Clearance at end of fan blade	Aperture (between end of fan blade and shroud: 10 to 15 mm
B	Fan lap width	Lap at 2/3 or more of projected fan blade width (W)
C	Shroud ring width	Approx. 1/2 of projected fan blade width (W)
W	Projected width of fan blade	
d	Fan diameter	

* Roughly 10 mm for stationary equipment and 15 mm for on board equipment

9-4-2 Radiator standard capacity list

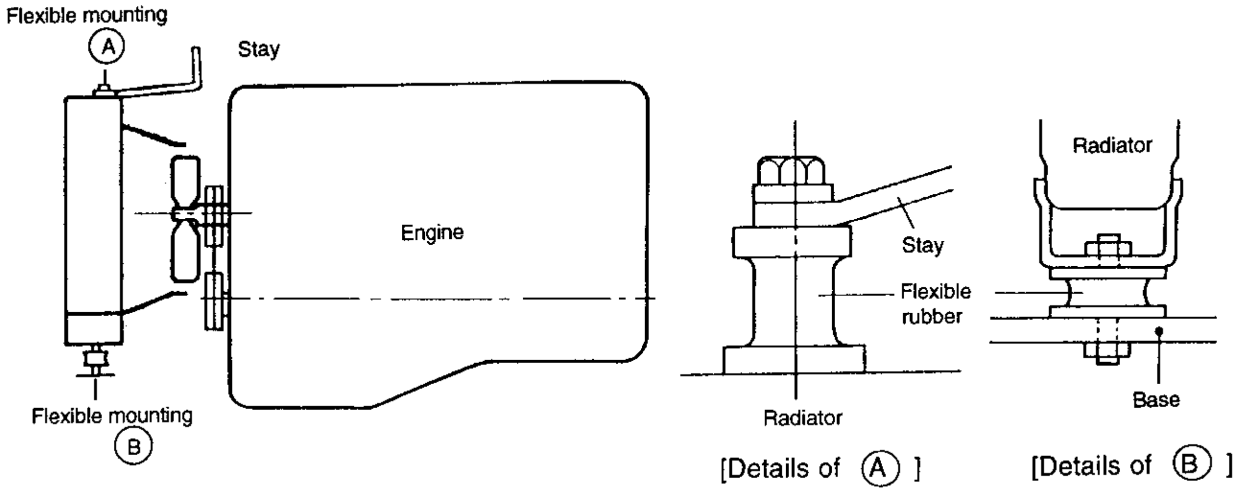
The hourly heat release rate (kcal/h) is used as the measure for indicating the radiator capacity in Yanmar. This value, however, is not the absolute value but the rate under specified test conditions. When a particular radiator is mounted on a given engine, the fan shape, fan rpm, cooling water flow rate and/or ambient temperature, therefore, may be different from the test conditions and so the heat release may deviate from that specified on the drawing. In other words, the radiator heat release shown here indicates the relative radiator capacity.

The table below shows the capacities of standard radiators Yanmar orders for the TNE engines. The optimum radiator should be selected by referring to the instruction in Chapter 12, "Matching Test Procedure" since the radiator selected according to the table below is not always appropriate.

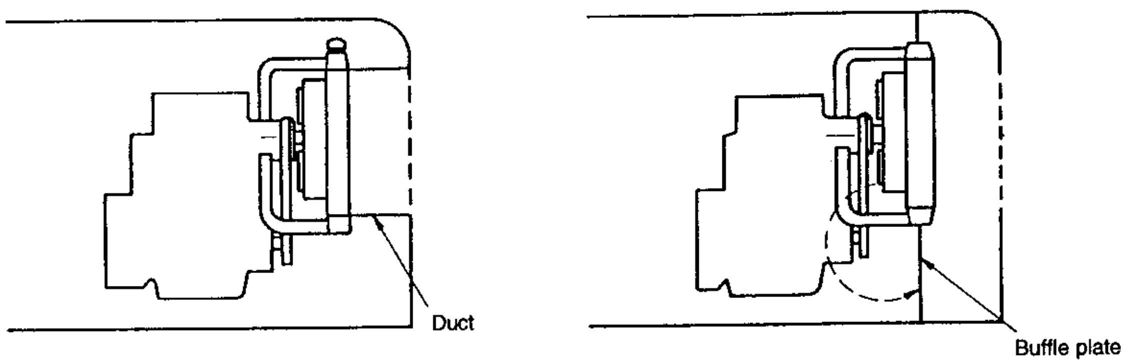
<table>
<tr><th rowspan="2">Model</th><th>Specification</th><th colspan="2">CL</th><th colspan="6">VM</th><th colspan="2">CH</th></tr>
<tr><th>rpm</th><th>1500</th><th>1800</th><th>2000</th><th>2200</th><th>2400</th><th>2600</th><th>2800</th><th>3000</th><th>3000</th><th>3600</th></tr>
<tr><td colspan="2">2TNE68</td><td colspan="2"></td><td colspan="8">19,700 kcal/h</td></tr>
<tr><td colspan="2">3TNE68</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE74</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">2TNE68-N</td><td colspan="2"></td><td colspan="8">19,700 kcal/h</td></tr>
<tr><td colspan="2">3TNE66-N</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE68-N</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE72-N</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE74-N</td><td colspan="2"></td><td colspan="8">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE78A</td><td colspan="10">20,500 kcal/h</td></tr>
<tr><td colspan="2">3TNE82A</td><td colspan="8">20,500 kcal/h</td><td colspan="2"></td></tr>
<tr><td colspan="2">3TNE84</td><td colspan="2">19,600</td><td colspan="8">24,200 kcal/h</td></tr>
<tr><td colspan="2">3TNE88</td><td colspan="2">19,600</td><td colspan="6">24,200 kcal/h</td><td colspan="2"></td></tr>
<tr><td colspan="2">3TNE84T</td><td colspan="2">19,600</td><td colspan="8">24,200 kcal/h</td></tr>
<tr><td colspan="2">4TNE84</td><td colspan="2">29,200</td><td colspan="8">35,500 kcal/h</td></tr>
<tr><td colspan="2">4TNE88</td><td colspan="2">29,200</td><td colspan="6">35,500 kcal/h</td><td colspan="2"></td></tr>
<tr><td colspan="2">4TNE84T</td><td colspan="8">35,500 kcal/h</td><td colspan="2"></td></tr>
<tr><td colspan="2">4TNE94</td><td colspan="7">47,800 kcal/h</td><td colspan="3"></td></tr>
<tr><td colspan="2">4TNE98</td><td colspan="7">47,800 kcal/h</td><td colspan="3"></td></tr>
</table>

9-4-3 Precautions for installation

(1) If the radiator is directly installed on the engine mount, the vibration of the engine is transmitted to the radiator. It is therefore necessary to support the radiator with vibration damping to enable the radiator to endure the vibration acceleration. The vibration acceleration must be kept at 59 m/s^2 {6G} or less.



(2) Driven machine with engine compartment
Provide a duct or baffle plate for the radiator to improve the cooling efficiency by preventing blow back of heated air.



(3) Other Precautions

1. Determine the opening in front of the radiator at 100 to 120% or more of the radiator front surface area.

2. Install a subtank for the radiator.
The subtank receives the cooling water discharged from the radiator overflow pipe due to the increased internal pressure of the radiator as the cooling water temperature rises. When the cooling water temperature drops and the radiator internal pressure decreases, the cooling water returns from the subtank to the radiator to lengthen the cooling water supply interval. For the calculation of the capacity, see section 9-8, "Subtank" in Chapter 9..

3. Never paint the radiator core.

4. Design a structure to allow the fan belt to be tensioned and replaced easily.

5. Carefully avoid contact of the cooling water piping with other parts, such as the V-belt.

9-5 Cooling Water Piping

9-5-1 Rubber hose conditions

The rubber hose to be used in the cooling system must comply with the heat resistance and pressure resistance conditions specified by Yanmar.
An improper rubber hose may be torn by the water pressure or deformed by temperature change (extreme coldness or heat), obstructing the cooling water flow. For use in an extremely cold area, it is recommended to protect the rubber hose by wrapping cloth.

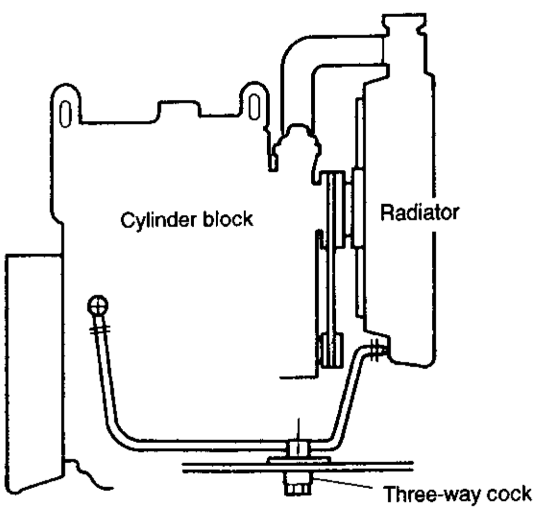
[Rubber hose material conditions specified by Yanmar]

Thickness	5 mm (The minimum allowable hose thickness is 3.5 mm.)
Pressure resistance	196 kPa (2 kgf/cm^2) or more
Heat resistance	393K {120℃} or more
Tensile strength	8820 kPa (90 kgf/cm^2) or more
Elongation	30% or more
Hardness	Hs70 ± 5
Material	EPDM (ethylene propylene diene rubber)

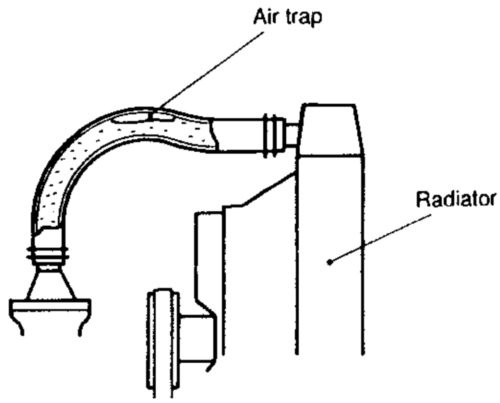
9-5-2 Precautions for piping

(1) The drain pipe should not protrude from the driven machine. It should be protected to prevent being damaged by an external obstacle. Take care to prevent the cooling water pipe from coming into contact with other parts.

(2) The cooling water must be designed to be drained from both the radiator and engine. The example using a three-way cock shown below is for draining both the radiator and engine at one point. Especially in the case of an engine for mounting on a vehicle, provide a drain pipe protecting structure to prevent any external obstacle from coming into contact with the pipe.



(3) When a cooling water hose is used to connect between the engine cooling water outlet and the radiator, arrange the piping without any convex portion.
A convex portion will obstruct air ventilation and cause air to enter the engine, resulting in partial heating and lowering of cooling performance.



(4) Always install the cooling water temperature alarm lamp. See section 9-7, "Cooling water temperature switch" in Chapter 9.

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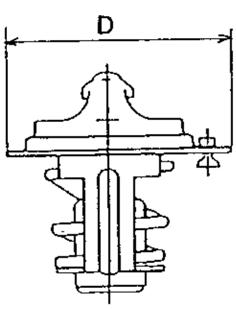
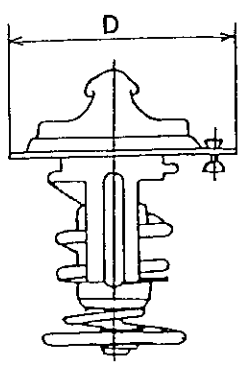
9-6 Thermostat

The thermostat is for automatic control of the engine cooling water temperature and is generally installed in the cooling water line between the cylinder head and radiator upper tank.
The purpose of the thermostat is to close the cooling water line to the radiator while the engine is cold to warm the engine up quickly. When the engine is warmed up, the thermostat valve starts to open to let the cooling water flow into the radiator. The thermostat installed in the TNE series engine is of the wax pellet type and has the performances shown in the table below. When cooling water is used for the heater, use the thermostat with a higher valve opening temperature (the shape is identical for each type).

	Standard			(For heater) option		
	2TNE68 3TNE68 3TNE74	2TNE68-N 3TNE66-N 3TNE68-N 3TNE72-N 3TNE74-N 3TNE78A 3TNE82A 3TNE84(T) 3TNE88 4TNE84(T) 4TNE88	4TNE94 4TNE98	2TNE68 3TNE68 3TNE74	2TNE68-N 3TNE66-N 3TNE68-N 3TNE72-N 3TNE74-N 3TNE78A 3TNE82A 3TNE84(T) 3TNE88 4TNE84(T) 4TNE88	4TNE94 4TNE98
Part code	129350-49800	129155-49800	121850-49810	119621-49800	129574-49800	121850-49800
Thermostat type	Wax pellet type					
Valve opening temperature	344K ± 1.5K (71℃ ± 1.5℃)			355K ± 1.5K (82℃ ± 1.5℃)		
Full opening temperature	358K (85℃)			368K (95℃)		
Maximum lift	8 mm or more					
Flange diameter D	φ44 mm		φ54 mm	φ44 mm		φ54 mm
ID color	Blue			None	Brown	None
Type	A	B		A	B	



A type



B type

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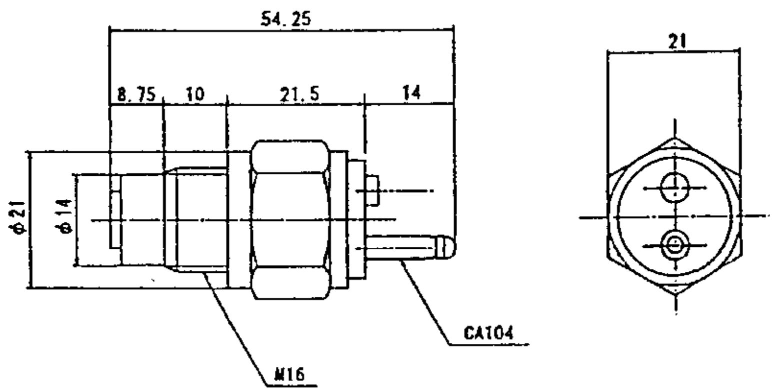
9-7 Cooling Water Temperature Switch

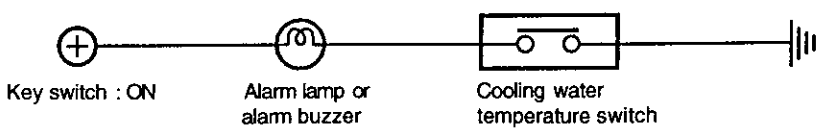
An abnormal temperature rise in the cooling water could cause a serious accident in the engine. A cooling water temperature switch is installed as standard to sense abnormal cooling water temperature and ensure safe operation of the engine. Provide an alarm lamp or buzzer on the machine to inform when the cooling water temperature rises over the specified temperature.

[Cooling water temperature switch specified for radiator installed in TNE series engine]

		All models of TNE series
Yanmar code No.		121250-44901
Operating temperature of cooling water temperature switch K {°C}	ON	383 ± 3 {110 ± 3}
	OFF	373 {100} or below
Contact point capacity		12 VDC–3.4 W or below
ID color		Gray



[Example of wiring diagram]



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9-8 Subtank

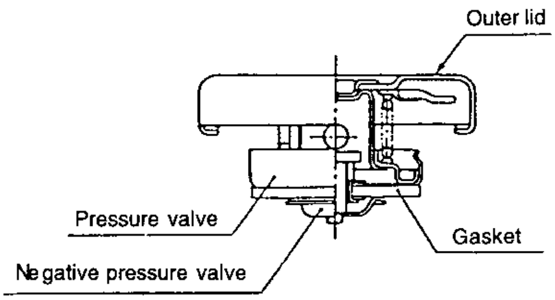
The radiator cooling system has a closed circuit, but due to the pressure cap structure that serves as the lid for the water feed port, the cooling water is continuously lost while the engine is repeatedly operated for an extended period of time.

Therefore, it is necessary to check and replenish cooling water periodically. The subtank is designed to greatly extend the replenishing interval.

9-8-1 Pressure cap structure

Beside serving as the lid for the water feed port, the pressure cap has a pressure regulation valve (hereafter referred to as "pressure valve") to maintain the cooling system under high pressure and a negative pressure regulation valve (hereafter referred to as "negative pressure valve") to prevent the cooling system from becoming negatively pressured.

Pressure cap



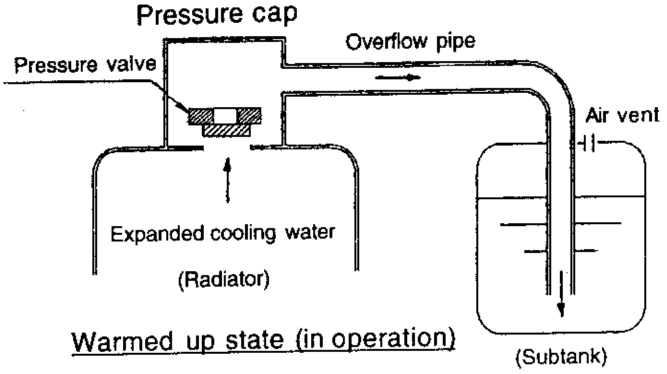
The pressure valve opens outward when the pressure in the radiator exceeds 88 kPa (0.9 kg/cm^2). Up to this point, it keeps the cooling water under high pressure to prevent it from boiling, simultaneously protecting the radiator from being damaged under higher pressure.

On the other hand, the negative pressure valve opens inward*1 and protects the cooling system from being crushed*2 when the cooling water is cooled and the pressure*4 inside the radiator becomes negative at 4.9 kPa (0.05 kg/cm^2) or less*3.

As described, the pressure cap protects the cooling system, and the subtank makes good use of this operation.

9-8-2 Function of subtank

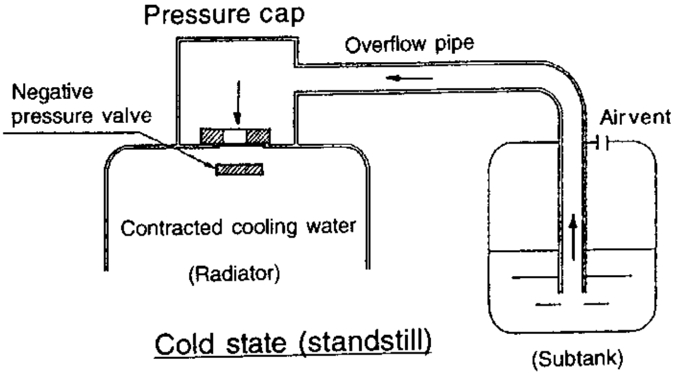
As mentioned, the pressure cap at the water feed port of the radiator discharges cooling water by opening the pressure valve in it when the internal pressure reaches 88 kPa (0.9 kg/cm^2) or more because of the expansion of the cooling water due to the temperature rise. If the engine is operated frequently, the cooling water in the radiator gradually decreases, and must be replenished. Discharged cooling water is guided to the subtank via an overflow pipe for reuse.



Warmed up state (in operation)

When the engine is driven, thermally expanded cooling water gradually opens the pressure valve of the pressure cap and is deposited in the subtank through the overflow pipe.

When the temperature rise of the cooling water stops before long and becomes constant, the overflow stops.



Cold state (standstill)

On the other hand, when the engine stops upon completion of work, the cooling water temperature rises temporarily, then it gradually drops. With the contraction of the cooling water inside the radiator, the pressure is lowered and ultimately reaches a negative pressure relative to the outside pressure.

When this negative pressure exceeds 4.9 kPa (0.05 kg/cm^2), the negative pressure valve in the pressure cap opens to allow the cooling water in the subtank to be sucked back into the radiator.

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As described, the overflown cooling water from the radiator is stored in the subtank without being lost and is available for reuse, extending the service duration of the radiator cooling water.

However, it is not possible to prevent the loss of cooling water by evaporation through the air vent hole. Sooner or later the cooling water decreases and needs replenishing.
For an engine equipped with the subtank, replenish the cooling water from the subtank (the initial feeding of cooling water should be made from both the radiator and the subtank, however).

9-8-3 Selection of Subtank Capacity

In order to select a proper subtank, calculate the quantity of the overflown cooling water due to the temperature rise as follows. It is a physical principle that even if the cooling water temperature and subsequently its density change, the total weight remains unchanged before and after the temperature change. In other words,

$$W = \rho_0 V_0 = \rho V$$

Where,

W : Cooling water weight

ρ_0 : Cooling water density in cold state (ρ_0 = 1 kg/liter)

V_0 : Cooling water quantity in cold state

ρ : Cooling water density in warmed up state

V : Cooling water quantity in warmed up state

To make the calculation easier, the cooling water density ρ_0 in the cold state is handled simply as 1 (kg/liter). To be exact, the density is 1 at 4℃, but a safer calculation result can be obtained this way.

The calculation procedures are as follows:

(1) Cooling water quantity V_o

Obtain the total cooling water quantity in the cooling system:

$$V_o = q_e + q_r + q_h$$

Where,

V_o : Total cooling water quantity (at cold or ordinary temperature)

q_e : Cooling water quantity in the engine cylinder block

q_r : Cooling water quantity in the radiator

q_h : Cooling water quantity in the radiator hose

(2) Overflow quantity Q

The cooling water V_o expands when the temperature rises and the density ρ_o drops.
Cooling water quantity V_o expands as follows: according to $W = \rho_o V_o = \rho V$

$$V = \frac{\rho_o}{\rho} \cdot V_o = \frac{V_o}{\rho}$$

On the other hand, the total content volume (that is, the content volume of cooling water in cold state, which is equal to V_o) is less affected by the temperature change.
Therefore, expanded cooling water V overflows from the cooling water system.

The overflown quantity Q is obtained by subtracting the total content volume V_o in the cooling water system from the expanded cooling water quantity V. That is,

$$Q = V - V_o = \frac{V_o}{\rho} - V_o = \left(\frac{1}{\rho} - 1\right) V_o$$

(3) Subtank inflow quantity q_s

However, once overflown, the cooling water loses temperature and contracts. To make the calculation easier, let us suppose that the overflown cooling water into the subtank has returned to the ordinary temperature. Then the overflow quantity Q will be deposited in the subtank after contracting to the following quantity:

$$\rho_o \cdot q_s = \rho \cdot Q = \rho \left(\frac{1}{\rho} - 1\right) \cdot V_o$$

$$q_s = (1 - \rho) \cdot V_o$$

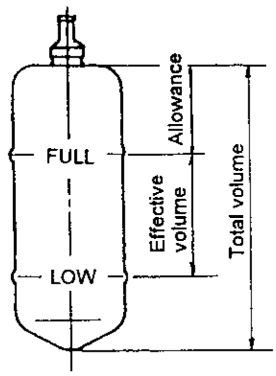
Now, let us decide what cooling water density ρ to apply to the calculation. Calculating with ρ = 0.955 at 105℃ of the allowable maximum cooling water temperature where the heat balance is established will be sufficient for selecting the subtank. In this case, the above equation becomes as follows:

$q_s = 0.045 \times V_o$

In other words, 4.5% of the total cooling water quantity V_o flows into the subtank and then is sucked back to the radiator again.

(4) Selection of subtank

To determine the subtank capacity, it is necessary to select a subtank that meets the following conditions: the effective quantity obtained by subtracting the LOW line on the subtank scale from the FULL line is greater than the inflow quantity q_s to the subtank, and that the excess quantity (allowance) obtained by subtracting the quantity of the FULL line from the total quantity in the subtank is also greater than the inflow quantity q_s to the subtank.



In practice, if the effective quantity is simply greater than the inflow quantity q_s to the subtank, no problem should occur. If the excess quantity (allowance) is small, part of the cooling water may overflow from the subtank in the early stage of operation. This may require the contamination to be cleaned

9-9 Heat Release to Cooling Water

9-9-1 Calculation of heat release to cooling water

Of the heat generated by combustion of the fuel, the calorific value carried away by the cooling system is calculated as follows:

$$q = \phi \times b \times P_o \times Hu \times 10^{-3}$$

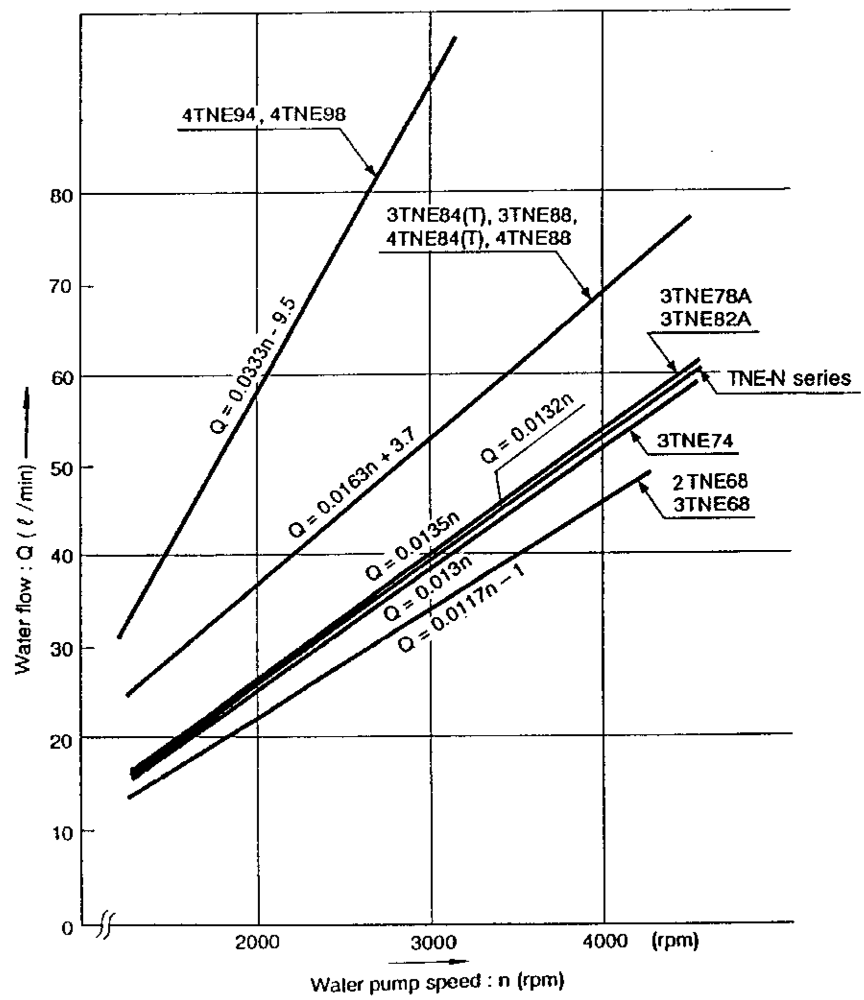
Where,

q	: Heat release to cooling water	kJ/h(kcal/h)
ϕ	: Ratio of calorific value carried away by cooling system (25% in DI engine, 30% in IDI engine for rough calculation)	
b	: Specific fuel consumption	g/kW • h (g/hp•h, g/PS•h)
P_o	: Engine output	kW (hp, PS)
Hu	: Lower calorific value of diesel fuel 4.3116×10^4	kJ/kg (10300 kcal/kg)

9-9-2 Discharge water flow from cooling water pump

Select the radiator according to the cooling water pump discharge flow table below and the heat release to the cooling water above.

(Cooling Water Pump Capacity)



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9-10 Discharging Cooling System

The standard specifications of the TNE series diesel engine call for a radiator cooling system. A large quantity of air is thus required for cooling the engine, and depending on the location of the machine installation, the treatment of the air may demand a difficult arrangement. A typical example is a disaster preventive and/or emergency generator equipment installed in a basement.

In such a case, the cooling water is supplied to the engine from the outside water supply facilities and the engine is cooled by draining water heated by the engine to outside.
As the result, the air-related arrangement only requires necessary air capacities for combustion and suppressing the room temperature rise (section 7-5, "Ventilation Capacity of Generator Room", Chapter 7). Comparatively small-scale ventilation equipment can meet the demand.

To do this, however, it is necessary to change the engine specifications from the present radiator cooling system to the discharging cooling system, and measures must be taken for the cooling water. This is mostly the work of the generator manufacturer and the construction company for local modification as follows.

9-10-1 Engine specification change

To change a radiator cooling type engine to a discharging cooling type, the following modifications are required:

(1) Removal of cooling fan

Since no radiator is used, it is not necessary to use the cooling fan.
Remove it for safety's sake. Leave the fan pulley installed, as it is used for driving the cooling water pump.

(2) Change of cooling water temperature switch

The working temperature of the cooling water temperature rise alarm switch on the radiator type engine is set at 383K (110℃). In the case of the discharging cooling specification engine, the cooling system is of the open air release type, so the cooling water reaches the boiling point at 373K (100℃), which makes the temperature switch useless. Consequently, when changing to the discharging cooling specification, replace with the temperature switch with the alarm setting for 368K (95℃).

	Cooling water temperature switch	
Application	For cooling with radiator	For cooling with discharging
Work set temperature K (℃)	383 ± 3 (110 ± 3)	368 ± 3 (95 ± 3)
ID color	Gray	White
Part No.	121250-44901	46150-503100

With the two changes above, the specification on the part of the engine is changed to the discharging cooling type.

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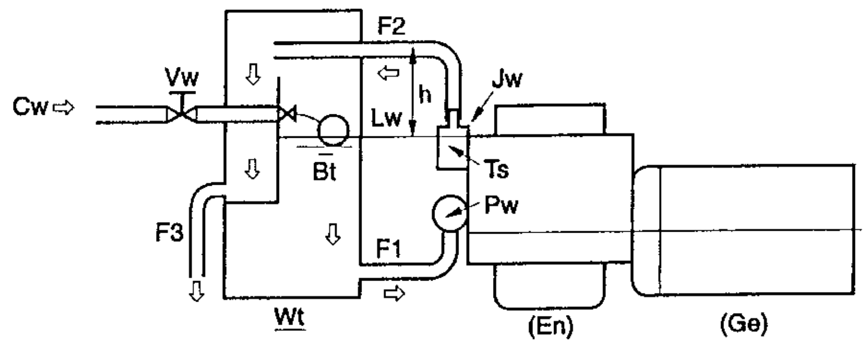
9-10-2 Examination of discharging cooling system

When supplying the engine with outside cooling water, either the city water supply or pressure water pumped up from the basement reservoir will be used. Direct coupling of the city water supply to the engine is not permitted due to hygienic considerations, and using the pressure water may cause malfunction. To prevent this, provide a low pressure water tank before the engine so that depressurized cooling water will be supplied to the engine.

When using the discharging cooling system, it is necessary to understand the characteristics of the cooling water pump installed in the engine. Originally being the pump for the radiator cooling system, it is designed for application with a closed circuit. In other words, by character, it is a low head large capacity type pump, hence has almost no discharge head when the engine cooling water outlet is released to the air. Moreover, it has no self-priming capability. Therefore, these two points should be carefully considered when designing the low pressure water tank and the cooling water piping.

(1) Low pressure water tank structure and piping

Low pressure water tanks and the pertinent piping are not available from the engine manufacturer, and have to be arranged by the driven machine manufacturer or construction contractors. Carefully consider the following points so as not to affect the engine performance:



Wt	: Low pressure water tank	Bt	: Ball tap
Pw	: Cooling water pump	En	: Engine
Ts	: Thermostat	Ge	: Generator
h	: Cooling water discharge head	Jw	: Cooling water outlet joint
F1	: Cooling water inlet pipe	Lw	: Low pressure water tank stop-water surface
F2	: Cooling water outlet pipe	Vw	: Valve
F3	: Overflow pipe	Cw	: Pressure water

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a) The reference of the low pressure water tank, piping and all other relative positions are based on the mount of the cooling water outlet joint J_w of the engine.

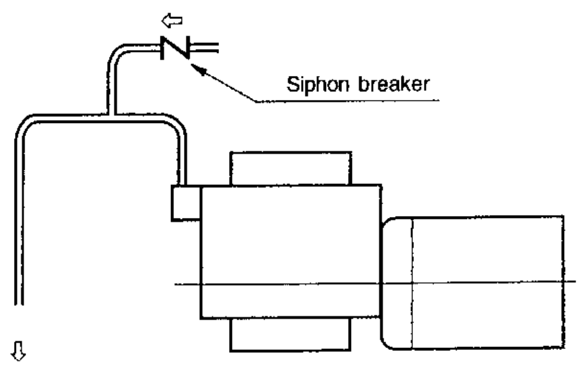
b) First, arrange the piping so that the piping height of cooling water outlet pipe F_2, that is, the cooling water discharge head h, is 100 to 300 mm or lower. Since the cooling water pump P_w is of the low head type, the higher piping position will cause a sharp decrease in the pump discharge capacity, leading to overheating of the engine.

c) When piping, avoid tight bends or drawing of the cooling water outlet pipe F_2.

d) Provide the low pressure water tank W_t with a valve V_w for receiving pressure water C_w. Install a ball tap B_t inside the water tank for automatic water supply. Mount the ball tap B_t so that its stop-water surface L_w is on the same level as the mounting position of the cooling water outlet joint J_w.

e) The cooling water outlet pipe F_2 need not be returned to the low pressure water tank W_t as shown in the figure above. The piping system would be better arranged, however, if the cooling water from the outlet pipe F_2 is drained outside from the overflow pipe F_3 of the low pressure water tank W_t.

f) When guiding the cooling water outlet pipe F_2 downward for discharge instead of connecting it to the low pressure water tank, provide a siphon breaker at the top position of the outlet pipe.



g) The capacity of the low pressure water tank W_t should be 30 to 50 liters approximately. Install the main body on the side of the engine cooling water pump and as close to the engine as possible as shown in the figure. (This is the same as the radiator position for a radiator cooled specification.) The main body of the low pressure water tank should be provided with a lid for maintenance, drain, and installation legs, etc.

(2) Operation and maintenance

The thermostat operates intermittently even after the engine starts operation until the cooling water temperature becomes stable. Therefore, cooling water too may be discharged intermittently, but this is not abnormal. Naturally, the intermittent discharge occurs when the load changes drastically.

The most important thing for the discharging cooling system is that since fresh water is used, the cooling water in the water tank or engine freezes if the engine room temperature drops below freezing temperature. When adopting the discharging cooling system, it is necessary to consider room temperature control.

(3) Calculation of cooling water consumption

Although cooling water is discharged intermittently, its consumption is predicted in the stable state with the following calculation formula:

$$Q_w = \frac{H_u \bullet b \bullet P_e \bullet \varphi \times 10^{-3}}{60 \bullet \gamma \bullet c \bullet (T_{wo} - T_{wi})} = \frac{H_u \bullet b \bullet P_e \bullet \varphi \times 10^{-3}}{60 \bullet c \bullet (T_{wo} - T_{wi})}$$

Where,

Q_w	: Cooling water consumption		ℓ/min	
H_u	: Lower calorific value of diesel fuel	4.3116×10^4	kJ/kg	(10300 kcal/kg)
b	: Specific fuel consumption		g/kWh	(g/hph, g/PSh)
P_e	: Engine output		kW	(hp,PS)
φ	: Cooling loss	IDI series: 0.3, DI series: 0.25		
γ	: Density	1	kg/ℓ	
c	: Specific heat	4.18605	kJ/kgK	(1 kcal/kg℃)
T_{wo}	: Cooling water outlet temperature	344	K	(71℃)
T_{wi}	: Cooling water inlet temperature		K	(℃)

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(Description)

For the specific fuel consumption and output, apply section 3-2 "Principle Specifications" in Chapter 3 or individual specification data.

Strictly speaking, the cooling loss φ varies with the engine series and its service speed range, but in the case of TNE series engines, no practical problem should occur if calculated with 30% for the IDI series and 25% for the DI series.

Cooling water inlet temperature T_{wi}, which is the temperature of pressure water, changes depending on where it is installed. For calculation, use data for the summer time cooling water temperature when it is presumed to be the highest.

For the cooling water outlet temperature T_{wo}, use the temperature 344K (71℃) when the thermostat starts opening. For calculation, the cooling water consumption is presumed to be maximum at this moment.

Care should be taken of the units when making various calculations. If using a unit specified in parentheses, apply this particular unit for every value. K for the cooling water outlet/inlet temperature stands for Kelvin, the absolute temperature unit.

The following relationship exists between absolute temperature and Centigrade temperature:

$$K = 273 + ℃$$

The present calculation is for the temperature difference, and so both K and ℃ produce the same result.

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10. Fuel System

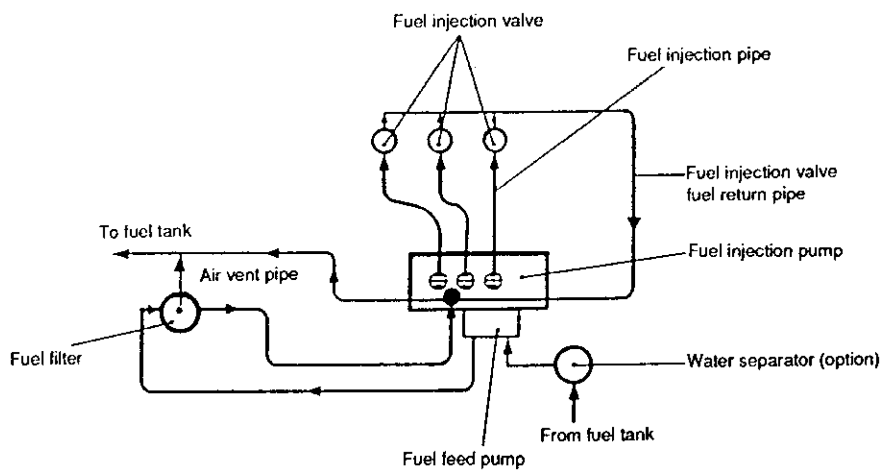
In the fuel system, the fuel injection system is especially important. The role of the fuel injection system is to inject the fuel in the misty state under a high pressure into the hot pressurized air in the combustion chamber. The output generated by the engine is determined by the amount of burned fuel. A function for accurate control of the fuel injected into the combustion chamber is necessary to ensure the specified engine speed and output.

The injection timing and period such as the timing of injection, injection rate and spray pattern as well as the sprayed fuel attainable distance, penetration, distribution state and degree of atomization in the combustion chamber in combination with the combustion chamber shape determine the air-fuel mixture formation and combustion pattern. These factors greatly influence the engine performance, exhaust emission (HC, CO, NO_2, etc.) and exhaust smoke density, etc. The role of the fuel injection system, therefore, is very important.

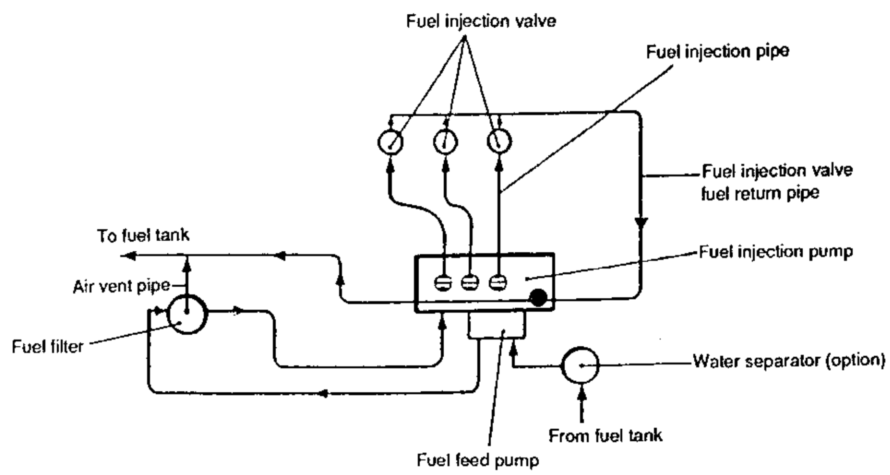
At the same time, in order for the fuel injection system to fully function, use of good quality fuel, maintenance of the fuel strainer, and careful installation of the fuel tank and piping are necessary.

10-1 Fuel System Diagram

(1) Special swirl chamber system



(2) Direct injection system



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10-2 Diesel Fuel Oil

Many types of diesel fuel are used for engines. Improper selection may cause accidents and low-quality fuel will shorten the service life of the fuel injection pump and nozzles. High-quality diesel fuel oil for automobiles should always be used for the TNE series engines.

Generally, use diesel fuel having properties equivalent to JIS Grade 2. Use JIS Grade 3- or Grade 3 Special-equivalent diesel fuel in cold areas according to the temperature. Care should be taken, however, not to mix different types of fuel oil when the season changes. The property analyses of JIS Grade 2, Grade 3 and Grade 3 Special diesel fuel oils as prescribed by JIS K 2204-1996 are shown in the following table. The analytical values shown here are almost the same as the properties in ISO 8217 DMA, BS (British Standard) 2869 Part A1 or Part A2, class A2 (Cetane Number: 45 min.).

Property / Type	Flash point K {°C}	Distillation temperature (90% distillation) K {°C}	Pour point K{°C}	Carbon residue (10%)	Cetane number	Kinetic viscosity {cSt} 303K {30°C}	Sulfur content (%)	CFPP plugging point
Grade 2	323 {50} or higher	623 {350} or under	265.5 {−7.5} or under	Under 0.1	45 or over	2.5 or higher	0.20 or under	268 {−5} or under
Grade 3	318 {45} or higher	603 {330} or under	253 {−20} or under			2.0 or higher		261 {−12} or under
Grade 3 Special			243 {−30} or under			1.7 or higher		254 {−19} or under

Notes: % : mass %
CFPP : Cold Filter Plugging Point

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Specification of Fuel in the Countries of the World

DIESEL FUEL SPECIFICATIONS

		U.S. ASTM D975 Grade No. 2-D	Canada CGSG Standard CAN2-3.6-M83 Type B	U.K. British Standard Inst. BS2869 Class A1	U.K. British Standard Inst. BS2869 Class A2	Germany Standards Committee for Matls. Testing DIN 51 601	Australia AIP PPTC Automotive Diesel Fuel	JAPAN JIS K2204 Grade 2	JAPAN JIS K2204 Grade 3
Cetane Number		*40 min	*40 min	50 min	45 min	45 min	45 min	45 min	45 min
Flash Point	K(℃)	325 (52)	–	329 (56)	329 (56)	328 (55)	–	323 (50)	318 (45)
Pour Point	K(℃)	–	–	Summer 273(0)max Winter 264(–9)max	Summer 273(0)max Winter 264(–9)max	Summer 273(0)max Winter 261(–12)max	–	265.5(-7.5) max	253(-20) max
Carbon Residue on 10% Residuum	mass%	0.35	–	0.2 max	0.2 max	0.1 max	–	0.1 max	0.1 max
Ash	mass%	0.01 max	–	0.01 max	0.01 max	0.02 max	–	–	–
Distillation Temperatures	K(℃) 85% Point	–	–	623(350) max	623(350) max	623(350) max	630(357) max	–	–
	90% Point	555~611 (282~338)	633(360) max	630(357) max	630(357) max	630(357) max	638(365) max	623(350) max	603(330) max
Kinematic Viscosity	mm²/s at 20℃	–	–	–	–	2.0~8.0	–	–	–
	30℃	–	–	–	–	–	–	2.5 min	2.0 min
	40℃	1.9~4.1	1.4~4.1	1.5~5.0	1.5~5.5	(1.5~4.5)	1.5~5.5	(2.1 min)	–
Sulfur	mass%	0.5 max	0.7 max	0.3 max	0.5 max	0.3 max	0.5 max	0.2 max	0.2 max

* Use fuel of cetane number above 45.

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10-3 Filtration System

When impurities are mixed in the fuel, wear of sliding parts such as the fuel injection pump plunger and delivery valve and sticking of the needle in the fuel injection valve occur. On the other hand, water in the fuel adversely affects the fuel injection system and causes engine abnormalities. A water trap is installed as a prefilter between the fuel tank and fuel feed pump and the fuel filter is installed on the inlet side of a fuel injection pump.

10-3-1 Fuel filter

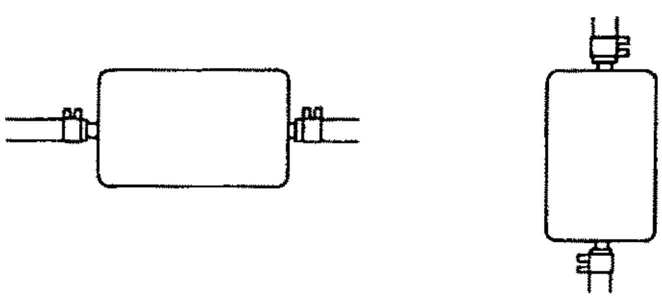
The fuel filter is installed as the main filter, a standard part, in all TNE series engines. The standard fuel filters consist of the paper element type with transparent plastic body and the cartridge type with metal body. One of these types should be used depending on the engine type. Principal specifications and applicable engine types are as follows:

	2TNE68(-N) 3TNE66-N 3TNE68(-N) 3TNE72-N 3TNE74(-N)	3TNE78A 3TNE82A	3TNE84(T) 3TNE88 4TNE84(T) 4TNE88	4TNE94 4TNE98
YANMAR code	119255-55620	119833-55620	129052-55620	119000-55600
Filtration area cm^2	432	432	900	2800
Nominal filtration rating µm	15	8	8	15
Element code	124550-55700	119810-55650	129100-55650	(Cartridge type)
Body material	Plastic	Plastic	Plastic	Metal

Cautions for installation

1. If the customer arranges the fuel filter, the filter must have the characteristics equivalent to or better than the current filter.
2. Install the fuel filter in a place where the ambient temperature is 333K {60℃} or below.
3. When a cartridge type filter is used at the customer, it must be installed vertically as illustrated below. Otherwise, air may be trapped.

[Poor example] [Good example]



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10-3-2 Water trap

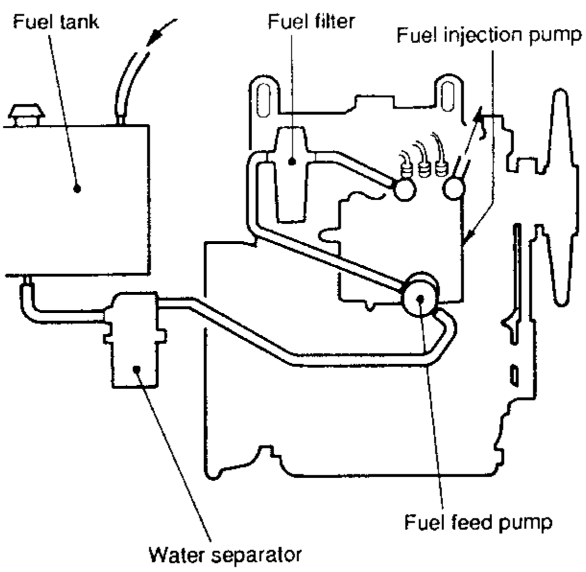
Fine water in the fuel tends to coagulate when the flow speed sharply drops. Coagulated water causes gravity separation because of the difference in specific gravity from the fuel. A water trap has a structure for making this phenomenon happen efficiently.

The water trap is generally installed between the fuel tank and fuel feed pump. When engines are used for industrial applications, water, dust and mud are very likely to enter the fuel tank. These impurities may be discharged by the water trap installed as a prefilter. Installation of the water trap protects the fuel feed pump, extends the service life of the fuel injection system by preventing the generation of rust, and also prevents the engine start failures caused by freezing in cold areas.

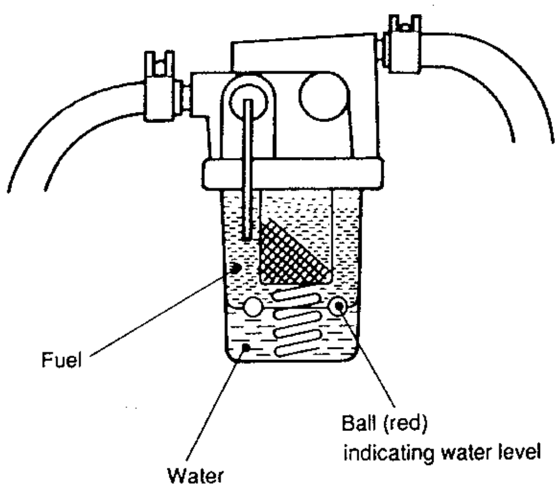
Cautions for water trap installation

1. As a rule, the water trap should be installed as standard equipment.
2. Select an element of 100 mesh or more.
3. Install the water trap in a place where the ambient temperature is 333K (60°C) or below.
4. Install the water trap between the fuel tank and fuel feed pump. If the water trap is installed near the fuel feed pump, oil and water separation in the water trap becomes difficult.
5. Install it near the bottom of the fuel tank for ease of maintenance and daily inspection.
6. Install the water trap at the lowest position in the fuel system.

[Installation of water separator]



[Structure of water separator]



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10-4 Fuel Tank

The fuel tank is generally made of steel plate or synthetic resin. Install a fuel gauge, fuel outlet pipe, fuel return pipe, fuel feed port strainer and drain cock on the fuel tank, and provide an air bleeder on the tank lid. A large air vent hole should also be provided at the oil filler port or strainer to prevent the fuel from overflowing from the strainer.

10-4-1 Fuel tank capacity calculation

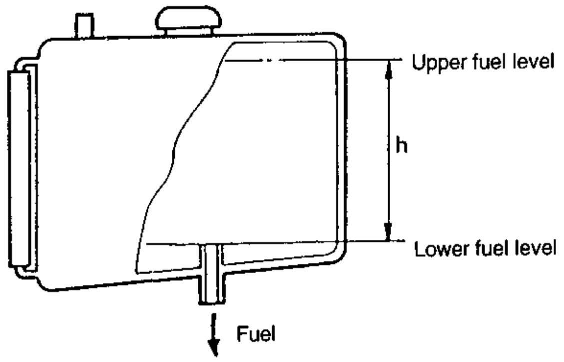
The fuel consumption by the engine is given by the following equation:

$$Q = \frac{b \times Pe}{1000 \times d}$$

Where,

Q	: Fuel consumption by engine	ℓ/h
b	: Specific fuel consumption	g/kWh (g/hph, g/PSh)
Pe	: Engine output	kW (hp, PS)
d	: Specific gravity of fuel (approx. 0.83)	

Calculate the fuel tank capacity by multiplying the fuel consumption per hour calculated by the equation above by the driven machine operating hours. The effective fuel tank capacity must be determined by providing a sufficient margin as shown by the height (h) shown in the figure below.



Example: Calculate the fuel consumption per hour when b=270 g/kW·h, Pe=20 kW and d=0.83.

$$Q = \frac{270 \times 20}{1000 \times 0.83} = \text{Approx. 6.5 liters per hour}$$

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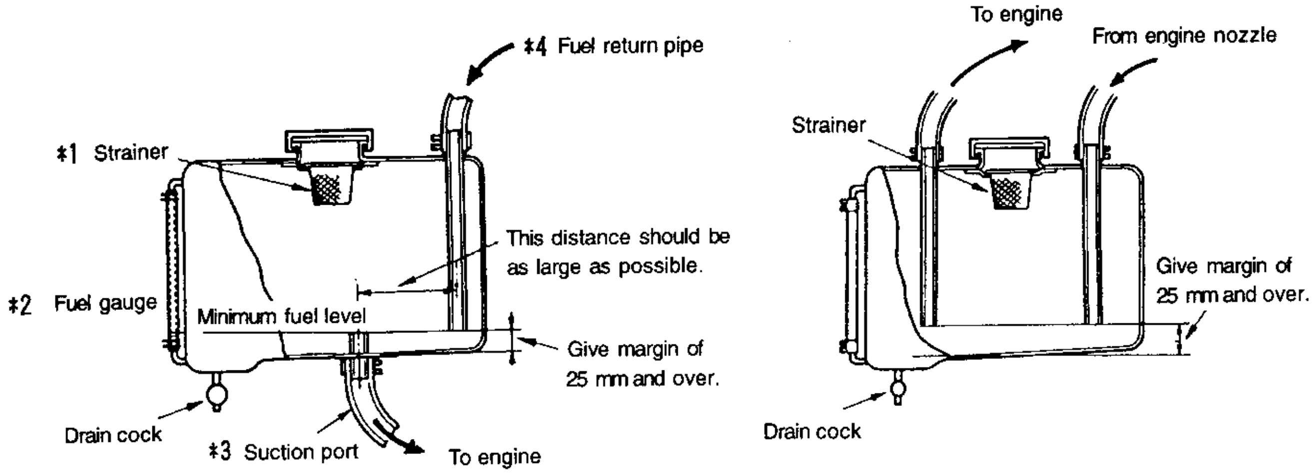
10-4-2 Fuel tank structure

(1) Pay attention to the following points when designing the fuel tank:

[When the suction port is at the bottom of the tank] [When the suction port is at the top of the tank]



**1. Strainer : Use an approx. 40 mesh element which can be removed and replaced.*

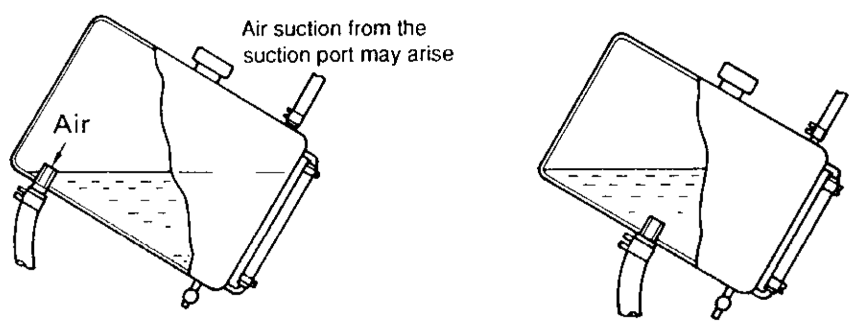
**2. Fuel gauge : The minimum fuel level line on the gauge must be above the position of the fuel suction port (to prevent air suction).*

**3. Suction port : To be installed at the center of the tank to prevent air suction during inclined operation, but avoid installing just under the fuel port..*

**4. Position the end of the fuel return pipe as close to the minimum fuel level as possible.*

[Reason why the suction port should be at the center of the tank]

(Poor example) **(Good example)**

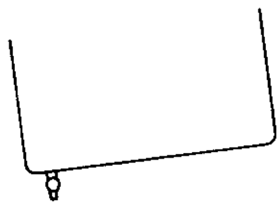


(2) Drain cock and fuel tank shape

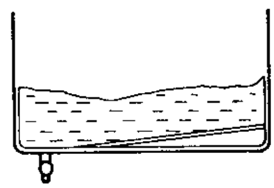
Drain cock installation by lowering the bottom by one step

Inclined bottom

Drain cock installation by inclining the tank



Drain cock installation by doubling the bottom of the fuel tank



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10-5 Fuel Feed Pump

The function of the fuel feed pump is to force-feed the fuel from the fuel tank installed far from or below the engine to the fuel injection pump. A mechanical diaphragm type and a plunger type fuel feed pump is adopted in the TNE series engine. The fuel feed pump is installed on the side wall of the fuel injection pump and is driven by the camshaft of the fuel injection pump. Use a solenoid pump depending on the fuel tank position. Study its use when the fuel feeding performance of a mechanical fuel feed pump is insufficient or for easier air bleeding from the fuel system or easier starting. 12 and 24 VDC types are available. See the separate "TNE Option Menu" for details.

[Fuel feed pump types]

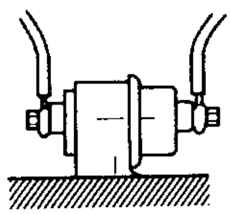
- Fuel feed pump
  - Mechanical type (on engine)
    - Diaphragm type
    - Plunger type
  - Solenoid type
    - Diaphragm type
    - Plunger type

Precautions for installation

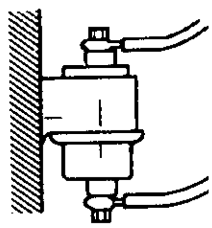
(1) To install an electromagnetic fuel feed pump

1. Remove the mechanical fuel feed pump installed on the fuel injection pump and cover the opening port.
2. Install the fuel feed pump at a place not splashed with rainwater. This type of fuel feed pump is not waterproof.
3. Install the fuel pump horizontally in a place involving little vibration.

Good example



Poor example



(2) Other cautions

1. When the minimum fuel level in the fuel tank is 50 mm or more above the fuel injection pump in a stationary driven machine, the fuel feed pump is unnecessary.
2. When installing the fuel feed pump, install a prefilter (100 mesh). This may be replaced with the water trap of a genuine Yanmar part.
3. The prefilter and water trap must be installed in a position near the lower level of the fuel tank where maintenance (especially air bleeding) can be performed easily.

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10-6 Precautions Concerning Fuel System

(1) Design and install for easy maintenance operations such as fuel tank draining, fuel trap draining and cleaning and replacing the fuel filter element.

(2) The fuel tank structure and installation position must be such that the fuel temperature remains below 333K (60℃) irrespective of the tank position, piping connection, operating condition and seasonal change (ambient temperature).

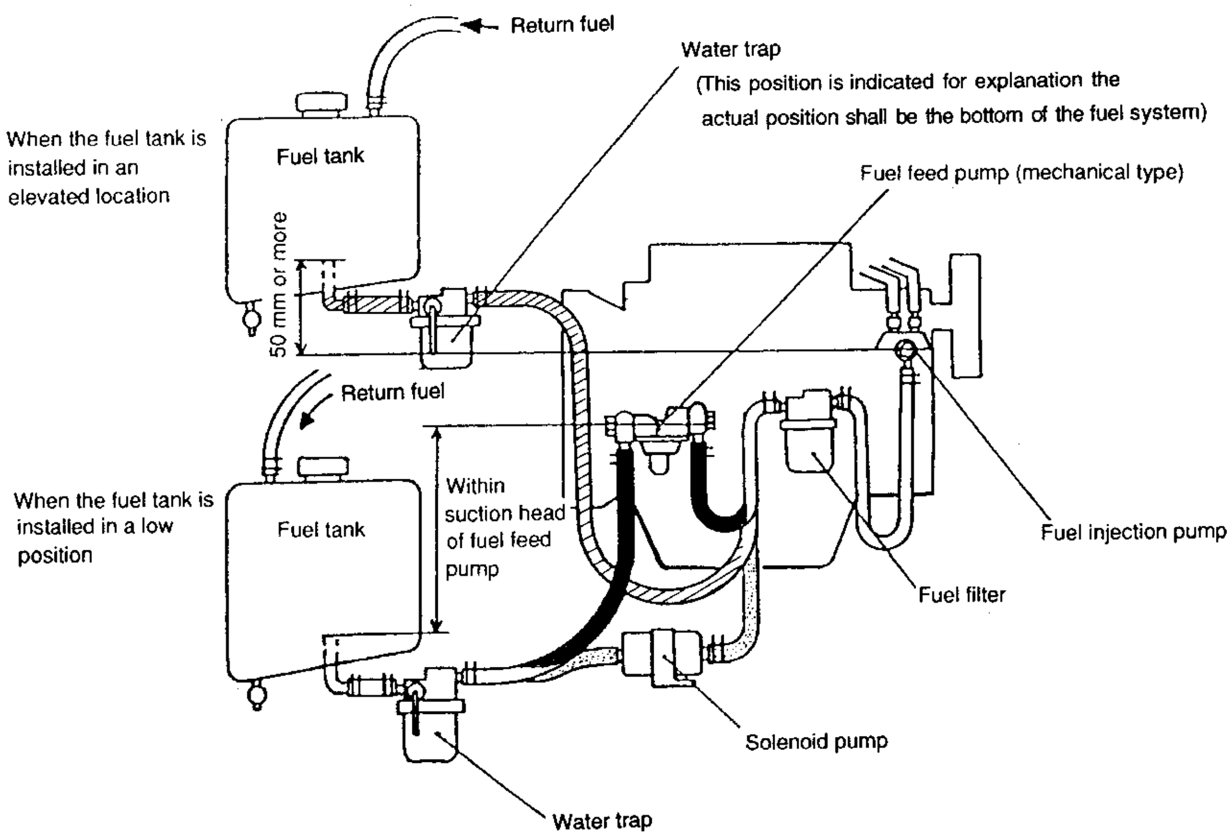
(3) The fuel tank design and installation position must prevent any fuel spilled when filling the tank from causing any trouble by contaminating electrical part, exhaust system or other equipment.

(4) If the fuel splashes the rubber isolator, the rubber will deteriorate, decreasing the vibrating damping performance. The fuel tank must be installed to allow easy fuel supply without spilling fuel oil on the rubber isolator.

(5) When replacing the fuel oil, replace it not only in the fuel tank but also in the water trap, fuel feed pump and fuel filter.

(6) Clean the inside of the fuel tank thoroughly and leave no scale, sand or mud.

(7) The basic fuel piping is shown in the figure below.



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Performance of fuel feed pump

	Mechanical (standard)		Solenoid (optional)	
	IDI engine	DI engine	IDI engine	DI engine
Suction head (mm)	500	800	1000	
Current (V-A)	—	—	12-1.5	

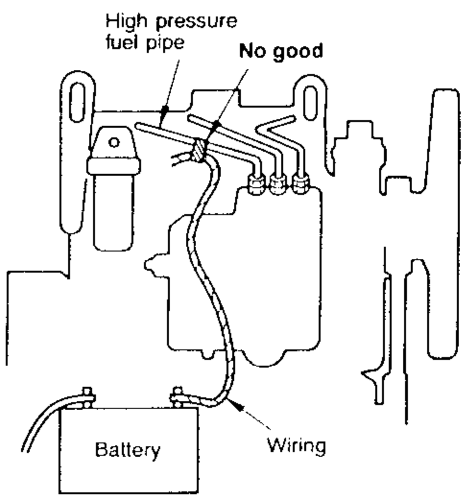
(8) The fuel pipe and exhaust pipe must be installed with a sufficient distance between them to prevent fire by unexpected ignition.

[Distance guideline]

Between fuel piping and exhaust pipe	At least 100 mm
Between fuel filter and exhaust pipe	At least 50 mm

(9) Do not let the high pressure fuel pipe touch other parts. Any contact may cause a serious accident. Do not fix the electrical parts wiring at the high pressure fuel pipe or fuel piping and others.

Poor example



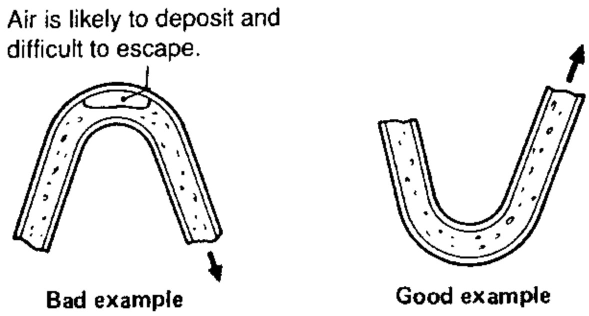
(10) The fuel pipe should be clamped as required.

(11) The standard fuel pipe material is shown below.

	Inner wall	Outer wall
Material	Nitrile butadiene rubber compound	Chloroprene rubber compound
Thickness (mm)	1.4	0.9
Pressure resistance	294 kPa (3 kgf/cm^2) or more	
Heat resistance	353K to 253K {80℃ to –20℃}	
Weather resistance	Required	

∗ PVC hose is not suitable as an engine fuel hose because of high thermal deformation.

(12) Employ U-shaped (bottom-shaped) piping to allow air bleeding, as the air is likely to remain in the reverse U-shaped piping.



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11. Lubricating System

The lubricating system force-feeds lubricating oil at an appropriate viscosity to the crankshaft main bearing, connecting rod large and small end bearings, camshaft bearings, valve train, fuel pump drive mechanism, fuel injection pump and moving portions of accessories such as the turbocharger to lubricate and cool these parts.

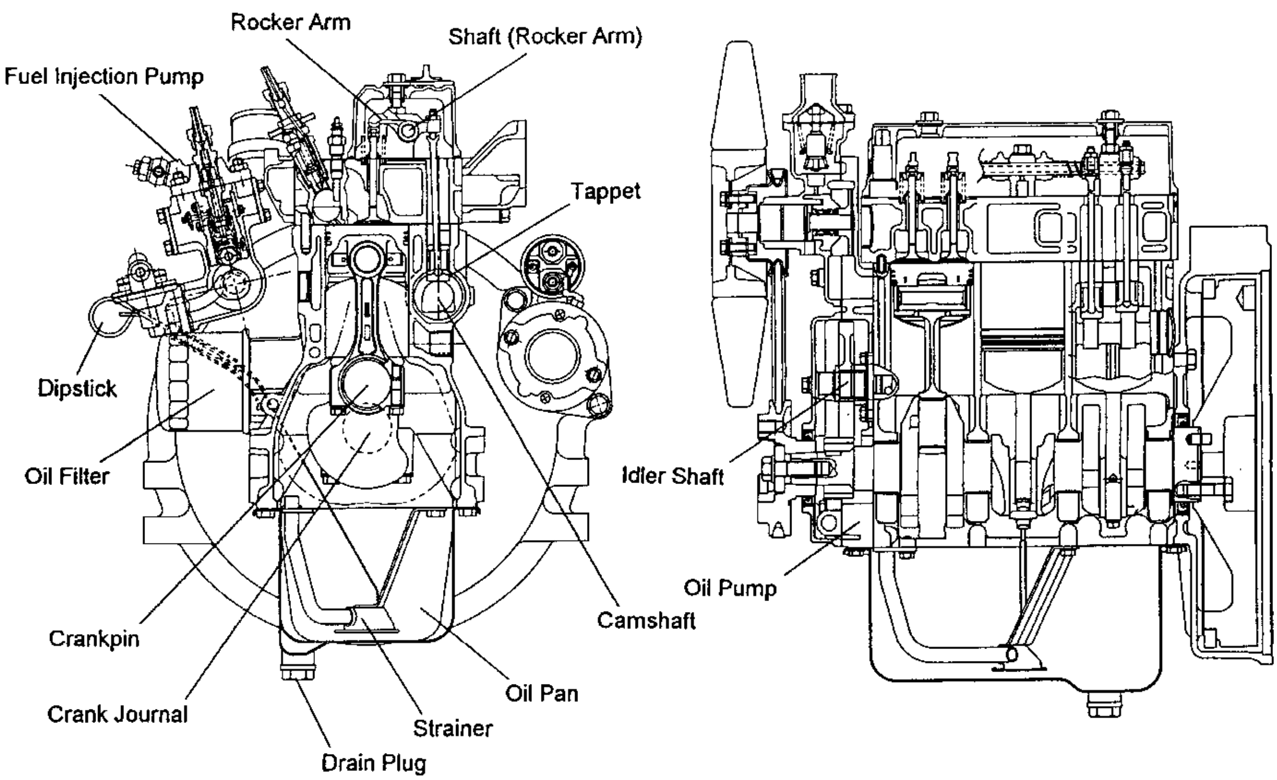
For pistons, cylinders and gears, lubricating oil at an appropriate temperature is supplied by splash lubrication or through piston cooling nozzles to cool and lubricate them. If any of these function is lost, the engine cannot attain the design performance. The lubricating oil consumed and degraded through engine operation. To maintain the lubricating system performance, use of suitable lubricating oil for each industrial equipment as well as maintenance and inspection are very important.

11-1 Lubricating System Diagram

The engine lubricating system consists of wet sump lubrication and dry sump lubrication. The TNE series engines use a wet sump lubrication system. In this system, lubricating oil is pumped up from the (oil sump) oil pan below the crank chamber by the lubricating oil pump through the lubricating oil suction pipe for lubrication through the lubricating circuit.

On the other hand, the dry sump lubrication system supplies lubricating oil from a tank installed outside the crank chamber for circulation. This system is adopted to a large marine engine.

The TNE series engine lubricating system are as shown in the following figure:



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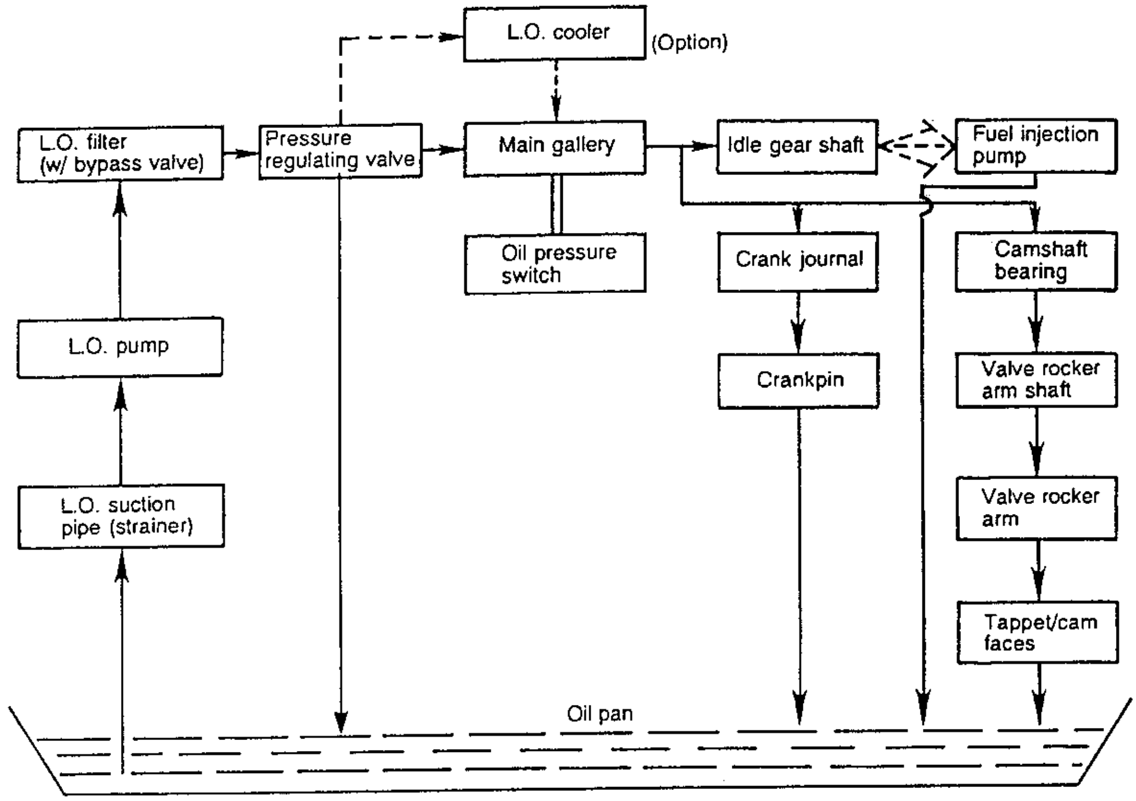
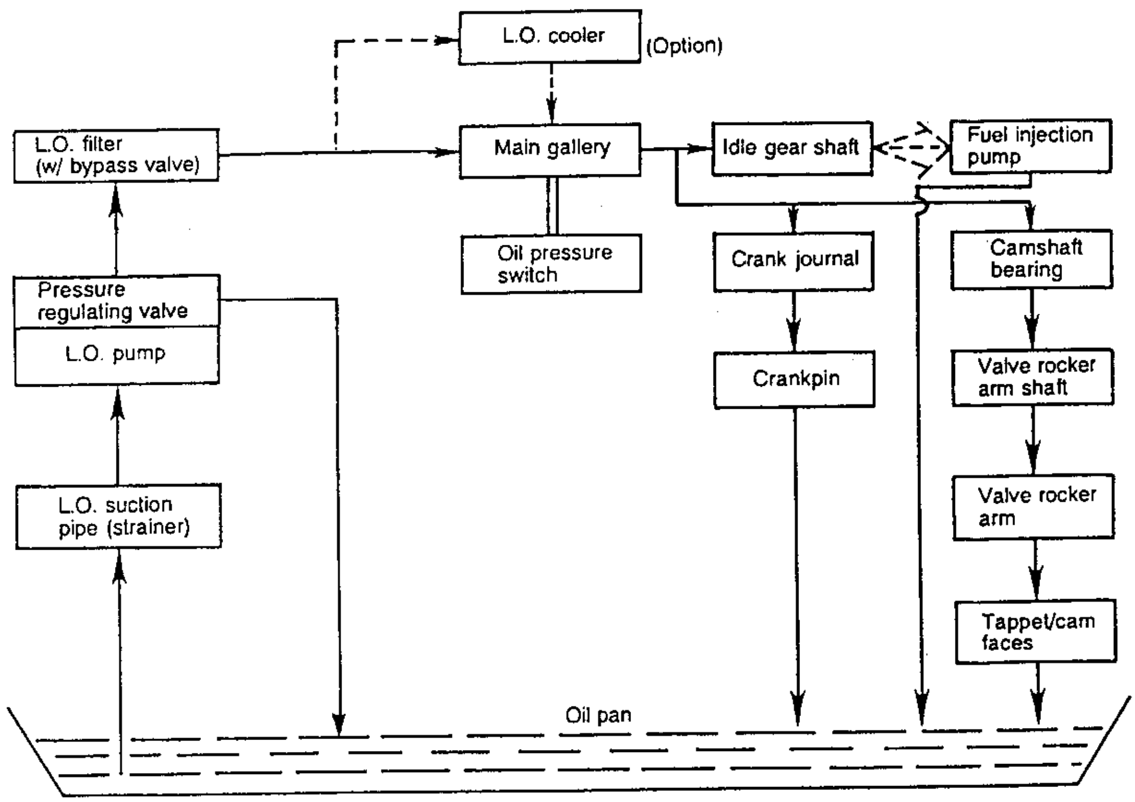
(1) Special swirl chamber system
2TNE68, 3TNE68, 3TNE74



(2) Special swirl chamber system
2TNE68-N, 3TNE66-N, 3TNE68-N, 3TNE72-N, 3TNE74-N



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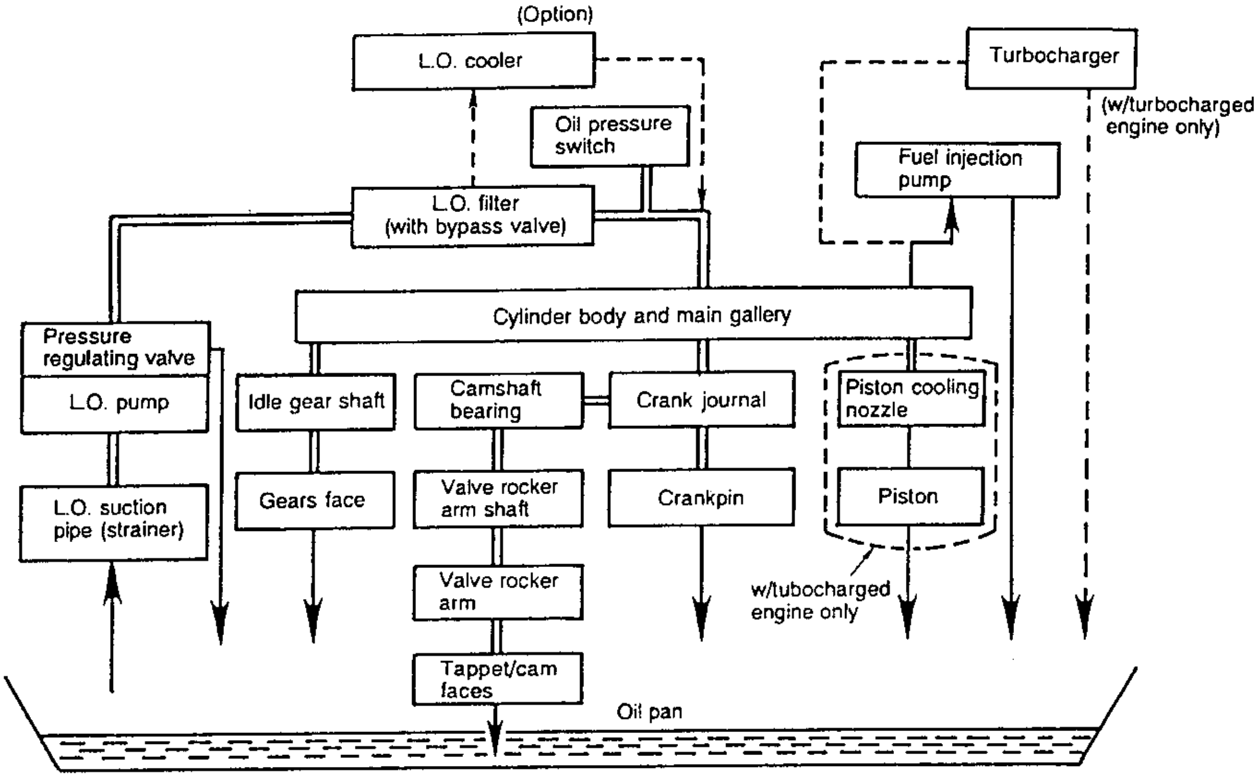
(3) Direct injection engine
3TNE78A, 3TNE82A, 3TNE84(T), 3TNE88, 4TNE84(T), 4TNE88, 4TNE94, 4TNE98



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11-2 Lubricating Oil

Lubricating oil used for industrial engines varies with the engine application and environmental temperature. The lubricating oil properties are classified according to the required functions for this purpose.

Engine manufacturers recommend the appropriate lubricating oil according to the API service classification and SAE service grades. The lubricating oil class, however, varies not only with the operating conditions and environment but also with the type of fuel to be used. If the fuel used has high sulfur content, it is important to use high grade lubricating oil with excellent properties, as the products generated by combustion must be removed by the lubricating oil.

11-2-1 API service classification

Engine lubricating oil has much improved performance owing to the advanced refining technology and additives, thus contributing to the development of non-opening or service-free engines. Such advanced performance, however, is not all-around. Thus it is important to determine the possible severest condition the engine may most likely encounter and use the matching lubricating oil to such condition. The classification method to this end is what we call API service classification. In short it is the classification method that indicates durability and good quality of lubricating oil. As the classification number progresses, the lubricating oil has higher durability and quality. API stands for American Petroleum Institute.

For TNE series engines, use lubricating oil of CC class or over of API Service Classification.

Uses of API Service Class CC and Class CD

API service class	Uses
CC	Lubricating oil for diesel engines operated under relatively severe conditions preventing high temperature deposit, rusting, corrosion and low temperature sludge generation.
CD	Lubricating oil for diesel engines operated under severest conditions, excellent in performances

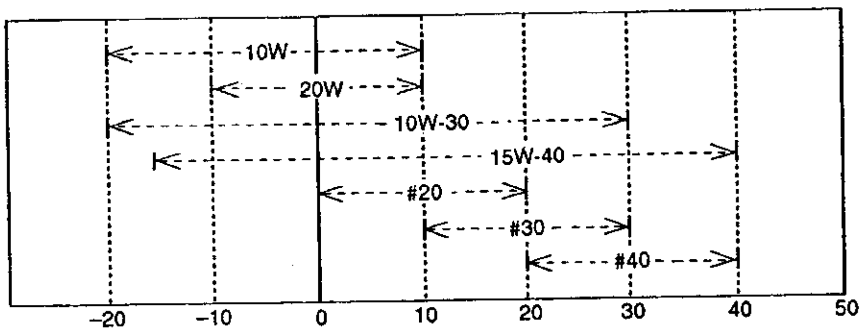
11-2-2 SAE service grade

Generally lubricating oil viscosity has property to drop sharply as the temperature rises, and the degree of such change differs by the type of lubricating oil. On the other hand, engine requirements call for lubricating oil that does not increase its viscosity and frictional resistance at low temperature so that cold starts of the engines are rendered easy. During high engine output, the oil temperature rises but it is desired that the lubricating oil will not lower viscosity excessively so that oil film can be fully retained even under high temperature. In other words, the lubricating oil viscosity is required to be less sensitive to the change of temperature. The SAE Service Grade represents relative arrangement of viscosity according to the level. SAE stands for the Society of Automotive Engineers.

As the engine oil viscosity classification, classification by SAE is used in Japan, Europe and America. The SAE viscosity classification is in two types: 20, 30, 40 and 50 as values measured with a capillary viscometer at high temperatures, and 5W, 10W, 15W and 20W as viscosities at low temperatures. W stands for Winter. An oil satisfying both the high-temperature classification and low-temperature classifications is called multi-grade oil, and an oil satisfying only the low- or high-temperature classification is called single grade oil. For industrial engines, it is recommended to use the SAE service grade lubricating oil that can endure use in a wide temperature range.

Use multi-grade oil as lubricating oil for the TNE series engines.

Selection of viscosity (SAE Service grade)



Atmospheric temperature (°C)

15W-40/10W-30 can be used almost throughout the year.

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11-2-3 Oil temperature

As the oil temperature rises, the oil film becomes thinner, and so hydrodynamic lubrication changes to boundary lubrication, increasing the friction loss and leading to seizure. As the lubricating oil temperature greatly influences the engine service life, always conduct a heat measurement after the engine is installed to the driven machine. If the temperature of lubricating oil exceeds the specified limit, review the installation configuration or oil cooler equipment.

Oil temperature and engine oil replacement interval

API service classification	Maximum lubricating oil temperature	Engine oil replacement interval	Fuel oil used
CC	≦388K {115℃}	Every 200 hours	Diesel fuel
	≦393K {120℃}	Every 150 hours	
CD	≦388K {115℃}	Every 300 hours	
	≦393K {120℃}	Every 200 hours	

* *In a sound-insulated type driven machine, design the air circulation near the oil pan to prevent the lubricating oil temperature from rising.*
The maximum lubricating oil temperature represents the limit lubricating oil temperature when the temperature of the environment the driven machine is used in reaches the maximum level. Care should be taken not to use the engine beyond the limit temperature.

11-3 Lubricating Oil Pump

A trochoid oil pump is adopted for the TNE series engines for forced lubrication. The table below shows the delivery performamce for reference.

Lubricating oil pump	Engine rpm 2500 rpm			Engine rpm 3600 rpm			Number of teeth
	Speed rpm	Delivery rate l/min	Discharge pressure kPa (kgf/cm^2)	Speed rpm	Delivery rate l/min	Discharge pressure kPa (kgf/cm^2)	Crankshft/ pump
2TNE68 3TNE68	2100	8.3	245 (2.5)	3024	11.9	294 (3.0)	21/25
3TNE74	2200	11.0	245 (2.5)	3168	15.8	294 (3.0)	22/25
2TNE68-N 3TNE66-N 3TNE68-N	2100	7.0	245 (2.5)	3024	7.9	294 (3.0)	21/25
3TNE72-N 3TNE74-N	2200	8.9	245 (2.5)	3168	10	323.4 (3.3)	22/25
3TNE78A 3TNE82A 3TNE84, 88 4TNE84, 88	2414	14.8	294 (3.0)	3476	15.2	343 (3.5)	28/29
3TNE84T 4TNE84T	2414	15	343 (3.5)	3476	16.6	392 (4.0)	28/29
4TNE94 4TNE98	2759	16	343 (3.5)	—	—	—	32/29

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11-4 Lubricating Oil Filtering System

The purpose of the lubricating oil filtering system is to supply clean lubricating oil to the moving portions of the engine while carrying impurities away.

11-4-1 Lubricating oil suction pipe

The lubricating oil suction pipe is installed between the oil pan and lubricating oil pump. A metallic strainer is attached to the end of the suction pipe to trap large foreign matter.

11-4-2 Oil filter

The purpose of oil filter is to prevent wear or seizure of the moving portions of the engine and to extend the lubricating oil replacement interval by cleaning it and preventing deterioration. The lubricating oil contains soot generated by combustion of fuel and lubricating oil, oxides, worn metal particles, etc. If these impurities are not removed, wear of moving portions, sticking on hot metal surfaces, and obstruction of heat radiation arise, which accelerate corrosion of bearings, rusting of metal surfaces and degradation of lubricating oil. The oil filter is intended for removing these impurities. The oil filter installed on the TNE series engine uses a cartridge type paper element. If the oil pressure difference between the inlet and outlet of this filter reaches 78.5 to 118 kPa {0.8 to 1.2 kg/cm^2} due to element clogging, etc., the relief valve is operated to bypass the lubricating oil directly to the oil gallery to prevent engine seizure. Continuous flow of unfiltered lubricating oil inside the engine generates extremely dangerous conditions for the engine. Therefore, be sure to replace the oil filter at regular intervals, based on the maintenance schedule.

[Oil filter installed on TNE series engines]

Engine model	IDI specification	DI specification
Filtration area (cm^2)	800	1200
Yanmar code No.	119305-35150	129150-35151

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11-5 Oil Pan

The capacity of the oil pan depends on the application of the engine. That is, the capacity must be selected based on estimated inclination angle, service life of lubricating oil, and installation conditions. For selection of the oil pan, refer to the TNE "Option Menu."

Standard oil pans are divided into shallow and deep types according to the engine specification classification (CL, VM, CH and VH) principle concept of which is as follows:

One of the specification requirements on the engines installed to the construction and agricultural machines, that is VM specification, is to have as low total engine height as possible. High engine installation position makes it easy to install the oil drain right under the oil pan. Because of these, the standard oil pan of VM specification is shallow type installed with the drain plug directed downward.

On the other hand, one of the specification requirements on the engines installed to the generator, compressor, etc., that is the engines of CL, CH and VH specifications, is continual operation for an extended span of time. To realize this, it is necessary to install as large capacity oil pan as possible. In the case of CH and VH specifications, a large capacity oil pan is advantageous from the viewpoints of oil temperature suppression and the prevention of early oil degradation because the engine is operated at high speed. Moreover, a generator, compressor, etc. are frequently installed directly to the ground for operation, which precludes the oil drain from being installed under the oil pan. For these reasons, standard oil pan of CL, CH and VH specifications are of deep type and have the drain plug installed horizontally.

Driven machines are used for quite a different way, and it is necessary to determine an oil pan that most fittingly meets the purpose, function and structure of the driven machine.

For the currently set oil pan specifications, see the separate "TNE Option Menu."

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11-6 Inclined Performance

The TNE series engine uses a wet sump lubrication system oil pan. If the engine is operated at an inclination angle exceeding the maximum inclination angle, air is taken in from the lubricating oil suction pipe and lubricating oil cannot circulate through the engine. Air pockets are then generated in the lubricating oil system and the temperature of engine parts rise, causing an accident.

To prevent such accident, it is necessary to check the oil level by using the dipstick. The maximum inclination angle refers to an angle when the oil level is at the minimum oil level mark of the dipstick.

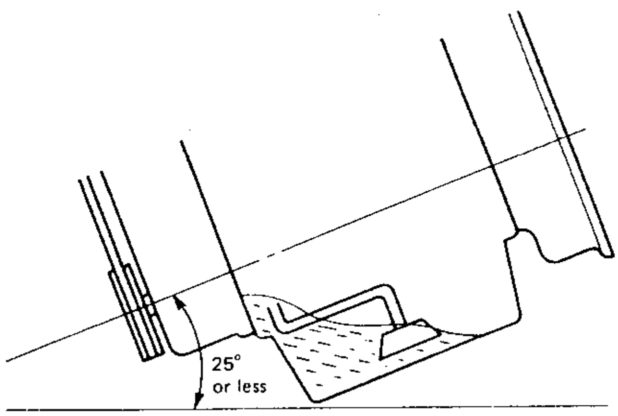
The maximum inclination angle for the TNE series engine with standard oil pan is as follows:

Continuous operation	25° for all directions
Instantaneous operation (within 3 min.)	30° for all directions

* *The above values have been confirmed in the statistic tests using a single engine.*
For the driven machine with significant movement, identify the inclination characteristics associated with the loading conditions.

If the engine must be used at an angle exceeding the maximum inclination angle, consult Yanmar.

[Inclination angle during continuous operation]



*Keep the engine flat, while supplying lubricating oil or cooling water.

11-7 Breather System

Pressure variation occurs inside the crankcase due to the reciprocating motion of the piston. The purpose of the breather system is to maintain the normal pressure inside the crankcase. The breather system is provided either as an intake circulation system or release system. The release system releases upward pressure variation and blow by gas into the open air through the pipe installed at the valve rocker arm chamber. In the release system, periodic maintenance is required, because sand or the like accumulates on the end of the pipe and causes clogging. If the breather system is clogged, the pressure inside the crankcase rises and failure occurs such as oil leak from the oil seal and packing. This system, however, is decreasing because of a social requirement.

The intake circulation system refers to a method for burning the breather gas inside the crankcase again by having it taken in by the intake manifold. In the intake circulation system, the valve rocker arm chamber and intake manifold are connected by a pipe to release pressure variation, and the breather gas in the crankcase is sucked into the intake manifold for recombustion. In a turbocharged engine, however, breather gas cannot be sucked because the air pressure on the intake manifold side is structurally high. In that case, the breather gas is returned to the inlet side of the turbocharger.

If the lubricating oil is supplied over and above a prescribed quantity by mistake, violent oscillation of driven machine or its inclination allows the lubricating oil to be taken in to the intake manifold with the breather gas, possibly causing the so called oil hammer phenomenon. In the case of the engine adopting the intake circulation system, therefore, lubricating oil level control using the level gage (dipstick) is very important.

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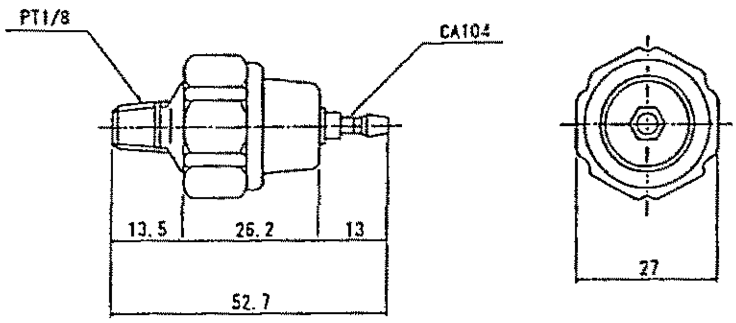
11-8 Lubricating Oil Pressure Switch

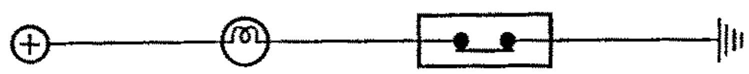
Decreased lubricating oil pressure may cause a serious accident to the engine. Therefore, a lubricating oil pressure switch is mounted to detect a lubricating oil pressure and to ensure safe operation of the engine. Use it in combination with the warning lamp or buzzer to inform on the hazardous state the engine has entered.

[Lubricating oil pressure switch mounted on the TNE series engine]

	All models of TNE series engine
Yanmar code No.	124160-39450
Actuation pressure of lubricating oil pressure switch	<49.0 ± 9.8 kPa (0.5 ± 0.1 kgf/cm^2)
Contact capacity	12 VDC/0.4 A, 24 VDC / 0.2 A



[An example of wiring diagram]



[Cautions on use]
The contact point of the lubricating oil pressure switch is closed when no pressure is present in the lubricating oil system. That is, if the key switch is turned ON before engine operation, the warning lamp will immediately light up. During operation, the oil pressure is at high level and the pressure switch contact is open and the warning lamp turns OFF. If the engine operation is stopped using the stop lever without turning the key switch OFF, the oil pressure drops to close the pressure switch contact, and the lamp lights up again.

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12. Matching Test Procedure

12-1 Purpose of Matching Test

All of engine perofrmance are the performances of the single engine unit under the standard atmospheric conditions as preconditions as described in section 3-1 in Chapter 3. Engines are installed to any of those driven machines and the locations these machines are operated at are literally spread all over the world and it is quite usual that their operating environments are totally different from the standard atmospheric conditions.

Therefore, it is quite important to know in advance whether a driven machine including the engine can fully function in a given operating environment without problem.

If it is possible to reproduce the same conditions as the operating conditions in a laboratory, the performance can be verified with ease. But actually, there is almost no such facilities.

The substitute performance verification method is a series of test called the matching test. In short, this represents a series of test for predicting how the test data collected under the actual test conditions change under the operating environment of the driven machine or under the conditions specified by customer and determining whether the result would adversely influence the performance of the driven machine. This method includes the suggestions for improvement work to make in order to meet the functional requirement.

In other words, the matching test should be necessarily conducted for the driven machine as a whole, not merely with a single engine alone. Thus it is imperative to have the driven machine manufacturer's permission to use their facilities and be favored by their assistance.

The matching test is the function verification test of the driven machine as a whole including the engine. This test is divided into three types: the heat balance test, the output matching test and installed state checking. The test, evaluation and improvement should be conducted not separately, but simultaneously as much as possible.

It is necessary that the verification of reliability and durability should be conducted by the driven machine manufacturer.

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12-2 Required Items to Be Prepared for Test

Sampling of data differs by the application and purpose of the driven machine and so do the measuring instruments and tools to be prepared. Select necessary items without fail from among the measuring instruments stated below:

12-2-1 Measuring instruments

	Measuring instrument	Measuring items and cautions on carrying the instruments, etc.
1	Barometer	To measure the atmospheric pressure during the test (or inquire to weather bureau).
2	Dry and wet-bulb thermometer	To measure the outside temperature with a dry and wet-bulb thermometer. Also to obtain the relative humidity from the temperature difference from the thermometer. Measurement to be taken in a well-ventilated place in the shade without being influenced by the temperature of the subject machine for the test.
3	Tachometer	High pressure fuel pipe clamping type, or non-contact type (optical reflection type or magnetic pulse type) to measure the engine revolution in the operating state. Check the battery.
4	Thermocouple	For exhaust temperature measurement: 1073 K (800℃) heat resistance × 1 For other temperature measurement: 773 K (500℃) × 5 Carry extra thermocouples just in case of disconnection.
5	Six-point type digital thermometer	Thermometer for the above thermocouples for measuring the temperature of respective portions. Carry a relay extension cord depending on the conditions of the subject machine. Check the battery.
6	Vibration meter	To measure acceleration and amplitude in both directions. Check if AC power supply is available on the test site. Take metal fittings for mounting the pickup and adhesive agent.
7	Stopwatch	To measure data measurement intervals and the speed of running vehicle.
8	Angle meter	To measure the hill climbing angle of a vehicle.
9	Anemometer	For measuring radiator air flow rate.

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12-2-2 Engine parts

	Engine parts	Tool carrying cautions, etc.
1	Exhaust gasket	For measuring exhaust temperature. Two gaskets required including one for repairing the test subject machine. Use the following gaskets for other them the special exhaust manifold.

Engine model	IDI series	3TNE78A 3TNE82A 3TNE84 3TNE88	4TNE84 4TNE88	3TNE84T	4TNE84T	4TNE94 4TNE98
Code No.	121000 -13201	124701 -11911	129400 -13201	CL129403 -18091	CL129403 -18091	129400 -13201
Pitch	52 × 52	52 × 52	62 × 62	VM129403- 18091	VM129403- 18081	62 × 62
Inside diameter	d 45	d 50	d 61	CH129403 -18081	CH129792 -13521	d 61

2	Fully opened thermostat	In the heat balance test, if the engine cooling water outlet port temperature is predicted under 85℃, use the fully opened thermostat for the test. If the temperature is predicted to exceed 85℃, the standard thermostat should remain unchanged. No replacement needed. Special care required for heat balance test during winter.
3	Packing	For the thermostat cover. For repair after replacing with the fully opened thermostat. Two sets for repairing possible breakage during the test.

	2TNE68, 3TNE68, 74	2TNE68-N, 3TNE78A, 82A 3TNE66-N, 68-N, 3TNE84 (T), 88 3TNE72-N, 74-N, 4TNE84 (T), 88	4TNE94, 98
For thermostat cover	129350 -49541	129795-49551	129900 -49540
For thermostat main unit	—	129150-49811	121850 -49550

12-2-3 Tools

	Tool	Tool carrying cautions, etc.
1	Phillips and straight-edge screwdrivers	For digital thermometer terminal For cooling water hose band
2	Wrench set	For bolts of the exhaust outlet port for fixing the thermocouples and for bolts of thermostat cover for replacing the thermostat. For bolts of installed silencer, air cleaner, etc.
3	T box wrench set	For carrying the above mentioned work efficiently.
4	Instantaneous bonding agent	For fixing metal fixtures of vibration measuring pick-up.
5	Double-stick tape	For mounting the vibration meter pick-up. In the case the subject machine is merchandise and not allowed to inflict any damages.
6	Pliers	For mounting high pressure pipe type tachometer pick-up.
7	Cutting pliers	For various works.
8	Tape measure	For measuring the speed of running vehicle.

12-2-4 Data recording paper

	Data recording paper	Tool carrying cautions, etc.
1	Sample machine data	Rated speed performance curve, load performance curve during operation. Specific fuel consumption data also effective depending on the case.
2	Test plan	Arrangement for the matching test, etc.
3	Measured data recording sheet	See attached sheet.
4	Installed state check sheet	See attached sheet.
5	Memo pad	

12-2-5 Other

In addition to the above, the following items may be needed: calculator, scale, camera, operation manual, service manual, etc.

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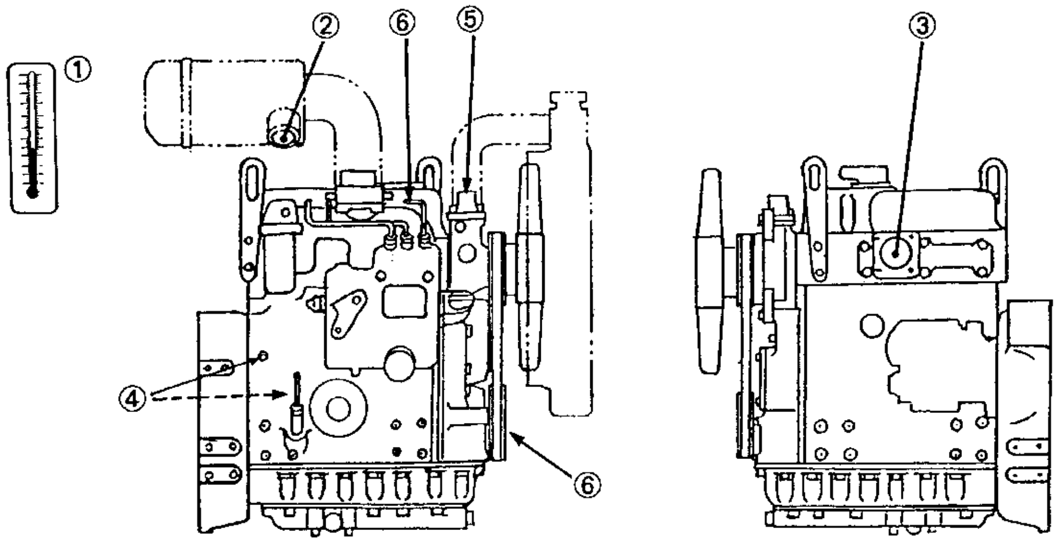
12-3 Measuring Instruments Mounting Instructions



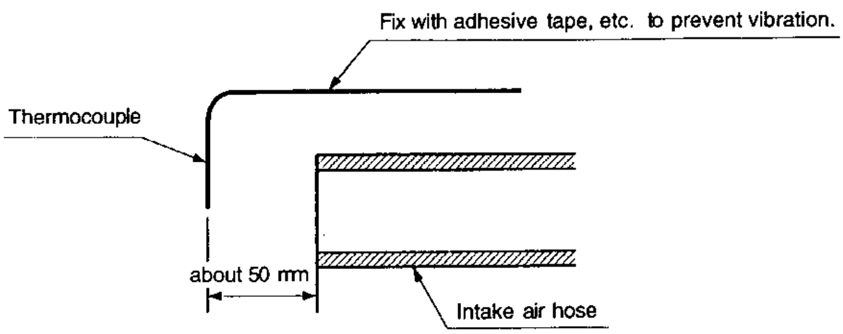
Of the matching tests, particularly important test is the heat balance test. The purpose of this test is to measure the temperature of respective sections. If the measuring instrument is improperly mounted, incorrect temperature may be measured leading to misjudgement. Follow the instructions below for correct mounting of the measuring instruments.

(1) Atmospheric temperature (dry and wet-bulb thermometer)

Measure in a well ventilated place not exposed to direct sunlight.
Set the dry bulb/wet bulb thermometer in a place not influenced by the heat from the driven machine or engine (blowing of the radiator or radiation heat from the exhaust system, etc.).
The atmospheric temperature will be the calculation basis for the temperature rise value of respective sections.
Obtain relative humidity from the temperature difference between the dry and wet bulbs.

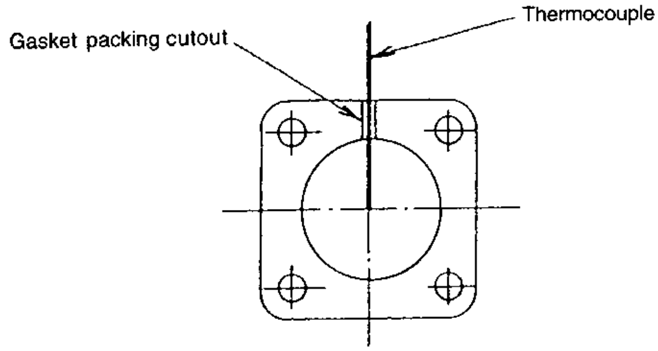
(2) Intake air temperature (use a thermocouple)

To measure, bring the end of the thermocouple to the air cleaner inlet or at about 50 mm away from the intake extension hose end.
Avoid the heat radiated from the exhaust system.



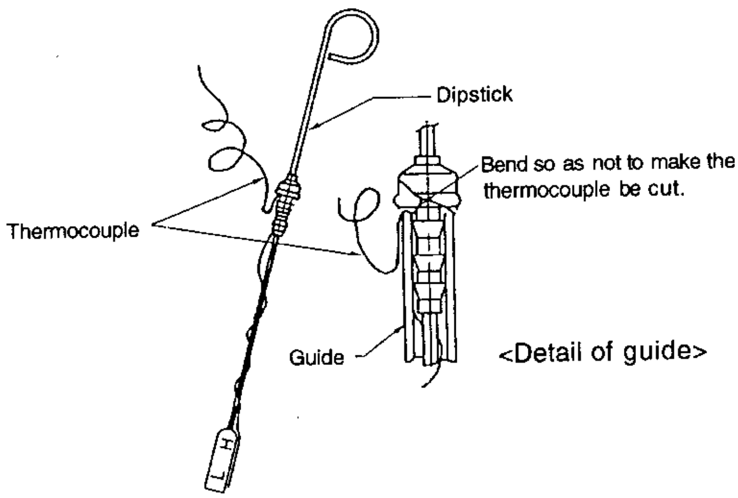
(3) Exhaust temperature: thermocouple

Measure the exhaust temperature at the exhaust manifold outlet (or the outlet port of turbocharger).
Insert the thermocouple by cutting out the gasket. If cut groove is too wide, the exhaust gas may leak or the thermocouple stops slowly.
Fix the flange on the exhaust pipe side so as to have the end of the thermocouple positioned at the center of the exhaust port.
Care should be taken for not allowing the end of the thermocouple to run out of the center of the exhaust port.



(4) Lubricating oil temperature: thermocouple

Measure the temperature of lubricating oil in the main gallery. A dedicated adapter will be required. If the dedicated adapter is not available, substitute it with the temperature of the lubricating oil in the oil pan.
Measure the temperature at the lower level (L) mark on the dipstick.
Fix the thermocouple to the dipstick so that the end of the thermocouple will be positioned at the lower level mark on the dipstick.
Normally, it would be sufficient to wind the lead of the thermocouple around the dipstick. Care should be taken to ensure that the end of the thermocouple will not be separated from the dipstick after the assembly.



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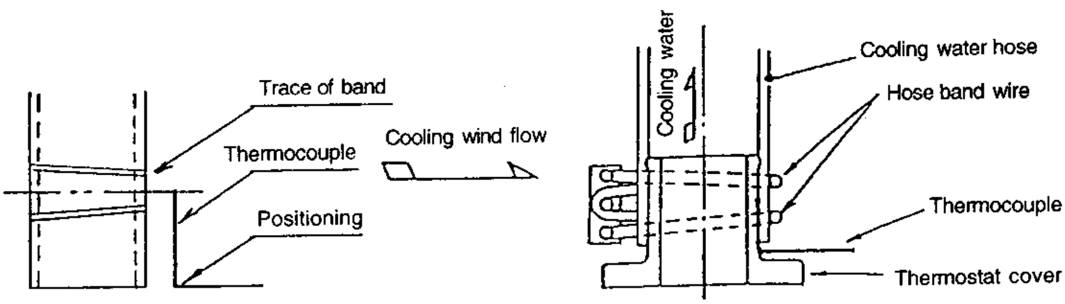
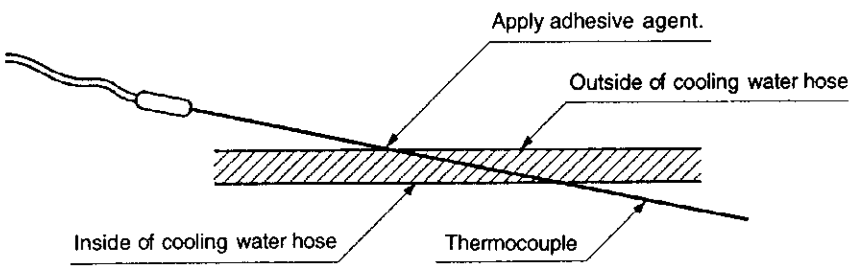
(5) Cooling water temperature: thermocouple

Measure the cooling water temperature at the engine outlet port or radiator inlet port.
Insert the thermocouple to the cooling water hose fitting portion (hose band portion).
Insert the leading end of the thermocouple to the middle between two wires of the hose band so as not to cause water leakage as illustrated below.
Mount the thermocouple on the leeward of the cooling wind so as not to be influenced by it.
Before mounting, loosen the hose bands to withdraw the cooling water hose once, then position the leading end of the thermocouple in advance by aiming at the middle of the trace of the two bands on the circumference of the hose.



If water leaks in the above setting, prick a hole on the cooling water hose with an eyeleteer as diagonally as possible to insert the thermocouple directly.



Before starting the mounting work and removing the cooling hose, drain the cooling water in the engine to a level where no water leaks from the hose at.
If the engine cooling water outlet port temperature is predicted to drop to 358 K (85°C) or below, use the thermocouple in fully opened state.
Care is required for the matching test particularly during cold season.
If data is taken using the standard thermostat when the engine cooling water outlet port temperature is 358 K (85°C) or below, the final evaluation would be difficult.

(6) Engine speed

In the case of a high pressure pipe type tachometer, mount a pick-up to the straight pipe of the high pressure pipe near the fuel injection valve. Use the pliers to firmly tighten it.
Non-contact type tachometer (optical reflection type or magnetic pulse type) are effective in measuring the engine speed of stationary and open type driven machine.
The optical reflection paper is usually pasted on to the crank pulley.

(7) Other temperature (use thermocouple, etc.)

Measure the temperature of respective portions as may be required:

- Temperature inside the engine compartment
- Fuel temperature at the fuel injection pump inlet port
- Ambient temperature around the electrical parts

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12-4 Preparation for Matching Test Operation

Upon completion of preparation for temperature and speed measurement as described in the preceding subsection, start preparation for operating the driven machine.
First check the lubricating oil and cooling water level and make sure that no hazardous matters are on or around the rotating portions.
If the driven machine has an enclosure (engine compartment), open the enclosure before starting engine.
While warming the machine up, check leakage of oil, water, gas from the mounting of the thermocouple and other portions to ensure that all is clear for operation.
Close the enclosure (engine compartment) and start loaded operation.

Loaded operation greatly varies by the type of the driven machine.
If designed for the same purpose, a driven machine has different working pattern as determined by respective manufacturer.
Therefore, it is necessary to fully consult with the driven machine manufacturer and the engine manufacturer on the setting of loaded operation before actually entering the matching test.
Basically both sides should verify the following items:

(1) Test is to be made under a load actually applied by the user.

(2) Test by following the working pattern of the driven machine manufacturer.

(3) Conduct the test under a maximum load capacity of the driven machine.

Normally the matching test is conducted at the driven machine manufacturer's laboratory, test site or tentatively arranged place and that in other season than the driven machine is usually used.
That is, the load is also substituted depending on the case.
Therefore set up the load test details through mutual consultation so as to avoid unrealistic matching test.

Irrespective of the type of the driven machine, the minimum condition is to get ready for applying a maximum load to the driven machine.

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12-5 Heat Balance Test

It is important for retaining the quality of driven machine and the quality of engine to make judgement on whether a newly developed driven machine maintains normal level of the cooling water temperature, lubricating oil temperature, inlet air temperature, the temperature around important parts and components, etc. under the customer-specified atmospheric temperature condition.
In other words, it is important to improve the driven machine structure, obtain allowable atmospheric temperature condition applicable, and find the driven machine load that will hold under a specified condition.
The purpose of heat balance test is to obtain necessary back data to base the judgement on and to make such judgement.

Conduct the loaded operation after making preparation as described in the preceding subsection and sample the temperature data from respective portions after stabilization.
Depending on the driven machine and season, it will take 30 to 50 minutes before the temperature of respective portions becomes stable.
If the load changes, the cooling water temperature and the exhaust temperature change sharply, but the lubricating oil temperature is comparatively stable.
Therefore, data sampling may be completed when the lubricating oil temperature becomes stable.

12-5-1 How to interpret test data and criteria

Various matters can be judged from the stable temperature data obtained from the test.
Although a final, comprehensive judgement is necessary, how to interpret discrete temperature data and make judgement are described below.

Test Data Interpretation and Criteria

	Measured temperature item	Allowable maximum temperature (criteria)	Improvement review item
1	Atmospheric temperature	Though depending on customer's specification, the allowable maximum atmospheric temperature shall be normally 40℃. This will constitute the calculation basis for reviewing the temperature of respective portions when the atmospheric temperature reaches 40℃.	
2	Cooling water temperature	The allowable maximum cooling water temperature shall be 105℃. This has to be strictly adhered to irrespective of the atmospheric temperature condition. (Provided the radiator's pressure cap is for 0.9 kgf/cm^2.) Normally check if converted allowable atmospheric temperature exceeds 40℃ or not when the converted cooling water temperature reaches 105℃. Basically match the allowable atmospheric temperature to the operating environment of the driven machine, however. Set the conversion rate between the atmospheric temperature rise and the water temperature rise to 1.0. That is, if the atmospheric temperature rises by 1℃, the water temperature also rises 1℃.	Engine compartment shape (Wind outlet or inlet), Blowing of heated wind, Fan diameter, Fan number of revolution, Radiator capacity, Load capacity
3	Lubricating oil temperature	The allowable maximum lubricating oil temperature shall be 115℃. This has to be strictly adhered to irrespective of the atmospheric temperature condition. If it exceeds 115℃ as the result of an improvement, the allowable maximum lubricating oil temperature shall be 120℃, and strict adherence to the lubricating oil replacement interval as described in 1-1 Applicable Standard No. 5 in Chapter 1 shall be needed. Normally make judgement as to whether the converted lubricating oil temperature exceeds 115℃when the allowable atmospheric temperature is set to 40℃. Conversely, a converted allowable atmospheric temperature may be examined when the converted lubricating oil temperature reaches 115℃. The conversion rate for the atmospheric temperature rise and the lubricating oil temperature rise shall be normally 0.8. If the atmospheric temperature rises 1℃, convert the lubricating oil temperature rise as 0.8℃.	Engine compartment shape (Wind outlet and inlet) Heated wind blowing, Wind around the oil pan, Review of the oil cooler, Load capacity
4	Intake air temperature	Set the development target for allowable intake air temperature to such that will suppress the temperature rise from the atmospheric temperature to 5℃ or below. If the allowable intake air temperature cannot be lowered to or under 10℃ after adding intake hose for improvement, it is necessary to review on the driven machine capacity since the engine output would be influenced as the atmospheric temperature rises.	Engine compartment shape (Wind outlet and inlet), Heated wind blowing, Air cleaner position, Intake air hose position, Load capacity

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Measured temperature item		Allowable maximum temperature (criteria)	Improvement review item
5	Temperature inside engine compartment	Set the development target for allowable temperature inside the engine compartment to such that will suppress the temperature rise from the atmospheric temperature to 10℃ or below. As this is difficult for the intake type cooling fan, improve ventilation so as to have the following fuel oil temperature and electrical parts ambient temperature meet the conditions.	Engine compartment shape (Wind outlet and inlet), Heated wind blowing, Fan type, Panel position
6	Fuel oil temperature	Set the development target for the fuel oil temperature at the fuel injection pump inlet port to 60℃ or below irrespective of the atmospheric temperature. If the fuel oil temperature should rise higher, the engine output will be adversely influenced. This can be a check point in such n occasion. The temperature conversion rate shall be 1.0.	Engine compartment shape (Wind outlet and inlet), Heated wind blowing, Fan type, Panel position
7	Ambient temperature around electrical parts	Set the development target for the ambient temperature around such electrical parts as the starting motor, generator, respective relays, etc. to 80℃ or below irrespective of the atmospheric temperature. Even if the ambient temperature is under 80℃, care should be taken not to allow the stagnation of the air. If the ambient temperature is above 80℃, degradation of electrical parts and components may be caused.	Engine compartment shape (Wind outlet and inlet), Heated wind blowing, Fan type, Panel position
8	Exhaust temperature	For the exhaust temperature, see section 12-6 Output Matching Test.	

The above-mentioned criterion are reviewed from the side of the engine as principle, but it is important to mind not to sacrifice the practical applicability of driven machines from the viewpoints of comprehensive judgement.

To this end, accumulated experiences on the part of driven machine manufacturer present a major judgement base material.

So it is very important to balance the notions on both parties before making the final judgement.

12-5-2 Heat balance evaluation

This sub-subsection describes how to evaluate the heat balance by examining respective temperature data collected from the matching test by quoting actual numeric values.
Suppose that the final stable temperatures of respective portions obtained from the loaded operation are as follows:

			(Calculation example)
Ta	: Atmospheric temperature	K (°C)	(19°C)
Tw	: Cooling water engine outlet port temperature	K (°C)	(87°C)
To	: Lubricating oil temperature	K (°C)	(101°C)
Tx	: Intake air temperature	K (°C)	(34°C)

The following temperatures are also necessary for the heat balance evaluation:

Tmw	: Allowable maximum temperature of cooling water	378 K (105°C) (Pressure cap : 0.9 kgf/cm^2)
Tmo	: Allowable maximum temperature of lubricating oil	388 K (115°C) or conditional 393 K (120°C)
Tcw	: Cooling water use limit atmospheric temperature	K (°C)
Tco	: Lubricating oil use limit atmospheric temperature	K (°C)
Tdif	: Intake air temperature rise value (Tx – Ta)	K (°C)

For reference, K is the unit for absolute temperature and pronounced as Kelvin.
It is related to °C as follows:

K = 273 + °C

(1) Cooling water temperature evaluation

a) This is to evaluate the cooling water use limit atmospheric temperature Tcw by estimating it when the cooling water reaches the allowable maximum temperature Tmw = 378 K (105°C) from the atmospheric temperature Ta and the cooling water temperature Tw data obtained from the test.
Calculate the estimated Tcw as follows:

Tcw = (Tmw – Tw) + Ta
= (105 – 87) + 19
= 37°C (Calculation example)

It is necessary to evaluate the cooling water use limit atmospheric temperature Tcw by considering the environment (season, maximum temperature on record, etc.) the driven machine is operated in.

b) For example, if this driven machine is to be used in Japan, it is generally practiced to set the limit atmospheric temperature Tcw at 40°C.
In the present calculation example, Tcw = 37°C, therefore, the heat balance is not met in this case.
In order to make Tcw = 40°C or higher, it is necessary to lower the water temperature at least the value calculated by the following calculation:

$$
\begin{aligned}
&(\text{Target Tcw} - \text{Test result Tcw}) \times 1 \\
&= (40 - 37) \times 1 \\
&= 3.0^{\circ}\text{C (Calculation example)}
\end{aligned}
$$

To do this, it is necessary to improve the air flow by reviewing the engine compartment shape of the driven machine, review the fan diameter, speed, radiator capacity, etc. and conduct the heat balance test once again.

c) Or if it is difficult to change the cooling system specifications, to obtain the load ratio for the use limit atmospheric temperature Tcw to clear the target value by decreasing the application load is another purpose of the heat balance test.
If the driven machine happens to be a snowplow, Tcw = 37°C of the calculation example is excessive a quality for the snowplow, so it is possible to evaluate the necessity for conversely miniaturizing the size of radiator to promote the cost reduction.

(2) Lubricating oil temperature evaluation

a) This is to estimate and evaluate the lubricating oil use limit atmospheric temperature Tco when the lubricating oil reaches the allowable maximum temperature Tmo = 388 K (115°C) from the atmospheric temperature Ta and the lubricating oil temperature To data from the test.
Calculate the estimated Tco as follows:

$$
\begin{aligned}
\text{Tco} &= (\text{Tmo} - \text{To}) / 0.8 + \text{Ta} \\
&= (115 - 101) / 0.8 + 19 \\
&= 36.5^{\circ}\text{C (Calculation example)}
\end{aligned}
$$

It is necessary to evaluate the lubricating oil use limit atmospheric temperature Tco by considering the environment (season, maximum temperature on record, etc.) the driven machine is operated in.

b) In the present calculation example, Tco = 36.5℃.
How to evaluate this and how to take measure shall be considered along with the improvement work for the cooling water temperature.
For example, if this driven machine is to be used in Japan, the limit atmospheric temperature Tco is generally set at 40℃.
While Tco = 36.5℃ in the present calculation example, it does not meet the heat balance in this case.
In order to make Tco = 40℃ or more, it is necessary to lower the lubricating oil temperature by the result of the following calculation or lower:

$$\begin{aligned}&(\text{Target Tco} - \text{Test result Tco}) \times 0.8\\&= (40 - 36.5) \times 0.8\\&= 2.8^{\circ}\text{C} \text{ (Calculation example)}\end{aligned}$$

To do this, the engine compartment shape of the driven machine may be reviewed to improve the air flow around the oil pan, or depending on a case, the oil cooler installation may be reviewed.
Since the lowering of the cooling water temperature is effective in lowering the lubricating oil temperature, the cooling water system may be reviewed for improving the lubricating oil temperature.

c) Or, if it is difficult to change the present engine specifications, to obtain the load ratio for the use limit atmospheric temperature Tco to clear the target value by decreasing the application load is another purpose of the heat balance test.
If this driven machine happens to be a snowplow, Tco = 36.5℃ of the calculation example is too excessive a quality for the snowplow.
So if the engine is equipped with the oil cooler, it may be removed and the heat balance test may be conducted once again.

(3) Intake air temperature evaluation

a) This is to examine and evaluate how high the engine intake air temperature Tx has risen to the ambient atmospheric temperature Ta.
Supposing the intake air temperature rise value to be Tdif, it will be obtained by the following equation :

$$\begin{aligned}\text{Tdif} &= \text{Tx} - \text{Ta} \quad \text{K } (^{\circ}\text{C})\\&= 34 - 19\\&= 15^{\circ}\text{C} \text{ (Calculation example)}\end{aligned}$$

In this case, the unit of Tdif is either K or ℃, but since Tdif represents temperature difference, the numerical value itself will be the same irrespective of K or ℃.

b) If the intake air temperature rises, it adversely influences the engine output.
Therefore, it is necessary to feed the air having the temperature close to the atmospheric temperature as much as possible.
In the prototype stage of the driven machine, examine the air cleaner position, intake air hose direction, etc. by setting the target Tdif at 5℃ or below.
While it depends ultimately on the result of the output matching (seen section 12-6 in Chapter 12), no major adverse effect is given to the engine output for practical application if T dif is below 10°C. In the calculation example above T dif is 15°C therefore it is necessary to improve the positioning of the air cleaner intake port or intake air hose.
But the appropriateness of the intake port position or intake air temperature rise value Tdif shall be determined in a comprehensive judgement with the output matching.

(4) Temperature evaluation of various portions

In the heat balance test, the evaluation of the cooling water, lubricating oil and intake air temperatures are most important as thus far described.
As to the temperature of other portions, proceed with the evaluation and improvement according to the descriptions provided in section 12-5-1.

12-6 Output Matching Test

Horse power necessary for a driven machine to operate (required horsepower or demand horsepower) can be calculated from the operating capacity of a driven machine.
A driven machine manufacturer selects an engine that can output power equivalent to the required horsepower according to the calculation result.

It is quite rare, however, that the required horsepower of the driven machine is verified by measurement from the motoring, etc.
Most are obtained from the calculation as described above.
The calculation process always requires "machine efficiency".
But machine efficiency differs by machine, and except part of electrical machinery whose efficiency can be estimated by calculation, the machine manufacturer's empirical values are mostly used or if it is difficult to predict, then appropriately estimated values are often used.
This causes uncertainty of required horsepower.

On the other hand, selected engines are measured of their rated output by operating them one by one before shipment using a dynamometer.
Therefore the indicated output of the engines are assured.
It is very important for the engine manufacturer and the driven machine manufacturer as well to know before mass production whether the engine and the driven machine are balanced in term of output upon installation, whether the engine meets the operating capacity, how much allowance it has, and so forth.

As thus described, the matching test refers to a series of procedures for conducting test with the engine installed to the driven machine, making verification and evaluation of the required horsepower of the driven machine to the engine output.

12-6-1 Output matching evaluation

Engine output during operation can be estimated from various data such as the exhaust temperature, intake air temperature, atmospheric temperature, humidity, atmospheric pressure as measured along with the heat balance test and from the test engine performance data.
This is the same thing as knowing required horsepower of a driven machine.

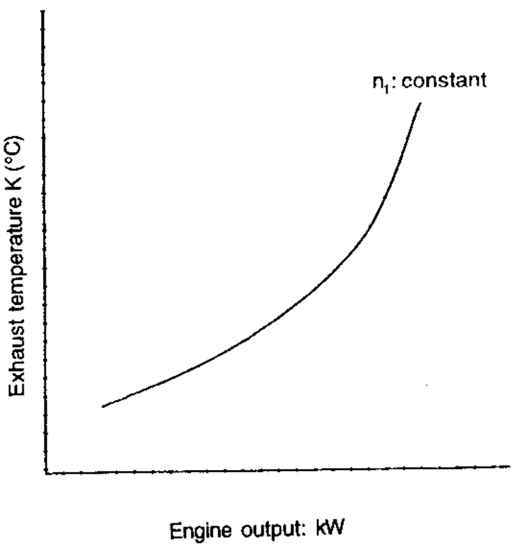
In other words, to conduct the output matching test, it is necessary for the engine manufacturer to test the sample engine for the matching test and collect performance data proper to this particular engine.
Without these data, it may be difficult for certain driven machines to be evaluated or judged on their output matching test.

The output matching test method, in short, applies the correlation between the exhaust temperature and the engine output. Exhaust temperature for a certain output has repeatability.
Therefore, if the exhaust temperature of an engine having the exhaust temperature data of 400°C at 10 kW output, measured upon installation to a driven machine reads 400°C, then the required horsepower of the driven machine can be judged as 10 kW.

Actually, the atmospheric condition at the time of matching test varies and the evaluation is not that simple, but anyway, the required horsepower of the driven machine will be estimated finally by converting it to under the engine's standard atmospheric condition.

(1) Sample engine performance curve

The engine performance curve can be measured with various methods according to the purpose. Performance required for the output matching test is called "constant speed performance curve."



This curve is obtained by plotting the exhaust temperature while applying a load to the engine being operated at a rated speed.

Care should be taken on this data, however, since it is not applicable to the engine of different E/# if of the same engine type.

It is also necessary to conduct the output matching test before the engine service hour exceeds 30 hours as much as possible.
Engines used for an extended period of time have their break-in effect in advanced state, which may cause the output and exhaust temperature relationship to mismatch with the initial data.

(2) Apparent engine output

In most cases, required horsepower of driven machine changes under the atmospheric conditions. Part of driven machines that handle the air may be influenced by not much as to affect the output matching evaluation.

On the other hand, engines change output, as described in Chapter 4, by the atmospheric condition. Therefore, when referring to the output, it is necessary to have the atmospheric standard, which is what we call the standard atmospheric condition.

Supposing that the required horsepower of a driven machine under the standard atmospheric condition is PkW, then the engine output too is balanced at PkW.
If the atmospheric condition changes at random, the required horsepower of the driven machine remains unchanged but the engine output PkW changes, breaking the balance between the two.
To restore the balance, the engine governor operates or the engine regulator handle is adjusted to maintain the engine output at PkW.

As the result, the engine fuel injection quantity changes.
Therefore the fuel injection quantity under the standard atmospheric condition will be equivalent to that at Po kW instead of PkW.

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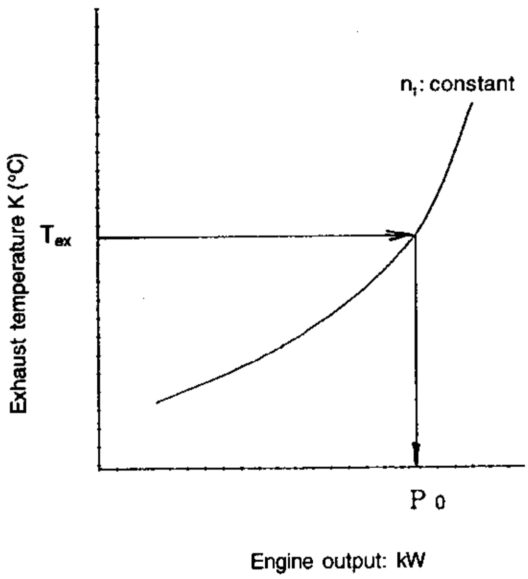
In other words, to operate the driven machine of PkW under the random atmospheric condition, an engine output of "Po kW converted to under the standard atmospheric condition" will be required.



This Po kW may be called an apparent engine output under the random atmospheric condition,
The reason why it is called "apparent" is because the actual engine output at this time is P kW as the driven machine always demands.

In other words, if the apparent engine output Po kW is found from the output matching test under the actual atmospheric conditions, then required horsepower P kW of the driven machine can be obtained as illustrated.

The Po kW can be obtained from the exhaust temperature Tex of the matching test and the engine constant speed performance curve as shown in the figure to the left.

(3) Calculation of estimated required horsepower

If apparent engine output Po kW is known from the exhaust temperature Tex, the required horsepower P kW of the driven machine can be obtained by getting the output correction coefficient from then atmospheric condition.

a) Calculation of output correction coefficient
For calculating the output correction coefficient, equation stated in 4-1 in Chapter 4 shall be used. In this case, either one of the two calculation formulas must be used depending on the atmospheric condition.
Necessary data are as follows:

Px	: Atmospheric pressure at test time	kPa	{mmHg}
Φx	: Relative humidity at test time	%	%
Tx	: Intake air temperature at test time	K	{℃}
Psx	: Saturation vapor pressure at test time	kPa	{mmHg}

b) Calculation of estimated required horsepower
Care should be taken because the handling of coefficients k and α will be reversed depending on which calculation formula is used.

i) Calculation of estimated required horsepower when correction coefficient k is obtained by using the calculation procedure applied when the atmospheric condition is comparatively close to the standard atmospheric condition as shown in Section 4-1-1.

$P = Po / k$

Po : Apparent engine output
P : Required horsepower of driven machine
k : Correction factor

ii) Calculation of estimated required horsepower when correction coefficient α is obtained by using the calculation procedure applied when the atmospheric condition is remarkably different from the standard atmospheric condition as shown in Section 4-1-2.

$$P = \alpha \cdot Po$$

Po : Apparent engine output
P : Required horsepower of driven machine
α : Correction factor

(4) Output matching evaluation

Evaluation of output matching refers to reviewing whether required horsepower P of driven machine obtained with the above-mentioned procedures has allowance to the engine output, or what happens if the engine loses output during summer.

One of the criteria of the evaluation is whether it matches the handling of output as described in section 3-1 "TNE engine output setting condition" in Chapter 3.

Since there are all types of driven machines, it is not possible to set up a uniform criterion.
But it is checked whether the required horsepower constitutes an overload to the engine or not, and by working jointly with the driven machine manufacturer, functional problems are examined and the final judgement is made.

For an example, if judged as overloaded as the result of the output matching test on a generator, consultation will be made with the driven machine manufacturer whether to raise the efficiency of the generator or to lower the generator output indication, etc.

12-7 Installation State Check

Literally this means to check the state the engine is installed to the driven machine.

The main check point is if the structure allows the engine maintenance or whether any problem is present about the piping, wiring and the installation of equipment.
That is, quality check is conducted before the driven machine enters the mass production stage.

Of course the check points will be different by the driven machine.
An example of check sheet stating the standard check items is shown in the following subsection.

12-8 Various Forms Required for Matching Test

Various record sheets and evaluation sheets are necessary when conducting the matching test.
It is not necessarily required to use these forms, but typical examples of forms are shown as follows.

YANMAR DIESEL ENGINE CO. LTD.

ENGINE INSTALLATION

EVALUATION

CUSTOMER'S NAME: ____________________

TYPE OF APPLICATION: ____________________

ENGINE MODEL: ____________________

ENGINE RATED POWER: ____________________

IF YOUR MACHINE IS SOLD TO CALIFORNIA STATE, YOU SHALL MEET YANMAR STANDARDS WITH * TO COMPLY WITH CARB ULG REGULATION AND REPORT TO YANMAR DIESEL ENGINE CO. LTD. UNDER THE NAME OF AUTHORIZED PERSON.

CUSTOMER'S AUTHORIZED PERSON ____________________

TITLE:

REPLY FROM YANMAR DIESEL ENGINE CO. LTD.

☐ ACCEPTABLE FOR MASS PRODUCTION

☐ ACCEPTABLE FOR MASS PRODUCTION WITH FOLLOWING CONDITIONS ____________________

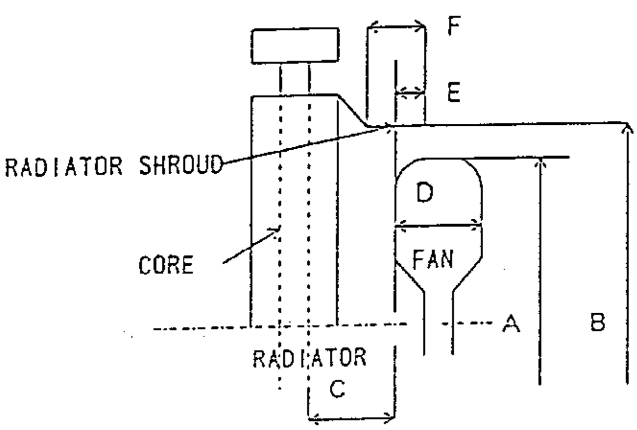
☐ NOT ACCEPTABLE FOR MASS PRODUCTION FOLLOWING MODIFICATION MUST BE REQUIRED ____________________

YANMAR DIESEL ENGINE CO. LTD. ____________________

TITLE:

1. GENERAL INFORMATION		
1-1	CUSTOMER'S NAME	
1-2	CUSTOMER'S ADDRESS	
1-3	ENGINE MODEL/ENGINE NO.	
1-4	ENGINE RATING (Hp/rpm)	
1-5	TYPE OF APPLICATION	
1-6	MACHINE MODEL/MACHINE NO.	
2. OPERATING CONDITION		
2-1	TERRITORY	☐ NORTH AMERICA ☐ CENTRAL AMERICA ☐ SOUTH AMERICA ☐ EUROPE ☐ AFRICA ☐ MIDDLE EAST ☐ ASIA ☐ OCEANIA * ☐ CALIFORNIA STATE ☐ OTHERS ( ) * If your machines are sold to California State, you shall meet engine performance with * mark less than our standards to comply with CARB ULG REGULATION.
2-2	AMBIENT TEMPERATURE	MIN. ℃ to MAX. ℃
2-3	ALTITUDE	m to m
3. INTAKE AIR SYSTEM		
3-1	AIR CLEANER SIZE/MAKER NAME	AIR CLEANER SIZE: MAKER:
3-2	TYPE OF AIR CLEANER	☐ PAPER ELEMENT ☐OIL BATH ☐ OTHERS ( )
3-3	RAIN CAP OR PRECLEANER	☐ INSTALLED (☐ RAIN CAP ☐ PRE-CLEANER) ☐ NOT INSTALLED
3-4	AIR CLEANER POSITION	☐ INSIDE OF BONNET ☐ OUTSIDE OF BONNET ☐ OTHERS ( )
3-5	AIR INTAKE POSITION	☐ INSIDE OF BONNET ☐ OUTSIDE OF BONNET ☐ OTHERS ( )
3-6	AIR INTAKE INDICATOR	☐ NOT INSTALLED ☐ YES INSTALLED IF YES, WHAT TYPE ☐ MECHANICAL ☐ ELECTRIC
* 3-7	INTAKE AIR RESTRICTION REFER TO APPLICATION MANUAL 7-3 FOR MEASUREMENT	STANDARDS kPa (mmHg) *YANMAR LESS THAN 2.27 kPa (250 mmAq) BOTH L-A & TNE SERIES

4. EXHAUST SYSTEM		
4-1	SIZE OF SILENCER/MAKER NAME	SIZE OF SILENCER: MAKER:
4-2	POSITION OF SILENCER	
4-3	TAIL PIPE EXIT POSITION	
4-4	MIN. EXHAUST PIPE DIAMETER	mm
* 4-5	EXHAUST BACK PRESSURE REFER TO APPLICATION MANUAL 8-1 FOR MEASUREMENT	kPa (mmAq) * YANMAR STANDARDS 3TNE84/88-CL : LESS THAN 6.37 kPa (650 mmAq) 3TNE74-VH : LESS THAN 11.77 kPa (1200 mmAq) 3TNE84T-CL : LESS THAN kPa (mmAq) OTHER THAN ABOVE TNE : LESS THAN 9.09 kPa (1000 mmAq) L-A : LESS THAN 3.00 kPa (330 mmAq)
5. COOLING SYSTEM		
5-1	PULLEY RATIO	(CRANKSHAFT PULLEY/FAN PULLEY)
5-2	TYPE OF COOLING FAN	☐ PUSHER TYPE ☐ PULLER TYPE
5-3	MATERIAL OF COOLING FAN	☐ STEEL TYPE ☐ PLASTIC TYPE ☐ OTHERS ( )
5-4	COOLING FAN DIAMETER × NUMBER OF BLADES	mm × BLADES
5-5	RADIATOR MAKER / CAPACITY	MAKER NAME: CAPACITY: kcal/Hr
5-6	RADIATOR SPECIFICATION IF PROCURED LOCALLY	FIN PITCH: CORE AREA: PRESS. CAP:
5-7	SKETCH OF RADIATOR INSTALLATION	A : COOLING FAN DIA. mm B : RADIATOR SHROUD DIA. mm : CLEARANCE BETWEEN FAN AND SHROUD (B-A)/2: mm (10 TO 15 mm) C : DISTANCE FROM END OF CORE TO END OF FAN mm (min. 1 Inch) D : COOLING FAN WIDTH mm E : LAPPED DISTANCE mm (COOLING FAN & SHROUND) F : SHROUND RING WIDTH mm



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6. FUEL SYSTEM		
6-1	PRIMARY FILTER	☐ NOT INSTALLED ☐ INSTALLED I F YES, WHAT TYPE ☐ WATER TRAP MAKER: TYPE: ☐ PRIMARY FUEL FILTER MAKER: TYPE:
6-2	FINAL FUEL FILTER	☐ YANMAR STANDARD FUEL FILTER INSTALLED (P/N:) ☐ LOCAL PROCUREMENT (MAKER: MODEL:) FILTRATION AREA: cm^3 MESH SIZE: micron
6-3	FUEL FEEDING METHOD	☐ GRAVITY FUEL ☐ MECHANICAL FUEL FEED PUMP (☐ YANMAR STANDARD ☐ OTHERS) ☐ ELECTRIC FUEL FEED PUMP (MAKER: TYPE:)
7. LUBRICATING OIL SYSTEM		
7-1	LOCATION OF LUB. OIL DRAIN ON OIL SUMP PAN	☐ BOTTOM OF OIL SUMP PAN ☐ SIDE OF OIL SUMP PAN ☐ OTHERS (LOCATION:)
7-2	LUB. OIL COOLER	☐ NOT INSTALLED ☐ INSTALLED (☐ YANMAR STANDARDS ☐ OTHERS)
8. ELECTRIC SYSTEM		
8-1	BATTERY SIZE	
8-2	BATTERY CABLE RESISTANCE FOR MORE DETAIL REFER TO APPLICATION MANUAL 13-5	YANMAR STANDARDS LESS THAN 2/1000 Ω (STARTER MOTOR: LESS THAN 2 kW) LESS THAN 12/10000 Ω (STARTER MOTOR: MORE THAN 2 kW)
8-3	STARTER CABLE RESISTANCE FOR MORE DETAIL REFER TO APPLICATION MANUAL 13-5	YANMAR STANDARDS LESS THAN 5/100 Ω
9. ENGINE VIBRATION		
9-1	MAX. VIBRATION LEBEL	☐ VIBRATION LEVEL IS MEASURED IF SO, ATTACH THE RESULT. AND FIND ☐ ACCEPTABLE ☐ NOT ACCEPTABLE ☐ VIBRATION LEVEL IS NOT MEASURED. AND FIND ☐ ACCEPTABLE ☐ NOT ACCEPTABLE

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10. HEAT BALANCE TEST

10-1	MAX. ALLOWABLE AMBIENT TEMP. FOR COOLING WATER	℃	YANMAR STANDARD MORE THAN 40℃
10-2	MA. ALLOWABLE AMBIENT TEMP. FOR LUB. OIL	℃	YANMAR STANDARD MORE THAN 40℃

10-3 TEST RESULT: REFER TO APPLICATION MANUAL 12 FOR TESTING METHOD

No.	TIME	ENGINE SPEED	EXHAUST TEMP	ENGINE LUB. OIL TEMP	ENGINE COOLING WATER TEMP.		AIR INTAKE TEMP.	AMBIENT TEMP.	REMARKS
					IN	OUT			
	rpm	℃	℃	℃	℃	℃	℃	℃	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

11. MAINTENANCEABILITY

11-1	LUB. OIL CHECK BY DIPSTICK	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-2	LUB. OIL SUPPLY THROUGH FILLER CAP	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-3	LUB. OIL DRAIN THROUGH DRAIN PLUG ON OIL PAN	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-4	ENGINE LUB. OIL FILTER REPLACEMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-5	COOLING WATER QUANTITY CHECK BY RADIATOR CAP	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-6	COOLING WATER SUPPLY THROUGH RADIATOR CAP	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)

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11-7	COOLING WATER DRAIN	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-8	RADIATOR FIN CLEANING	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-9	FAN BELT TENSION ADJUSTMENT & REPLACEMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-10	AIR CLEANER ELEMENT CLEANING & REPLACEMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-11	FUEL SUPPLY TO FUEL TANK	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-12	WATER DRAIN FROM FUEL TANK	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-13	FUEL FILTER ELEMENT CLEANING & REPLACEMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-14	PRIMARY FILTER CLEANING & REPLACEMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-15	AIR BLEEDING FROM FUEL SYSTEM	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
11-16	BATTERY ELECTROLYTE CHECK & SUPPLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12. SERVICEABILITY		
12-1	ENGINE FOOT BOLT RE-TIGHTENING	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-2	CYLINDER HEAD COVER DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-3	CYLINDER HEAD BOLT RE-TIGHTENING	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-4	CYLINDER HEAD DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-5	VALVE CLEARANCE ADJUSTMENT	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-6	FUEL INJECTION VALVE DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-7	FUEL INJECTION PUMP DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-8	FUEL FEED PUMP DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-9	OIL PAN DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)

12-10	COOLING WATER PUMP DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-11	STARTER MOTOR DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-12	GENERATOR DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
12-13	PISTON DIS- AND RE-ASSEMBLY	☐ GOOD ☐ NORMAL ☐ POOR (REMARKS:)
13. PARTS INTERFERENCE		
13-1	CONTACT OF COOLING FAN AND OTHER PARTS	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-2	CONTACT OF FAN BELT AND OTHER PARTS	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-3	CONTACT OF RADIATOR HOSE AND OTHER PARTS	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-4	CONTACT OF FUEL PIPE AND OTHER PARTAS	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-5	FUEL PIPING SHALL NOT BE NEAR HOT AREA LIKE EXH. MANIFOLD	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-6	CONTACT OF WIRING HARNESS AND OTHER PARTS	☐ NO ☐ NEED MODIFICATION (REMARKS:)
13-7	WIRING HARNESS SHALL NOT BE NEAR HOT AREA LIKE EXH. MANIFOLD	☐ NO ☐ NEED MODIFICATION (REMARKS:)
14. OTHERS		
14-1	WHETHER THE AIR CLEANER IS FREE FROM INTRUDING RAIN	☐ YES ☐ NEED MODIFICATION (REMARKS:)
14-2	WHETHER THE SILENCER IS FREE FROM INTRUDING RAIN	☐ YES ☐ NEED MODIFICATION (REMARKS:)
14-3	DRAIN HOLE ON SILENCER	☐ YES ☐ NO
14-4	DRAIN HOLE ON STARTER MOTOR IS DOWNWARDS	☐ YES ☐ NO

13. Electrical System

As the diesel engine is a compression ignition engine, the engine must be rotated by an external force to obtain the compressed air at the time of starting. The starting motor to be operated by the battery voltage is installed on the engine for this reason.

The battery and generator are installed to supply power to the engine starting/stopping system and control panel lamps, and various other electrical parts are installed on the engine. Twelve (12) V is the standard voltage for electrical parts for the TNE series engines.

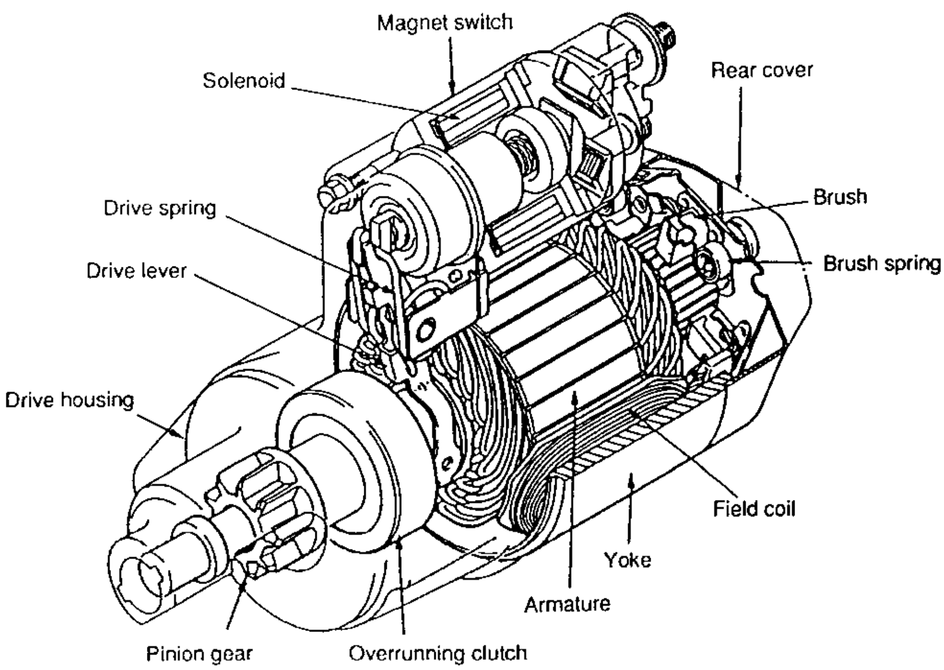
13-1 Starting Motor

Though the starting motor is used only when starting the engine, cautions for operating environment and installation must fully be taken into consideration to make the most of its performance.

(1) Starting motor types

Various mechanisms are used for engaging and disengaging the starting motor pinion smoothly and surely to and from the flywheel ring gear. The most widely used type is the conventional magnetic engaging type. The TNE series engine uses this type. In this type the pinion gear is pushed by the solenoid force via the drive gear for engagement with the flywheel ring gear.

[Structure of conventional type starting motor]



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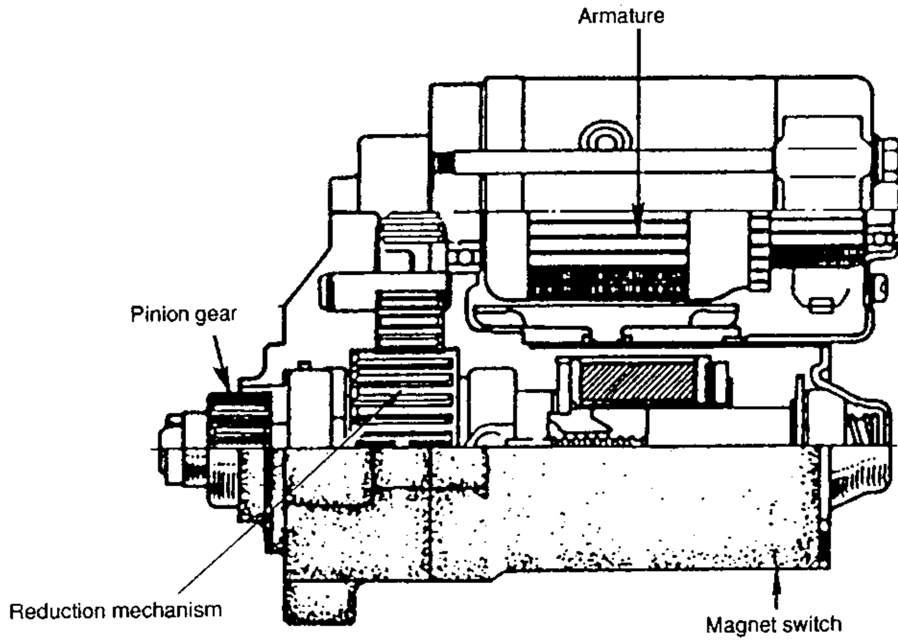
The conventional type (preceding figure) whose pinion gear and armature shafts are coaxial and a reduction type in which the pinion gear and armature shafts are not coaxial are available. In the reduction type, a small high-speed motor rotates the pinion gear by reducing the armature revolving speed to 1/3 to 1/4. This type is smaller in size than the standard type with the same output. An example is shown in the figure below.

[Structure of gear reduction type starting motor]



(2) Starting motor selection

The objective of the starting motor is to crank the engine. The starting motor capacity varies with the engine size and the required starting torque from the driven machine. As the required starting torque varies greatly with the temperature, the starting motor capacity must be selected to generally satisfy such condition. The standard starting motor and engine combinations are as shown in 1-3, Chapter 1, but it is necessary to check the connected load state when determining the starting motor.

(3) Precautions for use

① Wiring

The starting motor output depends not only on the battery capacity but also on the wiring resistance. Especially, when the wiring resistance between the key switch and magnetic switch is great, defective pinion engagement may arise. Therefore, it is necessary to keep the starting motor cable resistance within 0.05 Ω. As the starting motor requires a large current, sufficient starting motor performance cannot be obtained if the battery cable wiring resistance is high, so the appropriate battery cable diameter must be considered. See section 13-5 for the method of selecting the cable diameter .

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② Temperature
When the ambient temperature rises, wearing of the metal bearing in the starting motor tends to increase. Temperature rise also causes the magnet switch operating voltage to rise, resulting in the lowering of the starting motor performance due to decreases of pulling force and the pinion malfunction. To prevent these problems, keep the ambient temperature below 353 K {80℃} during engine operation. On the other hand, in cold area, the lubricating oil in the sliding portion may freeze or increases in viscosity, causing pinion malfunction. Use grease for low temperatures.

③ Oil
Generally, abnormal wear or defective conductivity of the brushes and contacts occur if oil enters the armature ommutator or magnetic switch contact of the starting motor.
Be careful not to splash oil to the starting motor.

④ Dusts
Dust deposit on the armature shaft pinion sliding section increases the resistance and causes defective pinion engagement. Carefully perform inspection and maintenance.

⑤ Vibration
Give full consideration to the vibration isolating structure to prevent resonance when the driven machine is installed.

⑥ Water
If water enters the pinion sliding section, commutator or magnetic switch contact, the starting motor may lose its function due to rusting. Never allow the starting motor to be splashed with water. Since the water-proof performance of the starting motor is in the R2 level of JIS D 0203, never subject it to steam or pressurized washing. The R2 level refers to the water spray test for examining the performance of a part indirectly exposed to rainwater or splash.

⑦ Salt damage
On a road in cold area where salt is sprayed to prevent the freezing or on a seaside road, salt damages as mentioned below are expected to occur. Therefore, consideration shall be given to the construction of the bonnet, cover, etc. on the driven machine side to prevent direct salt damages to the engine.

1. Rusting of threaded portion, malfunction of sliding section
2. Short circuit or burning of terminals by galvanic corrosion
3. Defective contact of insert type terminals

⑧ Operation
To prevent the starting motor from burning, turn the power on normally for 15 seconds or less at a time. Never exceed 30 seconds even in cold season.
Wait at least 30 seconds before turning the power ON again.

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⑨ Safety
To prevent the starting motor from overrunning (over speed and/or excessive duration of energization) due to an operation error of the starting switch, installation of safety relay is recommended. The safety relay automatically cuts off the starting motor circuit during engine start when it reaches the prescribed speed. During engine operation, it prevents pinion gear engagement due to the operation error of the starting switch.

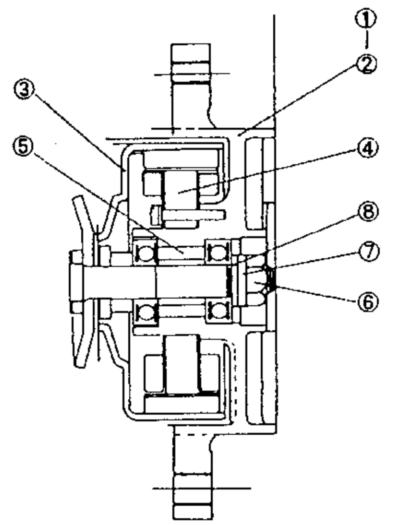
13-2 Charging Generator

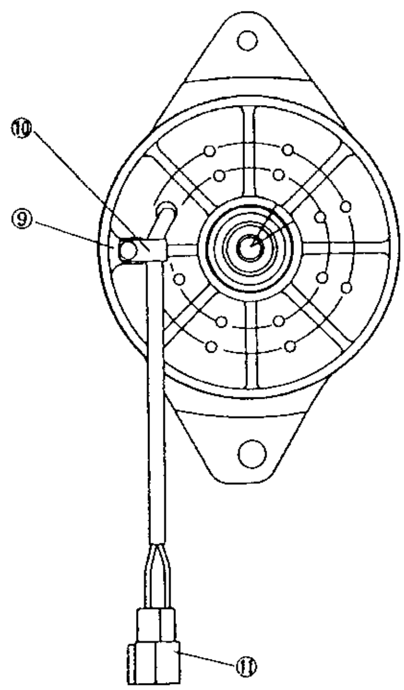
The generator is driven by the engine via a belt. Its power generation capacity varies by the engine speed. The generator charges the battery and supplies power to the electric load.
Generators are classified into AC generators and DC generators. The TNE series engines adopts the AC generator. The AC generator is further classified into the altemator with a built-in IC regulator and the dynamo using a permanent magnet.

(1) Features of dynamo

The dynamo is a sort of magneto generator using a permanent magnet as the field. The generated alternating current is rectified into a direct current by a separately installed current limiter.

[Dynamo structure]





① Plate complete
② Plate
③ FW complete
④ Stator
⑤ Collar
⑥ Hexagon nut
⑦ Spring washer
⑧ Plain washer
⑨ Washer set screw
⑩ Clamp
⑪ Coupler

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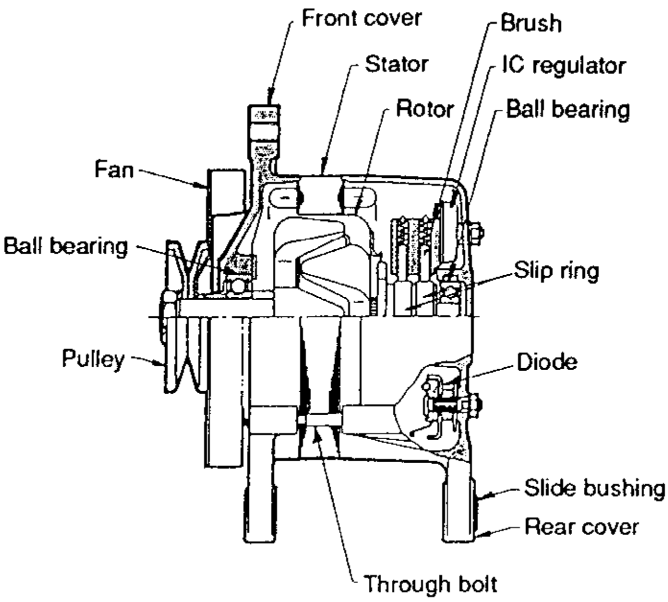
(2) Features of alternator

In place of the permanent magnet used in the dynamo, the alternator uses an exciting field coil. The generated alternating current is rectified by the IC regulator in the alternator to directly supply a direct current.

[Alternator structure]



(3) Generator capacity

The generator capacity must be able to supply the necessary power to the electrical system during engine operation and to charge the battery to make it always usable. The generator types used for the TNE engines are as shown in the table below. In actual selection, also consider the engine speed range and electrical system load. For details, refer to the separate TNE "Option Menu"

Nominal output	Dynamo	Alternator
12 V, 15 A	O	—
12 V, 20 A	O	—
12 V, 40 A	—	O

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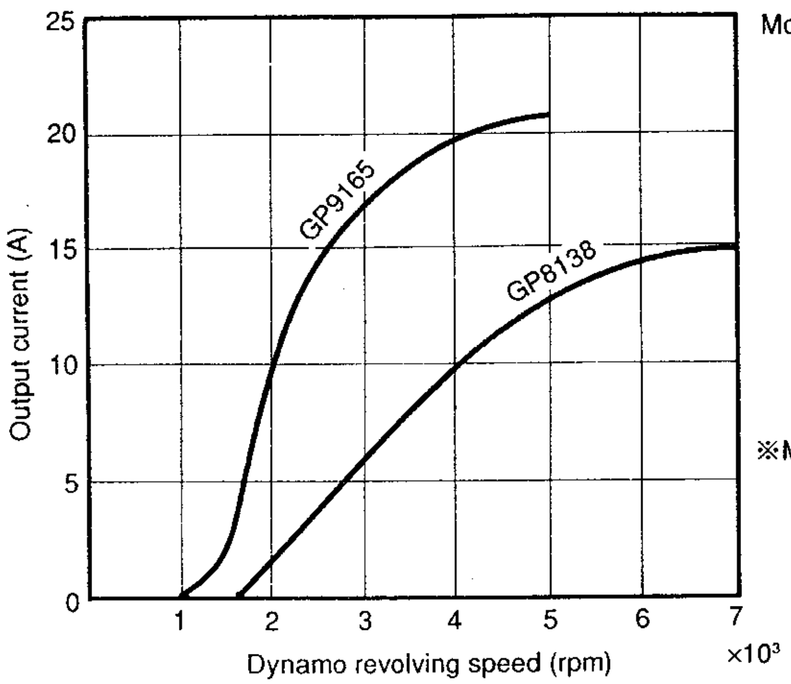
(4) Output characteristics

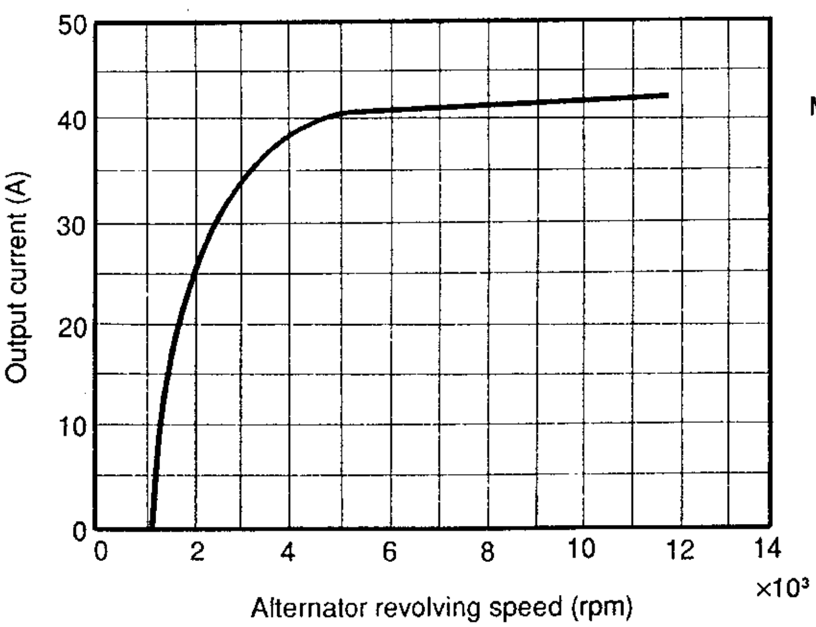
① Dynamo output characteristics



Models: GP8138 (nominal 12 V, 15 A)
GP9165 (nominal 12 V, 20 A)

※Measuring condition:
Battery voltage 12V
(when the engine is warm)

② Alternator output characteristics



Model: LR140-714
(nominal 12 V, 40 A)

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13-3 Regulator

The electric output from the generator is an alternating current. The electronic circuit for rectifying it to a direct current to charge the battery and supply the power to the DC electrical parts is generally called a regulator.

The AC to DC conversion is performed in various ways. Of the two types of charging generators, the alternator has a built-in IC regulator in the body. Yanmar calls this type an alternator with built-in IC regulator.

On the other hand, in the case of a dynamo, the regulator is not built in the body, but is provided separately. Yanmar calls this type of regulator a "current limiter."

The "alternator with built-in IC regulator" and "dynamo" have different circuits for converting the AC to DC, but both of them output a DC current. A major difference in use is in the charging lamp turn-off control.

When the power is ON, the charging lamp for both the IC regulator and current limiter types is applied with the voltage and lights up. Upon reaching a prescribed charging voltage after operation, the earth side of the voltage of the lamp for the IC regulator type rises, making the voltage to and from the lamp the same. With the loss of potential difference, the lamp turns OFF. Strictly speaking, some minor potential difference will remain, which prevents the LED lamp from going completely blackout. This is not abnormal, however.

On the other hand, the lamp of the current limiter type regulator turns OFF upon the regulator reaching a prescribed charging voltage and the power to the lamp being turned OFF. If this charging lamp circuit is used as the signal for other control circuit, it is necessary to recognize the difference in the lamp turn-off control method. At any rate, the charging lamp turns OFF when the regulator reaches the prescribed charging voltage.

Once turned OFF, the lamp will no light up again even if the charging voltage drops and charging performance is degraded as long as the circuit remains in normal condition, which should be well taken note of. If the charging lamp lights up during operation, it may be caused by any of the following reasons:

① Open or short circuit
② Abnormality of generator
③ Breakage of generator drive V-belt

Since the regulator uses electronic parts, avoid connecting the battery with the wrong polarities or disconnecting the battery cable during operation as it may cause trouble.

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13-4 Battery

The battery is used for supplying power to the starting motor when starting the engine.
It also supplies power to the electric load and the exciting current to the charging generator at the time of starting.

13-4-1 How to check the battery

(1) Battery types

Battery types are roughly classified into alkaline storage and lead storage batteries. Alkaline storage batteries are mostly used for large capacity engines for emergency use. Lead storage batteries are mostly used for industrial engines.

(2) Battery capacity

The battery capacity is represented in Ah (ampere-hour). It represents the total quantity of electricity (Ah) to be discharged at a constant current. In other words, it is the product of the discharge current (A) and the number of hours (h) until the final discharge voltage. Even if the same battery model is used, the total quantity of electricity to be discharged decreases as the discharge current increases.

* *It is not impossible to continue battery discharge until the terminal voltage reaches 0 V in principle, but such a discharge makes it impossible to restore the battery to its original state. Discharge, therefore, must be terminated at a proper voltage level.*
This voltage for discharge termination is called the final discharge voltage.

> Ah = Discharge current (A) × Discharge time (h) until final discharge voltage
> * *For example, if the final discharge voltage is reached upon discharging at 10 A for 5 hours, the capacity of this battery is said to be 50 Ah (10 A × 5 h) at the 5-hour rate.*

* *For the reserve capacity and cold cranking current, see (6) in this section.*

(3) Electrolyte specific gravity and residual capacity

The specific gravity of the electrolyte is specified at 293 K {20°C} as the standard condition. The specific gravity varies according to the ambient temperature. Since the residual battery capacity decreases as the specific gravity drops, estimate the residual capacity by using a hydrometer as follows.

[Table 1:   Relation between electrolyte specific gravity and temperature]

The higher the electrolyte concentration, the more active the reaction becomes, but it also accelerates corrosion of the plates and other parts. Generally, the specific gravity is recommended to be 1.210 to 1.300 at 293 K {20°C},

Temperature	263K {-10℃}	273K {0℃}	283K {10℃}	293K {20℃}	303K {30℃}	313K {40℃}	323K {50℃}
Specific gravity	1.321	1.314	1.307	1.300	1.293	1.286	1.279
	1.311	1.304	1.297	1.290	1.283	1.276	1.269
	1.301	1.294	1.287	1.280	1.273	1.266	1.259
	1.291	1.284	1.277	1.270	1.263	1.256	1.249
	1.281	1.274	1.267	1.260	1.253	1.246	1.239
	1.271	1.264	1.257	1.250	1.243	1.236	1.229
	1.261	1.254	1.247	1.240	1.233	1.226	1.219
	1.251	1.244	1.237	1.230	1.223	12.16	1.209
	1.241	1.234	1.227	1.220	1.213	1.206	1.199
	1.231	1.224	1.217	1.210	1.203	1.196	1.189
	1.221	1.214	1.207	1.200	1.193	1.186	1.179

[How to read Table 1]
If the specific gravity at an electrolyte temperature of 313 K {40°C} is 1.266, the table shows the converted specific gravity at 293 K {20°C} is 1.280. Then look up for 1.280 in Table 2 below, showing that the residual battery capacity is 100%.

[Table 2]

Electrolyte specific gravity		Residual capacity
Battery A	Battery B	(%)
1.280	1.260	100
1.230	1.210	75
1.180	1.160	75
1.130	1.110	25
1.080	1.060	0 (Perfect discharge)

* The values of batteries A and B are the values when the specific gravity of the electrolyte is at 293 K {20°C}.
The specific gravity at 293 K {20°C} varies by the battery manufacturer.

Another method for calculating the electrolyte specific gravity is as follows:

$$S_{20} = St + K\,(t - 20)$$

Where,

S_{20} : Specific gravity converted to 20℃
St : Measured specific gravity at t℃
t : Temperature at the time of measurement (℃)
K : Temperature coefficient

Measured specific gravity	K
Less than 1.06	0.0003
1.06 to 1.09	0.0004
1.09 to 1.13	0.0005
1.13 to 1.19	0.0006
1.19 to 1.35	0.0007

(4) Battery related terms

No.	Term	Meaning
①	Nominal voltage	Standard voltage (V) used for indication of battery voltage
②	Capacity (5-hour rate)	Product of 5-hour rate current and time (hours) until final discharge voltage, or quantity of electricity (Ah) discharged at 5-hour rate until reaching the final discharge voltage
③	5-hour rate current	Indicates the battery charging/discharge current(A) obtained by dividing the (5-hour rate) capacity by 5
④	High rate discharge characteristics	Discharge characteristics at a current near the automobile engine starting current
⑤	Final discharge voltage	Battery terminal voltage (V) where discharge must be stopped
⑥	Charge acceptability	Characteristic showing acceptability of charging at a constant voltage of a discharged battery
⑦	Reserve capacity	Measure of automotive battery capacity in duration (minute) of continuous discharge at 25 A of a fully charged battery maintained at 298 K±2 K {25±2°C} to 10.5 V
⑧	Cold cranking current	Measure of engine starting performance in discharge current (A) of an automobile battery at 258K {−18°C} to cause voltage drop to 7.2 V upon lapse of 30 seconds
⑨	Heavy-load life	Number of repeated discharge/charge cycles in the heavy-load range with one discharge depth at 20% or more in the life test method
⑩	Light-load life	Number of repeated discharge/charge cycles in the light-load range with one discharge depth at 10% or less in the life test method

(5) Battery types

The table below shows the types of batteries specified in JIS D 5301-1991.

Type	5-hour rate capacity (Ah)	High rate discharge characteristic at 285 K {-15℃}				Life		Charge accept-ability (A)	(Reference)	
		Discharge current (A)	Duration (min)	Voltage after 5 sec (V)	Voltage after 30 sec. (V)	Heavy-load life (cycle)	Light-load life (cycle)		Standard capability	
									Reserve capacity (min)	Cold cranking current 255K {-18℃} (A)
26A17R			1.8	8.4					35	225
26A19R	21					250	800	2.6		201
28A19R			1.9	8.8					36	248
32A19R	24		2.6	9.3		275	900	3.0	42	294
26B17R	21		1.8	8.4		250	800	2.6	35	225
28B17R	24		2.3	9.0			900	3.0	38	246
34B17R	27	150	3.0	9.2		200	1000	3.3	47	279
28B19R	24		2.3	8.9	–	275		3.0	40	247
34B19R	27		3.0	9.2		225	1100	3.3	49	272
36B20R	28		3.5			250	1300	3.5	52	274
38B20R				9.5						332
46B24R			4.2				1500		71	325
50B24R	36			9.7		300		4.5		390
55B24R		300	2.0	8.6			1800		79	433
32C24R	32	150	3.0			200	1600	4.0	57	238
50D20R	40		4.0	9.6		285	2200	5.0	78	306
55D23R	48		1.9	8.0		315	3100	6.0	99	356
65D23R		300	2.5	8.5	8.4		3400		111	420
70D23R	52		2.7	8.8		320		6.5	112	490
75D23R			2.9	8.9	–		3800		118	520
48D26R	40	150	4.0	9.0		285	2500	5.0	81	278
55D26R	48		1.9	7.8		315	3100	6.0	101	348
65D26R	52	300	2.5	8.4	8.3	330	3400	6.5	113	413
75D26R			2.9	8.9	8.8		3800		123	490
80D26R	55		3.5	9.2	9.1	330	3800	6.5	133	582
65D31R	56		2.8		8.2	345	4100	7.0	126	389
75D31R	60	300	3.3		8.7	375	4400		137	447
95D31R	64		4.3		9.3		4700	8.0	159	622
95E41R	80		4.0		8.8	415		10.0	182	512
105E41R	83		4.5		9.1	430	–		199	577
115E41R	88		2.6		8.3			11.0	212	651
130E41R	92		3.0		8.8	485			229	799
115F51	96		2.6	–	8.2			12.0	228	638
150F51	108		3.3		9.0			13.5	270	916
145F51	112		3.4		8.8	600		14.0	269	780
170F51	120	500	4.4		9.4			15.0	304	1045
145G51			3.6		8.6				294	754
180G51	128		4.8		9.4	700		16.0	344	1090
165G51	136				9.0	785		17.0	343	983
195G51	140		5.4		9.5	700			362	1146
190H52	160		5.6		9.0	785		20.0	421	924
245H52	176		7.8		9.9	800		22.0	460	1532

∗ *Type code designation method*

28 B 19 R

- R — Terminal position (R, L or no code)
- 19 — Battery length (cm)
- B — Battery width x box height class (eight classes A to H)
- 28 — Performance rank at electrolyte specific gravity of 1.280 at 293K {20°C} (relative performance indication and not absolute value indication)

13-4-2 Battery charging

If an engine is frequently operated, the battery is constantly being charged to pose no problem. But if it is stored for an extended period of time, it may not restore the charge after recharging. Guideline for a long-term storage and charging time is as follows:

(1) Guideline for self discharge and charging cycle

Batteries self-discharge (natural discharge) without being used. Self-discharge per day is 0.5 to 1.0% of the battery capacity.

To start an engine, residual battery capacity of 40 to 50% will be enough to do it at ordinary temperature. By considering the charging efficiency and battery life, it is desirable to charge batteries before the residual battery capacity reaches 60 to 70% or below.

In other words, if a 100% capacity battery that self-discharges at the rate of 1% a day is shelved, it will have self-discharged 30% of the capacity after 30 days or one month. Thus the residual battery capacity is 70%. Therefore, for the maintenance of batteries, they need re-charging if shelved for one month at most.

(2) Guideline for charging time

When charging the battery with the generator of the engine, the charging time can be obtained from the following equation provided the generator output and the battery's residual capacity (as obtained from 13.4.1(2)) are known:

$$Hc = \frac{Cb\,(1-\alpha)}{Ac \bullet \beta}$$

Where,

Hc	:	Charging time	h
Cb	:	Nominal capacity of battery	Ah
Ac	:	Generator output	A
α	:	Residual capacity rate of battery	%
β	:	Charging efficiency	0.8

With regard to the generator output Ac, it is necessary to examine the specifications of a pertinent engine as the capacity of generator installed to the engine varies by the objective of the driven machine. If the specifications of the generator are found, then using the Ac value, charging time (operating time) is calculated by referring to the data on the relation between the engine speed and the charge output Ac in the separate TNE Option Menu.

Calculation example

> Here is a driven machine installed with a 3TNE84-SA system engine.
> The battery is 75D31(N70Z) with nominal 60 Ah.
> Measured result of the battery electrolyte indicates a residual capacity of 75%.
> If the battery is recharged with the generator installed to the engine, how many hours should the engine be operated to regain a 100% battery capacity?

First examine what sort of generator this 3TNE84-SA is equipped with. From actual inspection or pertinent catalog it is found that it has a 40A generator. From actual measurement it is found that the crank pulley diameter is 110 mm. The engine's maximum revolution is 3000 rpm, but it will be operated at approx. 1000 rpm for the sole purpose of charging.
On the basis of the above-mentioned data and from the table in Section 8 Generator Charge Current in the TNE Option Menu, the charge current Ac is 16.7 A.

$$Hc = \frac{60\ (1 - 0.75)}{16.7 \times 0.8}$$

$$= 1.12h$$

Hc	:	Charging time (operating time) h
Cb	:	60 Ah
Ac	:	16.7 A
α	:	75%
β	:	0.8

That is, the battery will regain its full capacity after about one hour and some minutes of operation.

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(3) Starting motor battery discharge and charging

It is often asked how much engine operation it takes for the battery to restore original charge capacity after starting the engine with the starting motor.

Theoretically, it can be calculated if cranking current that flows through the starting motor, duration the starting motor is energized and the generator output are given. Although it is not possible to make a sweeping statement about the cranking current and the energized duration, the concept and the example of calculation are shown below:

a) Battery discharge

$$q = Sa \times \frac{t}{3600}$$

q	:	Battery discharge	Ah
Sa	:	Mean cranking current	A
t	:	Energized duration of starting motor	sec

b) Operating time for restoring discharged potential

$$Hc = \frac{q}{Ac \bullet \beta}$$

Hc	:	Charge time (operating time)	h
q	:	Battery discharge	Ah
Ac	:	Generator output	A
β	:	Charging efficiency	0.8

(Descriptions)

Since mean cranking current varies depending on the output level of the starting motor, size of the torque of driven machine, ordinary or low temperature, it is not possible to give a definite numerical value.

To make a guideline calculation, the following current values may be used without any practical problem, however:

Starting motor output ≦kW	Mean cranking current A
1.0	170
1.2	215
1.4	260
2.0	290

Moreover, it is normally several seconds to energize the starting motor, but when making calculation, the target duration of 20 sec for the cold starting test will be sufficient for the guideline time of energization.

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Calculation example

> What is the battery discharge that occurs when a 3TNE84-SA series engine is started one time, and how many hours does it take to restore the charge? Charging should be made while operating at 2400 rpm.

The starting motor output of this engine is 1.2 kW. Therefore, you set an approximate mean cranking current at 215 A. By energizing the starting motor for 20 sec with allowance, the battery discharge will be calculated as follows:

$$q = 215 \times \frac{20}{3600}$$

$$= 1.19 \text{ Ah}$$

q : Battery discharge
Sa : 215 A
t : 20 sec

To restore this discharge while operating the engine at 2400 rpm, first look up the Option Menu for the output of 40 A alternator same as the calculation example of (2), which is 37.8 A. Therefore, necessary operating time for restoring the discharge is as follows:

$$Hc = \frac{1.19}{37.8 \times 0.8}$$

$$= 0.04 \text{ h}$$

Hc : Charging time (operating time) h
q : 1.19 Ah
Ac : 37.8 A
β : 0.8

That is, if the engine is operated for 0.04 hour or 2.4 minutes, the discharge made by starting the engine once can be restored.

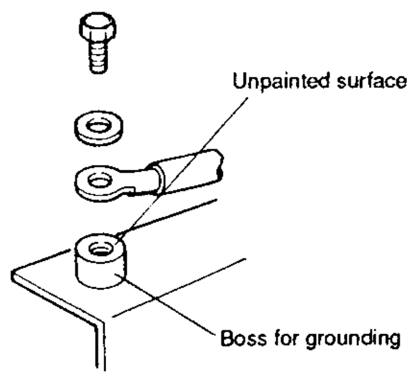
13-5 Wiring

The wiring is an important electric component affecting all functions of an industrial engine. If the wiring is not correct, the wiring resistance may be excessive and cause malfunctioning of electrical parts or overheating/burning. When selecting each cable, strictly check that the voltage drop is within the allowable range and connect the cable correctly. Carefully confirm the characteristics of electrical parts and ensure that the wiring is adequate.

13-5-1 Cautions in wiring

1. The specified current must be maintained.
2. Insulation must be perfect.
3. The wiring must be as short as possible without acute bends, and the cable diameter must ensure sufficient strength.
4. Connection must be made perfectly to avoid loosening or short circuit.
5. The wiring route must be away from a portion involving contact with heat or oil. Provide a protection device, if necessary.
6. The wiring must be fixed securely to prevent disconnection by vibration. Be especially careful to prevent resonance with the engine.
7. Study the use of waterproof couplers depending on the ambient conditions.
8. Connect the grounding cable securely at an unpainted portion.

[Grounding method]



9. The wiring must be connected securely to each terminal with a coupler or screw.
10. Study the battery cable length and battery position to prevent opposite battery cable connection.
11. Electric parts (starting switch, timer, relays, diodes, current limiter, etc.) other than those directly mounted on the engine must be installed in well-ventilated places not exposed to rainwater where the vibration acceleration is below 39.2 m/s^2{4G}.

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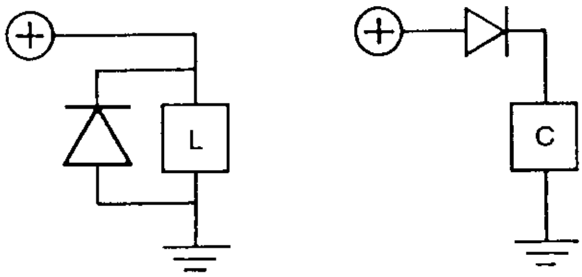
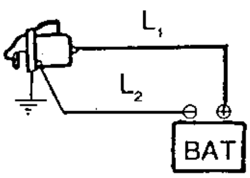
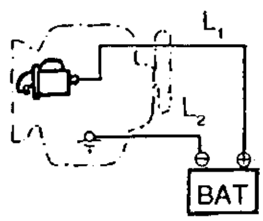
12. Check for any surge voltage or surge current in normal operation and conceivable erroneous operation and confirm that no surge occurs.
(Especially, provide a free wheeling diode for a L load and a reverse blocking diode for a C load.



13-5-2 Battery cable selection

(1) Connection examples

	Example 1	Example 2
Connection example	Starting motor 	
Battery cable length	$L_1 + L_2$	$L_1 + L_2$

✱1. Battery cable length : The overall length of ⊕ and ⊖ cables between the starting motor and the battery.

(2) Selection of cable size and length

[Table 1]

Rated voltage	12 V	
Starting motor rated output	Less than 2 kW	2 kW or more
Allowable resistance of whole battery cable circuit (Ω) ($L_1 + L_2 + {}^*\alpha$)	0.002 or less	0.0012 or less

$^*\alpha$: *Resistance (Ω) of a battery switch or other electric component having high resistance*

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[Table 2]

Nominal sectional area (cable size) (mm^2)	Conductor resistance (Ω/m) of low voltage cable for automotive use (AV cable) [at 20℃]
15	0.00138
20	0.000887
30	0.000520
40	0.000428
50	0.000337
60	0.000287
85	0.000215
100	0.000168

$$\text{Battery cable length (m)} = \frac{\text{Allowable resistance of whole battery cable circuit }(\Omega) - \alpha(\Omega)}{\text{Battery cable conductor resistance }(\Omega/\text{m})}$$

Example:

Calculate as follows to obtain the cable length when a battery cable with a nominal sectional area of 60 mm^2 is used for a 1.8 kW starting motor:

- Assume the resistance of the battery switch, etc. is 0 Ω.
- As the rated output of the starting motor is less than 2 kW, the allowable resistance of the whole battery cable circuit is 0.002 Ω (from Table 1).
- Conductor resistance for nominal sectional area of 60 mm^2: 0.000287 Ω/m
- $0.002 \div 0.000287 = 6.97 \fallingdotseq 7$ m
- The cable length as a total of the ⊕ and ⊖ sides must be 7 m or less.

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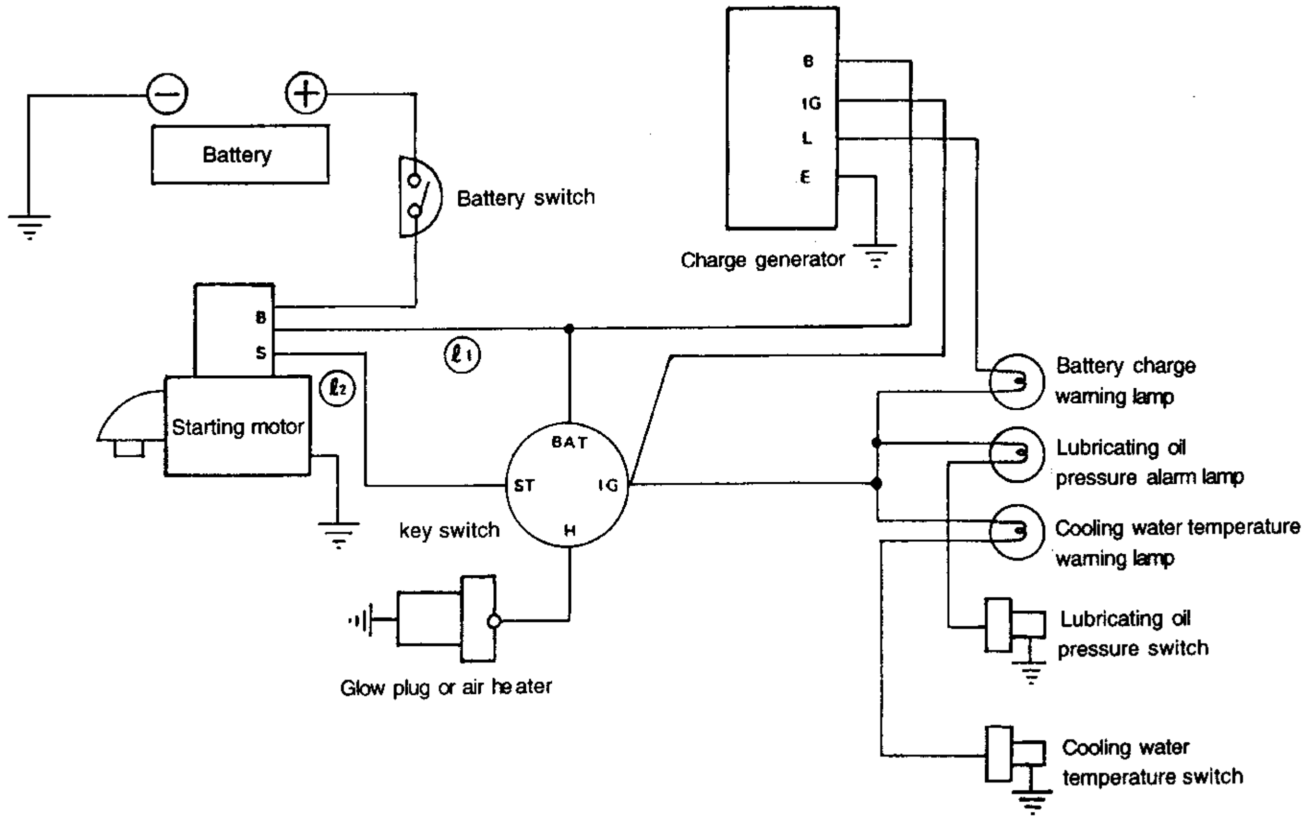
13-5-3 Starting motor cable selection

(1) Connection example

✱ *Starting motor cable length: $\ell_1 + \ell_2$*



(2) Cable size and length selection

Rated voltage	12 V	
Starting motor rated output	Less than 2 kW	2 kW or more
Allowable starting motor cable resistance (Ω) ($\ell_1 + \ell_2$)	0.05 or less	

Nominal sectional area (mm²) (Cable size)	Conductor resistance (Ω/m) of low voltage cable for automotive use (AV cable) [at 20℃]
0.5f	0.0367
0.5	0.0327
0.75f	0.0244
0.85	0.0208
1.25f	0.0147
1.25	0.0143
2	0.00881
3	0.00559
5	0.00352
8	0.00232

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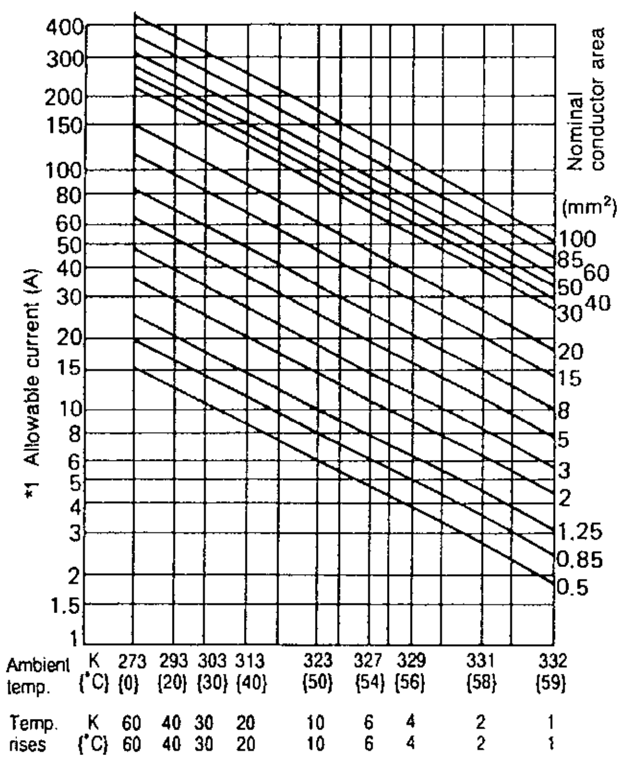
13-5-4 Selecting cables for general electrical components

For a general electrical component, select a cable of sufficient size and length so that the voltage drop does not exceed 5% when the specified current for the electrical component flows. The cable must also have sufficient strength.

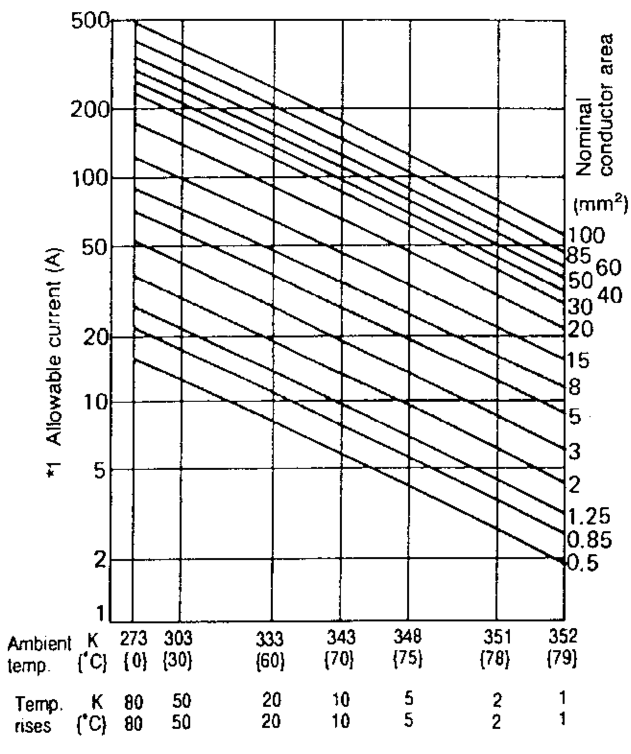
13-5-5 Cable temperature rise and allowable current

The cable insulator is degraded by the temperature rise during current conduction. It is therefore necessary to check the cable capacity and use a cable of an appropriate size. The figures below show the relationship between the allowable current at 333 K {60°C} and 353 K {80°C}, nominal conductor sectional area and temperature rise of AV cable (low-voltage cables for automotive use). Be careful as the cable types vary by the country.

[Figure 1] Allowable current for AV cables at ambient temperature of 333 K {60°C}



[Figure 2] Allowable current for AV cables at ambient temperature of 353 K {80°C}



**1. Allowable current : The maximum current is determined for a cable by considering the mechanical strength and insulation degradation caused by temperature rise. This is called the allowable current.*

Read the above figures as follows:

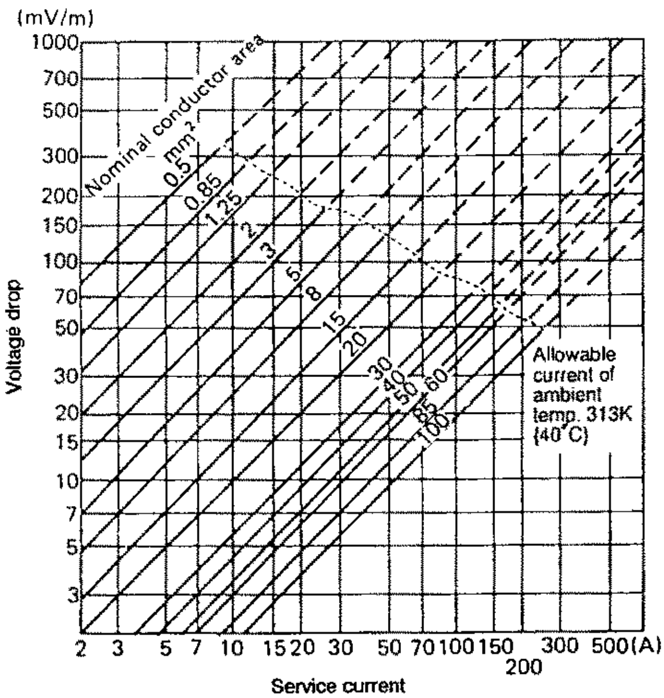
When the allowable maximum temperature for AV cable is 333 K {60°C} for example (Figure 1), use of a cable whose nominal sectional area is 0.5 mm^2 when the ambient temperature is 323 K {50°C} causes an allowable current of 6A to flow to raise the cable temperature by 10 K {10°C} to 333 K {60°C}.

The figure shows the case where a single cable is used. When the bound cable is used, the allowable current varies due to the radiation from each cable. When the bound cable is used, therefore, multiply the allowable current in the figure above by the coefficient in the table below to obtain the allowable current.

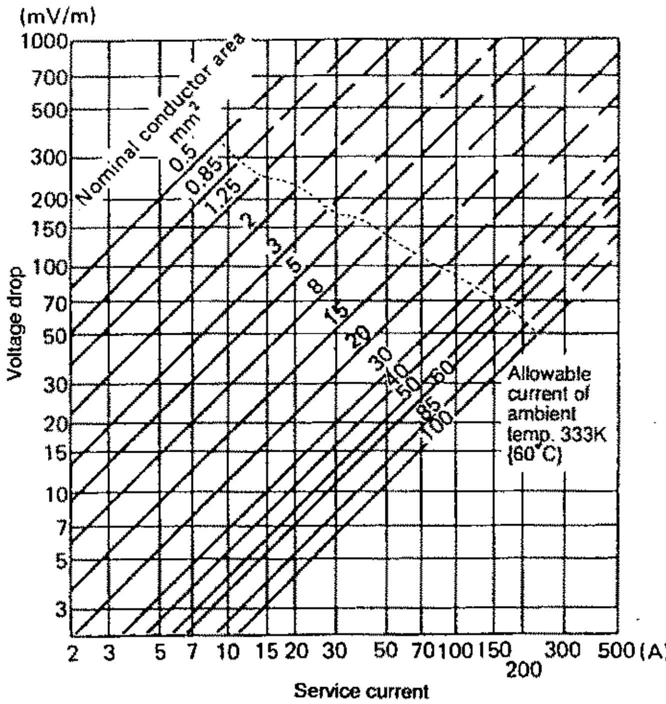
Number of bound cables	1	2	3	4	5	6, 7
Coefficient	1.00	0.80	0.70	0.60	0.55	0.50

13-5-6 Allowable current and voltage drop

[Figure 3] Current and voltage drop in AV cable at 333 K {60°C}



[Figure 4] Current and voltage drop in AV cable at 353 K {80°C}



Read the above figures as follows:

When the allowable maximum temperature for an AV cable is 333 K {60°C} (Figure 3), the voltage drops by 100 mV(0.1 V) per 1 m when a current of 10 A flows through a cable whose nominal conductor sectional area is 2 mm^2.

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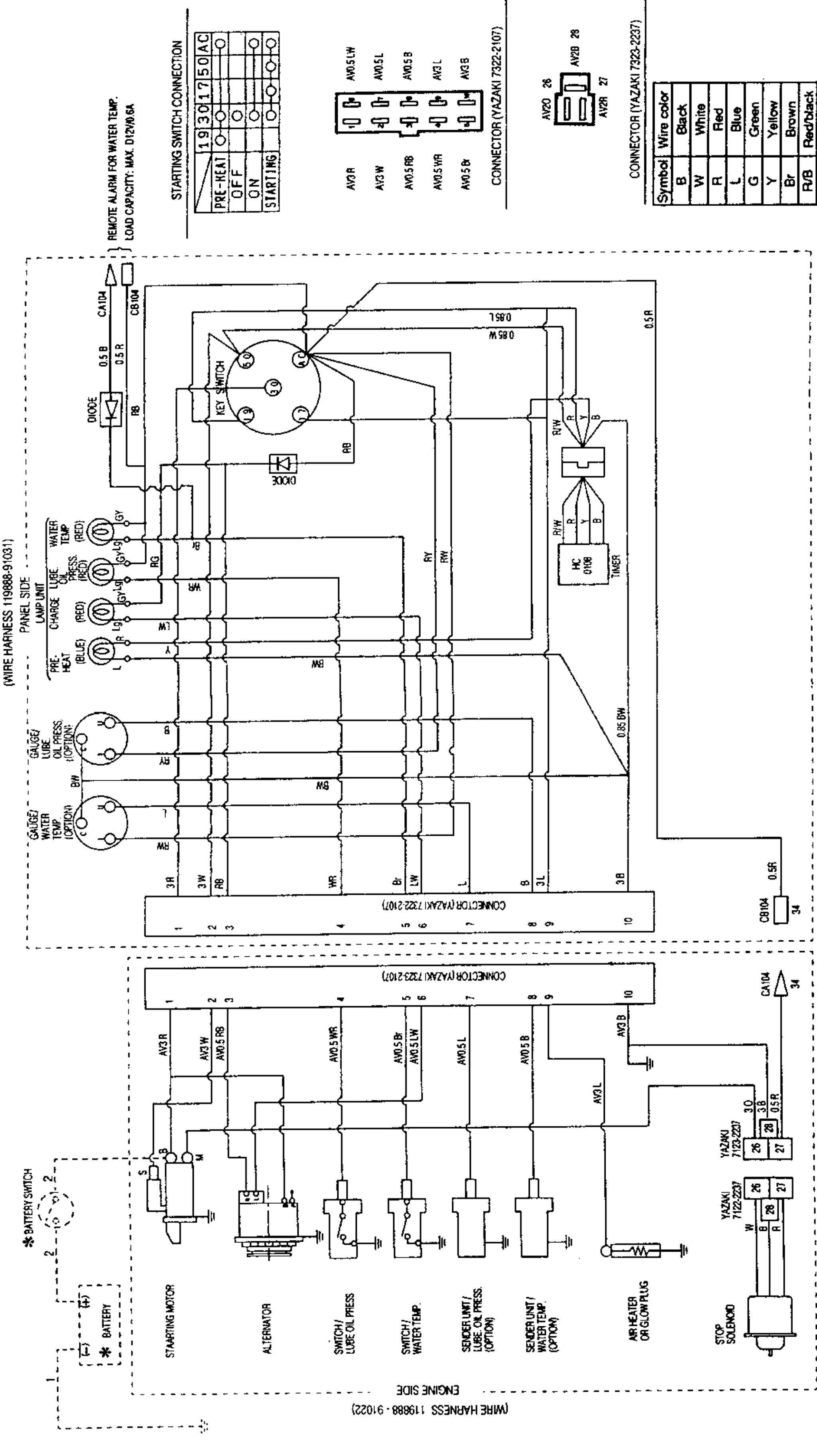
13-5-7 Cable heat resistance comparison

Cables applied to engines of industrial machines are mostly AV cable, while cables used for equipment engines and their control circuits are either IV or HIV cable. For their heat resistance, quote the data in the following table upon receipt of inquiry from customer:

		AV cable	IV cable	HIV cable
JIS	No.	C3406	C3307	C3317
	Name	Low-voltage cables for automobiles	600 V Polyvinyl chloride insulated wires	600 V Grade heat-resistant polyvinyl chloride insulated wires
Heat resistance temperature		120℃/120 hours	100℃/48 hours	120℃/120 hours
Flame resistance		Must go out spontaneously within 15 sec.	Must go out spontaneously within 60 sec.	Must go out spontaneously within 60 sec.

13-5-8 Wiring guide

The following wiring diagram is an example for the VM, CL and CH specifications.

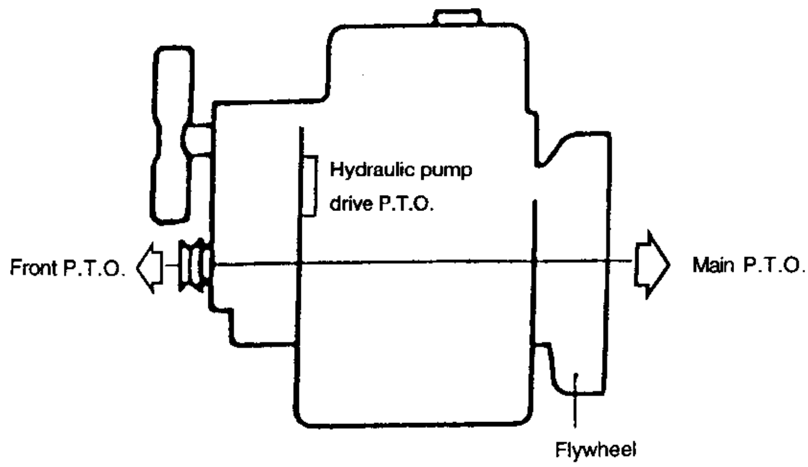


Symbol	Wire color
B	Black
W	White
R	Red
L	Blue
G	Green
Y	Yellow
Br	Brown
R/B	Red/black
W/R	White/red
L/W	Blue/white
B/Y	Black/yellow
B/R	Black/red
W/R	White/red
R/W	Red/white
R/Y	Red/yellow
B/W	Black/white
P/B	Pink/black

NOTE:
1) PARTS MARKED ✱ ARE NOT PRODUCED BY YANMAR.
2) BATTERY CABLE 1 AND 2 SHALL HAVE TOTAL RESISTANCE BELOW 2/1000 Ω.

14. Power Systems

To make the most of engine performance, it is necessary to study the position of power systems and the method according to the driven machine application. The power systems can be divided into the main P.T.O., front P.T.O. and hydraulic pump drive P.T.O by the position of them.



14-1 Caution for Direct Coupling

100% of the engine output may be obtained by the main P.T.O. from the flywheel side. The allowable torque take-off from the front P.T.O. side is shown in the table below, but the radiator position, etc. must be studied separately .

Allowable torque in front P.T.O. (direct coupling)

Model	Allowable torque Nm (kgf-m)
2TNE68(-N), 3TNE66-N, 3TNE68(-N)	23 (2.4)
3TNE72-N, 3TNE74(-N)	25 (2.6)
3TNE78A, 3TNE82A, 3TNE84(T), 3TNE88	43 (4.4)
4TNE84(T), 4TNE88	57 (5.9)
4TNE94, 4TNE98	(Option) 63 (6.5)

Note: The torque values above shows static torques, and not dynamic or impact torques.

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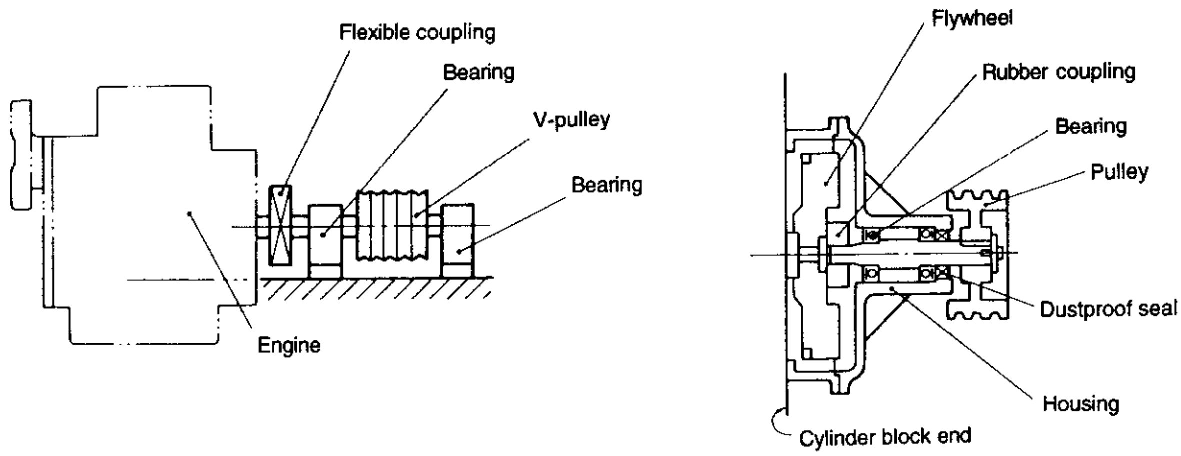
14-2 Caution for Side Load

(1) For a side belt drive, provide external bearings (outer metals). External bearings should also be provided for transmitting a large power or for driving with multiple belts. If external bearings are omitted, the engine may be damaged due to crankshaft bend or increased flexure of the crankshaft arm portion.

[External bearing installation example]



(2) If a side belt drive is required when external bearing cannot be used because of the driven machine space, see 14-3, 14-4 and 14-5. Section 14-3 describes the V-belt study. First calculate the side load for V-belt driving according to the required horsepower and speed. For a side belt drive from the main P.T.O., check that the side load is within the allowable range in section 14-4. For a belt drive from the front P.T.O. side, check the same according to the diagram in 14-5.

(3) Prepare the following data before starting the study:

1. Engine type
2. Required horsepower and speed for driven machine
3. Effective diameter of pulleys (on the engine side and driven machine side: d1, d2, D1 and D2)
4. V pulley overhang (L and ℓ)
   * *When two or more belts are used, adapt to the center of the V-pulley.*
5. Types and numbers of belts used.
6. Relative positions of engine and driven machine (a1, a2, b1 and b2)
7. Belt tensioning direction, angle (α, β) and belt center-to-center distance (C1, C2)
   How to calculate C1 and C2

$$C1 = \sqrt{a1^2 + a2^2}$$
$$C2 = \sqrt{b1^2 + b2^2}$$

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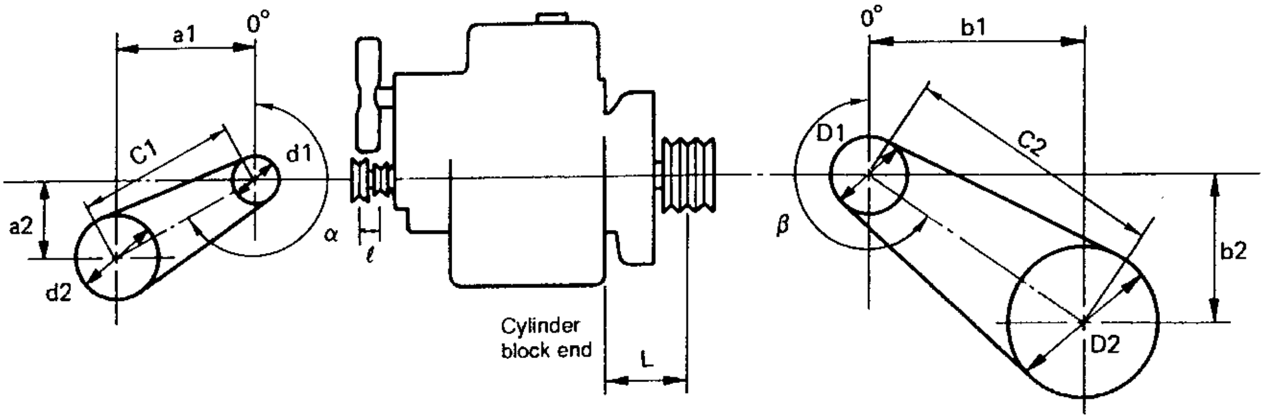
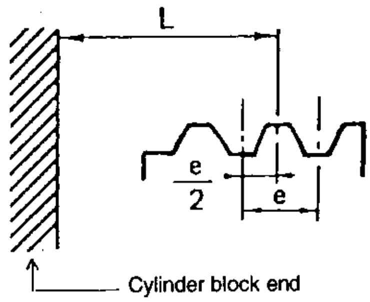


L dimension: To measure distance L where 2 or more V-belts are used, select a position at the center of 2 V-belts farthest and nearest from the cylinder block.



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14-3 Selection of V-belts

Determine the type, length and number of V-belts to be used as follows:

① V-belt type selection
Select the type according to the design power and revolving speed of the small V-pulley.

② V-belt length
Determine the V-belt length and distance between shafts.

③ Number of V-belts

1. Calculate the transmission capacity per V-belt.
2. Determine the number of V-belts according to the design power and operating conditions.

(1) V-belt type selection

Select the V-belt type according to the design power and small V-pulley revolving speed shown below by referring to the V-belt selection table((1)-③).
If the desirable type is near the border between two types, study both types and select the one that is more suitable.

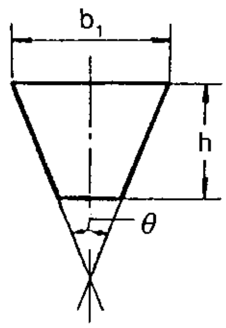
① V-belt types

[Table 14-1]

mm

Type	b1	h	θ rad (°)
A	12.5	9.0	0.70 {40}
B	16.5	11.0	
C	22.0	14.0	
D	31.5	19.0	

[Belt size]



② Design power

$$P_d = P_N \times (K_O + K_i)$$

P_d : Design power (kW)
P_N : Load power (kW)
K_O : Service factor (See Table 14-2.)
K_i : Idler correction factor (See Table 14-3.)

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[Table 14-2 Service factor (K_O)]

Example of machine using V-belt	Multiple-cylinder engine		
	Operating hours		
	Intermittent use for 3 to 5 hours a day	Ordinary use for 8 to 10 hours a day	Continuous use for 16 to 24 hours a day
Agitator (fluid) Blower (7.5 kW or under) Centrifugal pump/compressor Light load conveyer	1.0	1.1	1.2
Belt conveyer (sand, grain) Dough mixer Blower (over 7.5 kW) Generator Line shaft Laundry machine Machine tool Punch/press/shear Printing press Rotary pump Rotary/vibrating screen	1.1	1.2	1.3
Bucket elevator Exciter Compressor (reciprocating type) Conveyer (bucket/screw) Hammer mill Paper mill/beater Piston pump Roots blower Crusher Woodworking machinery Textile machinery	1.2	1.3	1.4
Crusher Mill (ball/rod) Hoist Rubber processing machinery (roll/calender/extruder)	1.3	1.4	1.5

**1. Add 0.2 to each of the values above when the start/stop operation frequency is high, when maintenance/inspection is not easy, if wear is likely to occur due to much dusts, when used in a hot location or when the belt is likely to be stained with oil or water.*

**2. Determine the service factor by using the table above as the reference for any driven machine other than those listed in the table.*

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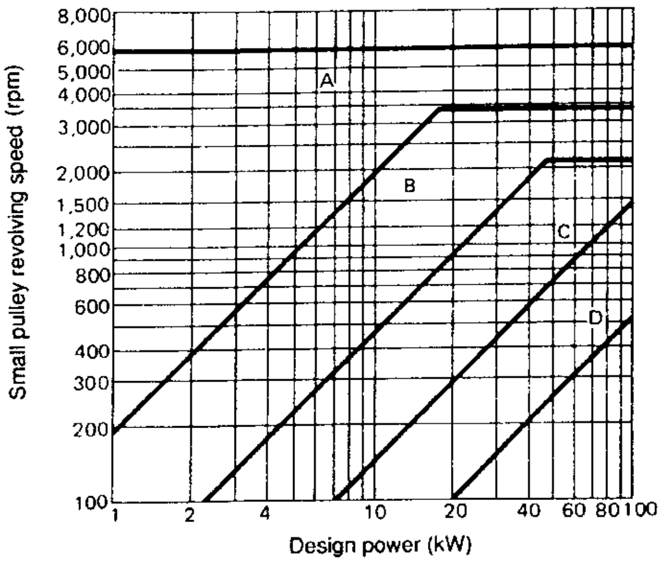
[Table 14-3 Idler correction factor (Ki)]

No.	Idler position	Factor
1	Use from inside of V-belt on loosening side	0
2	Use from outside of V-belt on loosening side	0.1
3	Use from inside of V-belt on tensioning side	0.1
4	Use from outside of V-belt on tensioning side	0.2

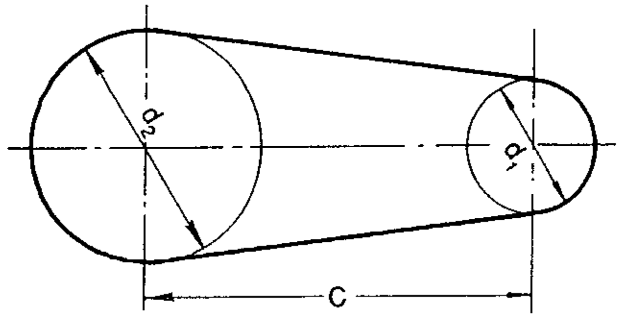
* *No. 4 is not desirable as it is not an ordinary form of use.*

③ V-belt selection table



(2) Determination of V-belt length

Calculate V-belt length L (mm) corresponding to the distance C (mm) in the design stage according to the following equation, and select a V-belt nearest to the length from those in Table 14.4.



$$L = 2C + 1.57\,(d_1 + d_2) + \frac{(d_2 - d_1)^2}{4C}$$

Where,

d_1 : Nominal diameter of small V-pulley (mm)

d_2 : Nominal diameter of large V-pulley (mm)

C : Distance between shafts (mm)

[Table 14-4 V-belt length]

(mm)

Nominal	Belt length (L)			
No.	A	B	C	D
20	508	–	–	–
21	533	–	–	–
22	559	–	–	–
23	584	–	–	–
24	610	–	–	–
25	635	635	–	–
26	660	660	–	–
27	686	686	–	–
28	711	711	–	–
29	737	737	–	–
30	762	762	–	–
31	787	787	–	–
32	813	813	–	–
33	838	838	–	–
34	864	864	–	–
35	889	889	–	–
36	914	914	–	–
37	940	940	–	–
38	965	965	–	–
39	991	991	–	–
40	1016	1016	–	–
41	1041	1041	–	–
42	1067	1067	–	–
43	1092	1092	–	–
44	1118	1118	–	–
45	1143	1143	1143	–
46	1168	1168	–	–
47	1194	1194	–	–
48	1219	1219	1219	–
49	1245	1245	–	–
50	1270	1270	1270	–
51	1295	1295	–	–
52	1321	1321	1321	–
53	1346	1346	–	–
54	1372	1372	1372	–
55	1397	1397	1397	–
56	1422	1422	–	–
57	1448	1448	–	–
58	1473	1473	1473	–
59	1499	1499	–	–

(mm)

Nominal	Belt length (L)			
No.	A	B	C	D
60	1524	1524	1524	–
61	1549	1549	–	–
62	1575	1575	1575	–
63	1600	1600	–	–
64	1626	1626	–	–
65	1651	1651	1651	–
66	1676	1676	–	–
67	1702	1702	–	–
68	1727	1727	1727	–
69	1753	1753	–	–
70	1778	1778	1778	–
71	1803	1803	–	–
72	1829	1829	1829	–
73	1854	1854	–	–
74	1880	1880	–	–
75	1905	1905	1905	–
76	1930	1930	–	–
77	1956	1956	–	–
78	1981	1981	1981	–
79	2007	2007	–	–
80	2032	2032	2032	–
81	2057	2057	–	–
82	2083	2083	2083	–
83	2108	2108	–	–
84	2134	2134	–	–
85	2159	2159	2159	–
86	2184	2184	–	–
87	2210	2210	–	–
88	2235	2235	2235	–
89	2261	2261	–	–
90	2286	2286	2286	–
91	2311	2311	–	–
92	2337	2337	2337	–
93	2362	2362	–	–
94	2388	2388	–	–
⋮	⋮	⋮	⋮	⋮
360	–	–	–	9144
390	–	–	–	–
420	–	–	–	–

(3) Distance between shafts

Calculate the distance between shafts corresponding to the selected V-belt length L (mm) using the following equation:

$$C = \frac{B + \sqrt{B^2 - 2(d_2 - d_1)^2}}{4}$$

Where,

C : Distance between shafts (mm) corresponding to V-belt length
d_1 : Nominal diameter of small V-pulley (mm)
d_2 : Nominal diameter of large V-pulley (mm)
B : $L - 1.57 (d_1 + d_2)$(mm)

(4) Minimum adjusting margin

Obtain the minimum adjusting margin from the table below, considering the V-belt installation and tensioning margin.

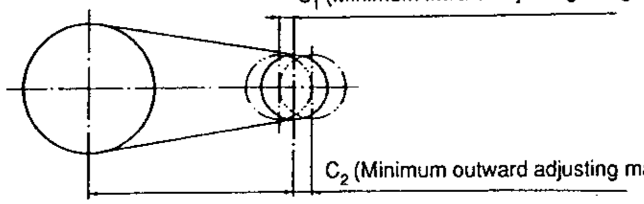


Table 14-5 Minimum adjusting margin

(Unit: mm)

<table>
<tr><th rowspan="2">V-belt nominal No.</th><th colspan="4">Minimum inward adjusting margin (C_1)</th><th rowspan="2">Minimum outward adjusting margin (C_2)</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>38 or below</td><td rowspan="3">20</td><td rowspan="2">25</td><td>–</td><td rowspan="3">–</td><td>25</td></tr>
<tr><td>39 to 60</td><td rowspan="4">40</td><td>40</td></tr>
<tr><td>61 to 90</td><td rowspan="4">35</td><td>50</td></tr>
<tr><td>91 to 120</td><td rowspan="3">25</td><td rowspan="4">50</td><td>65</td></tr>
<tr><td>122 to 155</td><td>75</td></tr>
<tr><td>160 to 190</td><td rowspan="3">50</td><td>90</td></tr>
<tr><td>200 to 240</td><td rowspan="4">–</td><td>40</td><td>100</td></tr>
<tr><td>250 to 270</td><td rowspan="3">–</td><td rowspan="2">65</td><td>115</td></tr>
<tr><td>280 to 330</td><td rowspan="2">–</td><td>130</td></tr>
<tr><td>360 to 420</td><td>75</td><td>160</td></tr>
</table>

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(5) Determining the number of V-belts

Determine the number of V-belts in a multiple-belt drive as follows:

$$Z = \frac{P_d}{P_c}$$

Where,

Z : Number of V-belts

P_d : Design power (kW)

P_c : Corrected transmission capacity per V-belt (kW)

$P_c = P \times K_L \times K_\theta$

P : Transmission capacity per V-belt (See (6) below.)

K_L : Length correction factor (See Table 14-6.)

K_θ : Contact angle correction factor (See Table 14-7.)

Table 14-6 Length correction factor (K_L)

Nominal No.	Type			
	A	B	C	D
20 to 25	0.80	0.78		
26 to 30	0.81	0.79		
31 to 34	0.84	0.80		
35 to 37	0.87	0.81		
38 to 41	0.88	0.83		
42 to 45	0.90	0.85	0.78	
46 to 50	0.92	0.87	0.79	
51 to 54	0.94	0.89	0.80	
55 to 59	0.96	0.90	0.81	
60 to 67	0.98	0.92	0.82	
68 to 74	1.00	0.95	0.85	
75 to 79	1.02	0.97	0.87	
80 to 84	1.04	0.98	0.89	
85 to 89	1.05	0.99	0.90	
90 to 95	1.06	1.00	0.91	
96 to 104	1.08	1.02	0.92	0.83
105 to 111	1.10	1.04	0.94	0.84
112 to 119	1.11	1.05	0.95	0.85
120 to 127	1.13	1.07	0.97	0.86
128 to 144	1.14	1.08	0.98	0.87
145 to 154	1.15	1.11	1.00	0.90
155 to 169	1.16	1.13	1.02	0.92
170 to 179	1.17	1.15	1.04	0.93
180 to 194	1.18	1.16	1.05	0.94
195 to 209		1.18	1.07	0.96
210 to 239		1.19	1.08	0.98
240 to 269			1.11	1.00
270 to 299			1.14	1.03
300 to 329				1.05
330 to 359				1.07
360 to 389				1.09
390 to 419				
420				

* *In the table above, the 1.00 type V-belt is the reference length V-belt.*

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[Table 14-7 Contact angle correction factor (K_θ)]

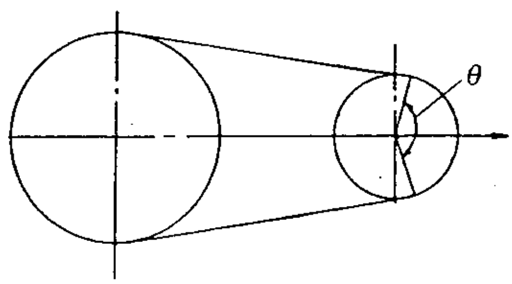
$\frac{d_2-d_1}{C}$	Contact angle at small V-pulley θ(°)	Contact angle correction factor K_θ
0.00	180	1.00
0.10	174	0.99
0.20	169	0.98
0.30	163	0.96
0.40	157	0.94
0.50	151	0.93
0.60	145	0.91
0.70	139	0.89
0.80	133	0.87
0.90	127	0.85
1.00	120	0.82
1.10	113	0.79
1.20	106	0.77
1.30	99	0.74
1.40	91	0.70
1.50	83	0.66

(6) V-belt transmission capacity

The transmission capacity per V-belt is the standard transmission capacity plus the additional transmission capacity according to the rotation ratio, and is calculated with the following equation. The standard transmission capacity of a V-belt is the transmission capacity of the V-belt in the standard length with the contact angle θ at 3.14 rad {180°}.

The rotation ratio is the nominal diameter of the large V- pulley divided by the same of the small V-pulley.

[Contact angle θ]



* *The V-belt in the standard length refers to the V-belt whose length correction factor in Table 14-6 is 1.00.*

$$P = d_1 \bullet n\,[C_1\,(d_1 \bullet n)^{-0.09} - \frac{C_2}{d_1}\,C_3\,(d_1 \bullet n)^2] + C_2 \bullet n\,(1 - \frac{1}{K_r})$$

Where,

P	: Transmission capacity per V-belt	(kW)
d_1	: Nominal diameter of small V-pulley	(mm)
n	: Revolving speed of small V-pulley × 10^{-3}	(rpm)
C_1, C_2, C_3	: Constant (See Table 14-8.)	
K_r	: Correction factor by rotation ratio (See Table 14-9.)	

[Table 14-8 Constants (C_1, C_2, C_3)]

Type	C_1	C_2	C_3
A	3.1149×10^{-2}	1.0399	1.1108×10^{-8}
B	5.4974×10^{-2}	2.7266	1.9120×10^{-8}
C	1.0205×10^{-1}	7.5815	3.3961×10^{-8}
D	2.1805×10^{-1}	2.6894×10	6.9287×10^{-8}

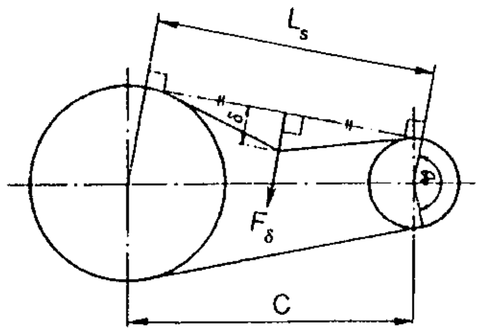
[Table 14-9 Correction factor by rotation ratio (K_r)

Rotation ratio	K_r
1.00 to 1.01	1.0000
1.02 to 1.04	1.0136
1.05 to 1.08	1.0276
1.09 to 1.12	1.0419
1.13 to 1.18	1.0567
1.19 to 1.24	1.0719
1.25 to 1.34	1.0875
1.35 to 1.51	1.1036
1.52 to 1.99	1.1202
2.0 or above	1.1373

(7) V-belt tensioning

Calculate the initial tension required for transmission according to equation (1), and tension the V-belt as shown below. Adjust the V-belt so that the V-belt deflection becomes δ when the center of the V-belt span length Ls is pressed with a force of F_δ. Calculate F_δ with equation (2) or (3), and δ with equation (4).

[V-belt tensioning]



$$F_o = 0.9\left\{500\left(\frac{2.5 - K_\theta}{K_\theta}\right)\frac{P_d}{Z \bullet \upsilon} + m\upsilon^2\right\} \quad \text{.............(1)}$$

When multiple belts are used $$F_\delta = \frac{AF_o + Y}{16} \quad \text{.........(2)}$$

When a single belt is used $$F_\delta = \frac{AF_o + \frac{L_s}{L}Y}{16} \quad \text{.........(3)}$$

$$\delta = 0.016 \cdot L_s \quad \text{.........(4)}$$

Where

F_o	: Initial tension	
P_d	: Design power	kW
m	: V-belt mass per unit length	(kg/m)(See Table 14-11.)
υ	: V-belt speed	(m/s)
Z	: Number of V-belts	
K_θ	: Contact angle correction factor (See Table 14-7.)	
F_δ	: Force (N) required for deflection δ at the center of span length L_s	(N)
L	: V-belt length	(mm)
A	: Constant (See Table 14-10.)	
Y	: Constant (See Table 14-11.)	
δ	: Deflection	(mm)
L_s	: Span length	(mm)

$$L_s = \sqrt{C^2 - \frac{(d_2 - d_1)^2}{4}}$$

C	: Distance between shafts	(mm)
d_1	: Nominal diameter of small V-pulley	(mm)
d_2	: Nominal diameter of large V-pulley	(mm)

[Table 14-10 Constant (A)]

For new belt	For tension adjustment
1.5	1.3

[Table 14-11 V-belt mass per unit length and constant (Y)]

Type	M	A	B	C	D	E
m (kg/m)	0.06	0.12	0.20	0.36	0.66	1.02
Y	10	15	20	30	60	110

(8) Shaft load

Calculate the shaft load from equations (5) and (6).
Use at least this value for calculating the shaft strength.

① Static shaft load

$$F_r = 1.5\left(2Z \cdot F_o \sin \frac{\theta}{2}\right) \quad \cdots\cdots (5)$$

② Dynamic shaft load

$$F_\ell = 9.8 \frac{2.5 - K_\theta}{K_\theta} \cdot \frac{102 P_d}{\upsilon} \sin \frac{\theta}{2} \quad \cdots\cdots (6)$$

Where,

F_r	: Static shaft load	(N)
F_ℓ	: Dynamic shaft load	(N)
F_o	: Initial tension	(N) [Equation (1)]
θ	: Small V-pulley contact angle	(°)
K_θ	: Contact angle correction factor	(See Table 14.7.)
P_d	: Design power	(kW)
υ	: V-belt velocity	(m/s)
Z	: Number of V-belts	

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The equation for calculation in conventional units are as follows:

$$F_O' = 0.9 \{ 51\frac{(2.5 - K_\theta)}{K_\theta} \quad \frac{P_d}{Z \cdot v} \quad + \frac{W}{g} \quad v^2 \} \quad \cdots\cdots (7)$$

When multiple belts are used

$$F_\delta' = \frac{AF_O' + Y'}{16} \quad \cdots\cdots (8)$$

When a single belt is used

$$F_\delta' = \frac{AF_O' + \frac{L_s}{L} \cdot Y}{16} \quad \cdots\cdots (9)$$

Where,

F_O' : Initial tension {kgf}
F_δ' : Force {kgf} required for deflection delta at the center of span length Ls (kgf)
g : Acceleration of gravity 9-8 {m/s^2}
w : V-belt weight per unit length {kgf/m}(See Fig. 14-12.)
P_d : Design power (kW)
Y' : Constant (See Table 14-12.)

The equations for calculating the shaft load are as follows:

① Static shaft load

$$F_r' = 1.5 (2Z \cdot F_O' \sin \frac{\theta}{2}) \quad \cdots\cdots (5)'$$

② Dynamic shaft load

$$F_\ell' = \frac{2.5 - K_\theta}{K_\theta} \cdot \frac{102P_d}{\upsilon} \quad \sin\frac{\theta}{2} \quad \cdots\cdots (6)'$$

Where,

F_r' : Static shaft load (kgf)
F_ℓ' : Dynamic shaft load (kgf)

[Table 14-12 V-belt weight per unit length and constant (Y')

Type	M	A	B	C	D	E
W (kg/m)	0.06	0.12	0.20	0.36	0.66	1.02
Y'	1.0	1.6	2.0	3.1	6.1	11.2

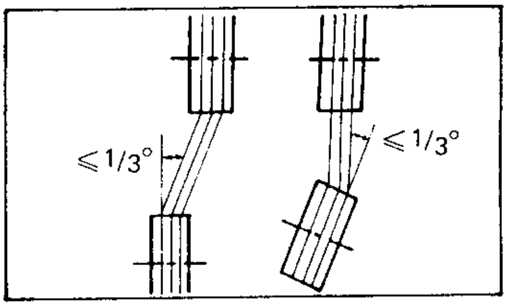
(9) Cautions for installation

① Applicable belt length limit
When two or more belts are used, the difference in length of each belt must be kept within the allowable range in the table shown below. If the applicable limit is exceeded, the V-belt may come off from the pulley during operation or the V-belt durability may be lost.

Table 14-13 Applicable V-belt length limit (difference)

Belt length	Applicable limit length (difference)
150 cm or less	4 mm
150 cm to 230 cm	6 mm

② Belt centering
If the belt centering is incorrect, the service life will be shortened. Keep the belt deflection angle within 1/3°



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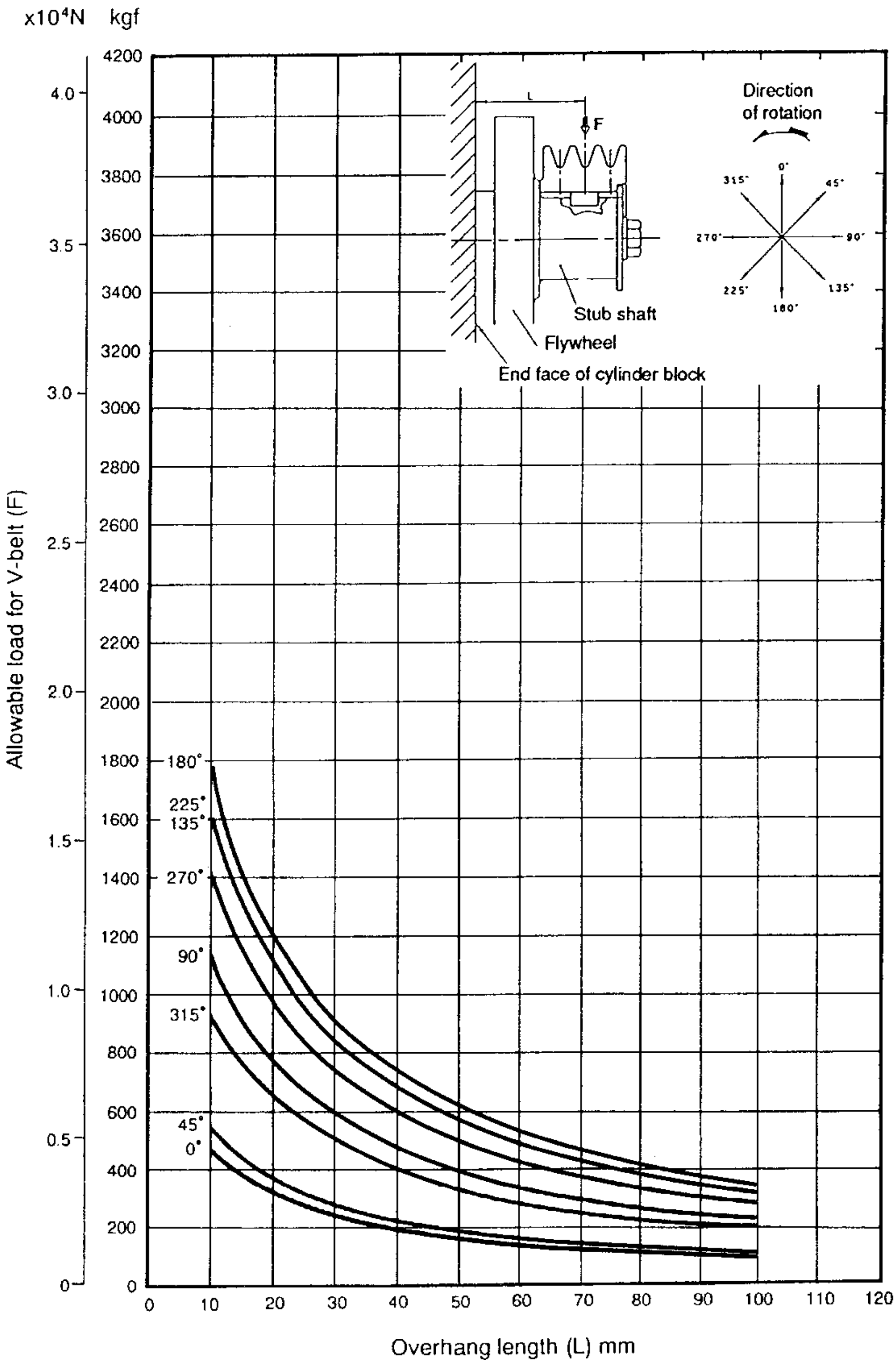
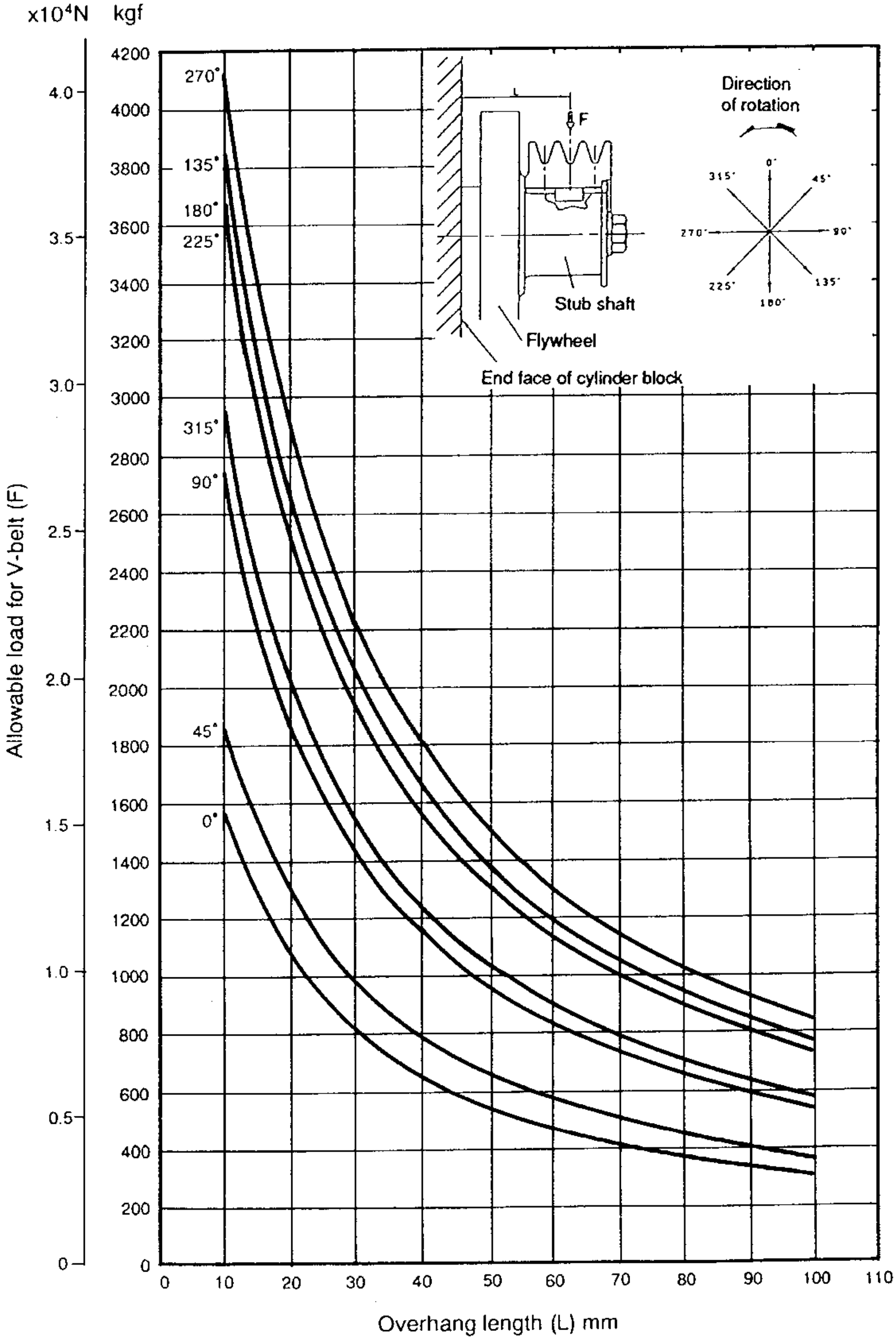
14-4 Allowable Side Load for Main P.T.O.

3TNE66-N
3TNE68(-N)



* *The allowable load is 1/2 of the above in the case of a dynamic load.*

3TNE72-N
3TNE74(-N)



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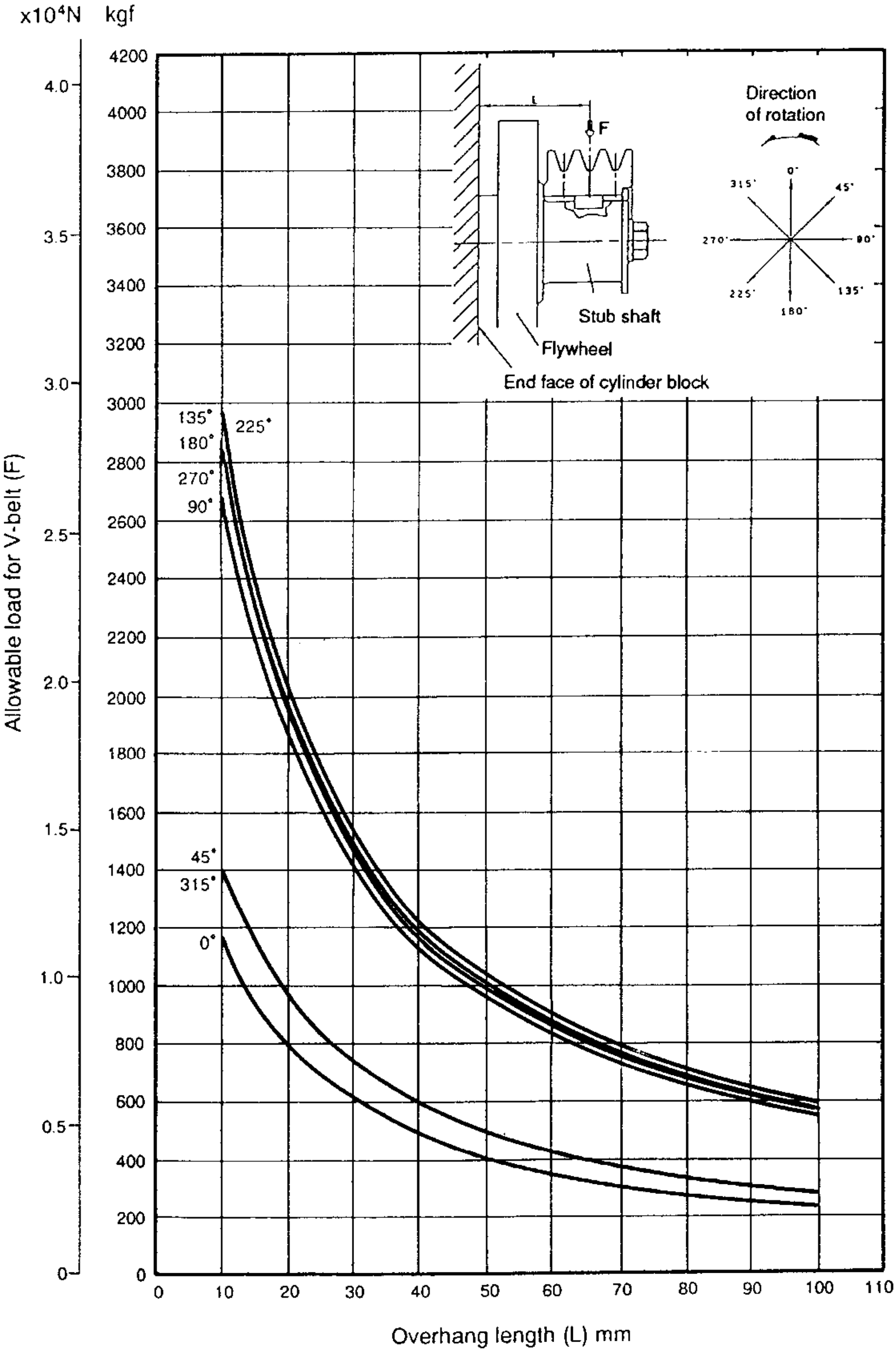
3TNE78A, 3TNE82A



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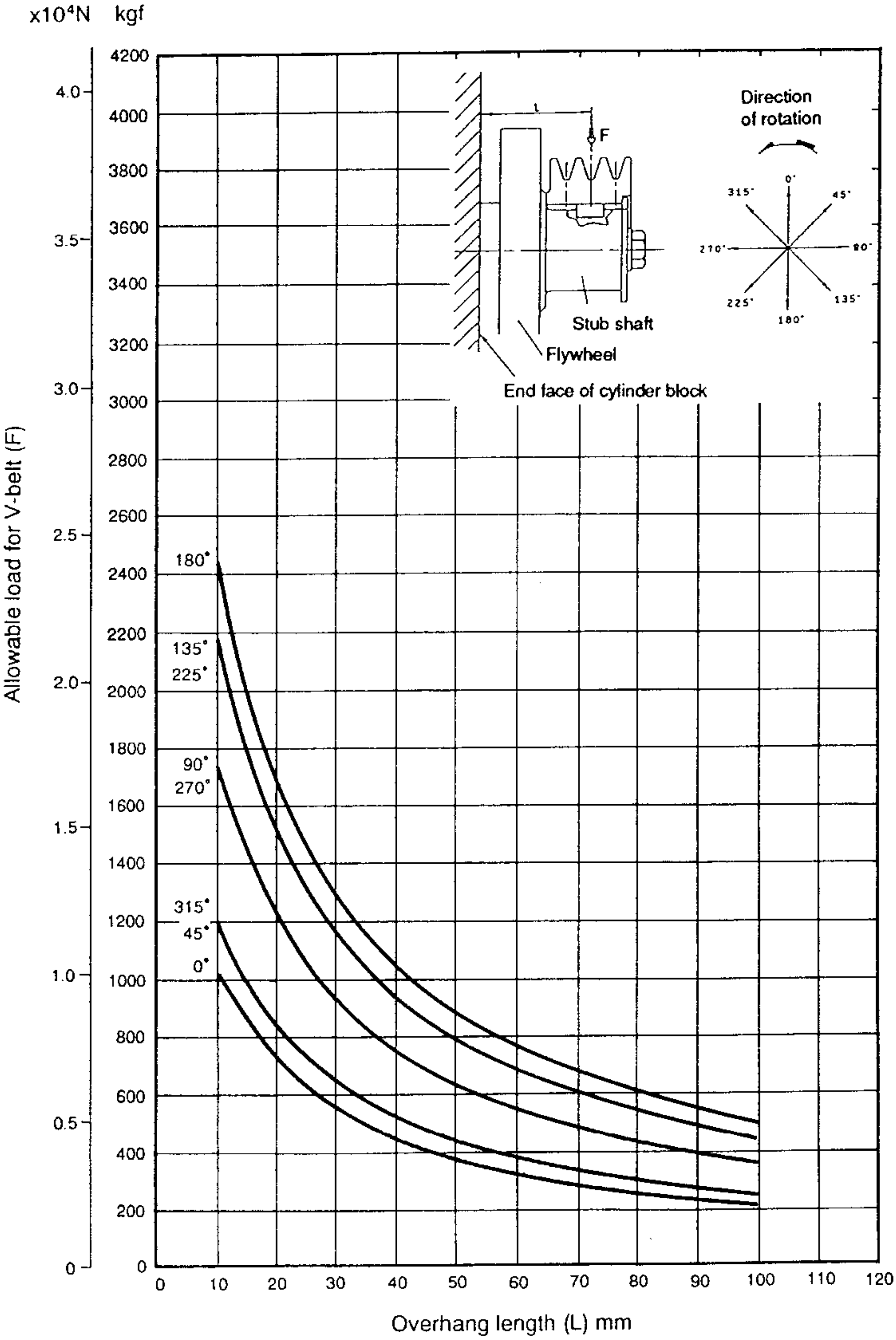
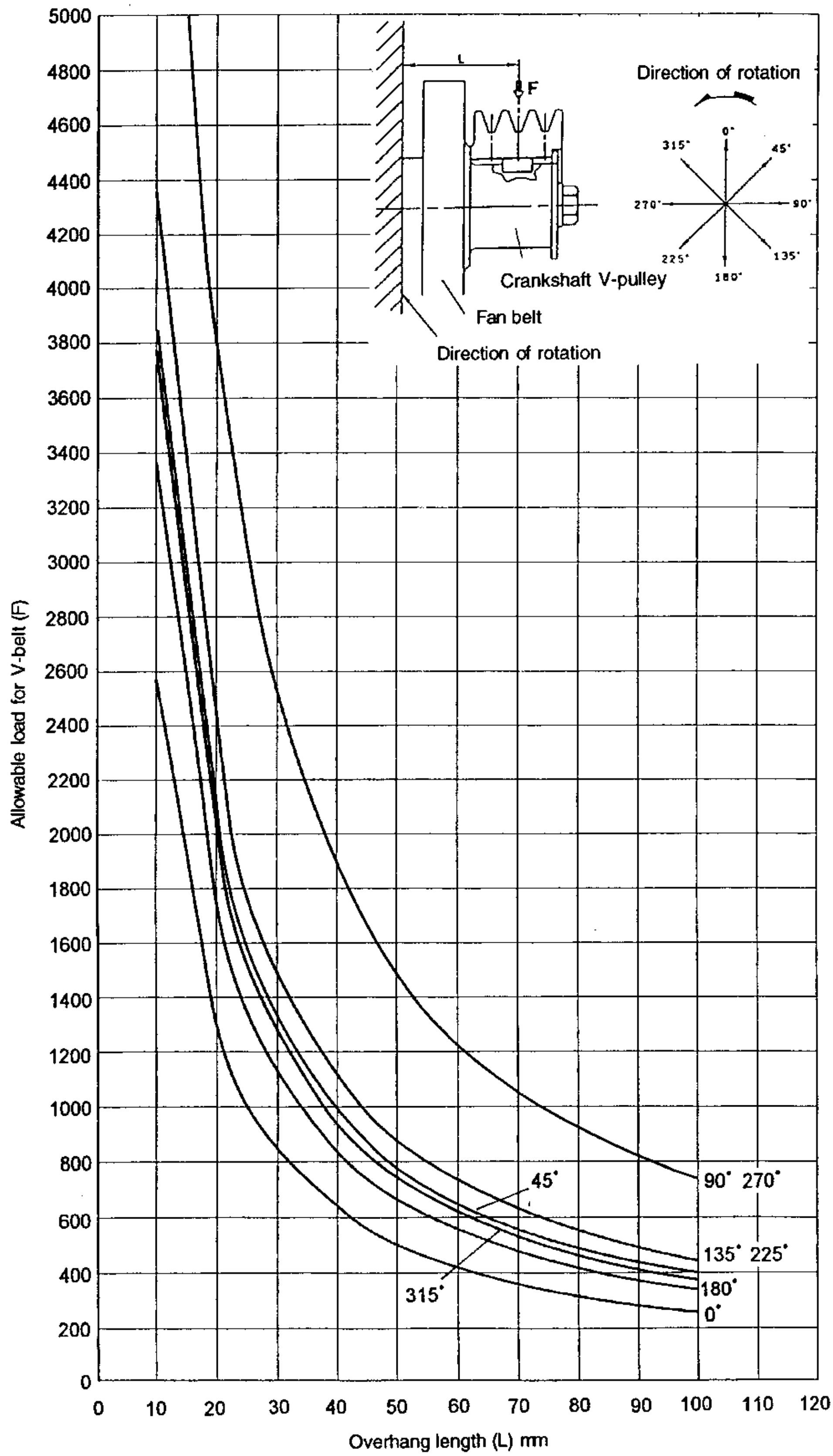
3TNE84, 3TNE88, 3TNE84T, 4TNE84, 4TNE88, 4TNE84T



4TNE94, 4TNE98



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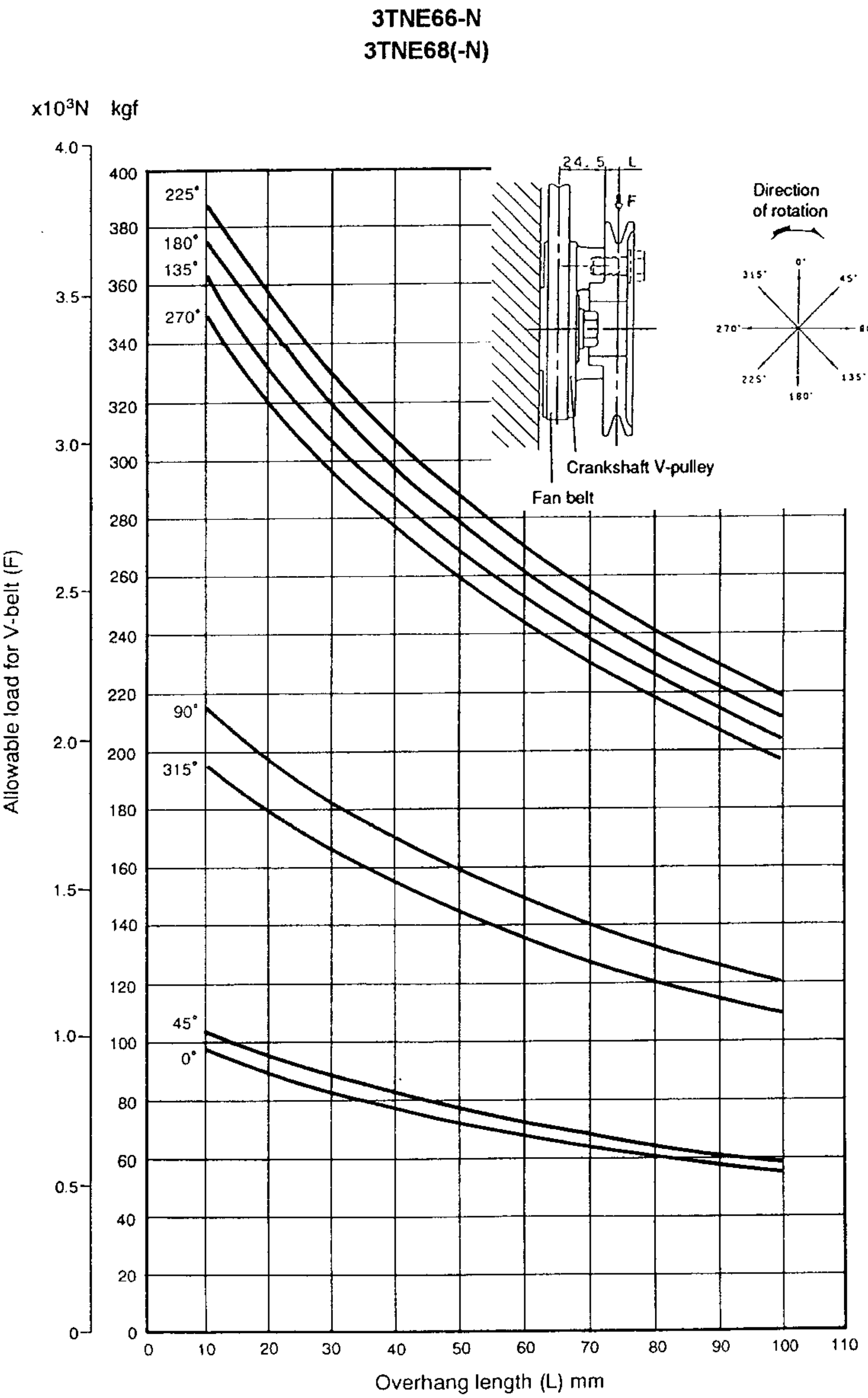
14-5 Allowable Side Load for Front P.T.O.



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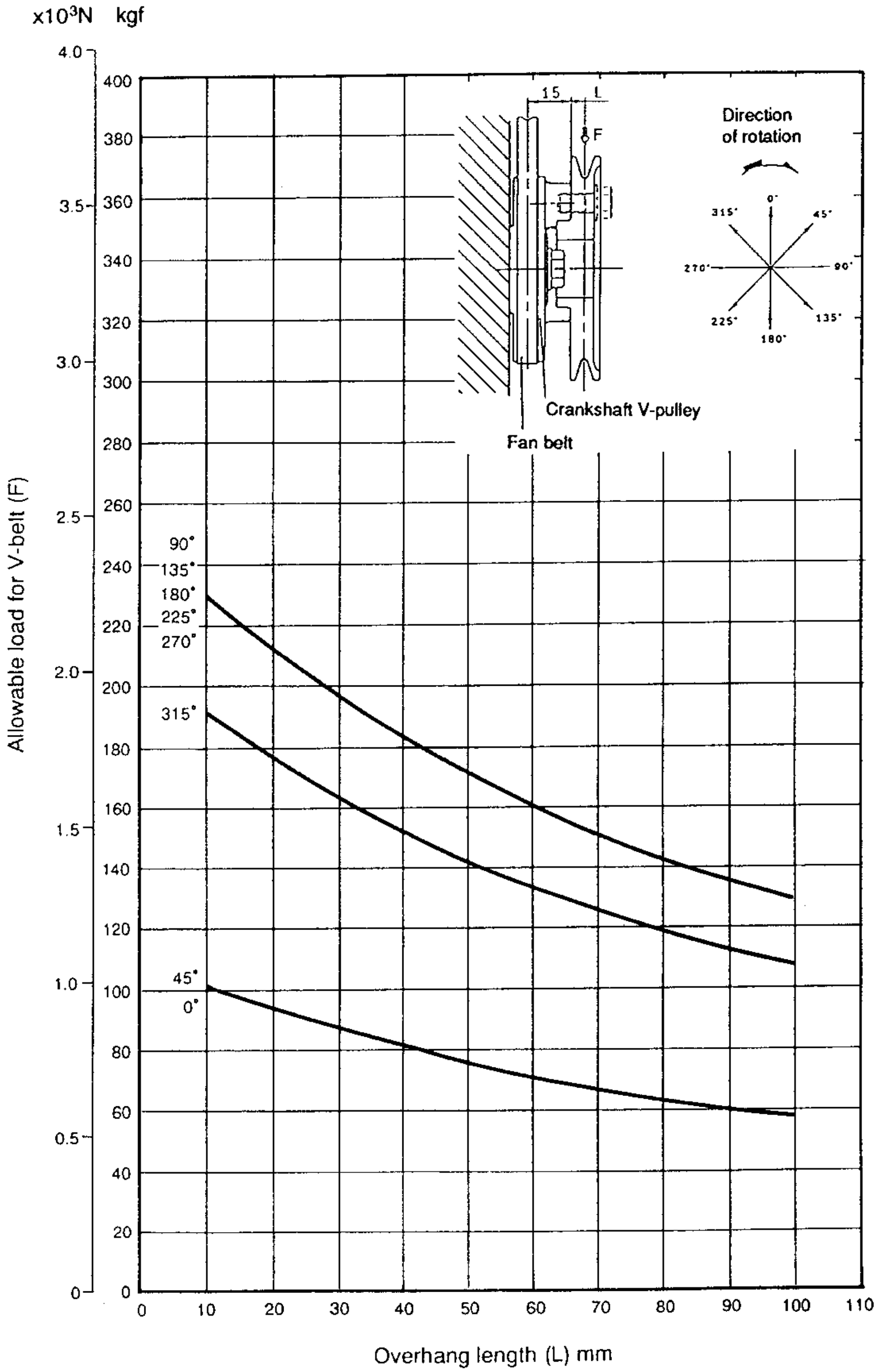
2TNE72-N
3TNE74(-N)



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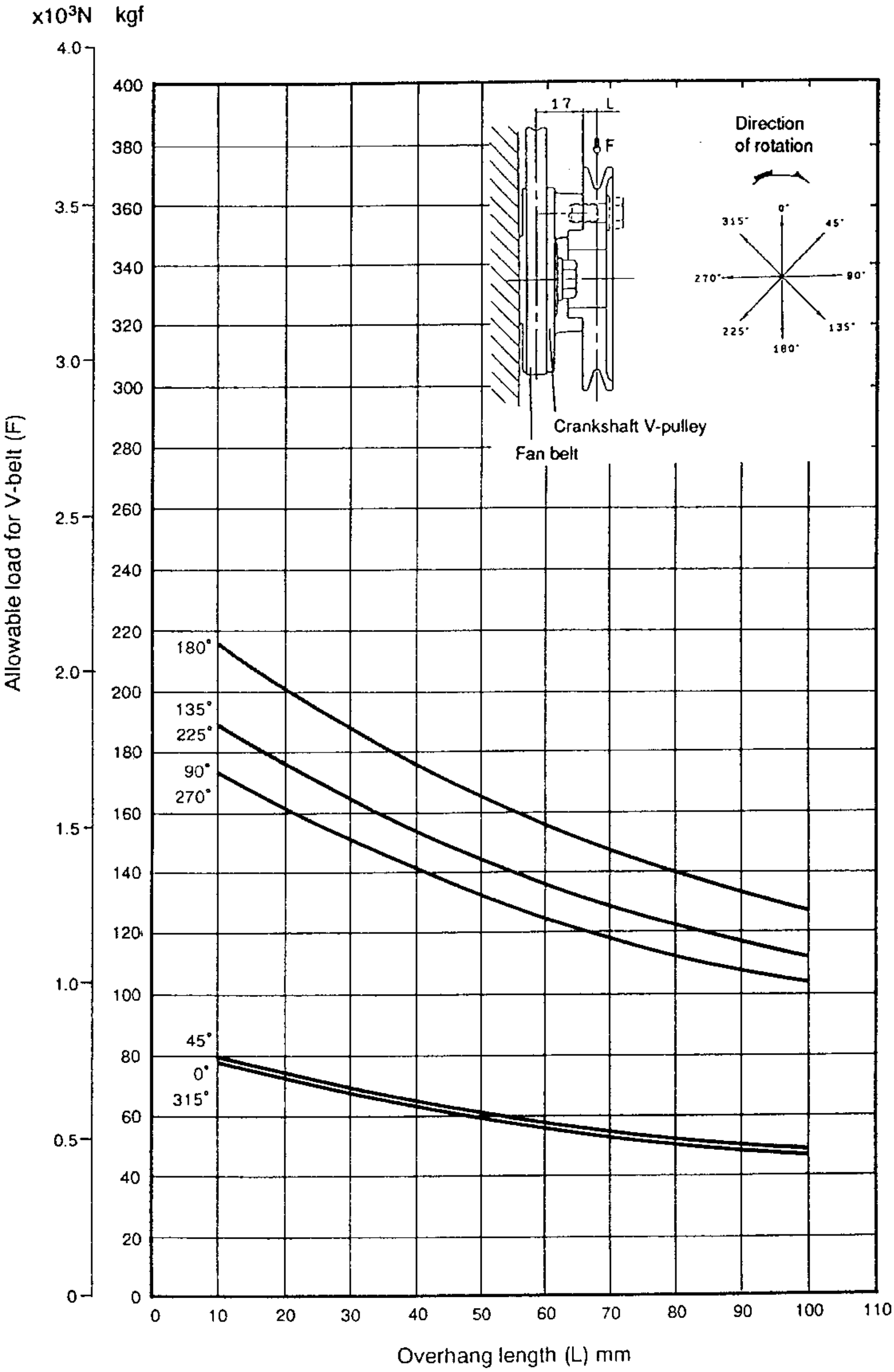
3TNE78A, 3TNE82A



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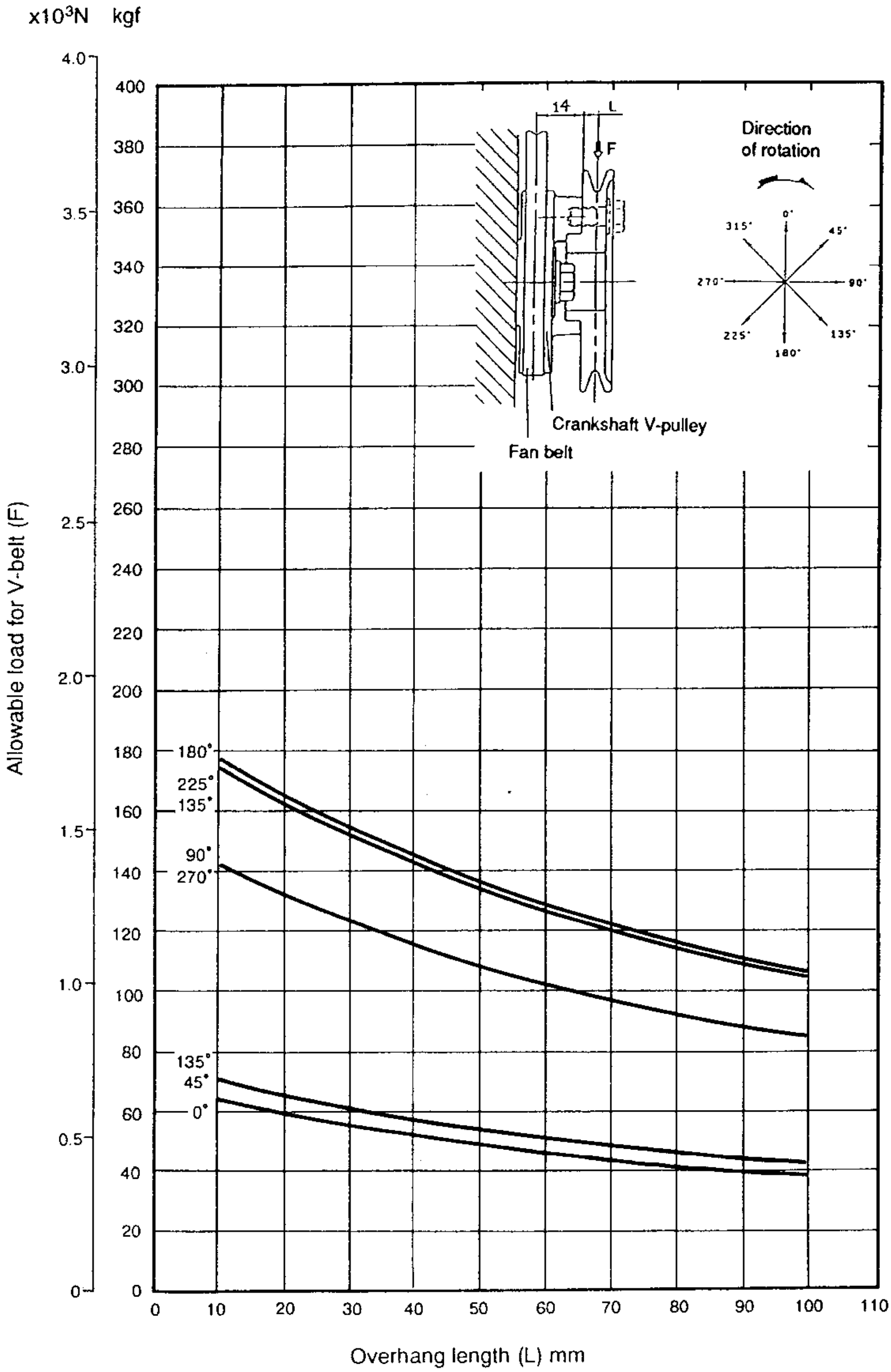
3TNE84, 3TNE88, 3TNE84T, 4TNE84, 4TNE88, 4TNE84T



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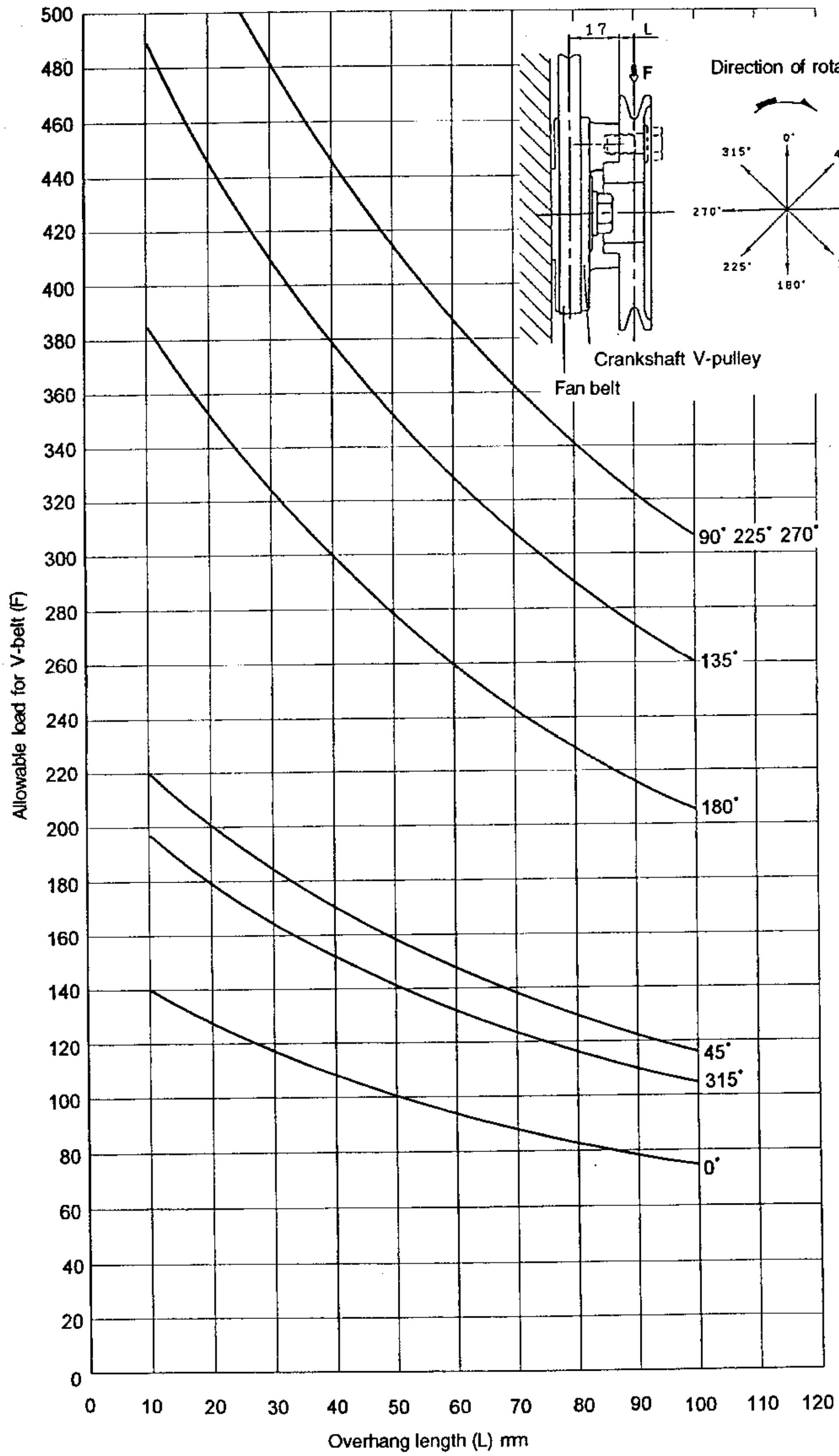
4TNE94, 4TNE98



14-6 Cautions for Hydraulic Pump Drive P.T.O.

The hydraulic pump drive P.T.O. is positioned on the exhaust side of the engine gear case.
As the output of the hydraulic pump drive P.T.O. is determined by the strength of the P.T.O. gear on the engine side, select the pump output within the allowable output by referring to Subsection 14-7.

Prepare the following data before the study:

1. Hydraulic pump type and manufacturer
2. Pump capacity (Q)
3. Pump speed (rpm)
4. Delivery pressure (relief pressure)(kgf/cm^2)
5. Hydraulic pump shaft end shape and mounting dimensions on engine side (Refer to the TNE "Option Menu" for the mounting dimensions.)

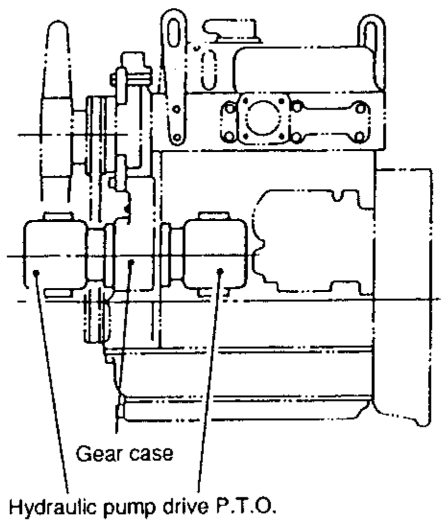
(1) Required power

The hydraulic pump driving power or the required power is the power required for the engine to drive the hydraulic pump. The required power is calculated with the following equation:

$$kW = \frac{Q \times P \times N}{612 \times 1000 \times \eta} \text{ (kW)}$$

Where,

kW	: Required power	(kW)
Q	: Pump capacity	(cc/rev.)
P	: Delivery pressure (relief pressure)	(kgf/cm^2)
N	: Pump speed	(rpm)
η	: Pump efficiency (Refer to the manufacturer's catalog for the pump efficiency. If unknown, assume it as 0.9 for the calculation.)	



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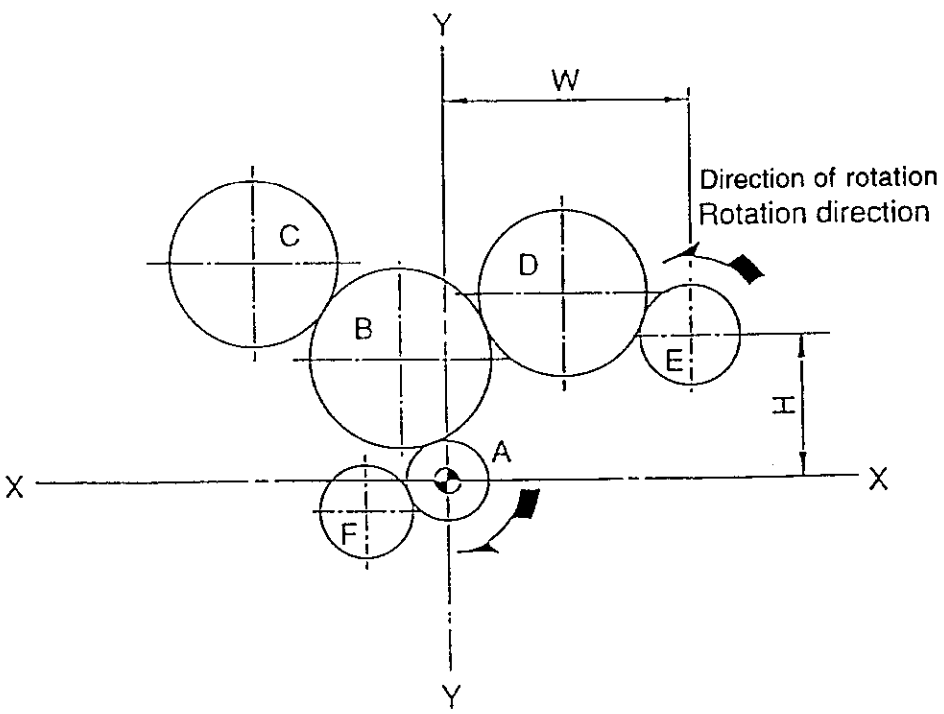
(2) Gear train

Code	Name		Number of teeth			
			2TNE68(-N) to 3TNE68(-N)	3TNE72-N, 3TNE74(-N)	3TNE78A to 4TNE84(T)	4TNE94/98
A	Crank gear	◎	21	22	28	32
B	Idle gear	◎	47	47	43	50
C	Fuel pump drive gear	◎	42	44	56	64
D	Cam gear	◎	42	44	56	64
E	Hydraulic pump drive gear	△	28	27	31	26
F	Lubricating oil pump drive gear	◎	25	25	29	29
Gear ratio : A/E			0.750	0.815	0.903	1.231
Position of hydraulic pump : W/H(mm)			127.1/80	137/80.178	162.3/65.979	178.5/107.5

◎: Standard part
△: Option



View from gear case side

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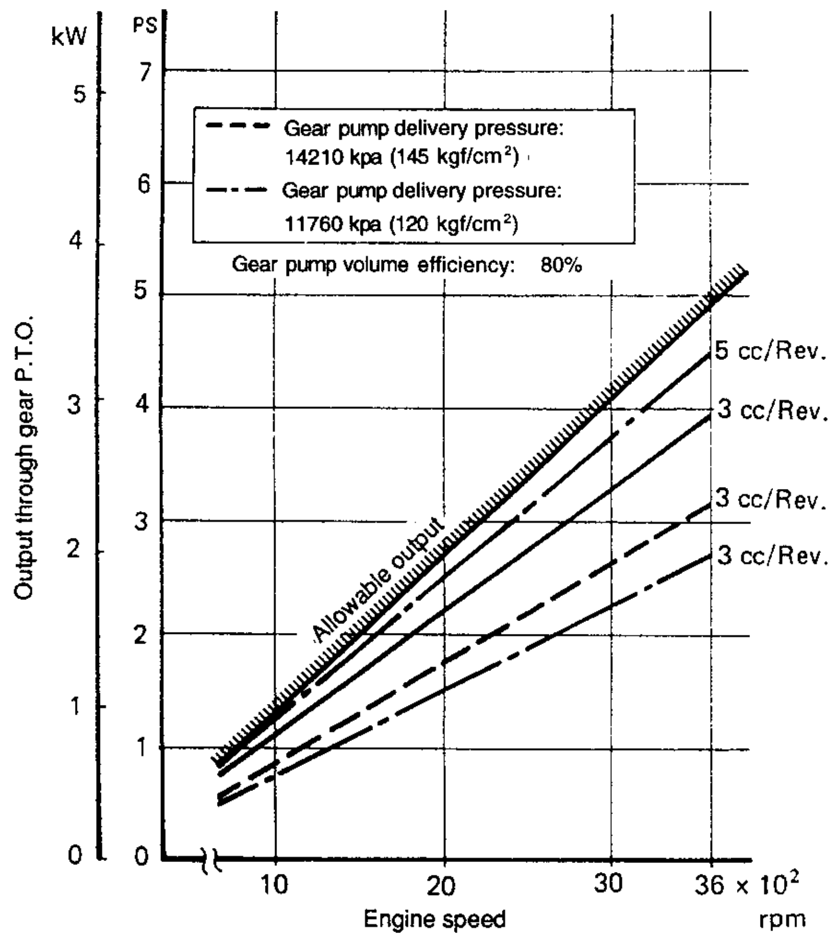
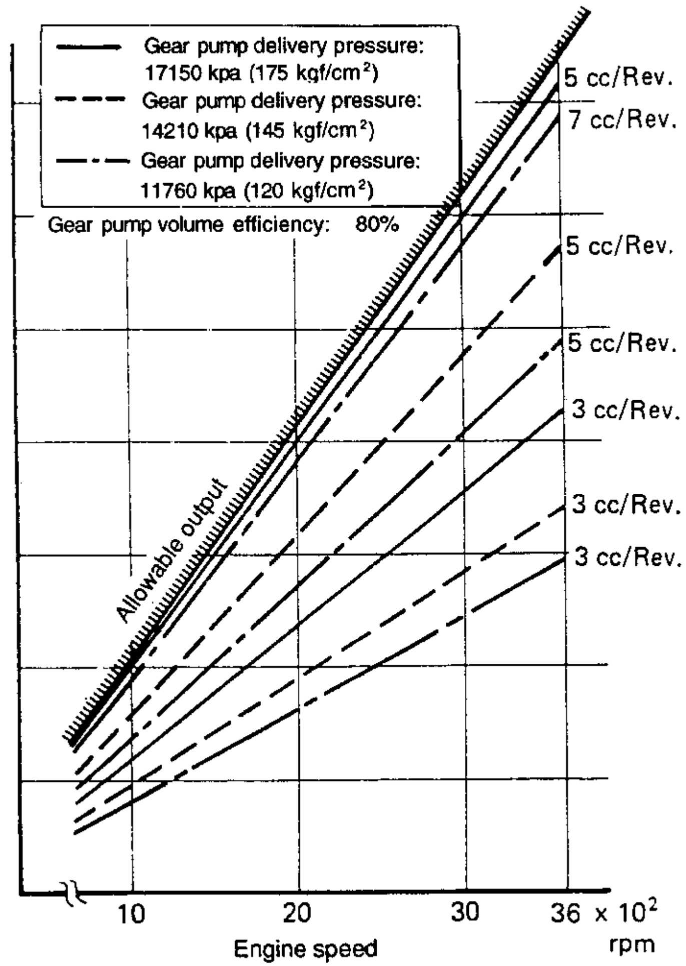
14-7 Allowable Load for Hydraulic Pump Drive P.T.O.

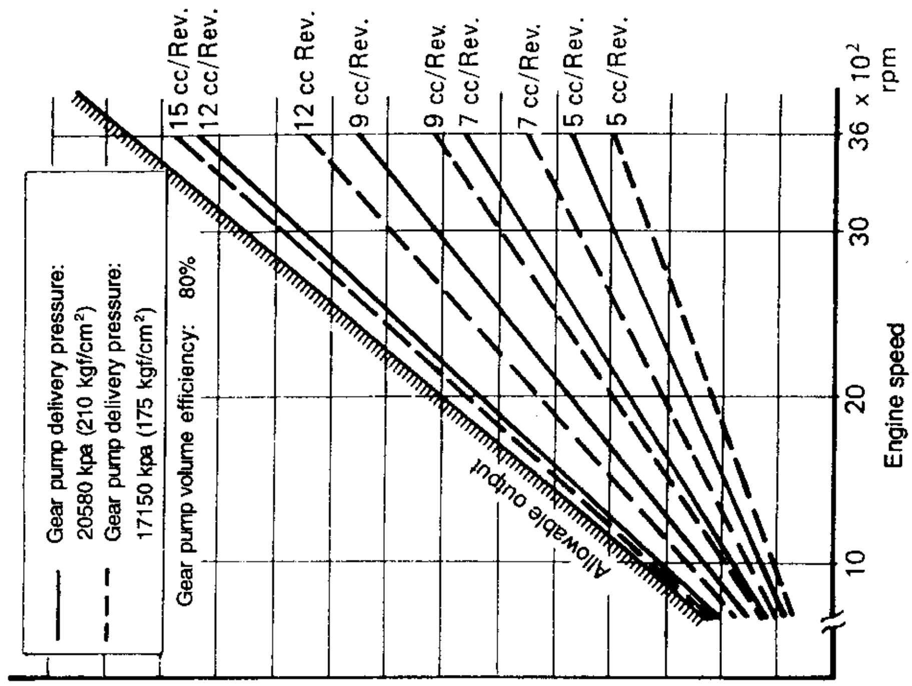
3TNE66-N, 3TNE68(-N)



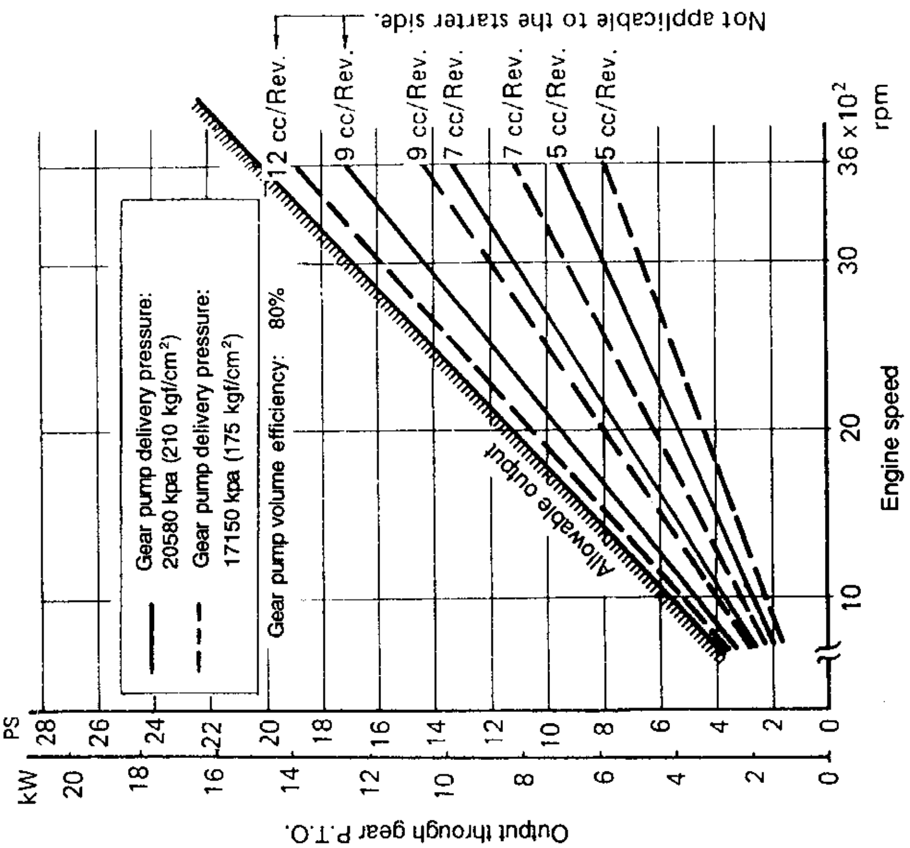
3TNE72-N, 3TNE74-(N)

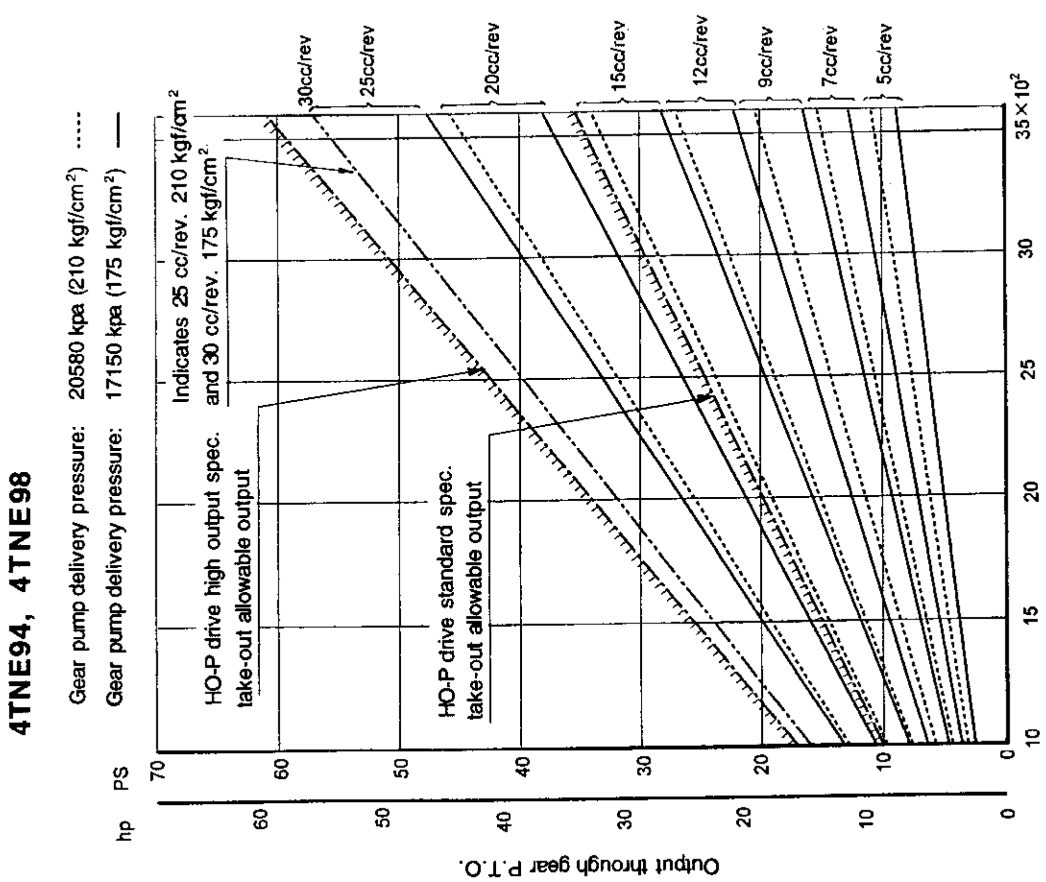


4TNE84(T), 4TNE88



3TNE78A, 3TNE82A
3TNE84(T), 3TNE88





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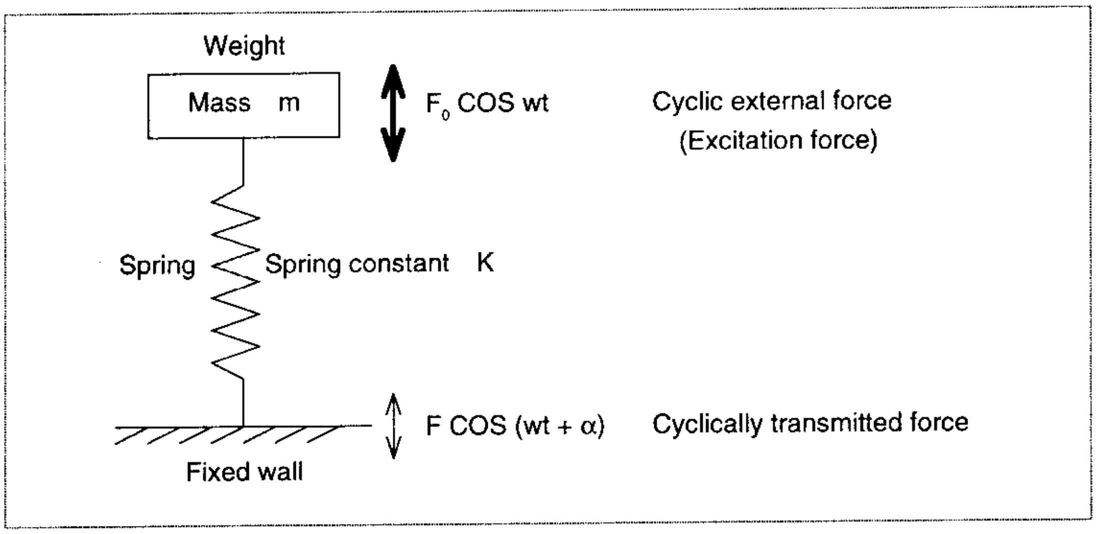
15. Vibration Isolation System

The internal combustion engine generates various types of vibration from its reciprocating parts and rotating parts. The vibration is minimized at the design stage of the engine but perfect elimination is theoretically impossible. Therefore, it is necessary to provide the engine with a vibration isolation system to minimize the vibration transmitted to the driven machine side.

The diagram below shows a spring having a spring constant K mounted on a fixed wall on which a weight m is loaded. The total system is called a vibratory system. When the weight is gently pulled up and then released suddenly, it vibrates cyclically. This is called natural vibration, and the period is called natural frequency. On the other hand, when cyclic external force F_0 is applied to this weight periodically, the vibration is called forced vibration and the period is called forced frequency.

Now, if the weight m is fixed to the fixed wall, the excitation force F_0 is directly transmitted to the fixed wall. This may be undesirable for the fixed wall side. To prevent this, a spring is provided between the weight m and the fixed wall. Then force F transmitted to the fixed wall can be reduced smaller than the excitation force F_0 by appropriate selection of the spring constant K.

[Vibration system]



This spring structure is called the vibration control equipment. Generally, a rubber isolator is used for the spring system. When selecting an actual rubber isolator, use the total mass of the engine and driven machine unit for the weight of mass m, and substitute the fixed wall with the chassis or bench floor for examination. Therefore, the driven machine manufacturer must examine the machine as the vibratory system, while the engine manufacturer must arrange for such vibration isolation materials as unbalanced force and forced frequency data, etc.

The following shows an example of the calculation method used to select the rubber isolator. Note that the calculation is solely for estimating the rubber specifications. The final selection of the optimal rubber isolator to be used is made after conducting an on-board test using rubber of the specifications obtained from the calculation and those preceding or following them.

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15-1 Principle of Vibration Isolation

15-1-1 Principle of vibration isolation and vibration transmissibility

A rubber isolator is used for two occasions: one is for preventing vibration generated by machine operation from being transferred to the base (Figure 1); and the other is for preventing the vibration in the base from being transferred to the machine (Figure 2).

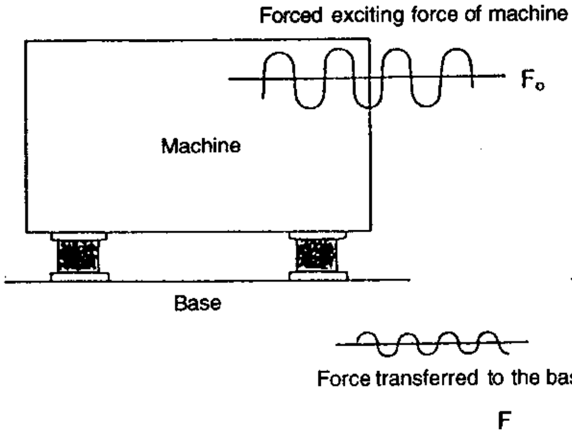

Figure 1

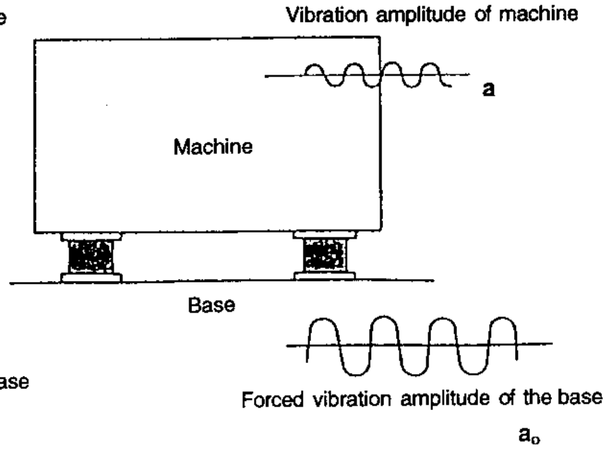

Figure 2

When a machine is provided with a vibro-isolating support, assume the excitation force of the machine as F_o and the force transferred to the base as F. The ratio of transferred vibration is called the transmissibility and is given by equation (1):

$$\tau = \frac{F}{F_o} = \frac{a}{a_o} = \left| \frac{1}{1 - (\frac{n}{f})^2} \right| \quad \cdots\cdots (1)$$

τ : Transmissibility
F_o : Forced excitation force of machine
F : Force transferred to the base
a_o : Forced excitation amplitude of the base
a : Amplitude transferred to the machine
n : Forced frequency generated from the machine (See section 15-2-3.)
f : Natural frequency when vibro-isolating support is provided

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The curves of vibration transmissibility in Figure 3 are graphic representations of Equation (1).

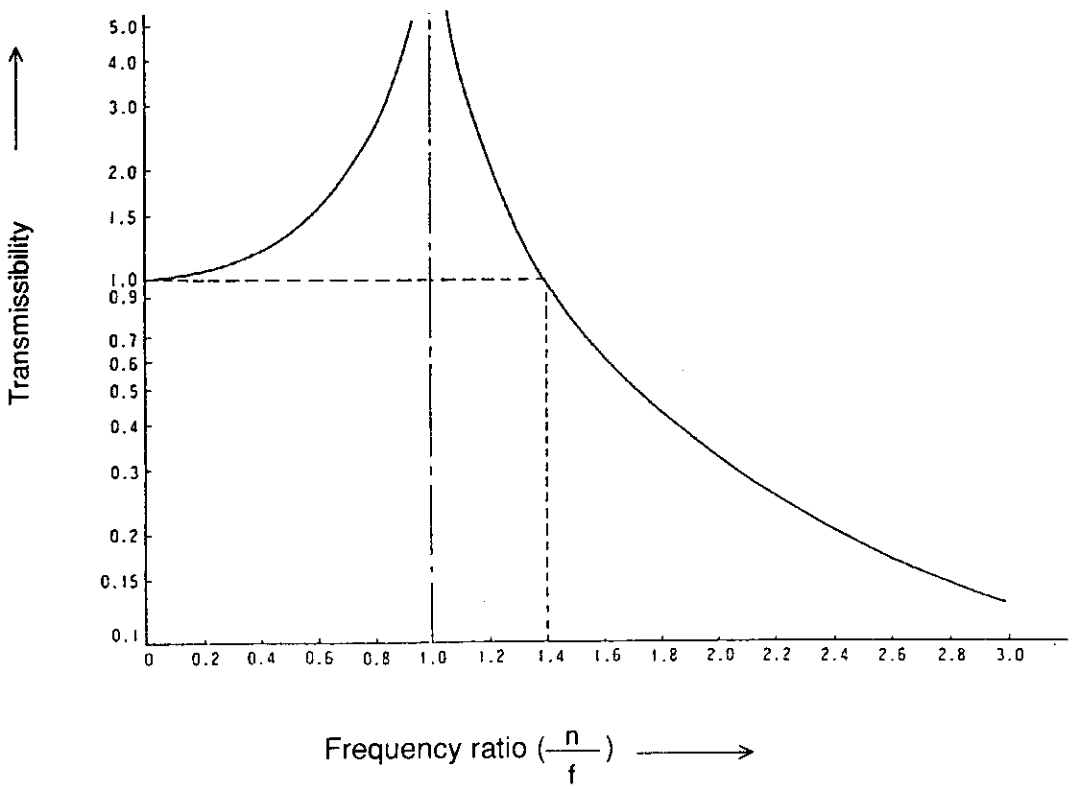

Figure 3 Transmissibility versus frequency ratio curve

15-1-2 Frequency ratio and vibration damping effect

The vibration transmissibility is determined by the forced frequency (n) of machine and natural frequency (f) with vibro-isolating support.

Frequency ratio	Transmissibility	Vibration isolation effect
$\frac{n}{f} = 1$	$\tau \rightarrow \infty$	Resonance
$\frac{n}{f} = 1.4$	$\tau = 1$	No vibration isolation effect
$\frac{n}{f} > 1.4$	$\tau < 1$	Effective vibration isolation

Normally, select 2 to 3 for $\frac{n}{f}$.

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15-1-3 How to obtain natural frequency when supported with rubber isolator

The natural frequency can be obtained from equation (2) using the machine weight and the spring constant of the rubber isolator.

$$f = \frac{1}{2\pi}\sqrt{\frac{K \times g}{W}} \quad \text{(Hz) ------ (2)}$$

f : Natural frequency (Hz)
K : Dynamic spring constant of rubber isolator (kg/cm)
(1.4 times the catalog value)
g : Acceleration of gravity 980 980 cm/sec^2
W : Load on one piece of rubber isolator

Figure 4 shows the graphic representation of equation (2).

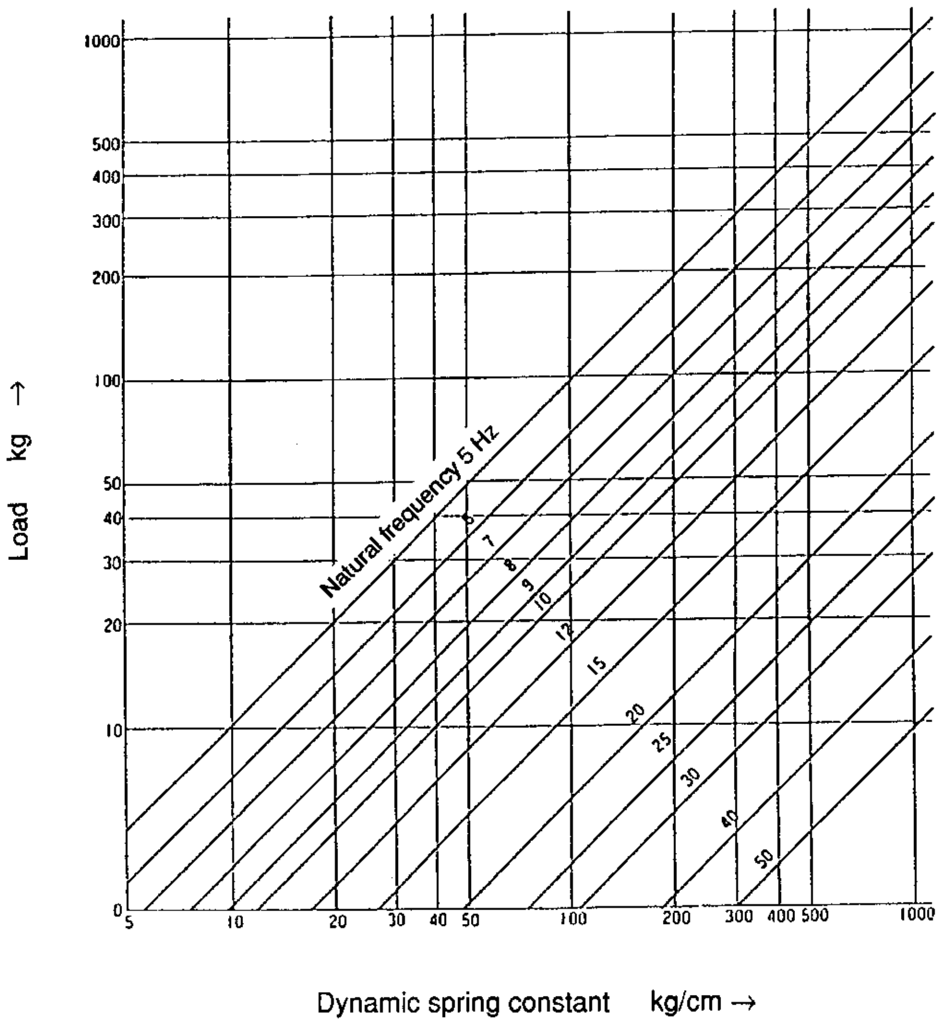

Figure 4

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15-2 Calculation of Rubber Isolator

15-2-1 Selection procedures of vibro-isolating support

Determination of vibro-isolating support position	The support points are determined so that the static load of every support point is distributed as equally as possible.
Determination of natural frequency and spring constant	Obtain according to section 15-1, "Principle of Vibration Isolation."
Selection of rubber isolator	Select the appropriate type of rubber isolator from the manufacturer's catalog according to the spring constant of the rubber isolator, allowable load and mounting method.

15-2-2 Examples of selection

(1) Design specification

Machine	:	Refrigerator		
Weight	:	Engine	:	1,296 kg
		Refrigerator	:	980 kg
		Coupling and bed	:	800.5 kg
Engine speed	:	Normal	:	1600 rpm ($\fallingdotseq$27 Hz)
		4-cylinder engine		
		* 2nd order reciprocating excitation force		n$\fallingdotseq$53.3 (Hz)
Support point	:	8 points		

(2) Calculation of static spring constant

1) Support load
Static load (W) at each support point is obtained from the following equation:

$$W = \frac{3076.5}{8} \fallingdotseq 385 \text{ (kg)}$$

2) Determination of natural frequency
If a vibration transmissibility in the vicinity of 10% is targeted, n/f = 3 from the curve of vibration transmissibility, and the natural frequency (f) can be obtained from the following equation:

$$f = \frac{n}{3} = \frac{1600 \times 2}{3} = 1067 \text{ (cpm)} \fallingdotseq 17.8 \text{ (Hz)}$$

3) Calculation of dynamic spring constant
Because the static load per point is 385 kg, the dynamic spring constant can be calculated from:

$$f = \frac{I}{2\pi}\sqrt{\frac{K \times g}{W}} \text{ (Hz)}$$

$$K = (2\pi f)^2 \times \frac{W}{g}$$

$$= (2 \times 3.14 \times 17.8)^2 \times \frac{385}{980} = 4914 \text{ kg/cm}$$

4) Calculation of static spring constant
From the following equation for static spring constant:

$$\text{Static spring constant} = \frac{\text{Dynamic spring constant}}{1.4}$$

$$K_s = \frac{K}{1.4} = \frac{4914}{1.4} = 3510 \text{ kg/cm}$$

(3) Selection of rubber isolator

The result of the above calculation:

Static load per support point of rubber isolator	:	385	kg
Static spring constant	:	3510	kg/cm

(4) Verification of vibration isolation effect

Suppose that the following rubber vibration isolators are selected as closest to the above result:

Allowable load	:	800	kg
Static spring constant	:	3200	kg/cm

Then,

1) Natural frequency of the support system is obtained from the following equation:

$$f = \frac{I}{2\pi}\sqrt{\frac{K \times g}{W}} \text{ (Hz)}$$

$$= \frac{I}{2\pi}\sqrt{\frac{1.4 \times 3200 \times 980}{385}} = 17.0 \text{ Hz}$$

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2) The vibration transfer ratio is obtained from the following equation:

$$\tau = \frac{1}{(\frac{n}{f})^2 - 1} \times 100$$

$$= \frac{1}{(\frac{53.3}{17})^2 - 1} \times 100 = 11\%$$

3) Vibration isolation effect

$$100 - \tau = 100 - 11 = 89\%$$

Therefore, the vibration isolation effect is 89%.

(5) Verification by the on-board installation test

Verify that the same effect is obtained as calculated from the actual machine test. If the effect is insufficient, conduct further verification with machine tests by using rubber isolator types preceding or following the tested isolator to find the most effective rubber vibration isolator.

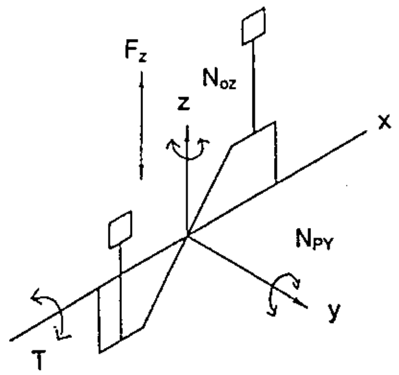
15-2-3 Vibration improvement

As stated in the preceding section, if the test result of the rubber isolator produces a poor vibration isolating effect, conduct tests again using various types of rubber isolator in practice. The rubber isolator should be selected in consideration of the vibration characteristics of the engine.

The forced frequency and direction of vibration of an engine differ with the number of cylinders. The table below indicates the vibration characteristics of an engine. When examining vibration improvement, use this table to find which spring constant of rubber isolator having which direction should be changed for the best effect.

Degree and direction of exciting force to be avoided by vibration damping system

Exciting force / Number of cylinders	Torque alternation (lowest order)	Unbalance force				
		Inertia force by reciprocating mass		Inertia couple force by rotating mass	Inertia couple force by reciprocating mass	
		1st order	2nd order	1st order	1st order	2nd order
	T kg.m	F_z kg		N_{oz} kg.m	N_{py} kg.m	
1	1/2 order	○	○	--	--	--
2	1/2 order	--	○	○	○	--
3	1-1/2 order	--	--	○	○	○
4 (90° crank)	1/2 order	--	--	--	○	○
4 (180° crank)	2nd order	--	○	--	--	--
5	2-1/2 order	--	--	--	○	○
6	3rd order	--	--	--	--	--



T : Rolling
F_z : Vertical motion
N_{oz} : Yawing
N_{py} : Pitching

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15-3 Vibration Isolation Materials

If vibration fails to reach the target value as the result of tests using a rubber isolator of the calculated specifications, conduct tests again by using various types of rubber isolator to find a practical solution. In this case, select a rubber isolator by considering the engine vibration characteristics.

Engines differ in the size of unbalance force (excitation force), forced frequency and the direction of vibration with the number of cylinders. These vibration characteristics are outlined in a separate table for reference when trying to improve the vibration characteristics.

Generally, unbalance force and torque alternation are jointly called excitation force, and the materials concerning it always involve the term "order." This indicates the number of times of excitation force generated during one rotation of an engine. For example, excitation force of 2nd order refers to the vibration that causes the excitation force to be generated two times during one engine rotation.

Specifically, when an engine is driven at 2600 rpm, the excitation force of 2nd order is generated two times the engine rotation, or 5200 times a minute. This is called the forced frequency, and is expressed in unit of cpm and by the following formula:

$$n = h \cdot N$$

Where,
n : Forced frequency of excitation force in cpm
h : Order of excitation force
N : Engine speed in rpm

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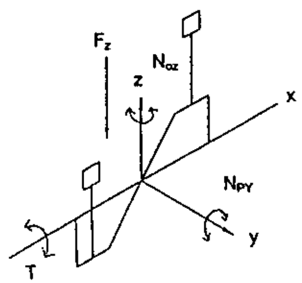
15-3-1 Excitation force

(1) Unbalance force

Engine speed (rpm)

Engine model	1st order inertia force by reciprocating mass F_{Z-1} (kg)	2nd order inertia force by reciprocating mass F_{Z-2} (kg)		1st order couple force by rotating mass N_{OZ-1} (kg – m)	1st order couple force by reciprocating mass N_{PY-1} (kg – m)	2nd order couple force by reciprocating mass N_{PY-2} (kg – m)
2TNE68	—	—	Note 1	$8.24\times10^{-7}\times N^2$	$1.425\times10^{-6}\times N^2$	—
			Note 2	$-3.10\times10^{-7}\times N^2$		
3TNE68	—	—	Note 1	$4.469\times10^{-7}\times N^2$	$2.468\times10^{-6}\times N^2$	$8.712\times10^{-7}\times N^2$
			Note 2	$-1.227\times10^{-6}\times N^2$		
3TNE74	—	—	Note 1	$1.227\times10^{-6}\times N^2$	$3.707\times10^{-6}\times N^2$	$1.291\times10^{-6}\times N^2$
			Note 2	$-7.724\times10^{-7}\times N^2$		
2TNE68-N	—	—		$8.24\times10^{-7}\times N^2$	$1.425\times10^{-6}\times N^2$	—
3TNE66-N	—	—		$2.287\times10^{-7}\times N^2$	$2.063\times10^{-6}\times N^2$	$3.749\times10^{-7}\times N^2$
3TNE68-N	—	—		$4.469\times10^{-7}\times N^2$	$2.468\times10^{-6}\times N^2$	$8.712\times10^{-7}\times N^2$
3TNE72-N	—	—		$8.363\times10^{-7}\times N^2$	$3.350\times10^{-6}\times N^2$	$6.215\times10^{-7}\times N^2$
3TNE74-N	—	—		$1.127\times10^{-6}\times N^2$	$3.707\times10^{-6}\times N^2$	$1.291\times10^{-6}\times N^2$
3TNE78A	—	—		$1.367\times10^{-6}\times N^2$	$5.788\times10^{-6}\times N^2$	$1.906\times10^{-6}\times N^2$
3TNE82A	—	—		$1.367\times10^{-6}\times N^2$	$5.860\times10^{-6}\times N^2$	$1.930\times10^{-6}\times N^2$
3TNE84(T)	—	—		$2.338\times10^{-6}\times N^2$	$8.379\times10^{-6}\times N^2$	$2.753\times10^{-6}\times N^2$
3TNE88	—	—		$2.338\times10^{-6}\times N^2$	$9.174\times10^{-6}\times N^2$	$3.014\times10^{-6}\times N^2$
4TNE84(T)	—	$6.763\times10^{-5}\times N^2$		—	—	—
4TNE88	—	$7.404\times10^{-5}\times N^2$		—	—	—
4TNE94	—	$1.050\times10^{-4}\times N^2$		—	—	—
4TNE98	—	$1.329\times10^{-4}\times N^2$		—	—	—



Note 1: With unbalance moment to V-pulley and flywheel

Note 2: Without unbalance moment to V-pulley and flywheel

(2) Torque alternation by gas pressure: T

Engine model	Torque alternation T (kg•m)					
	1/2 order	1st order	1-1/2 order	2nd order	3rd order	4th order
2TNE68	7.6	7.9	7.7	7.0	4.7	2.9
3TNE68	—	—	11.6	—	7.1	—
3TNE74	—	—	14.8	—	9.1	—
2TNE68-N	7.6	7.9	7.7	7.0	4.7	2.9
3TNE66-N	—	—	9.6	—	5.9	—
3TNE68-N	—	—	11.6	—	7.1	—
3TNE72-N	—	—	12.7	—	7.8	—
3TNE74-N	—	—	14.8	—	9.1	—
3TNE78A	—	—	17.8	—	10.8	—
3TNE82A	—	—	19.6	—	12.0	—
3TNE84	—	—	22.1	—	13.5	—
3TNE88	—	—	24.2	—	14.6	—
3TNE84T	—	—	26.2	—	14.0	—
4TNE84	—	—	—	26.7	—	11.0
4TNE88	—	—	—	29.3	—	12.0
4TNE84T	—	—	—	31.4	—	11.0
4TNE94	—	—	—	37.5	—	15.3
4TNE98	—	—	—	44.8	—	18.3

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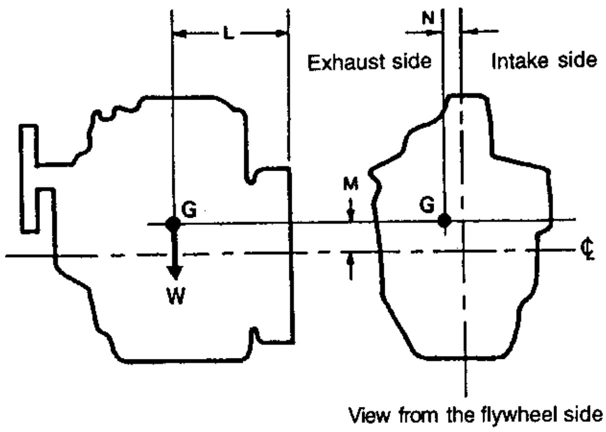
15-3-2 Engine weight and center of gravity



	L mm	M mm	N mm	W kg
2TNE68(-N)	141	56	8.5	66
3TNE66, 68(-N)	178	66	7.6	78
3TNE72, 74(-N)	177	72	18	98
3TNE78A, 82A	208	82	9.5	125
3TNE84, 88	213	92	11	152
3TNE84T	213	92	11	157
4TNE84, 88	266	92	4.6	190
4TNE84T	266	92	4.6	195
4TNE94, 98	280	111	28.5	233

Note: F-F specs., (excluding radiator, air cleaner and muffler) including intake manifold, exhaust manifold and flywheel housing.

G : Center of gravity
L : Distance from flywheel housing end
M : Distance from crankshaft center line
N : Distance from crankshaft center line
W : Weight (including cooling water and lubricating oil)
The data in this table is for the engines of general specifications.
If the customer's required specifications are known, apply the weight therein.

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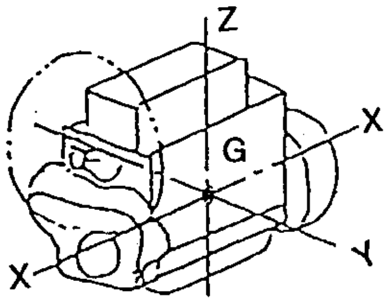
15-3-3 Engine moment of inertia



G : Center of gravity
Ix : X-axial
Iy : Y-axial
Iz : Z-axial

	Moment of inertia (kg-cm-sec^2)			Wet weight (kg)
	Ix	Iy	Iz	W
2TNE68 (–N)	9.64	11.49	8.59	66
3TNE66 –N	11.20	17.30	13.80	78
3TNE68 (–N)	11.20	17.30	13.80	78
3TNE72 –N	17.60	26.40	19.90	98
3TNE74 (–N)	17.60	26.40	19.90	98
3TNE78A	31.74	42.10	30.79	125
3TNE82A	31.74	42.10	30.79	125
3TNE84	47.25	60.86	43.49	152
3TNE84T	48.81	62.87	44.92	157
3TNE88	47.25	60.86	43.49	152
4TNE84	59.07	91.97	70.25	190
4TNE84T	60.62	94.39	72.10	195
4TNE88	59.07	91.97	70.25	190
4TNE94	120.4	164.1	118.3	233
4TNE98	120.4	164.1	118.3	233

16. Torsional Vibration

A 4-cycle engine continuously generates output by making one combustion in the piston per two revolutions of the crankshaft. It changes the reciprocating motion of the piston to the revolution of the crankshaft. Therefore the crankshaft is constantly loaded with tension, bending, torsion or their combination. When designing a crankshaft, care is taken to avoid fatigue breaking even if it is subjected to the repetition of these loads, but if a large load happens to be applied to the crankshaft in any form during operation, it may shorten the life of the crankshaft.

Consequently if a large stress is applied by the torsional motion, it may lead to a fatigue breaking of the crankshaft and transmission shaft. If the additional stress itself poses no problem, an excessive amplitude causes a fatigue breaking of the transmission gear system. Therefore, a very careful consideration of torsional vibration must be given in advance .

16-1 What Is Torsional Vibration?

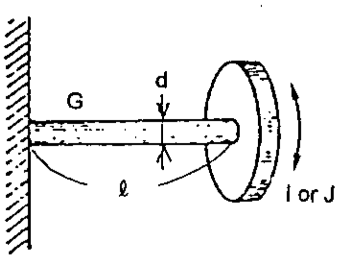


Fig. 1

Assume an elastic round bar with a disc on one end with the other end fixed on a wall (called one-degree-of freedom system) as shown in Figure 1. When the disc is twisted a little and released suddenly, the disc tends to return to its original position. Because of the inertia force of the disc, however, the disc overruns the original position and again tends to return to the original position.

The disc vibrates in this way around its axis. This type of vibration is called torsional vibration. If damping such as the air resistance or internal resistance of the bar does not act, the disc may continue to vibrate permanently.

In practice, because of damping, vibration is damped gradually until it comes to standstill. Such vibration as this where the disc vibrates only by its own inertia and the elasticity of the bar without outside force is called free vibration, and the number of vibrations per unit time (generally 1 minute) is called natural frequency (fn).

Natural frequency has always a constant value when the moment of inertia of the disc (generally expressed with I or J) and the elasticity of the bar (determined by the shear modulus G, diameter d and the length ℓ of the bar material) are determined. Natural frequency decreases as the moment of inertia of the disc increases or the elasticity of the bar decreases, and vice versa.

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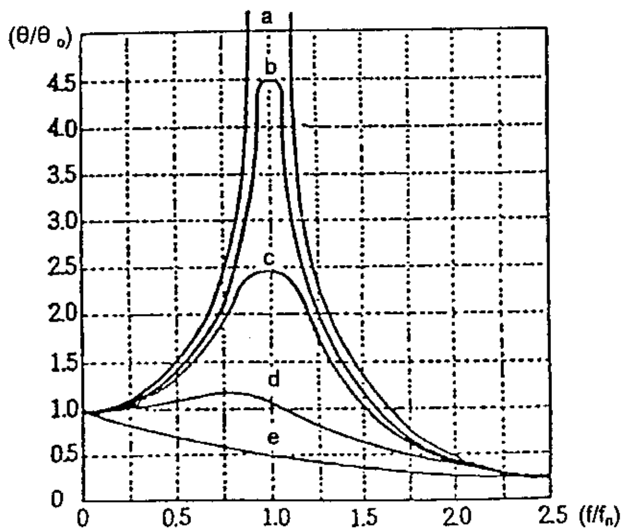

Fig. 2 Resonance curve

The free vibration as described above is caused simply by twisting and releasing the disc. If twisting force (exciting force) is periodically applied to the disc, the subsequent vibration is called forced vibration. If the frequency of the exciting force agrees with the natural frequency of the vibratory system, the bar twisting angle (amplitude) increases greatly. This state is called resonance. Figure 2 shows how amplitude θ of the vibratory system varies by the relation between the frequency f of exciting force and natural frequency f_n of the vibratory system. These curves are generally called resonance curves. Assume θ_0 is the bar angle of torsion when exciting force is applied statically.

In the case of a vibratory system having not such a large exciting force, θ/θ_0 becomes infinite at the resonance point that is f/f_n 1.0 as Figure a shows if no damping exists. Of course, actually it does not become infinite because of some form of damping. Nevertheless, in general, the amplitude will be several times the static angle of torsion θ_0.

As damping increases to b, c, d and upward, the amplitude at the resonance point decreases. When it reaches position e, it does not enter the vibrating state because of excessive damping resistance, hence the resonance point vanishes.

As described, the resonance phenomenon has to be avoided since the amplitude at the resonance point becomes quite large in forced vibration even if reduced by a certain level of damping. This is not merely confined to torsional vibration but applies to all machine parts in general.

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16-2 Torsional Vibration of Multi-Cylinder Engine

16-2-1 Equivalent vibration system

Section 16-1 describes the basic concept of the simplest so-called torsional vibration of one-degree-of-freedom system having a single disc. The free vibration form of a shaft having several discs attached is similarly determined.

In the case of a multi-cylinder engine shaft system as shown in Fig. 3(A), replace it with an ideal form of vibratory system like (B) consisting of shaft of uniform diameter and simple discs for the analysis. Such a vibratory system is called equivalent vibration system.

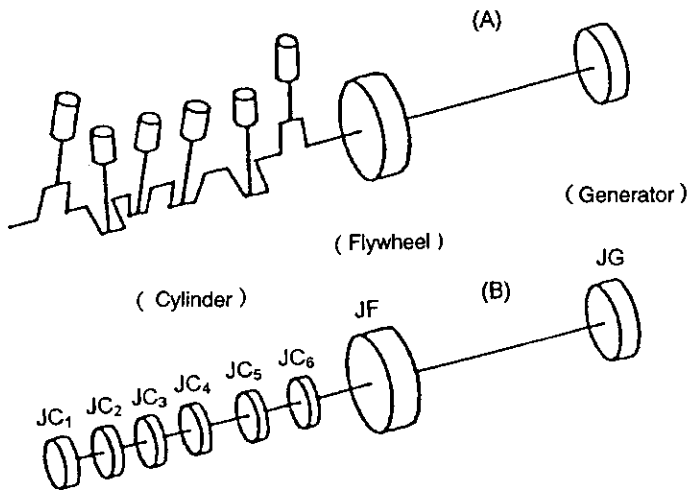

Fig. 3 Shaft system of multi-cylinder engine

When replacing with the equivalent vibration system, replace actual shaft such as the crankshaft and transmission shaft with the equivalent shafts having a diameter of 18.72 cm (in the case of a forged steel shaft) and the equivalent torsional stiffness (kg·cm/rad). The length of equivalent shaft is called equivalent length, which represents the size of elasticity of the equivalent vibration system. Also replace the crank (including the crankpin, crankarm, balance weight), flywheel, rotor of the generator, gear, front pulley, etc. with the equivalent discs (equivalent mass) having the moment of inertia equivalent to them.

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16-2-2 Free vibration of multi-cylinder engine

Figure 4 shows how the shaft of a multi-cylinder engine vibratory system replaced with the equivalent vibration system twist during free vibration (generally referred to as an elastic curve).

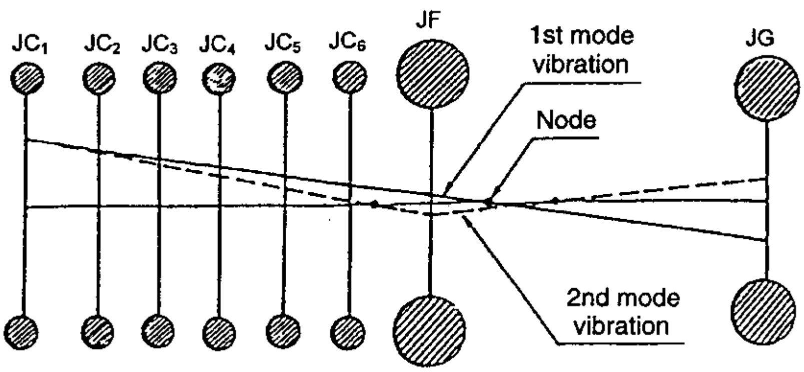

Fig. 4 Equivalent vibration system and elastic curves

Figure 4 shows the forms of two free vibration including so-called first mode vibration having only one node (beyond this node the shaft twists in the reverse direction) and second mode vibration having nodes at two locations. Theoretically, there are a number of free vibration forms such as 3rd mode, 4th mode and so forth. But generally speaking, first and second mode vibration cause most of the problem, followed by 3rd mode vibration that occasionally is a problem. Naturally, the natural frequency of these forms rises as the number of nodes increases.

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16-2-3 Harmonics of torque

Thus far the free vibration of a multi-cylinder engine shaft system has been described. Now assume an operating 4-cycle engine with its crankshaft revolving. Explosion is generated in one of the cylinders of a 4-cycle engine once every two revolutions of the crankshaft. The pressure change is rewritten as the torque change of the crankshaft (see Fig. 5.). While this represents an anharmonic change, the crankshaft torque consists of harmonically changing torques as shown in Figure 6, that is, a group of harmonics. The 1st or 2nd order stated in the figure refers to the torque alternation that repeats one time or two times at every revolution of the crank. The higher the degree of the order, the weaker the strength of harmonics. Because of many harmonics, multi-cylinder engines involve awkward problems of torsional vibration.

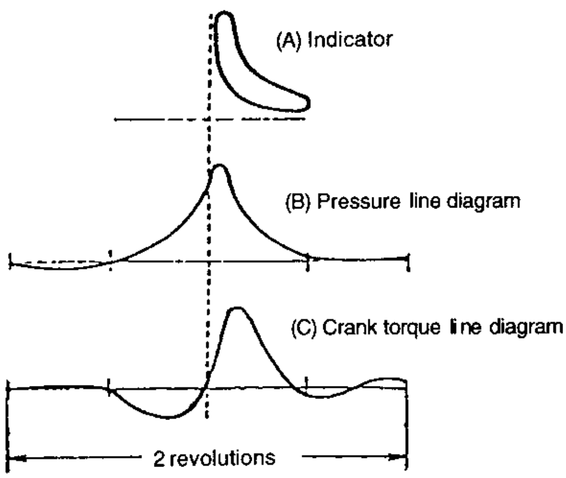

Fig. 5 Cylinder pressure change and crank torque change

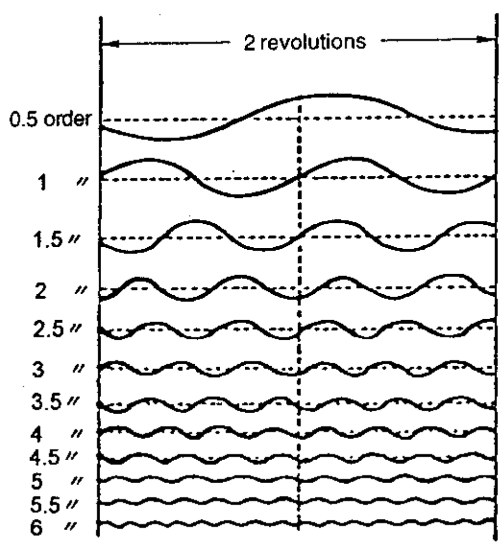

Fig. 6 Crank torque harmonics

16-2-4 Forced vibration of multi-cylinder engine

As described in the preceding section, torque harmonics of respective degrees of order act on the engine crankshaft as the source of vibration. Therefore, if only one natural frequency of the vibratory system is present, there will be generated a number of revolutions, called the critical speed, that resonates with the torque harmonics. The level of criticality in the critical speed is determined by the scale of work performed by the torque harmonics of the pertinent degree of order to vibration. Thus far descriptions of torque harmonics have been made for the single cylinder engine. In the case of a multi-cylinder engine, the level of criticality in the critical speed is determined by the size of total torque harmonics in consideration of the phases of respective cylinders of the pertinent degree of order.

In other words, the amplitude of vibration for the critical speed is proportional to the size of a job performed by the torque harmonics of the pertinent degree of order.

As described above, there are a number of critical speed, but their level of criticality is determined by the size of the torque harmonics. Therefore, it is not necessary to handle torque harmonics of a lower degree of order as objects of criticality. Consideration should be given to the degrees of order having the harmonics of a certain size or more.

Generally, with 4-cycle engines, torque harmonics of the degree of order equivalent to one half of the number of cylinders multiplied by an integer is called the major critical speed, which is an object of criticality.

With the 4-cycle engine,

$$\text{Major critical speed} = \frac{\text{Natural frequency}}{1/2 \times \text{Number of cylinders} \times \text{Integer}} \quad \cdots\cdots\cdots\cdots\cdots (1)$$

(Integer: 1, 2, 3, ...)

(The denominator represents a degree of order.)

Beside the major critical speed, there is a case where torque harmonics of other degrees of order than stated above may become the object of criticality depending on the crank layout and/or firing order. Table 1 indicates the degrees of order for critical speed that cause practical problems, and that have to be avoided.

Table 1 Order of critical speed that cause practical problems

(For 4-cycle engine)

Number of cylinders (crank layout)	First mode vibration	Second mode vibration
1 & 2	No consideration required for practical application	
3	3, 4-½, 6	No consideration required
4 (180° crank)	4, 6, 8	No consideration required
4 (90° crank)	4, 4-½, 5-½, 6-½, 7-½, 8	No consideration required
5	2-½, 5, 7-½,	5, 7-½,
6	3, 4-½, 6, 7-½,	6, 7-½, 9

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16-3 Actual Processing for Torsional Vibration

It is assumed that the reader understands the outline of torsional vibration of diesel engines described so far. This section describes how to process the torsional vibration for practical application. When planning a device using a diesel engine as the prime mover, it is important to ensure that no critical speed is present within or in the vicinity of the range of revolution at which the driven machine, whether a generator, a pump or other equipment, is driven. To do this, it is customary to select an appropriate natural frequency of a vibratory system configured with the engine and the driven machine.

Generally, a desired natural frequency is achieved by changing the equivalent length of the generator shaft or the transmission shaft of a pump or fan so as not to cause resonance with engine torque harmonics.

Therefore, when a rough plan for the machine is completed, it is necessary to review in advance the various materials needed for studying the torsional vibration of the engine, driven machine and the drive line, that is, the moment of inertia, etc. of the rotor (such as the generator rotor, pump vanes, fan, etc.) attached to the shaft.

This is laborious work but it has to be done to prevent accidents caused by torsional vibration. To do this, the driven machine manufacturer's cooperation is imperative.

16-4 Avoidance and Suppression of Torsional Vibration

To avoid the risk of torsional vibration, it is necessary, as already described, to either avoid the critical speed by changing the natural frequency or to suppress the amplitude of vibration to a lower level.

For the former, there are three methods; namely changing the natural frequency by changing the driven shaft system as described, by changing the equivalent length of the shaft system by inserting a flexible joint between the engine and the driven machine or by changing the equivalent mass by adding mass to the front pulley. For the latter, a rubber damper and/or viscous damper are used. If a damper is used for a constant-speed engine, the damper absorbs vibration energy constantly. In view of the durability of the damper, use of a damper for the constant-speed engine is not recommended.

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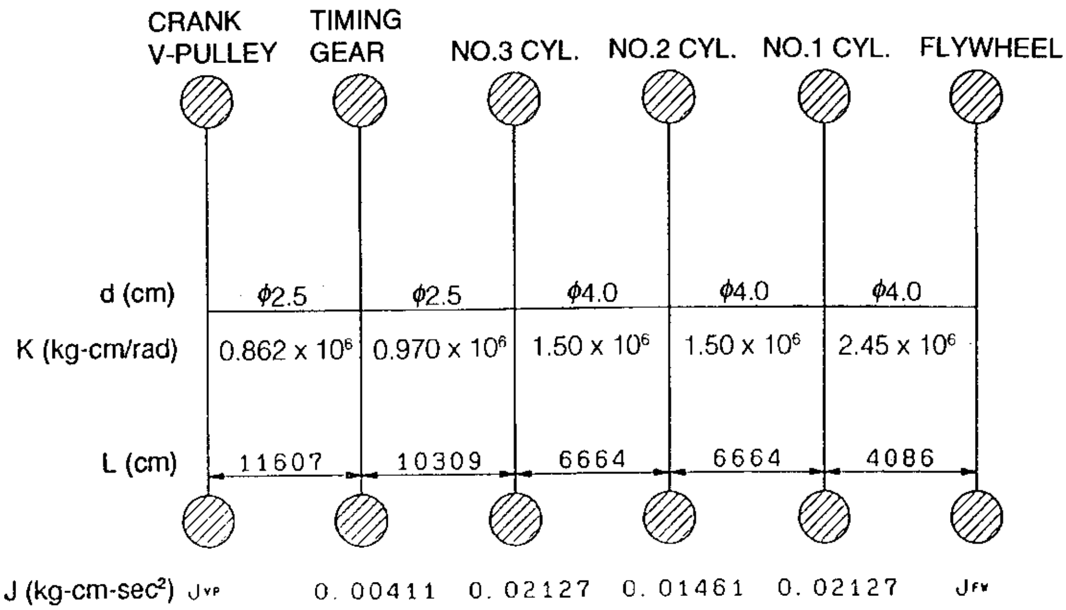
16-5 Torsional Vibration Equivalent Vibration System

(1) 3TNE68



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.00849	119260-21650 (φ95)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
1.1531	119260-21590	0.4520
1.8431	119600-21580	0.7225
2.5510	119643-21590	1.0000
2.6275	119688-21590	1.0320
1.7347	119645-21590	0.6800
1.1735	119233-21590	0.460
1.8431	119265-21590	0.7225

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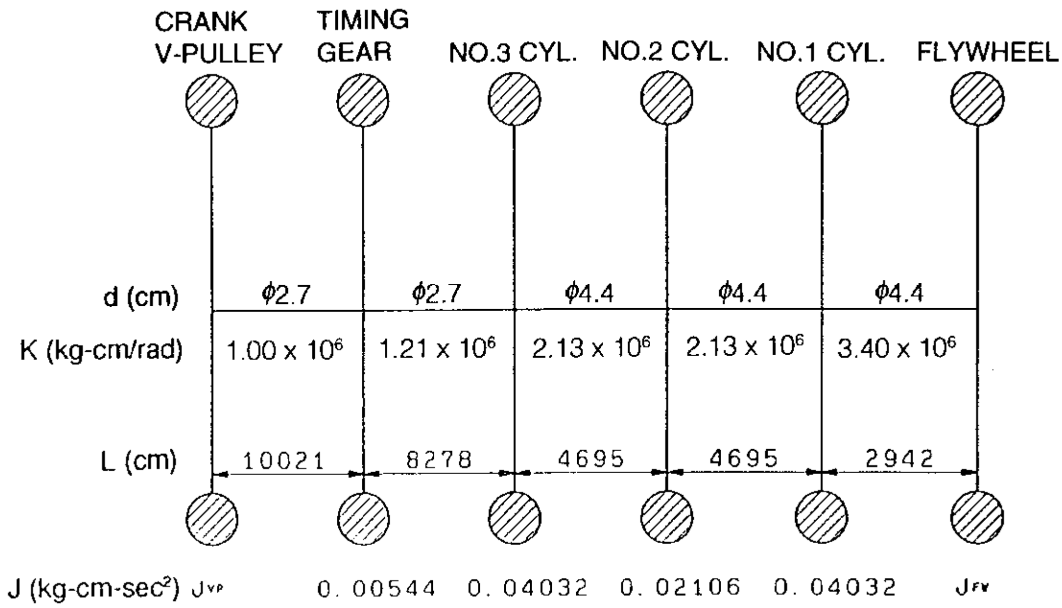
(2) 3TNE74



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.00842	119649-21650 (φ105)	
0.01300	119660-21651 (φ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
1.8431	119600-21580	0.7225
2.5510	119643-21590	1.0000
2.6275	119688-21590	1.0305
1.7347	119645-21590	0.6800
2.2194	119600-21570	0.8700
1.1735	119233-21590	0.460
1.8431	119265-21590	0.7225

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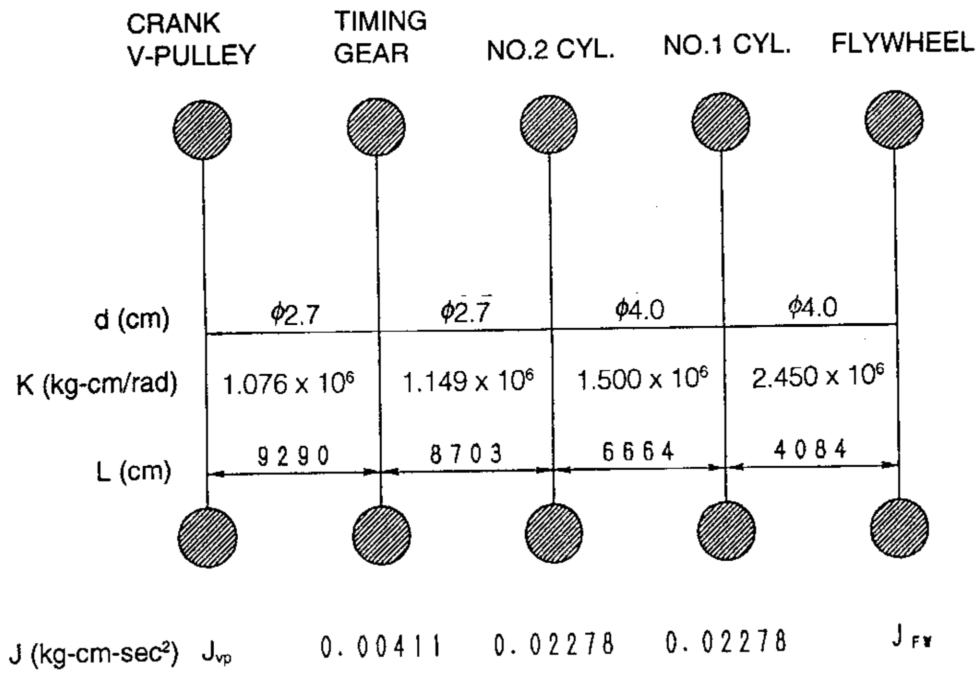
(3) 2TNE68-N



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

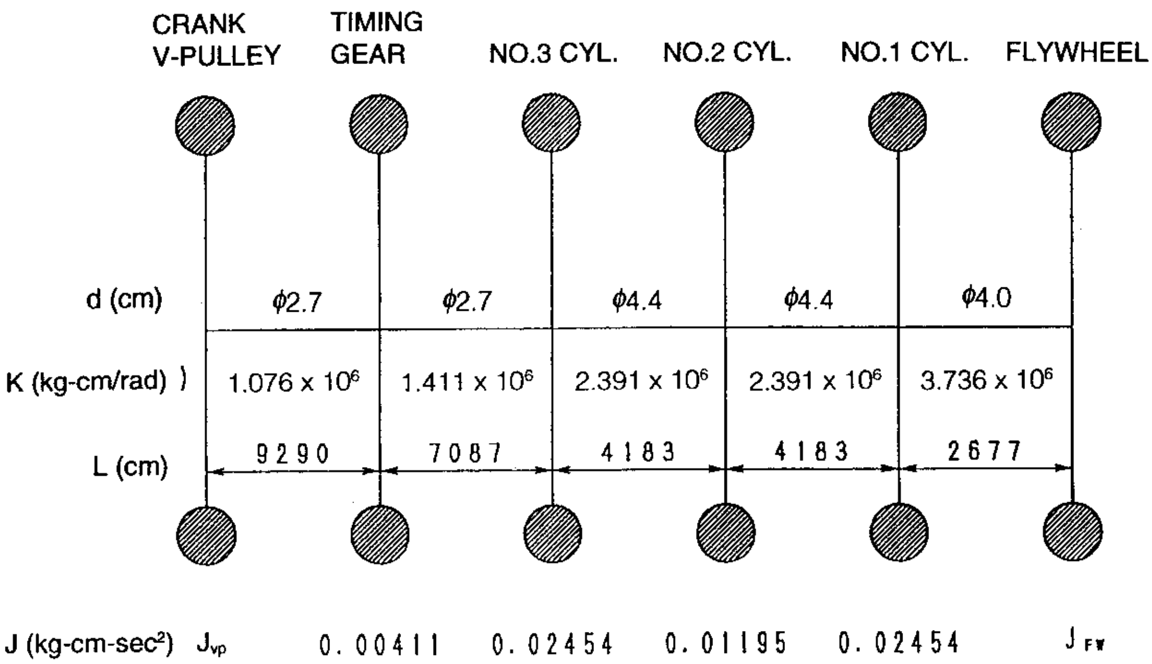
Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01276	119326-21650 (φ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
1.1531	119326-21580 (VM)	0.452

(4) 3TNE66-N



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01041	119275-21670 (φ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2

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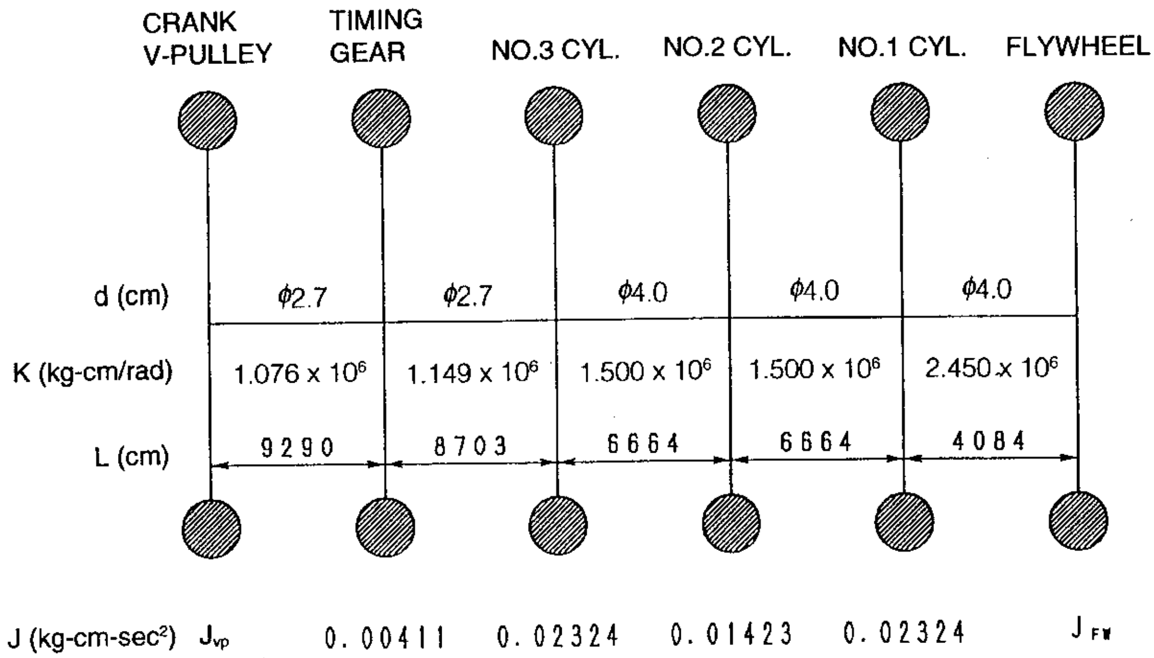
(5) 3TNE68-N



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

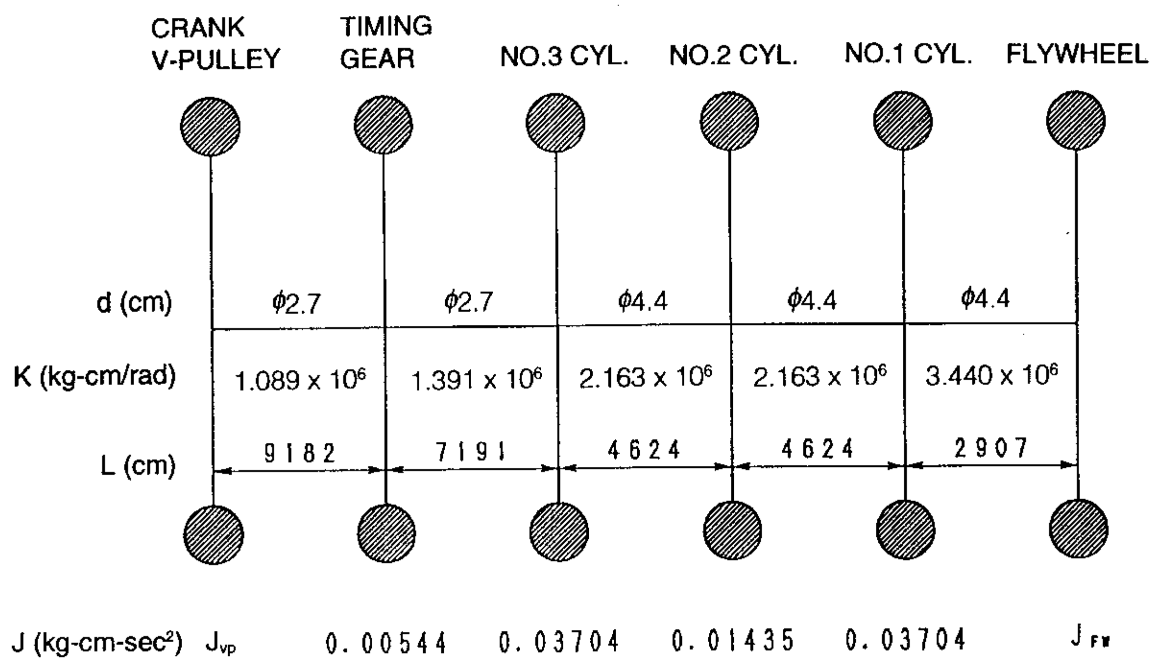
Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01276	119266-21650 (ϕ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
1.1531	119266-21590 (VM)	0.452

(6) 3TNE72-N



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

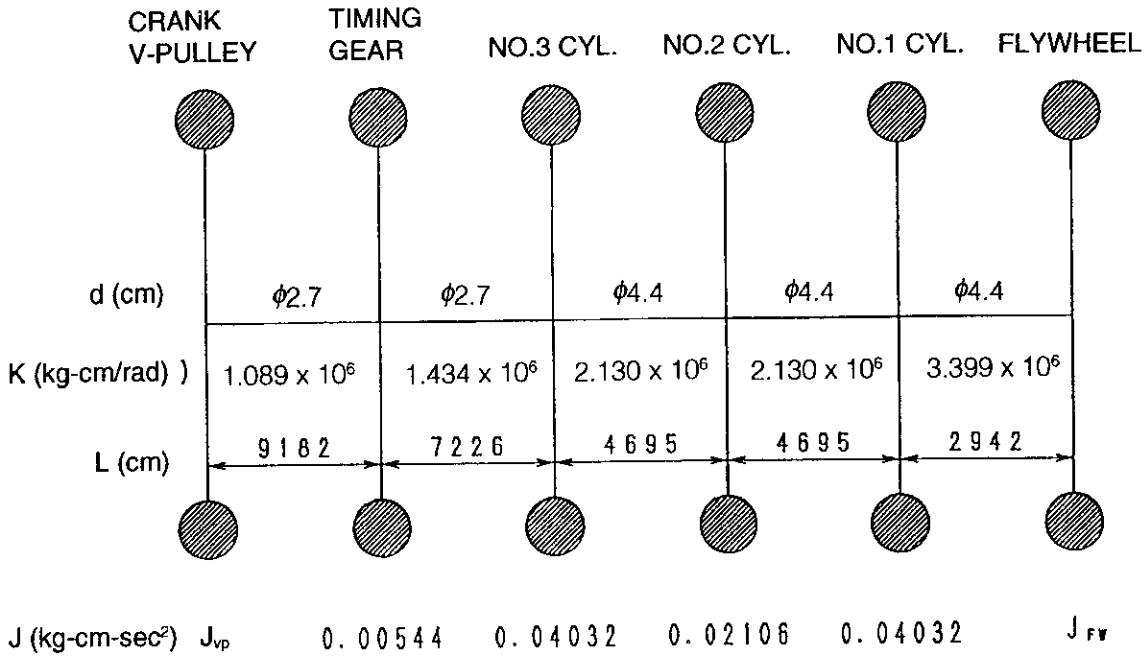
Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01041	119275-21670 (ϕ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
2.2194	119636-21580	0.8700

(7) 3TNE74-N



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

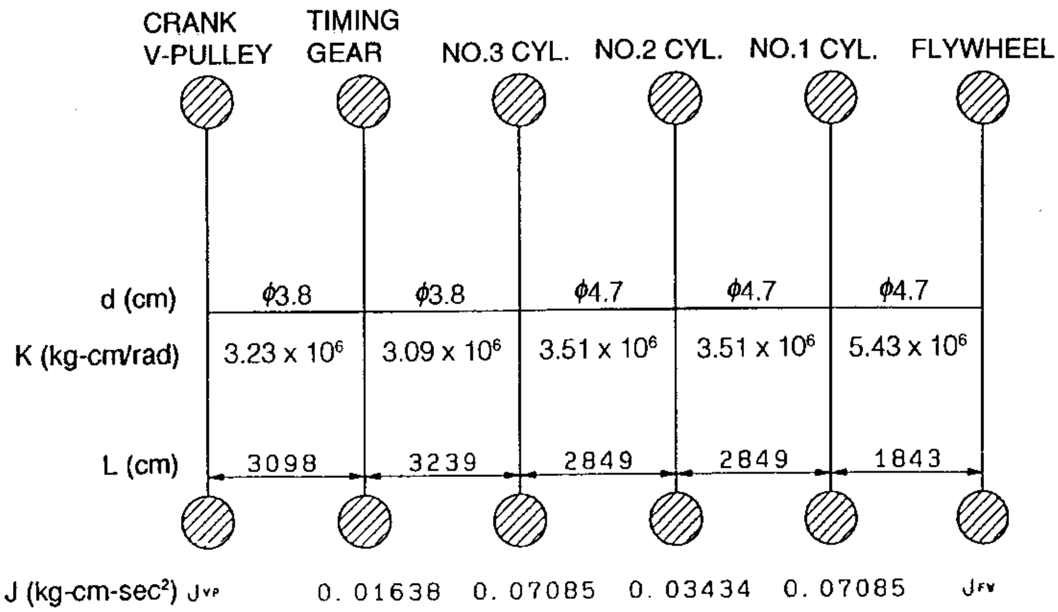
Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01276	119266-21650 (ϕ110)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
2.2194	119624-21580	0.8700

(8) 3TNE78A



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01794	171301-21650 (ϕ110)	
0.02364	129550-21650 (ϕ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171301-21590 (CL)	1.7400
2.2959	171301-21580 (CH)	0.9000
2.2449	171325-21590 (VM)	0.8800
2.6275	119888-21590	1.0300

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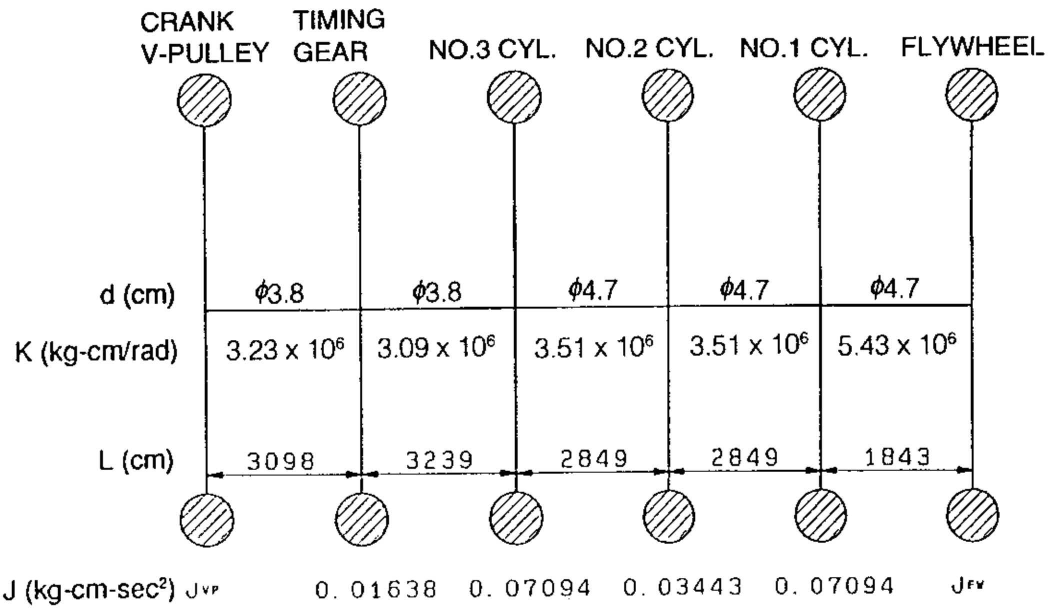
(9) 3TNE82A



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01794	171301-21650 (φ110)	
0.02364	129550-21650 (φ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171301-21590 (CL)	1.7400
2.2959	171301-21580 (CH)	0.9000
2.2449	171325-21590 (VM)	0.8800
2.6275	119888-21590	1.0300

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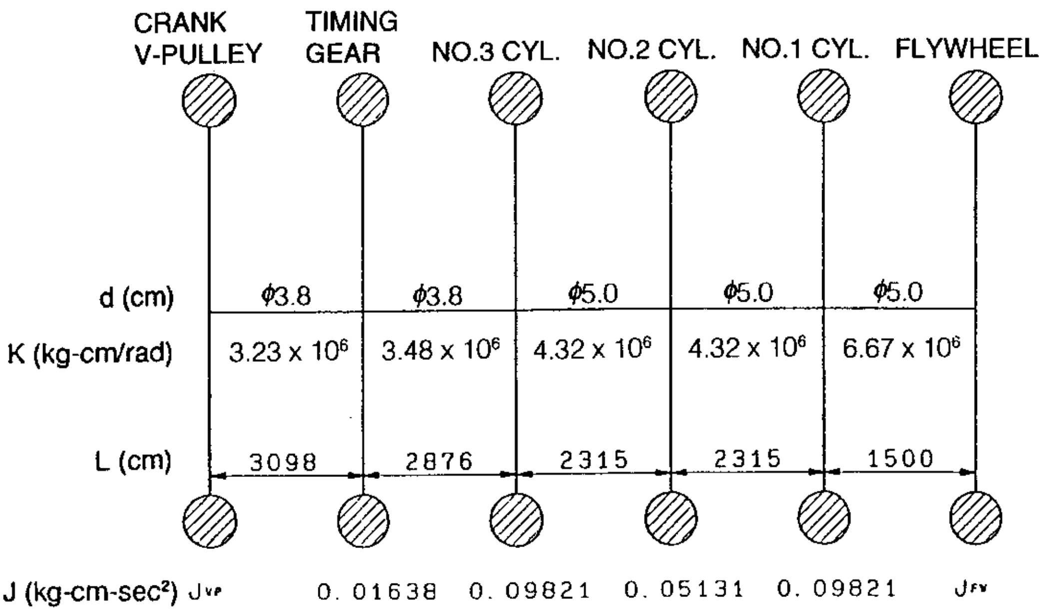

J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01612	171340-21650 (φ110)	
0.02383	129150-21651 (φ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171340-21590 (CL)	1.7400
3.3673	171350-21590 (VM)	1.3200
2.3214	171340-21580 (CH)	0.9100
2.2449	129128-21590 (VM)	0.8800
3.3418	129188-21590	1.3100

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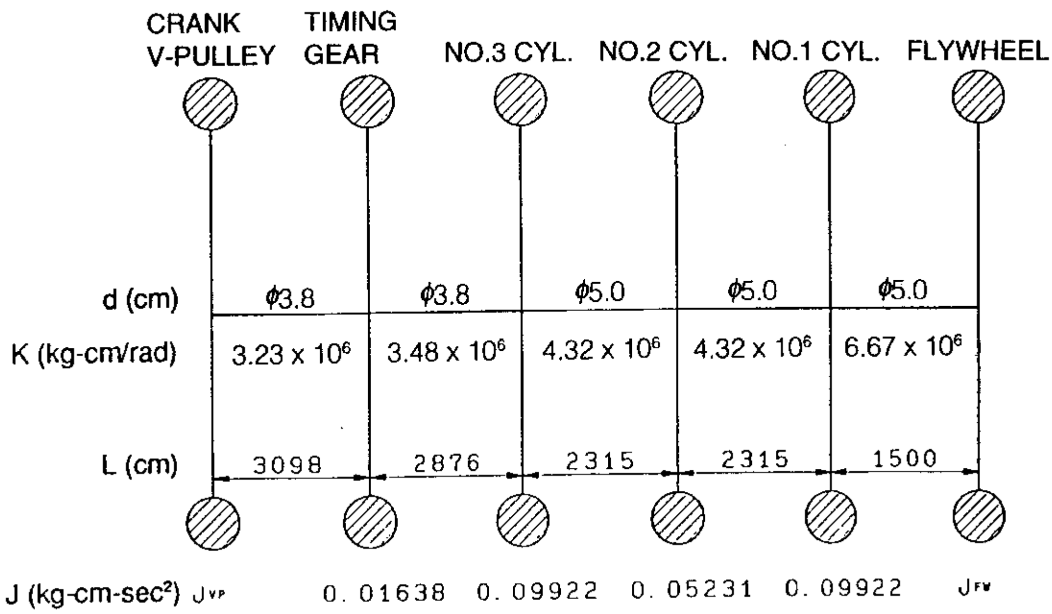
(11) 3TNE88



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

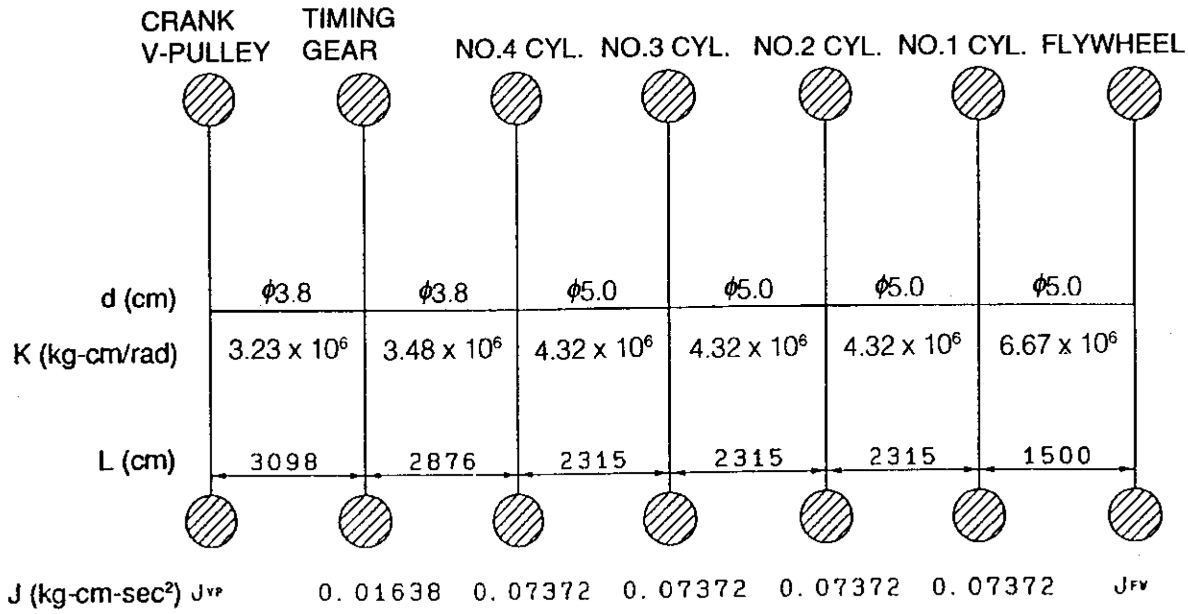
Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01612	171340-21650 (φ110)	
0.02383	129150-21651 (φ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171340-21590 (CL)	1.7400
3.3673	171350-21590 (VM)	1.3200
2.2449	129128-21590 (VM)	0.8800
3.3418	129188-21590	1.3100

(12) 4TNE84(T)



J: Moment of inertia (kg-cm-sec^2)

K: Spring constant (kg-cm/rad)

L: Equivalent length (cm)

d: Shaft dia. (cm)

J_{VP}: Moment of inertia of crank V-pulley

J_{FW}: Moment of inertia of flywheel

Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01794	171301-21650 (φ110)	
0.02364	129550-21650 (φ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171420-21590 (CL)	1.7400
2.0281	129403-21590 (VM)	0.7950
2.2449	129489-21590 (VM)	0.8800
2.3214	171420-21590 (CH)	0.9100
3.3418	129188-21590 (SAE#5)	1.3100

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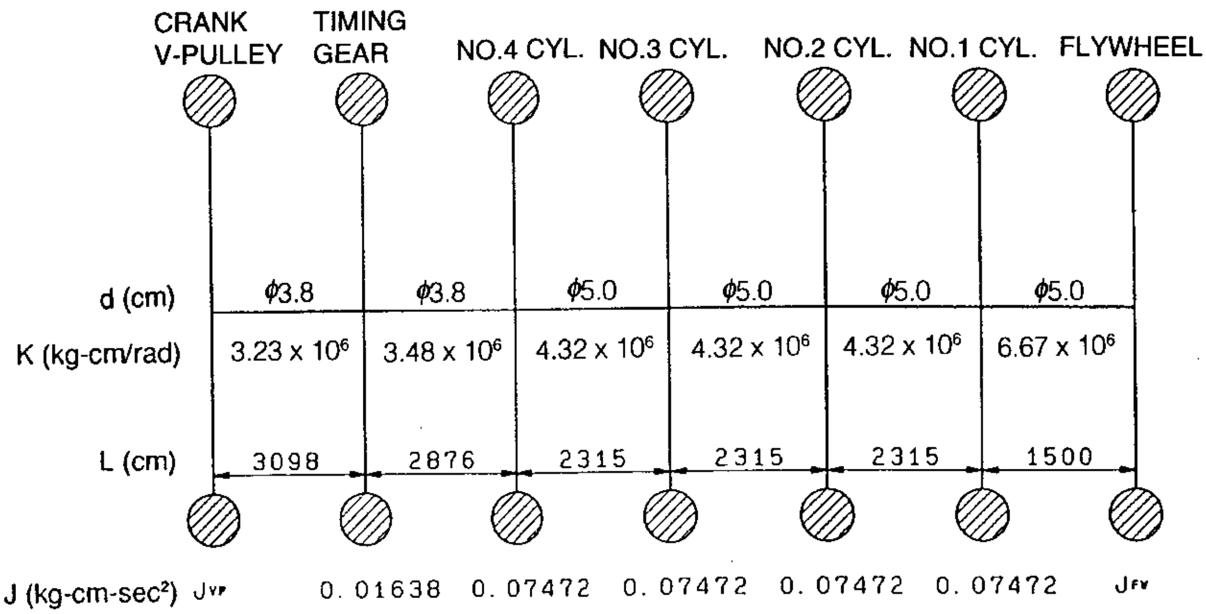
(13) 4TNE88



J: Moment of inertia (kg-cm-sec^2)

K: Spring constant (kg-cm/rad)

L: Equivalent length (cm)

d: Shaft dia. (cm)

J_{VP}: Moment of inertia of crank V-pulley

J_{FW}: Moment of inertia of flywheel

Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.01794	171301-21650 (ϕ110)	
0.02364	129550-21650 (ϕ120)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
4.4387	171420-21590 (CL)	1.7400
2.0281	129403-21590 (VM)	0.7950
2.2449	129489-21590 (VM)	0.8800
3.3418	129488-21590 (SAE#5)	1.3100

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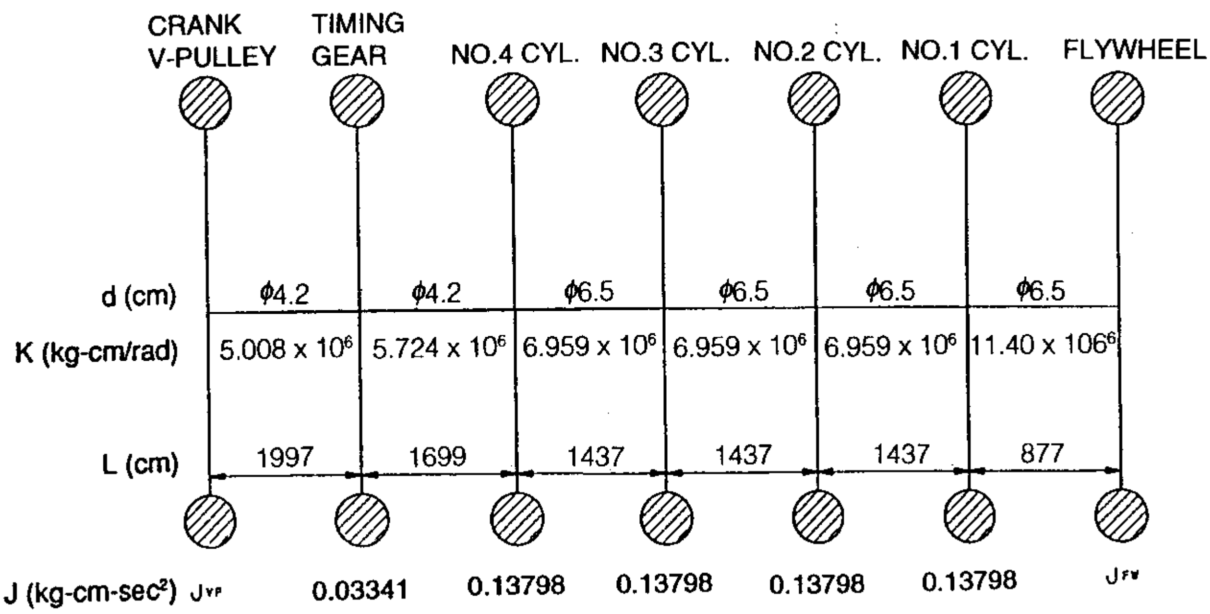
(14) 4TNE94



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.0135	129900-21690 (ϕ110)	
0.0168	129900-21650 (ϕ120)	
0.0217	129900-21660 (ϕ130)	
0.0255	129900-21670 (ϕ130)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
5.0510	129902-21580 (CL)	1.98
2.9847	129900-21580 (VM)	1.17
6.1734	129955-21590	2.42
7.2193	129920-21580	2.83

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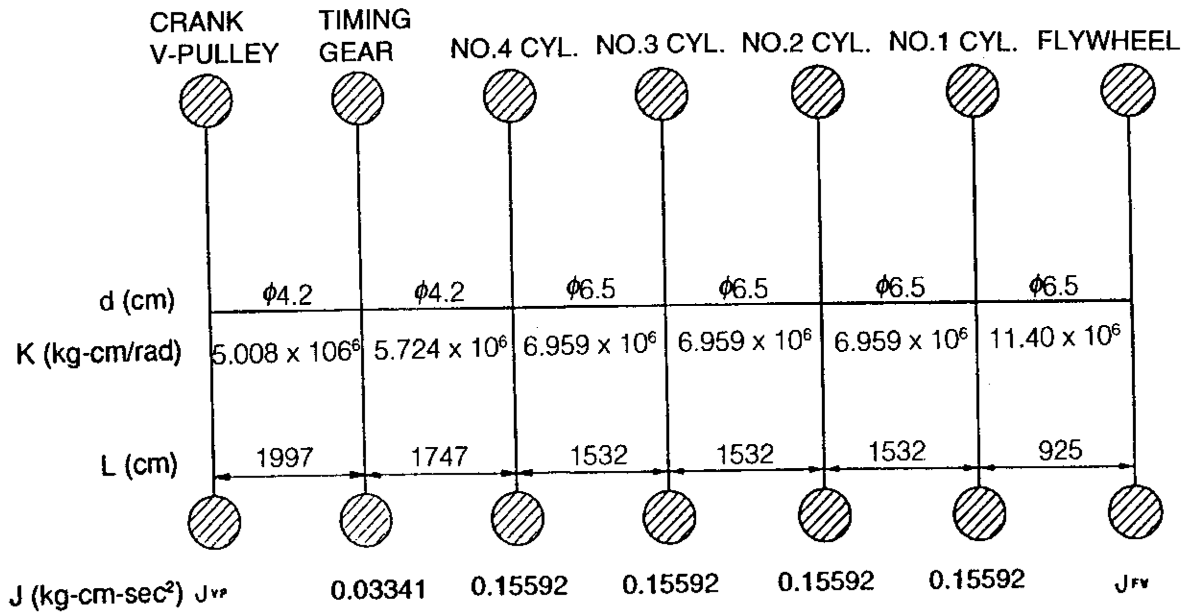
(15) 4TNE98



J: Moment of inertia (kg-cm-sec^2)
K: Spring constant (kg-cm/rad)
L: Equivalent length (cm)
d: Shaft dia. (cm)
J_{VP}: Moment of inertia of crank V-pulley
J_{FW}: Moment of inertia of flywheel
Equivalent shaft dia.: 18.72 cm

Crankshaft V-pulley moment of inertia

J_{VP}	Code No.	GD^2
0.0135	129900-21690 (φ110)	
0.0168	129900-21650 (φ120)	
0.0217	129900-21660 (φ130)	
0.0255	129900-21670 (φ130)	

Flywheel moment of inertia

J_{FW}	Code No.	GD^2
5.0510	129902-21580 (CL)	1.98
2.9847	129900-21580 (VM)	1.17
6.1734	129955-21590	2.42
7.2193	129920-21580	2.83

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17. Reference Materials for Engineering Calculation

Part of this technical reference is simplified to facilitate on-site calculation. Care should be taken when using this section when a high level of precision is required for design and tests.

17-1 Principal Conversion Table for the Engine Specifications

(1) Output

The output is in kW in principle, but hp and PS are also often used. Conversion factors are as follows:

kW	hp	PS
1	1.3410	1.3596
0.7457	1	1.0139
0.7355	0.9863	1

(Reference) 1 PS = 75 kgf • m/s
1 kW = 101.9716 kgf • m/s

(2) Pressure

Irrespective of lubricant pressure, JIS and SAE use only kPa (kilo Pascal) as the unit of pressure for engine performance.

kPa	MPa	kgf/cm^2	mmAq (H_2O)	mmHg (Torr)
1	1×10^{-3}	1.01972×10^{-2}	1.01972×10^{2}	7.50062
1×10^{3}	1	1.01972×10	1.01972×10^{5}	7.50062×10^{3}
9.80665×10	9.80665×10^{-2}	1	1×10^{4}	7.35559×10^{2}
9.80665×10^{-3}	9.80665×10^{-6}	1×10^{-4}	1	7.35559×10^{-2}
1.33322×10^{-1}	1.33322×10^{-4}	1.35951×10^{-3}	1.35951×10	1

1 kgf/cm^2 = 98 kPa
= 0.098 MPa
750 mmHg = 100 kPa

1 kPa = 0.0102 kgf/cm^2
1 Mpa = 10.2 kgf/cm^2
1 Pa = 1 N/m^2

(3) Specific fuel and lubricating oil consumption

g/kWh	g/hph	g/PSh
1	0.7457	0.7355
1.3410	1	0.9863
1.3596	1.0139	1

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(4) Torque

N • m	kgf • m
1	1.01972×10^{-1}
9.80665	1

1 kgf = 9.80665 N

17-2 Fuel Tank Holding Time

(1) Fuel consumption ℓ/h

$$B = \frac{b \times P_e}{d} \times 10^{-3}$$

B	:	Fuel consumption	ℓ/h
b	:	Specific fuel consumption	g/kWh (g/hph or g/PSh)
P_e	:	Rated output	kW (hp or PS)
d	:	Specific gravity of fuel	Diesel fuel : 0.83

(2) Fuel tank holding time h

$$t = \frac{V}{B}$$

t	:	Fuel tank holding time	h
V	:	Effective capacity of fuel tank	ℓ
B	:	Fuel consumption	ℓ/h

(3) Example of calculation

According to the specification sheet for the 3TNE84 series diesel engine, the continuous rating at 1800 rpm is 13.5 kW and the fuel consumption is 238 g/kWh. For how many hours will a fuel tank having an effective capacity of 20 ℓ last at the continuous rating?

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(a) Fuel consumption ℓ/h

$$B = \frac{b \times P_e}{d} \times 10^{-3}$$

$$= \frac{238 \times 13.5}{0.83} \times 10^{-3}$$

$$= 3.87 \ \ell/h$$

B	:	Fuel consumption		ℓ/h
b	:	Specific fuel consumption	238	g/kWh
P_e	:	Rated output	13.5	kW
d	:	Specific gravity of fuel	Diesel fuel:	0.83

(b) Fuel tank holding time h

$$t = \frac{V}{B}$$

$$= \frac{20}{3.87}$$

$$= 5.2 \ h$$

t	:	Fuel tank holding time		h
V	:	Effective capacity of fuel tank	20	ℓ
B	:	Fuel consumption	3.87	ℓ/h

17-3 Oil Pan Holding Time

(1) Lubricating oil consumption ℓ/h

$$C = \frac{c \times P_e}{d} \times 10^{-3}$$

C	:	Lubricating oil consumption	ℓ/h	
c	:	Specific lubricating oil consumption	g/kWh	(g/hph or g/PSh)
P_e	:	Rated output	kW	(hp or PS)
d	:	Specific gravity of lubricating oil	0.89	

(2) Oil pan holding time h

$$t = \frac{V}{C}$$

t	:	Oil pan holding time	h
V	:	Effective capacity of oil pan	ℓ
C	:	Lubricating oil consumption	ℓ/h

(3) Calculation example

> According to the specification sheet for the 3TNE74 series diesel engine, the effective capacity of the standard oil pan in CH specifications is 1.9 ℓ.
> When driven at the continuous rating of 17.4 kW for 3600 rpm, for how many hours will the oil pan last? The specific lubricating oil consumption is 0.8 g/kWh.

(a) Lubricating oil consumption ℓ/h

$$C = \frac{c \times P_e}{d} \times 10^{-3}$$

$$= \frac{0.8 \times 17.4}{0.89} \times 10^{-3}$$

$$= 15.64 \times 10^{-3} \text{ ℓ/h}$$

B	:	Lubricating oil consumption		ℓ/h
c	:	Specific lubricating oil consumption	0.8	g/kWh
P_e	:	Continuous rating	17.4	kW
d	:	Specific gravity of lubricating oil	0.89	

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(b) Oil pan holding time h

$$t = \frac{V}{C}$$

$$= \frac{1.9}{15.64 \times 10^{-3}}$$

$$= 121 \text{ h}$$

t	:	Oil pan holding time	h
V	:	Effective capacity of oil pan	1.9 ℓ
C	:	Lubricating oil consumption	15.64×10^{-3} ℓ/h

17-4 Mean Piston Speed

(1) Mean piston speed m/s

$$V_m = \frac{2S \cdot n}{60} \times 10^{-3}$$

V_m	:	Mean piston speed	m/s
S	:	Engine stroke	mm
n	:	Engine revolution	rpm

(2) Calculation example

> According to the specification sheet for the 3TNE84 series diesel engine, the piston stroke is 90 mm. What is the mean piston speed for 3600 rpm of engine revolution in CH specifications?

$$V_m = \frac{2S \cdot n}{60} \times 10^{-3}$$

$$= \frac{2 \times 90 \times 3600}{60} \times 10^{-3}$$

$$= 10.8 \text{ m/s}$$

V_m	:	Mean piston speed	m/s
S	:	Engine stroke	90 mm
n	:	Engine revolution	3600 rpm

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17-5 Total Displacement

(1) Total displacement cc

$$V_{st} = \frac{\pi}{4} D^2 SN \times 10^{-3}$$

V_{st}	:	Total displacement	cc
D	:	Bore	mm
S	:	Stroke	mm
N	:	Number of cylinders	

(2) Calculation example

> According to the specification sheet for the 3TNE74 series diesel engine, the cylinder bore is 74 mm, and the piston stroke is 78 mm. What is the total displacement of this engine?

$$V_{st} = \frac{\pi}{4} D^2 SN \times 10^{-3}$$

$$= \frac{\pi}{4} \times 74^2 \times 78 \times 3 \times 10^{-3}$$

$$= 1006 \text{ cc}$$

V_{st}	:	Total displacement		cc
D	:	Bore	74	mm
S	:	Stroke	78	mm
N	:	Number of cylinders	3	
π	:	3.1416		

(Reference)

Japan and America have different approaches to the processing of the decimal point.

Japanese system : Omits the figures below the decimal point.

American system : Counts fractions of .5 and over as a unit and discards the rest.

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17-6 Torque

(1) Torque T_{tq}

Output unit P_e		Torque T_{tq}	
		N • m	kgf • m
(a)	kW	$9550 \times \frac{P_e}{n}$	$973.8 \times \frac{P_e}{n}$
(b)	hp	$7121 \times \frac{P_e}{n}$	$726.1 \times \frac{P_e}{n}$
(c)	PS	$7024 \times \frac{P_e}{n}$	$716.2 \times \frac{P_e}{n}$

T_{tq} : Torque — N • m (or kgf • m)
P_e : Output — kW (hp or PS)
n : Engine speed — rpm

1 kgf • m = 9.80665 N • m

(2) Calculation example

According to the specification sheet for the 4TNE84T series diesel engine, the rated output for a rated revolution of 2400 rpm is 33.5 kW. What is the rated torque?

Since the output is in unit of kW, equation (a) is used.

(i) To obtain the rated torque in N • m unit

$$T_{tq} = 9550 \times \frac{P_e}{n}$$

$$= 9550 \times \frac{33.5}{2400}$$

$$= 133 \text{ N} \cdot \text{m}$$

P_e : Output — 33.5 kW
n : Engine speed — 2400 rpm

(ii) To obtain the rated torque in kgf • m

$$T_{tq} = 973.8 \times \frac{P_e}{n}$$

$$= 973.8 \times \frac{33.5}{2400}$$

$$= 13.6 \text{ kgf} \cdot \text{m}$$

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17-7 Net Mean Effective Pressure

(1) Net mean effective pressure P_{me}

Output unit P_e		Net mean effective pressure P_{me} kPa	Net mean effective pressure P_{me} kgf/cm²
(a)	kW	$\frac{120.0 \times P_e}{V_{st} \bullet n} \times 10^3$	$\frac{1224 \times P_e}{V_{st} \bullet n}$
(b)	hp	$\frac{89.49 \times P_e}{V_{st} \bullet n} \times 10^3$	$\frac{912.5 \times P_e}{V_{st} \bullet n}$
(c)	PS	$\frac{88.26 \times P_e}{V_{st} \bullet n} \times 10^3$	$\frac{900 \times P_e}{V_{st} \bullet n}$

P_{me} : Net mean effective pressure — kPa (kgf/cm²)
P_e : Output — kW (hp or PS)
V_{st} : Total displacement — ℓ (here no cc (metric) unit is in use)
n : Engine speed — rpm

1 kgf/cm² = 9.80665 × 10 kPa

(2) Calculation example

> According to the specification sheet for the 4TNE84T series diesel engine, the rated output for the rated revolution of 2400 rpm is 33.5 kW. What is the net mean effective pressure? The total displacement of the engine is 1995 cc.

Since the unit is in kW, equation (a) is used.

P_e : Output — 33.5 kW
V_{st} : Total displacement — 1.995 ℓ
n : Engine revolution — 2400 rpm

(i) To obtain the net mean effective pressure in unit of kPa

$$P_{me} = \frac{120.0 \times P_e}{V_{st} \bullet n} \times 10^3 = \frac{120.0 \times 33.5}{1.995 \times 2400} \times 10^3 = 840 \text{ kPa}$$

(ii) To obtain the net mean effective pressure in unit of kgf/cm²

$$P_{me} = \frac{1224 \times P_e}{V_{st} \bullet n} = \frac{1224 \times 33.5}{1.995 \times 2400} = 8.56 \text{ kgf/cm}^2$$

17-8 Fuel Injection

This value represents the fuel injection per 1000 strokes of one plunger of a fuel injection pump in weight.

(1) Fuel injection g/1000 st

$$Q = \frac{b \cdot P_e}{60 \cdot (n/2) \cdot N} \times 10^3$$

Q	:	Fuel injection quantity	g/1000 st
b	:	Specific fuel consumption	g/kWh
P_e	:	Output	kW
n	:	Engine speed	rpm
N	:	Number of engine cylinders	

(2) Calculation example

According to the specification sheet for the 4TNE98 series diesel engine, the rated output for the rated revolution of 2500 rpm is 51.1 kW and the specific fuel consumption is 224 g/kWh. What is the injection quantity?

Q	:	Fuel injection quantity		g/1000 st
b	:	Specific fuel consumption	224	g/kWh
P_e	:	Output	51.1	kW
n	:	Engine speed	2500	rpm
N	:	Number of engine cylinders	4 cylinders	

$$Q = \frac{b \cdot P_e}{60 \cdot (n/2) \cdot N} \times 10^3$$

$$= \frac{224 \times 51.1}{60 \times (2500/2) \times 4} \times 10^3$$

= 38.2 g/1000 st

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17-9 Cyclic Irregularity (or Coefficient of Speed Fluctuation)

(1) Meaning of cyclic irregularity

$$\delta = \frac{\omega_{max} - \omega_{min}}{\omega_{mean}} \times 100$$

δ	:	Cyclic irregularity	%
ω_{max}	:	Maximum angular velocity during 1 cycle	rad/sec
ω_{min}	:	Minimum angular velocity during 1 cycle	rad/sec
ω_{mean}	:	Mean angular velocity during 1 cycle	rad/sec

The revolution angular velocity of an engine fluctuates cyclically during one cycle. The cyclic irregularity represents the percentage of fluctuation from the mean angular velocity (JIS B 0108-8.13). A theoretical formula can be derived from this, but generally Sass' empirical formula as follows is used:

(2) Cyclic irregularity by Sass' empirical formula
The cyclic irregularity by Sass' empirical formula is expressed as a fraction with a numerator of 1. This is customarily used.
For Sass' constant used for this empirical formula, see item (3).

(a) If output is in unit of kW:

$$\delta = \frac{1}{\dfrac{n^3 \times GD^2}{K \times P_i} \times 0.7355}$$

δ	:	Cyclic irregularity	
n	:	Engine speed	rpm
GD^2	:	Inertia weight of flywheel	kg • m^2
K	:	Sass' constant	
P_i	:	Indicated output of engine $P_i = P_e / 0.8$	kW
P_e	:	Rated output of engine	kW

(b) If the output is in hp unit:

$$\delta = \frac{1}{\dfrac{n^3 \times GD^2}{K \times P_i} \times 1.0139}$$

P_i	:	Indicated output of engine $P_i = P_e / 0.8$	hp
P_e	:	Rated output of engine	hp

(c) If the output is in unit of PS:

$$\delta = \frac{1}{\dfrac{n^3 \times GD^2}{K \times P_i}}$$

P_i : Indicated output of engine: PS
$P_i = P_e / 0.8$
P_e : Rated output of engine PS

(3) Sass' constant K

Number of cylinders	Crank angle	Effect of supercharger	Sass' constant K
1	–	–	51×10^6
2	–	–	21×10^6
3	–	–	12.5×10^6
4	90°	–	11.8×10^6
	180°	–	2.7×10^6
5	–	–	4.8×10^6
6	–	None	1.6×10^6
	–	T	1.2×10^6
	–	HT, DT, UT	0.96×10^6

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(4) Calculation example

According to the specification sheet for the 4TNE98 series diesel engine, the rated output for a rated revolution of 1500 rpm is 34.6 kW. Based on the torsional vibration materials in Chapter 16, the inertia weight GD^2 of a flywheel is 1.98 kg • m^2 for CL specifications. What is cyclic irregularity for this combination?

Since the output is in unit of kW, formula (a) is used. The 4TNE98 has 4 cylinders, and all of the 4 cylinders of the TNE series use a 180° crank.

δ	:	Cyclic irregularity		
n	:	Engine speed	1500	rpm
GD^2	:	Inertia weight of flywheel	1.98	kg • m^2
K	:	Sass' constant (4-cylinder, 180° crank)	2.7×10^6	
P_i	:	Indicated output of engine	43.25	kW
		$P_i = P_e / 0.8$	(34.6/0.8)	
P_e	:	Rated output of engine	34.6	kW

$$\delta = \frac{1}{\dfrac{n^3 \times GD^2}{K \times P_i} \times 0.7355}$$

$$= \frac{1}{\dfrac{1500^3 \times 1.98}{2.7 \times 10^6 \times 43.25} \times 0.7355}$$

$$= \frac{1}{42}$$

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17-10 Thermal Efficiency and Heat Loss

(1) Thermal efficiency η

(a) If specific fuel consumption is in unit of kW:

$$\eta = \frac{8.6000 \times 10^2 \times P_e}{H_u \times b \times P_e \times 10^{-3}} \times 10^2$$

$$= \frac{83.50}{b} \times 10^2$$

η	:	Thermal efficiency		%
P_e	:	Engine output		kW
H_u	:	Lower calorific value of diesel fuel	10300	kcal/kg
b	:	Specific fuel consumption		g/kWh

1 kW = 8.6000×10^2 kcal/h

(b) If specific fuel consumption is in unit of hp:

$$\eta = \frac{6.23610 \times 10^2 \times P_e}{H_u \times b \times P_e \times 10^{-3}} \times 10^2$$

$$= \frac{60.54}{b} \times 10^2$$

η	:	Thermal efficiency		%
P_e	:	Engine output		hp
H_u	:	Lower calorific value of diesel fuel	10300	kcal/kg
b	:	Specific fuel consumption		g/hph

1 hp = 6.23610×10^2 kcal/h

(c) If specific fuel consumption is in unit of PS:

$$\eta = \frac{6.32529 \times 10^2 \times P_e}{H_u \times b \times P_e \times 10^{-3}} \times 10^2$$

$$= \frac{61.41}{b} \times 10^2$$

η	:	Thermal efficiency		%
P_e	:	Engine output		PS
H_u	:	Lower calorific value of diesel fuel	10300	kcal/kg
b	:	Specific fuel consumption		g/PSh

1 PS = 6.32529×10^2 kcal/h

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(d) Calculation example

The specific fuel consumption for the 4TNE98 series diesel engine for a rated output of 51.1 kW at the rated revolution of 2500 rpm is 224 g/kWh. What is the thermal efficiency?

Since the specific fuel consumption is in unit of kW, formula (a) is used.

$$\eta = \frac{83.50}{b} \times 10^2$$

$$= \frac{83.50}{224} \times 10^2$$

$$= 0.373 \times 10^2$$

$$= 37\%$$

(2) Exhaust loss ϕ_{ex}

$$\phi_{ex} = \frac{\{\eta_t \cdot V_{st} \cdot 10^{-3} \cdot n / (2 \times 60)\} \cdot c \cdot t_{ex}}{H_u \cdot b \cdot 10^{-3} \cdot P_e / 3600} \times 10^2$$

ϕ_{ex}	:	Exhaust loss	%
V_{st}	:	Total displacement	ℓ
n	:	Engine speed	rpm
η_t	:	Intake efficiency (if unknown, use 0.85)	
C_p	:	Specific heat at constant pressure	kcal/Nm^3°C
t_{ex}	:	Exhaust temperature	°C

Exhaust temperature t_{ex} °C	Mean specific heat c kcal/Nm^3°C
200	0.313
300	0.315
400	0.318
500	0.321
600	0.324

H_u	:	Lower calorific value of diesel fuel	10300 kcal/kg	
b	:	Specific fuel consumption	g/kWh	(g/hph, g/PSh)
P_e	:	Engine output	kW	(hp, PS)

$$\phi_{ex} = 2.9126 \times 10^{-3} \frac{V_{st} \cdot n \cdot \eta_t \cdot c \cdot t_{ex}}{b \cdot P_e} \times 10^2$$

Calculation example

> The specific fuel consumption of the 3TN78L series diesel engine for the rated output of 16.8 kW at the rated revolution of 2500 rpm is 245 g/kWh, and the exhaust temperature is 500°C. What is the exhaust loss?

ϕ_{ex}	:	Exhaust loss		%
V_{st}	:	Total displacement	1.232	ℓ
n	:	Engine speed	2500	rpm
η_t	:	Intake efficiency	0.85	
c	:	Specific heat at constant pressure	0.321	kcal/Nm³°C
t_{ex}	:	Exhaust temperature	500	°C
b	:	Specific fuel consumption	245	g/kWh
P_e	:	Engine output	16.8	kW

$$\phi_{ex} = 2.9126 \times 10^{-3} \frac{V_{st} \bullet n \bullet \eta_t \bullet c_p \bullet t_{ex}}{b \bullet P_e} \times 10^2$$

$$= 2.9126 \times 10^{-3} \frac{1.232 \times 2500 \times 0.85 \times 0.321 \times 500}{245 \times 16.8} \times 10^2$$

$$= 0.297 \times 10^2$$

$$= 30\%$$

(3) Cooling loss ϕ_{cw}

$$\phi_{cw} = \frac{(Q_p/60) \bullet \rho \bullet C_p \bullet (t_{wo} - t_{wi})}{H_u \bullet b \bullet 10^{-3} \bullet P_e / 3600} \times 10^2$$

ϕ_{cw}	:	Cooling loss		%
Q_p	:	Cooling water pump discharge		ℓ/min
ρ	:	Specific weight	1	kg/ℓ
C_p	:	Specific heat at constant pressure	1	kcal/kg°C
t_{wo}	:	Cooling water temperature at engine outlet		°C
t_{wi}	:	Cooling water temperature at engine inlet		°C
H_u	:	Lower calorific value of diesel fuel	10300	kcal/kg
b	:	Specific fuel consumption		g/kWh (g/hph, g/PSh)
P_e	:	Engine output		kW (hp, PS)

$$\phi_{cw} = 5.8252 \times \frac{Q_p \bullet (t_{wo} - t_{wi})}{b \bullet P_e} \times 10^2$$

Calculation example

> The specific fuel consumption of the 3TN78L series diesel engine for the rated output of 16.8 kW at the rated revolution of 2500 rpm is 245 g/kWh. According to separate materials, the pump discharge is 38 ℓ per minute. If the difference of engine cooling water temperature between the outlet and inlet of the engine is 5°C, what is the cooling water loss of the engine?

ϕ_{cw}	: Cooling loss		%
Q_p	: Cooling water pump discharge	38	ℓ/min
$(t_{wo}-t_{wi})$	: Temperature difference of cooling water between the outlet and inlet of the engine	5	°C
b	: Specific fuel consumption	245	g/kWh
P_e	: Engine output	16.8	kW

$$\phi_{cw} = 5.8252 \times \frac{Q_p \cdot (t_{wo} - t_{wi})}{b \cdot P_e} \times 10^2$$

$$= 5.8252 \times \frac{38 \times 5}{245 \times 16.8}$$

$$= 0.269 \times 10^2$$

$$= 27\ \%$$

(4) Other loss ϕ_o

$$\phi_o = 100 - (\eta + \phi_{ex} + \phi_{cw})$$

ϕ_o	: Other loss	%
η	: Thermal efficiency	%
ϕ_{ex}	: Exhaust loss	%
ϕ_{cw}	: Cooling loss	%

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17-11 Generator

(1) Relation of capacity (output), voltage and current of AC generator

(a) Single-phase AC generator

Capacity (KVA) = Voltage (E) × current (I) × 10^{-3}

Output (kW) = Capacity (KVA) × power factor (pf)

E :	Voltage	V (volt)
I :	Current	A (ampere)
pf :	Power factor	1.0 for a single-phase AC generator in general

(b) 3-phase AC generator

Capacity (KVA) = $\sqrt{3}$ × voltage (E) × current (I) × 10^{-3}

Output (kW) = Capacity (KVA) × power factor (pf)

E :	Voltage	V (volt)
I :	Current	A (ampere)
pf :	Power factor	0.8 for a 3-phase AC generator in general

(2) Power factor

Power factor is a term for expressing the property of the load, and not for matters concerning the characteristics of a generator.

The efficiency of a generator is affected if the power factor is different even if the output is the same. If an AC voltage is applied to capacitors, coil and resistors provided in series in the machine on the load side, the alternating current does not synchronize, resulting in a phase shift. This shift of phase is called power factor. (For more detailed descriptions, please refer to technical books.)

The power factor varies by machine; a rough guideline is as follows.
If more detailed studies are necessary when selecting generator, check with the electric machine manufacturer.

Examples of power factors for electric equipment (general)

Electric equipment	Power factor %
Incandescent lamp	100
Electric heater	100
3-phase induction motor	70 to 90
Fluorescent lamp (with safety device)	55
Neon tube lamp	40 to 50
Resistance welding machine	40 to 50
AC arc welding machine	40 to 50
DC arc welding machine	50 to 80

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When trying to decide on generator specifications, the type of load is unknown in advance. Therefore, the power factor of 1.0 is applied to a single-phase AC generator assuming the resistance load of an incandescent lamp and the heater for which the generator is comparatively frequently used.
In the case of a 3-phase AC generator, a power factor of 0.8 is customarily used as it is frequently used for the motor load.

(3) Generator capacity and engine output

i) Generator output (kW) = generator capacity (KVA) × power factor (pf)

ii) Engine output (kW) = generator output (kW) / generator efficiency (η)

iii) Quick reference table for 3-phase AC generator and engine output
Strictly speaking, it is not possible to select an engine without knowing the power factor (pf) and the generator efficiency (η) even if a certain generator capacity only is specified. If requested by a generator manufacturer to select the engine, always check on the generator efficiency (η) and the power factor (pf).

Since it is customary to use 0.8 as the power factor of a 3-phase AC generator, the required engine output can be obtained by using the generator efficiency (η) guideline as follows.

Select the engine so that the required engine output will be equivalent to or less than the continuous rated output for other than generators for special purposes.

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Quick reference table for 3-phase AC generator and engine output

η = guideline, Power factor = 0.8

Generator capacity P_G		Generator efficiency	Engine output P_E	Generator capacity P_G		Generator efficiency	Engine output P_E
kVA	kW	η	kW	kVA	kW	η	kW
1	0.8	68.0	1.2	37.5	30	86.8	34.6
2	1.6	70.0	2.3	40	32	87.0	36.8
3	2.4	72.0	3.3	45	36	87.4	41.2
5	4	77.0	5.2	50	40	87.8	45.6
6	4.8	78.0	6.2	56.25	45	88.2	51.0
6.25	5	79.0	6.3	60	48	88.4	54.3
7.5	6	82.0	7.3	62.5	50	88.5	56.5
10	8	82.0	9.8	75	60	89.1	67.3
12.5	10	82.0	12.2	80	64	89.3	71.7
15	12	83.0	14.5	100	80	90.0	88.9
18.75	15	83.0	18.1	120	96	90.0	107
20	16	84.0	19.0	125	100	90.0	111
25	20	85.2	23.5	130	104	90.0	116
30	24	85.9	27.9	140	112	90.0	124
31.25	25	86.0	29.1	150	120	90.5	133
35	28	86.5	32.4	160	128	90.5	141

(4) Relation of number of poles, frequency and revolution of the generator

$$n = \frac{120f}{p}$$

n : Generator revolution rpm

f : Frequency Hz

p : Number of poles (2, 4, 6, --- even number)

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17-12 Hydraulic Pump (gear)

(1) Discharge ℓ/min

Theoretical discharge $Q_t = 2\pi \cdot Z \cdot b \cdot m^2 \cdot N \cdot 10^{-6}$ ℓ/min

Real discharge $Q_r = \eta_v \cdot Q_t$ ℓ/min

- Z : Number of drive gear teeth
- b : Facewidth
- m : Module
- N : Drive gear revolution rpm
- η_v : Volume efficiency

(2) Driving horsepower (required horsepower)

(a) Theoretical driving horsepower (theoretical required horsepower)

		Discharge pressure P	
		kPa	kgf/cm²
Theoretical driving horsepower L_t	kW	$\frac{P \cdot Q_t}{60} \times 10^{-3}$	$\frac{P \cdot Q_t}{6 \times 102.0}$
	hp	$\frac{P \cdot Q_t}{60 \times 0.7457} \times 10^{-3}$	$\frac{P \cdot Q_t}{6 \times 76.04}$
	PS	$\frac{P \cdot Q_t}{60 \times 0.7355} \times 10^{-3}$	$\frac{P \cdot Q_t}{6 \times 75}$

- P : Discharge pressure kPa (or kgf/cm^2)
- Q_t : Theoretical discharge ℓ/min

1 kW = $1.0000 \times 10^3 \times N \cdot m/s = 102.0$ kgf • m/s
1 hp = $0.7457 \times 10^3 \times N \cdot m/s = 76.04$ kgf • m/s
1 PS = $0.7355 \times 10^3 \times N \cdot m/s = 75$ kgf • m/s

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(b) Real driving horsepower (real required horsepower)

$L_r = L_t / \eta_P$

- L_r : Real driving horsepower (real required horsepower)
- L_t : Theoretical driving horsepower (theoretical required horsepower)
- η_P : Total pump efficiency $\eta_P = \eta_V \cdot \eta_m$
- η_V : Volumetric efficiency of pump
- η_m : Mechanical efficiency of pump

(c) Guideline for efficiency

	Volumetric efficiency η_V	Overall efficiency η_P
Gear pump	75 to 85	65 to 80
Vane pump	85 to 93	75 to 85
Plunger pump	90 to 98	85 to 90

(3) Actual calculation method

Theoretical discharge Q_t is calculated by the hydraulic pump manufacturer. The driving horsepower (required horsepower) is examined by using discharge cc/rev per revolution of the pump which is usually stated in the hydraulic pump specification.

Discharge cc/rev already includes estimated volumetric efficiency. Therefore, the driving horsepower (required horsepower) is obtained by only taking the mechanical efficiency η_m of the pump into consideration.

(a) Discharge Q ℓ/min

$Q = q \cdot n \cdot 10^{-3}$

- Q : Discharge ℓ/min
- q : Discharge per revolution of hydraulic pump cc/rev
- n : Hydraulic pump revolution rpm

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(b) Driving horsepower (required horsepower)

		Discharge pressure P	
		kPa	kgf/cm^2
Driving horsepower L_h	kW	$\frac{P \cdot Q \times 10^{-3}}{60 \cdot \eta_m}$	$\frac{P \cdot Q}{6 \times 102.0 \cdot \eta_m}$
	hp	$\frac{P \cdot Q \times 10^{-3}}{60 \times 0.7457 \cdot \eta_m}$	$\frac{P \cdot Q}{6 \times 76.04 \cdot \eta_m}$
	PS	$\frac{P \cdot Q \times 10^{-3}}{60 \times 0.7355 \cdot \eta_m}$	$\frac{P \cdot Q}{6 \times 75 \cdot \eta_m}$

L_h : Driving horsepower (required horsepower) kW (hp, PS)
P : Discharge pressure kPa (or kgf/cm^2)
Q : Hydraulic pump discharge ℓ/min
η_m : Mechanical efficiency of hydraulic pump (if unknown, 0.9)

17-13 Water Pump Driving Horsepower (required horsepower)

Driving horsepower L_w	kW	$\frac{\gamma \cdot Q \cdot H}{60 \times 102.0 \cdot \eta_m}$
	hp	$\frac{\gamma \cdot Q \cdot H}{60 \times 76.04 \cdot \eta_m}$
	PS	$\frac{\gamma \cdot Q \cdot H}{60 \times 75 \cdot \eta_m}$

L_w : Driving horsepower (required horsepower) kW (hp, PS)
γ : Specific weight 1 kg/ℓ
Q : Water pump discharge ℓ/min
H : Head m
η_m : Mechanical efficiency of water pump
Check the efficiency with the manufacturer as it varies greatly with the model.

(Reference) Relation between the water temperature and suction head

Water temperature (°C)	Suction head (m)
0	6.7
20	6.8
40	4.7
60	2.3
70	0

(Under normal atmospheric conditions)

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17-14 Form Characteristics of Cooling Fan

Required horsepower	$\propto n^3 \cdot D^5$
Air capacity	$\propto n \cdot D^3$
Back pressure	$\propto n^2 \cdot D^2$
Noise	$\propto n^5 \cdot D^7$

n: Fan revolution
D: Fan diameter

This proportional expression is used for an estimation calculation if either n or D varies within a minor range.

17-15 Mesh Number and Size of Mesh

American system (Tyler)		German standard	
Mesh (Number of mesh/inch)	Size of mesh (mm)	Mesh (Number of mesh hole/cm^2)	Size of mesh (mm)
10	1.65	16	1.5
12	1.40	25	1.2
14	1.17	36	1.0
16	0.99	64	0.75
20	0.83	100	0.60
24	0.70	121	0.54
28	0.69	141	0.49
32	0.50	196	0.43
35	0.417	256	0.385
42	0.351	400	0.300
48	0.295	576	0.250
60	0.240	900	0.200
65	0.208	1600	0.150
80	0.175	2500	0.120
100	0.147	3600	0.102
150	0.104	4900	0.088
200	0.074	6400	0.075
250	0.062	10000	0.060
300	0.046		

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17-16 Centigrade-Fahrenheit Temperature Conversion

$$°C = \frac{5}{9} (°F - 32) \qquad °F = \frac{9}{5} \times °C + 32$$

Centigrade °C	Fahrenheit °F	Centigrade °C	Fahrenheit °F	Centigrade °C	Fahrenheit °F
–40	–40.0	30	86.0	74	165.2
–35	–31.0	31	87.8	75	167.0
–30	–22.0	32	89.6	76	168.8
–25	–13.0	33	91.4	77	170.6
–20	–4.0	34	93.2	78	172.4
–18	–0.4	35	95.0	79	174.2
–16	3.2	36	96.8	80	176.0
–14	6.8	37	98.6	81	177.8
–12	10.4	38	100.4	82	179.6
–10	14.0	39	102.2	83	181.4
–8	17.6	40	104.0	84	183.2
–6	21.2	41	105.8	85	185.0
–4	24.8	42	107.6	86	186.8
–2	28.4	43	109.4	87	188.6
0	32.0	44	111.2	88	190.4
1	33.8	45	113.0	89	192.2
2	35.6	46	114.8	90	194.0
3	37.4	47	116.6	91	195.8
4	39.2	48	118.4	92	197.6
5	41.0	49	120.2	93	199.4
6	42.8	50	122.0	94	202.2
7	44.6	51	123.8	95	203.0
8	46.4	52	125.6	96	204.8
9	48.2	53	127.4	97	206.6
10	50.0	54	129.2	98	208.4
11	51.8	55	131.0	99	210.2
12	53.6	56	132.8	100	212.0
13	55.4	57	134.6	101	213.8
14	57.2	58	136.4	102	215.6
15	59.0	59	138.2	103	217.4
16	61.8	60	140.0	104	219.2
17	63.6	61	141.8	105	221.0
18	65.4	62	143.6	106	222.8
19	67.2	63	145.4	107	224.6
20	68.0	64	147.2	108	226.4
21	69.8	65	149.0	109	228.2
22	71.6	66	150.8	110	230.0
23	73.4	67	152.6	112	233.6
24	75.2	68	154.4	114	237.2
25	77.0	69	156.2	116	240.8
26	78.8	70	158.0	118	244.4
27	80.6	71	159.8	120	248.0
28	82.4	72	161.6	122	251.6
29	84.2	73	163.4	124	255.2

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17-17 Hill Climbing Horsepower and Allowable Climbing Angle

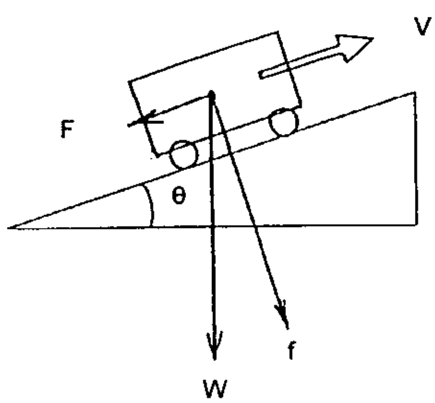
The required horsepower of a mobile driven machine can be divided into working, traveling and hill climbing horsepower.

The working horsepower refers to the horsepower at which the driven machine works at its maximum, and varies according to the workload. The traveling horsepower refers to the horsepower needed for moving the driven machine, which fluctuates sharply with the speed level and running resistance generated by the travel device (such as crawler, tire, etc.) and the road surface conditions (asphalt, soil, sand, farmland, etc.)

The required horsepower for both the working and the traveling must be measured with an actual machine test. The hill climbing horsepower can be calculated in advance. If the road surface conditions are assumed to be the same, the running resistance, that is, the traveling horsepower is assumed to remain unchanged for both the level and grade running.

(1) Hill climbing horsepower

The required horsepower for a driven machine having gross vehicle weight W to climb a grade of incline angle θ at running speed *V* can be obtained from the calculation formula given in the table below:



W: Gross vehicle weight: N (or kgf)
θ: Incline angle of a grade: rad (or deg)
V: Running speed: m/sec

$F = W \sin\theta$
$f = W \cos\theta$

(Reference)
1 kW = 1.0000×10^3 N • m/s = 102.0 kgf • m/s
1 hp = 0.7457×10^3 N • m/s = 76.04 kgf • m/s
1 PS = 0.7355×10^3 N • m/s = 75 kgf • m/s

	Gross vehicle weight W	
	N	kgf
kW	$V \cdot W \sin\theta \times 10^{-3}$	$\dfrac{V \cdot W \sin\theta}{102.0}$
hp	$\dfrac{V \cdot W \sin\theta}{0.7457} \times 10^{-3}$	$\dfrac{V \cdot W \sin\theta}{76.04}$
PS	$\dfrac{V \cdot W \sin\theta}{0.7355} \times 10^{-3}$	$\dfrac{V \cdot W \sin\theta}{75}$

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(2) Allowable hill climbing angle

A machine installed with an engine that meets the required hill climbing horsepower does not necessarily climb the hill. Another point that must be considered is the limit of climbing angle generated from the coefficient of friction between the traveling device or from the characteristics of the road surface itself.

In other words, it is meaningless to consider the hill climbing horsepower beyond the limit of slipping between the traveling device and the road surface or in case of collapse of the road surface itself.

The driven machine manufacturer's data are needed for the dynamic coefficient of friction between the traveling device and various road surface conditions and the characteristics of the road surface material itself. Supposing that the coefficient is μ, the allowable hill climbing angle will be as follows:

$$F < \mu \cdot f$$

$$W \sin\theta < \mu \cdot W \cos\theta$$

$$\tan\theta < \mu$$

$$\theta < \tan^{-1}\mu$$

Therefore, if coefficient μ that is determined by the environment of the driven machine is known, a target limit θ of the climbing angle can be calculated irrespective of the weight of the driven machine.

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18. Conversion Factors

To convert from English	To S.I. Metric	Multiply by	To old Metric	Multiply by
sq. in.	mm^2	645.16	cm^2	6.4516
sq. ft.	m^2	0.0929	m^2	0.0929
lb/cu. ft.	kg/m^3	16.0185	kg/m^3	16.0185
lbf	N	4.4482	N	4.4482
lbf/ft	N/m	14.5939	N/m	14.5939
Btu	kJ	1.0551	kcal	0.252
Btu/hr.	W	0.2931	kcal/hr	0.252
Btu/scf	kJ/nm^3	37.2590	$kcal/nm^3$	0.1565
in	mm	25.400	cm	2.540
ft	m	0.3048	m	0.3048
yd	m	0.914	m	0.914
lb	kg	0.4536	kg	0.4536
hp	kW	0.7457	kW	0.7457
psi	kPa	6.8948	kg/cm^2	0.070
psia	kPa abs	6.8948	bars abs	0.0716
psig	kPa gage	6.8948	ata	0.070
in.Hg	kPa	3.3769	cm Hg	2.540
in.H_2O	kPa	0.2488	cmH_2O	2.540
°F	°C	(°F–32) 5/9	°C	(°F–32) 5/9
°F(Interval)	°C (Interval)	5/9	°C (Interval)	5/9
ft-lb	N-m	1.3558	N-m	1.3558
mph	km/hr	1.6093	km/hr	1.6093
ft/sec	m/sec	0.3048	m/sec	0.3048
cu. ft.	m^3	0.0283	m^3	0.0283
gal (US)	L	3.7854	L	3.7854
cfm	m^3/min	0.0283	m^3/min	0.0283
scfm	nm^3/min	0.0268	nm^3/hr	1.61
To convert from English	**To S.I. Metric**	**Multiply by**	**To old Metric**	**Multiply by**
cm^2	mm^2	100		
kcal	kJ	4.1868		
kcal/hr	W	1.16279		
cm	mm	10		
kg/cm^2	kPa	98.0665		
bars	kPa	100.		
atm	kPa	101.325		
cm Hg	kPa	1.3332		
cmH_2O	kPa	9.8064		
nm^3/hr	nm^3/min	0.0176		

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