3. ENGINE PERFORMANCE

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ENGINE PERFORMANCE

1. OUTPUT

[1] GENERAL

The engine output depends upon the designed technical data (number of revolutions and displacement) and combustion efficiency (ups and downs of brake mean effective pressure, good and bad combustion performance) of engine.
It is calculated by the following formula.

Output = (Bmep × N × V) / 900

Bmep : Mean effective pressure (kg/cm^2)
N : Number of revolutions (min^{-1} (rpm))
V : Displacement (liter)

The mean effective pressure depends upon various internal factors (combustion method, whether turbo charger is provided, type of nozzle and fuel pump, and adjustment of each section such as fuel injection timing).

Energy obtained by combusting fuel in the engine is not completely utilized for engine output.
Although diesel engines are more efficient than gasoline engines, only 30 to 35% of the energy generated by the diesel engines is effectively utilized (See Fig. 3-1). The residual 65 to 70% is not utilized (heat loss). Supposing that the gross heating value of combusted fuel is 100%, its distribution is called the "heat balance".

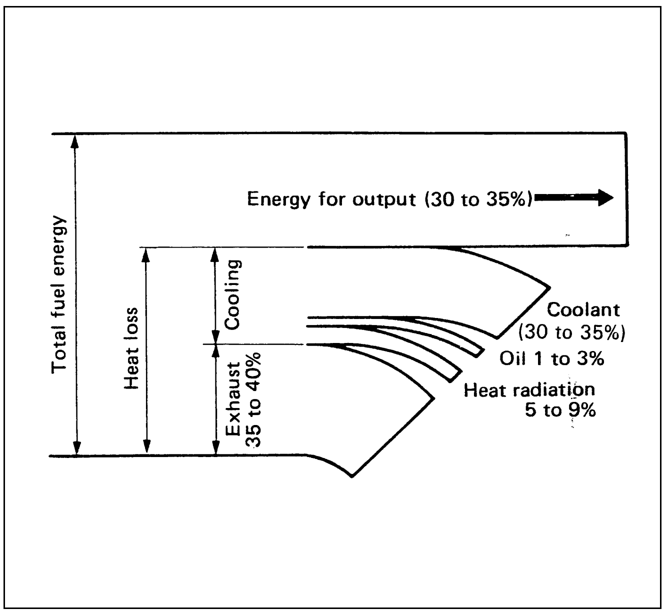


Fig. 3-1 Example of heat balance of diesel engine

In the above mentioned drawing, the ratio of the gross heating value (Qo) and the energy (heating value) (Qe) effectively utilized as the output is called the "thermal efficiency" (η e) and calculated by the following formula.

η e = Qe / Qo (%)

= Output (kW) × 3600 (kJ/hr) / 42700 × B

42700 : Lower calorific value of fuel (kJ/kg)
B : Fuel consumption (kg/hr)

[2] ACTUAL EFFECTIVE OUTPUT

The final output (actual effective output) of engine varies with various external factors such as horsepower loss due to the power consumed for driving the cooling fan and water pump, resistance of muffler and air cleaner, environmental conditions such as temperature, humidity, and altitude, type of applied fuel, and horsepower loss and transmission efficiency of equipment driven by the engine.
Thus the final output mainly depends upon the horsepower loss. Also the output varies with the time factors such as "aging and wear" and "maintenance", which depend upon the operating time. (See Fig. 3-2).

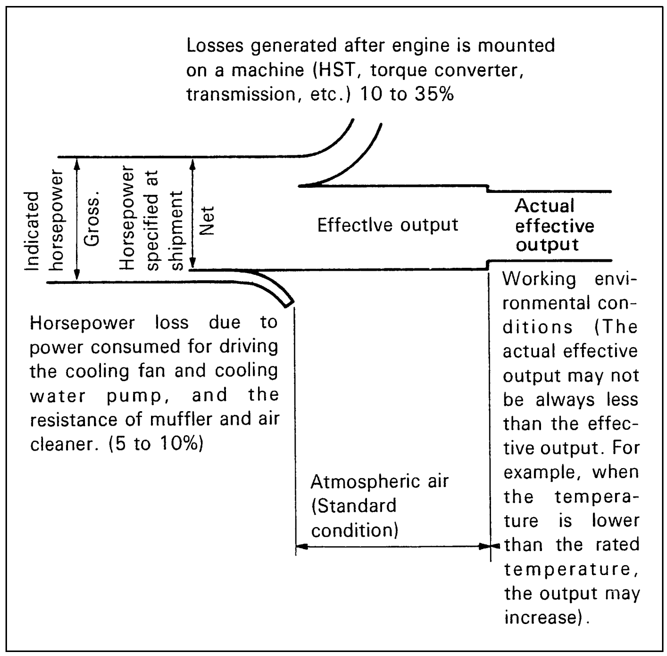


Fig. 3-2 Engine power loss

Fuel supply adjustment and governor setting are adjusted by KUBOTA according to each destination country in conformity with "JIS", "SAE" and "ISO" standards before shipment.
They may be adjusted to the output characteristic discussed with the Technical Department in case of special OEM requirements.
Engine performance is normally indicated by the output, torque and fuel consumption curves, which are closely related to each other.

[3] OUTPUT CHARACTERISTICS

When mounting an engine on a machine, it is risky to select an engine by its standard output alone (as shown in cataloge and other literatures) and comparing it with the required power of the machine. The following factors must be carefully considered when making a selection.

(1) For large load variations

Engines with large torque backup are suitable for frequent use with varying loads which require a broad torque range.
The amount of torque backup is indicated by torque rise (%).

Torque rise
= (Max. torque / Torque at rated output) × 100 - 100 (%)

As shown in the torque curve, KUBOTA engines have a high torque rise.

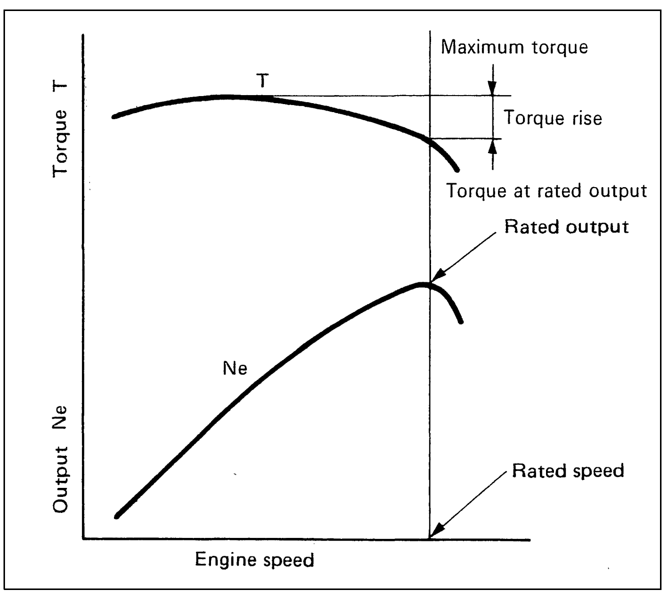


Fig. 3-3 Torque backup

(2) For constant speed applications

When an engine is to be used with a generator, for example, for which stable revolution characteristics are required, governor adjustment and inertia effect are needed to maintain the coefficient of revolution fluctuation at a minimum level. Unless these actions are taken, the generator voltage or frequency will vary largely with variation of engine revolution speed, preventing proper operation.

(3) For reduced engine speed applications

When an engine is to be operated slower than the rated speed in order to reduce the noise level below that of the rating, or due to the transmission unit to which the engine is connected, an optimum adjustment (including fan, pump and other equipment performance check) at that engine speed and output check is necessary.
Conditions for selection further vary with priority factors of the machine to which the engine is mounted. (e.g. emphasis on reduced fuel consumption, or larger output margin due to extremely long periods of operation.) There are many cases in which these factors are combined. It is suggested that careful review be given when determining the correct selection of an engine.

(4) Precautions for specifying engine output

When specifying the engine output characteristics it is necessary to consider the output decrease due to changes of ambient conditions, especially the temperature rise (rise of engine intake-air temperature as well as atmospheric temperature), power consumed by accessories and horsepower loss in the power transmission unit.

[4] FUEL CONSUMPTION

Whether the fuel consumption is efficient or not depends upon the specifications inherent to each engine such as combustion method (direct injection, swirl chamber, etc.), shape of combustion chamber, fuel injection timing, valve timing, type of nozzle, fuel pump, etc., and revolution speed.
The matching of engine and machine directly influences efficiency of fuel consumption.
Therefore sufficient consideration is required to select an engine to be mounted on each machine.

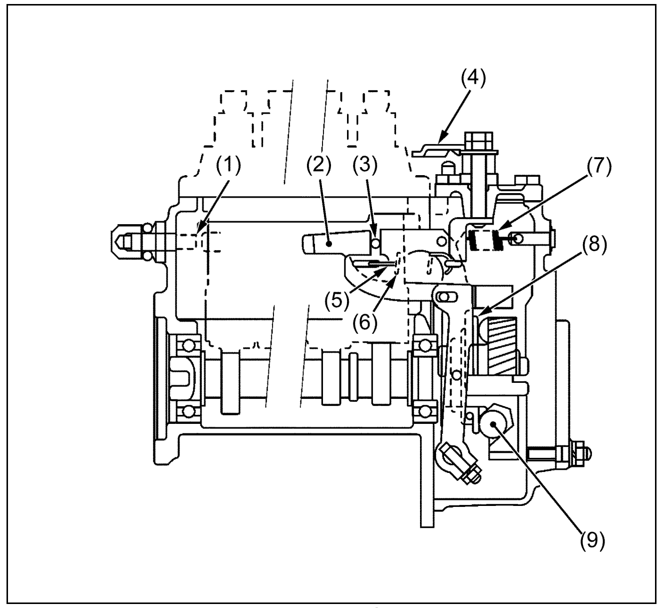
[5] GOVERNOR PERFORMANCE

In most machine including construction machines and industrial vehicles for cycle work involving starting -running -stop, -work, engine are used at varying loads.
Therefore the engine governor must have a speed control function that allows fast fuel supply control over the entire range.
KUBOTA engine use an all speed governor with an automatic fuel control mechanism that detects even small changes in rpm.
This allows optimum fuel supply at all times under various conditions such as the maximum engines speed, maximum load, low speed load, idling, starting and acceleration.
KUBOTA engine uses two kinds of mechanical governor.

1. Steel Ball Type (SM Series, 03-M Series)
2. Weight Type (05 Series, 07 Series and V3 Series)

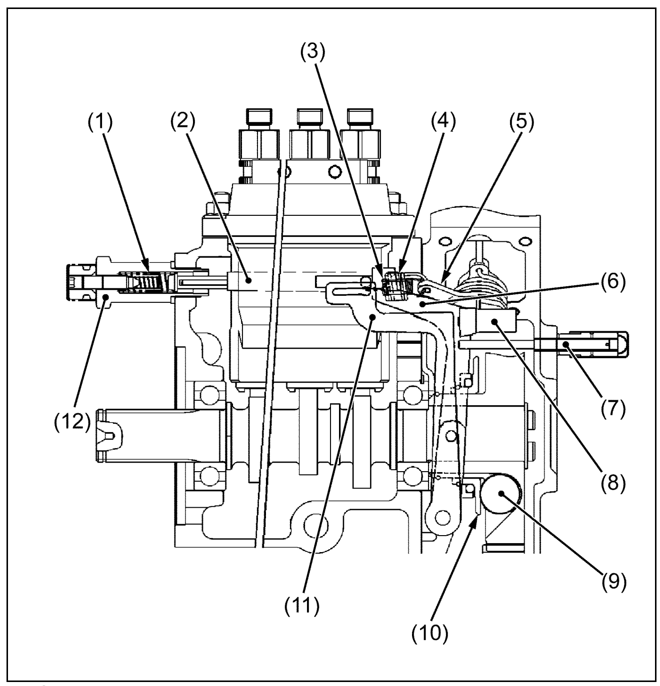
Steel Ball Type Governor
Several steel balls are incorporated into the fuel cam gear in such a way as it gives the steel balls centrifugal force in proportion to the revolving speed.
It has a structure in which the centrifugal force is transformed into thrust movement and controls the injection quantity of the fuel pump through the fork-lever, while being balanced with the tension of the governor spring, to keep the engine revolution constant.

Weight Type Governor
Two or three weights are incorporated into the fuel cam in such a way as it gives the weights centrifugal force in proportion to the revolving speed.
It has a structure in which the centrifugal force is transformed into thrust movement and controls the injection quantity of the fuel pump through the fork-lever, while being balanced with the tension of the governor spring, to keep the engine revolution constant.



(1) Idle limit spring
(2) Fork lever 1
(3) Control rack pin
(4) Speed control lever
(5) Governor spring 2
(6) Governor spring 1
(7) Start spring
(8) Governor sleeve
(9) Governor ball

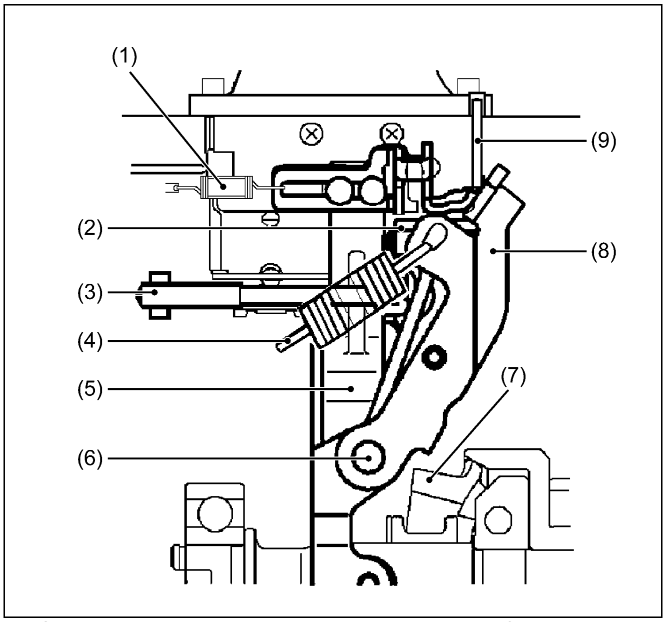
Fig. 3-4 Governor for S.M. series



(1) Start spring
(2) Control rack
(3) Governor spring 2
(4) Governor spring 1
(5) Governor lever
(6) Fork lever 1
(7) Adjusting screw
(8) Torque spring
(9) Governor ball
(10) Governor sleeve
(11) Fork lever 2
(12) Idling apparatus

Fig. 3-5 Governor for 03-M series

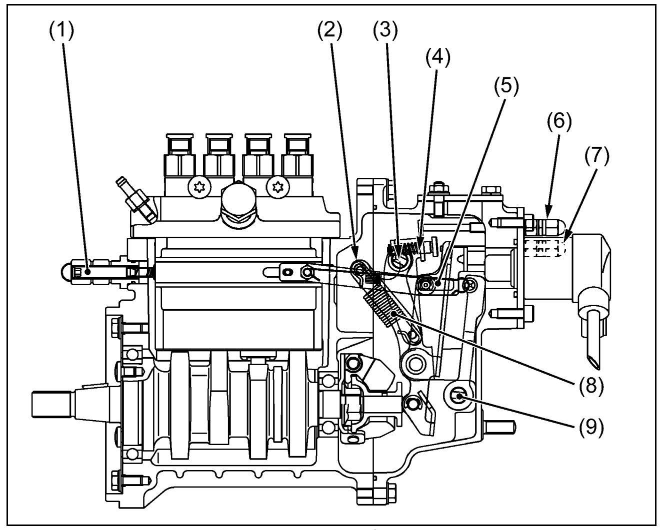
In the 05 series, the fuel cam shaft and the governor shaft are independent with each other and the governor weights are incorporated into the governor shaft. As the fork-lever, a three lever system with newly-employed floating levers (except BG type) has been employed to reduce the exhaust gas at the time of peak-torque.



(1) Start spring
(2) Floating lever
(3) Max torgue limiter
(4) Governor spring
(5) Fork lever 1
(6) Fork lever shaft
(7) Flyweight
(8) Fork lever 2
(9) Fuel limitation bolt

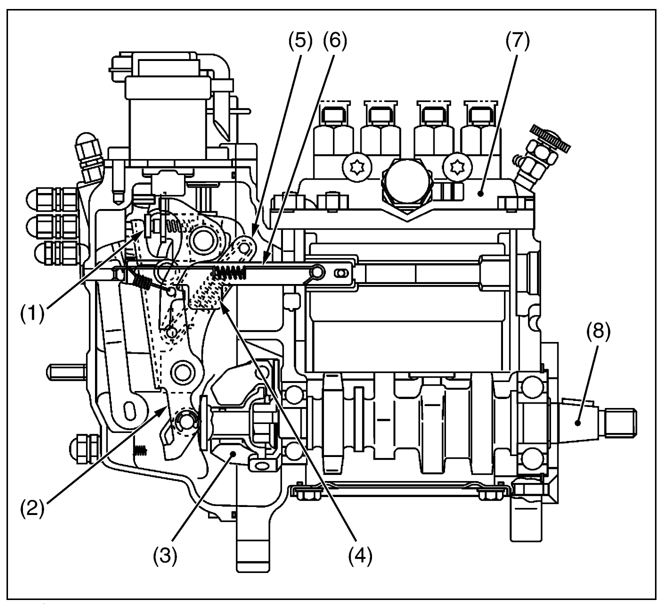
Fig. 3-6 Governor for 05 series

In the 07 and V3 series, the IPU (Injection Pump Unit) system is employed, where a PFR pump is mounted in the housing in which a torque-adjusting mechanism and a peak-torque adjusting mechanism along with a fuel cam, a governor mechanism, and others are incorporated.



(1) No-load maximum rotation
(2) Fork lever 2
(3) Speed control lever
(4) Spring pin
(5) Start spring
(6) Output limiting bolt
(7) Torque limiting bolt
(8) Governor spring
(9) Fork lever 1

Fig. 3-7 Governor for 07 series



(1) Spring pin
(2) Fork lever 1
(3) Flyweight
(4) Governor spring
(5) Fork lever 2
(6) Start spring
(7) Injection pump
(8) Fuel camshaft

Fig. 3-8 Governor for V3 series

KiSS issued 05, 2010 A

【Governor regulation】

Generator governor should be regulated as small as possible when load is changed, and recovered to normal level as quick as possible.
This is especially important when the engine is used for constant speed applications such as with generators.
Coefficient of regulation and stabilization period are defined as follow.

- Instant governor droop
  $= (N_1 - N_0) / N_0 \times 100\%$
  or $= (N_3 - N_0) / N_0 \times 100\%$

- Stabilized governor droop
  $= (N_2 - N_0) / N_0 \times 100\%$

- Stabilization period
  No load stabilization period = S_1 (sec)
  Load stabilization period = S_2 (sec)

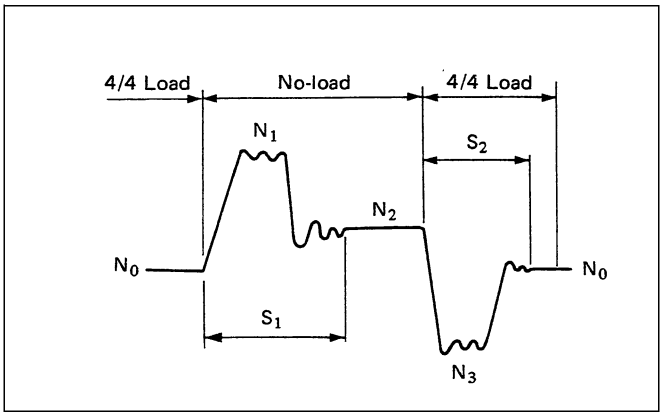


Fig. 3-9

1) For variable speed use (2000 ~ 3000 min^{-1} (rpm))

Instant governor droop (%)	: 10
Stabilized governor droop (%)	: 6～10
Stabilization period (sec)	: 5
Low idling (min^{-1} (rpm))	: 800

2) For constant speed use
(1500, 1800, 3000, 3600 min^{-1} (rpm))

Instant governor droop (%): 10
Stabilized governor droop (%): 5
Stabilization period (sec): 5

※ Rate of governor regulation differ with the engine margin against load.
※ Consult when utmost precision is required.

[6] NOISE

Often they are subject to government regulation. One of the major development objectives for KUBOTA engines is a substantial reduction of noise and vibration.

(1) KUBOTA's E-T.V.C.S (Three Vortex Combustion System) originally developed.

By offsetting the direction of fuel injection into the swirl chamber and designing the throat of the swirl chamber to match the concave recess on the piston head, E-TVCS activates diffusive combustion in the main combustion chamber.
The injection pump and nozzle designs are optimized to match the combustion chamber.
The E-series is a well balanced engine series with improved power output, fuel economy, engine start ups, reduced noise and cleaner emission.

(2) Highly rigid crankcase

The cylinder block is the main housing of engine and supports the other main parts.
The cylinder block is usually of integrated cast iron construction, and includes complete passages for coolant and lubricating oil.
Three kinds (the tunnel type, the hanger type and ladder frame type) are adopted in Kubota engines.

【S.M., 05 and 03-M series】

The crankcase has tunnel-type integral structure. It is highly rigid and the injection pump is built into the case.

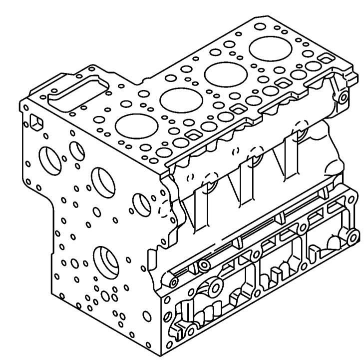


Fig. 3-10 Tunnel type cylinder block for S.M., 05 and 03-M series

【07 series】

The 07 series DI engine employs ladder frame structure type crankcases - the crankcase 1 with combustion part and the crankcase 2 which supports the crankcase 1.
The following benefits are in the ladder frame structure.

1. Minimizing parts.
2. Noise reduction.
3. Reduction of loss and dispersion on friction thanks to accuracy of axial concentricity.

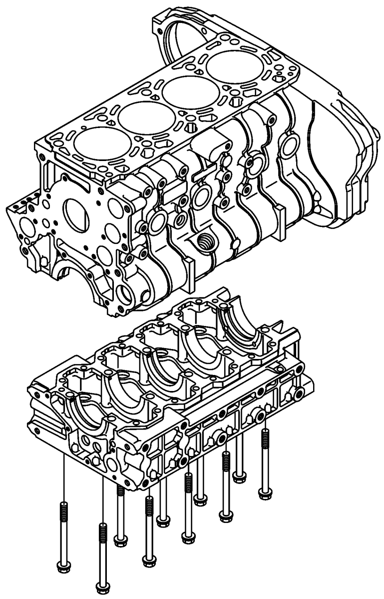


Fig. 3-11 Cylinder block for 07 series

【V3 series】

V3 series engine employs hanger type crankcase. The crankcase is divided into the two parts, i.e., the upper part and lower part. The upper part is combustion part and lower part support the upper part and reduces noise.

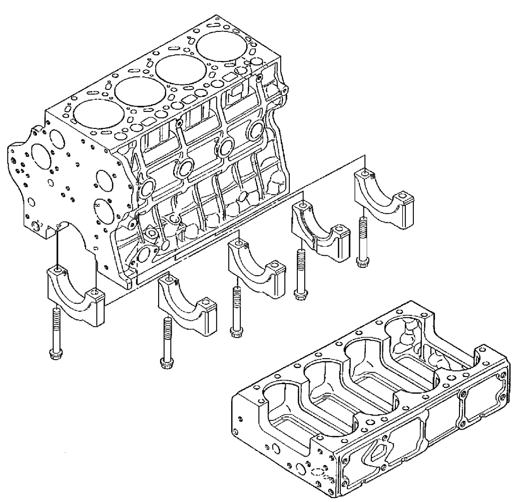


Fig. 3-12 Cylinder block for V3 series

(3) Consider to reduce mechanical noise

【SM, 05 and 03-M series】

The E3 engines employ Molybdenum disulfide coated pistons to further reduce piston slap noise and Half floating head covers to reduce radiated noise, in addition to the conventional measures to reduce mechanical noise such as a tunnel-type cylinder block, off set pistons, and steel strut pistons.

【The 07 engines】

In addition to employing a Ladder frame structure type crankcase, the rear side gear train (a new concept of transferring the gear train from the conventional front-side to the rear-side (the flywheel side)) and the Half floating head cover have been employed to reduce radiated sound.
For the pistons, in addition to the conventional off set pistons and steel strut pistons, Molybdenum disulfide coated pistons have been employed to further reduce piston slap noise.
In addition, the micro groove metal has been employed to reduce sliding-surface noise by reducing the oil clearance between the crankshaft and metal.

【The V3 engines】

In addition to the conventional measures to reduce mechanical noise like a Hanger type crankcase, off set pistons, and steel strut pistons, the E3 engines employ Molybdenum disulfide coated pistons to further reduce piston slap noise, Half floating head covers to reduce radiated sound, and, also, the micro groove metal to reduce sliding surface noise by reducing the oil clearance between the crankshaft and the metal.

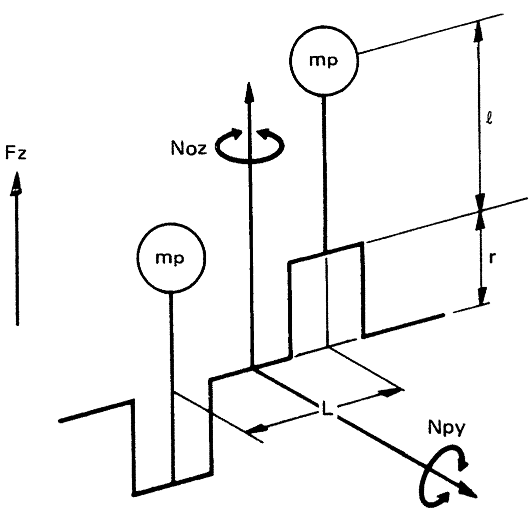
(4) Highly efficient governor

The installed high performance governor ensures stable revolution in the low speed range.
Therefore, it has become possible to set a lower value as the low idle speed. As a result, the noise has been reduced.

[7] VIBRATION

In order to reduce the vibration level as much as possible, special consideration has been taken in designing the crankshafts according to the number of cylinders and rotating parts such as the fan drive pulley, flywheel to minimize unbalanced inertia force and inertia couple of the reciprocating and rotating parts.
The crankshaft is made of a strong special steel alloy to reduce weight of the pin and arm sections. Alternating balance weights are used for each cylinder.
Other main parts are also made of special steel to reduce their weight and provide sufficient strength. The weight of the piston itself is reduced.
Thus, both the reciprocating mass and the rotating mass are reduced. The result is smaller inertia forces and smaller unbalanced inertia couple.
The table in TECHNICAL INFORMATION shows unbalanced forces of standard KUBOTA engines.

Unbalanced forces of engines



Fz : Unbalanced inertia force
Npy,Noz : Unbalanced inertia couple
mp : Reciprocating mass
r : Crankshaft radius
l : Center distance of rod metal
L : Cylinder distance
ω : Angular velocity
$\omega = 2\pi N / 60$
N : Engine speed r/min

Fig. 3-13 Unbalanced forces of engines

Fz : Unbalanced inertia force

No. of cylinders	Order	Fz
2	1	0
	2	$2mp \cdot r \cdot (r/l) \cdot \omega^2$
3	1	0
	2	0
4	1	0
	2	$4mp \cdot r \cdot (r/l) \cdot \omega^2$

Npy : Unbalanced inertia couple

No. of cylinders	Order	Fz
2	1	$(mp/2) \cdot r \cdot L \cdot \omega^2$
	2	0
3	1	$(3mp/2) \cdot r \cdot L \cdot \omega^2$
	2	$3mp \cdot r \cdot L \cdot (r/l) \cdot \omega^2$
4	1	0
	2	0

Noz : Unbalanced inertia couple

No. of cylinders	Order	Fz
2	1	$(mp/3) \cdot r \cdot L \cdot \omega^2$
	2	0
3	1	$(3mp/2) \cdot r \cdot L \cdot \omega^2$
	2	0
4	1	0
	2	0

2. OPERATING ENVIRONMENT

[1] GENERAL

For the standard engine output performance, the values measured under the standard conditions specified by the world principle standards such as JIS, SAE and ISO are used as the standard. However since engines are used all over the world, their output performance varies with the operating conditions and ambient conditions (altitude, humidity and temperature). If the ambient temperature varies largely, the environment is dusty, or the engine is operated at an unusual installation altitude, the engine performance is directly or indirectly influenced.
It is necessary to consider the balance between the output compensation in accordance with the ambient conditions, and actions to adapt the engine to the operating conditions.

[2] COLD ENVIRONMENTS

In cold environments starting is a major problem. Once the engine is started, the air density becomes larger and the intake efficiency also becomes higher. More output can be expected in cold areas. When the temperature is very low, extra care must be taken regarding fuel and oil changes in their viscosity, freezing of water contained in the piping, or of water adhering on the filter.
At an extremely cold temperature, the viscosity of hydraulic fluid and lubrication oil may increase and the torque of starter may exceed its permissible value, hindering proper starting.

Requirements for cold starting

Item \ Cold intensity			Low temperatures more than 258 K {-15 °C (5 °F)}	Intense cold more than 253 K {-20 °C (-4 °F)}	Extreme cold more than 248 K {-25 °C (-13 °F)}
Combustion	Fuel	For cold weather	No.1-D (ASTM D975-94)	No.1-D (ASTM D975-94)	No.1-D (ASTM D975-94)
	Preheating	Combustion chamber	Glow 10 sec	Glow 10 sec	Glow 10 sec
		Intake air	-	-	Preheating
		Engine body	-	-	Preheating
Turning force	Starter		Standard	Size up from std.	Size up from std.
	Battery		Standard	Size up from std.	Size up from std.
Lubrication	Oil	For cold weather	SAE #10W or SAE #10W30	SAE #5W or SAE #10W30	SAE #5W or SAE #5W20
Cooling	Coolant		Antifreeze	Antifreeze	Antifreeze
			-	-	Preheating

1) Above table may be changed by application due to the drag torque of various machines.
2) Material of all pipes, resins and rubbers must be cold resistant material in extreme cold condition.

[3] HIGH TEMPERATURES

High compartment temperatures can be caused by high ambient temperatures, small engine room, soundproof cases and other reasons.
Among these the most important factor is the temperature of the intake and cooling air.
Even if the engine is contained in a soundproof case, its output is not affected as long as sufficient cold air is taken in from the outdoor atmosphere. In order to prevent overheating, it is necessary to measure and check the temperature of intake air and exhaust gas. At an extremely hot temperature it is necessary to control the viscosity of fuel and lubrication oil, to maintain the cooling performance (prevent overheat) and to care about the temperature rise of electric equipment.

※ Output reduction
Output decreases as ambient temperature increases.
※ Radiation of cooling water
Care must be taken regarding the amount of radiation reduction, when an all seasons antifreeze is used for continuous operation at high temperature, or when a high density antifreeze is used.

Requirements for operation at high temperature

Item \ Temperature			High 30 to 40 °C (86 to 104 °F)	Extremely high 40 °C (104 °F) or higher
Combustion	Fuel	Type	No.2-D (ASTM D975-94)	No.2-D (ASTM D975-94)
		Temperature		
Lubrication	Oil	Type	SAE #30, 10W30,15W40	SAE #40 or 20W50
		Temperature	120 °C (248 °F) or lower	
Cooling	Reserve tank		Necessary to use	Necessary to use
	Radiator, fan		When necessary, use larger radiator and fan.	
Accessories	Permissible temperature		Starter, regulator, alternator, relay, timer : 80 °C (176 °F) or lower Emergency relay : 65 °C (149 °F) or lower	

[4] DUST

When the engine is to be used in extremely dusty areas or used continuously in a dusty environment, special care must be taken with air cleaner and radiator. The intake air must be cleaned with the air cleaner. Lowering of the radiator cooling capacity due to clogging dust must be prevented.

【Dust density】
A degree of dustiness is hard to express in numbers. Comparative indication of amount of dust contained per 1m^3 of air is one way to express dustiness.
Below are some examples :

1) Pavement : 0.0002 to 0.0004 g/m^3
2) Unpaved road : 0.005 to 0.01 g/m^3
3) Dusty road (after passing of a car on unpaved road 2) above) : 0.3 to 0.4 g/m^3
4) Construction site : 0.5 to 1.0 g/m^3
5) Extremely dusty operation : Over 1.0 g/m^3

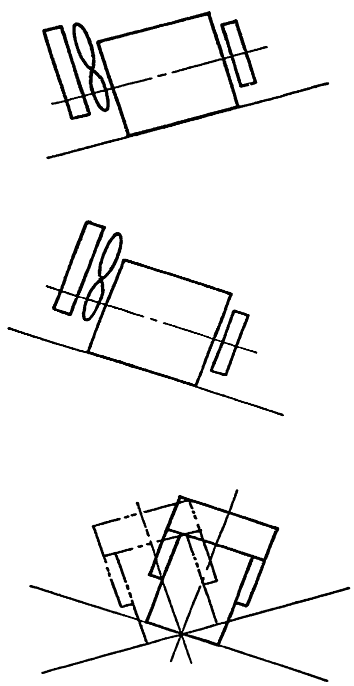
【Air cleaner】
Air cleaner type and capacity must be chosen according to the dust level in the operating environment and conditions for maintenance.
If an improper selection is made, especially when the capacity is less than needed, intake air resistance becomes higher, resulting in reduced output.
In order to maintain air tighten seals at the joining sections of intake system component parts and thus to prevent foreign matter from entering, it is necessary to ensure the security of the air intake system to prevent the component parts from being damaged.

[5] INCLINATION AND CENTER OF GRAVITY

Engine may be used inclined when it is used in a machine for working on slopes, during oscillation and when the engine is mounted at an angle. The tilted posture may be either momentary or continuous. Mounting the engine at an angle, even a small angle, should be avoided. When using an engine in a tilted posture continuously, the following points must be remembered.

1) If the engine is tilted to the front there is a possibility of an air pocket being created at the back of the cylinder head.
2) The effective volume of the oil pan becomes less, so air suction must be prevented.

Allowable angles for tilted operation are given below for engines with standard specifications.



	Less than 10 minutes continuous operation	Continuous operation
Front down	0.52 rad (30°)	0.35 rad (20°)
Rear down	0.52 rad (30°)	0.35 rad (20°)
Left or right side down	0.52 rad (30°)	0.35 rad (20°)

Fig. 3-14

Note : The engine for generator should be mounted level.
When the engine is mounted at an angle, the governor droop may worsen.

【Center of gravity】
With reference to tilted engines during operation, it is necessary to know the center of gravity position when checking for machine stability.

[6] DERATION OF ENGINE OUTPUT

Engine output is affected by atmospheric pressure, temperature and humidity.
An engine should be selected with sufficient power to meet the load demands under all operating conditions.
KUBOTA diesel engine performance curves are corrected to standard conditions explained in standards such as JIS, SAE an ISO.
Provided output should be corrected for various atmospheric conditions by above standards.
Deration coefficient table is shown in next page.
Deration of engine output is very important when selecting the proper engine model when using at high ambient temperature and in high altitude location.

Table of Factors Used to Convert Output Obtained under Standard Conditions to that under Specific Environmental Conditions.

Note 1. This table shows the factors used for modifying the output under the standard conditions (atmospheric pressure 100 kPa {750 mmHg} : atmospheric temperature 25 °C (77 °F) relative humidity 30% to that under specific environmental conditions.
The applicable standards are ISO 3046-1, JIS 8002. The factors are calculated according to the expressions specified in the standards.
2. This table is applicable to the naturally aspirated diesel engine.
3. The output under relative humidity other than 30% can be obtained by calculation.

Table 1 Conversion Factors under Relative Humidity of 30% and Mechanical Efficiency of 85% — Naturally aspirated diesel engine

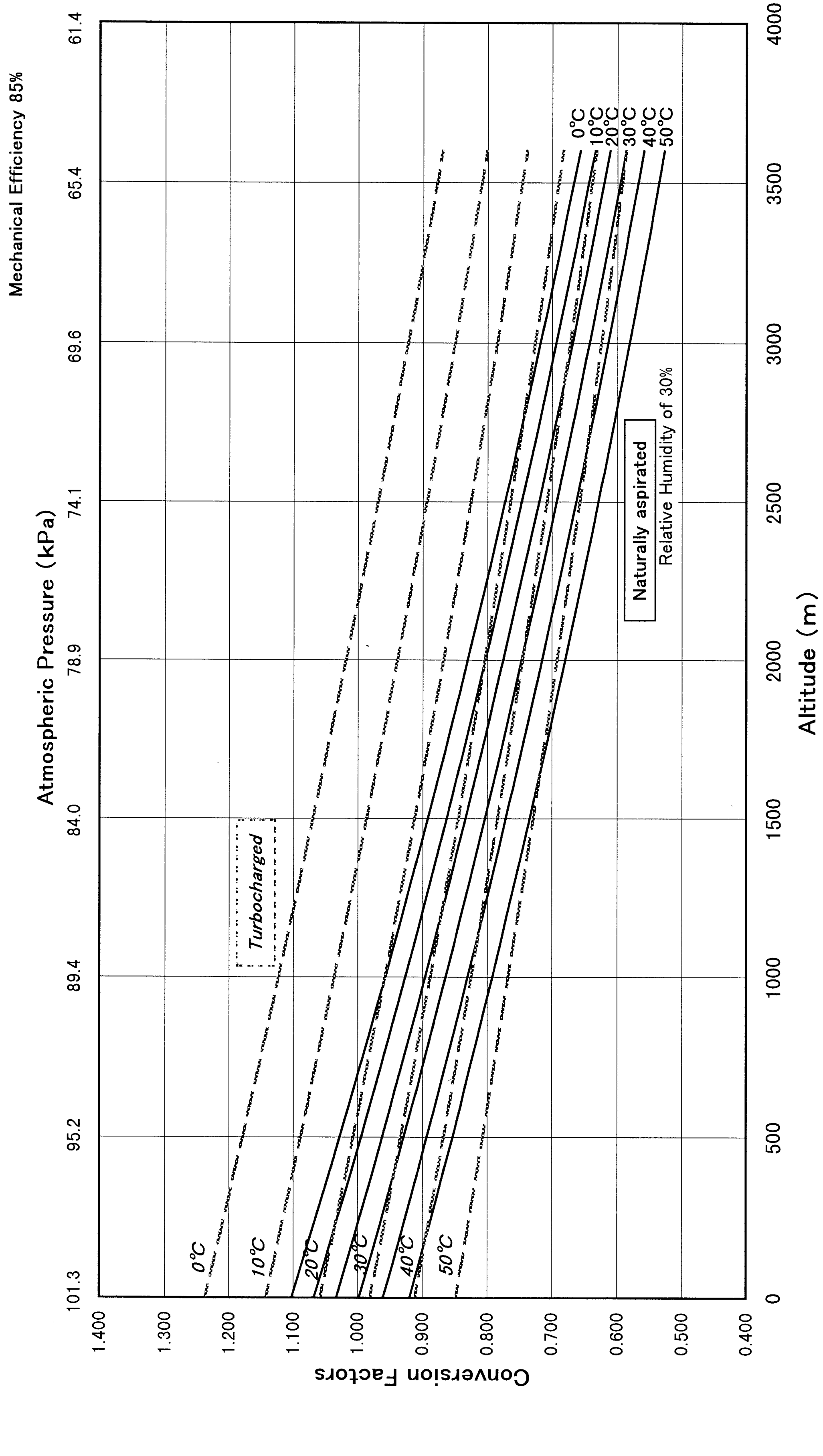
			Upper : Intake air temperature (℃) / Lower : Saturation vapor pressure (kPa)										
Altitude	**Atmospheric pressure**		**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
m	**mmHg**	**kPa**	**0.61**	**0.87**	**1.23**	**1.71**	**2.34**	**3.17**	**4.25**	**5.63**	**7.38**	**9.59**	**12.34**
0	760	101.3	1.102	1.085	1.067	1.050	1.033	1.016	0.998	0.980	0.961	0.941	0.919
100	751	100.1	1.087	1.070	1.053	1.036	1.019	1.001	0.984	0.966	0.947	0.927	0.906
200	741	98.8	1.072	1.055	1.038	1.021	1.004	0.987	0.970	0.952	0.933	0.914	0.893
300	732	97.6	1.057	1.040	1.023	1.007	0.990	0.973	0.956	0.938	0.920	0.900	0.880
400	723	96.4	1.042	1.026	1.009	0.993	0.976	0.959	0.942	0.925	0.906	0.887	0.867
500	714	95.2	1.028	1.011	0.995	0.979	0.962	0.946	0.929	0.912	0.893	0.874	0.854
600	705	94.0	1.013	0.997	0.981	0.965	0.949	0.932	0916	0.898	0.880	0.861	0.841
700	696	92.8	0.999	0.983	0.967	0.951	0.935	0.919	0.903	0.886	0.868	0.849	0.829
800	688	91.7	0.985	0.969	0.954	0.938	0.922	0.906	0.890	0.873	0.855	0.836	0.816
900	679	90.5	0.972	0.956	0.940	0.925	0.909	0.893	0.877	0.860	0.843	0.824	0.804
1000	671	89.4	0.958	0.942	0.927	0.912	0.896	0.880	0.864	0.848	0.830	0.812	0.792
1100	662	88.3	0.944	0.929	0.914	0.899	0.883	0.868	0.852	0.835	0.818	0.800	0.780
1200	654	87.2	0.931	0.916	0.901	0.886	0.871	0.855	0.840	0.823	0.806	0.788	0.769
1300	646	86.1	0.918	0.903	0.888	0.873	0.858	0.843	0.827	0.811	0.794	0.776	0.757
1400	638	85.0	0.905	0.890	0.875	0.861	0.846	0.831	0.815	0.799	0.783	0.765	0.746
1500	630	84.0	0.892	0.878	0.863	0.848	0.834	0.819	0.804	0.788	0.771	0.753	0.734
1600	622	82.9	0.880	0.865	0.851	0.836	0.822	0.807	0.792	0.776	0.760	0.742	0.723
1700	614	81.9	0.867	0.853	0.839	0.824	0.810	0.795	0.780	0.765	0.748	0.731	0.712
1800	607	80.9	0.855	0.841	0.826	0.812	0.798	0.784	0.769	0.753	0.737	0.720	0.701
1900	599	79.9	0.843	0.829	0.815	0.801	0.787	0.772	0.758	0.742	0.726	0.709	0.690
2000	592	78.9	0.830	0.817	0.803	0.789	0.775	0.761	0.747	0.731	0.715	0.698	0.680
2100	584	77.9	0.819	0.805	0.791	0.778	0.764	0.750	0.736	0.720	0.705	0.688	0.669
2200	577	77.0	0.807	0.793	0.780	0.766	0.753	0.739	0.725	0.710	0.694	0.677	0.659
2300	570	76.0	0.795	0.782	0.769	0.755	0.742	0.728	0.714	0.699	0.684	0.667	0.649
2400	563	75.1	0.784	0.771	0.757	0.744	0.731	0.717	0.703	0.689	0.673	0.657	0.639
2500	556	74.1	0.773	0.759	0.746	0.733	0.720	0.707	0.693	0.678	0.663	0.647	0.629
2600	549	73.2	0.761	0.748	0.736	0.723	0.710	0.696	0.683	0.668	0.653	0.637	0.619
2700	542	72.3	0.750	0.738	0.725	0.712	0.699	0.686	0.672	0.658	0.643	0.627	0.609
2800	535	71.4	0.739	0.727	0.714	0.702	0.689	0.676	0.662	0.648	0.633	0.617	0.600
2900	529	70.5	0.729	0.716	0.704	0.691	0.679	0.666	0.652	0.638	0.623	0.607	0.590
3000	522	69.6	0.718	0.706	0.693	0.681	0.669	0.656	0.643	0.629	0.614	0.598	0.581
3100	516	68.8	0.708	0.695	0.683	0.671	0.659	0.646	0.633	0.619	0.604	0.589	0.571
3200	509	67.9	0.697	0.685	0.673	0.661	0.649	0.636	0.623	0.610	0.595	0.579	0.562
3300	503	67.1	0.687	0.675	0.663	0.651	0.639	0.627	0.614	0.600	0.586	0.570	0.553
3400	497	66.2	0.677	0.665	0.653	0.642	0.630	0.617	0.604	0.591	0.577	0.561	0.544
3500	491	65.4	0.667	0.655	0.644	0.632	0.620	0.608	0.595	0.582	0.568	0.552	0.536
3600	484	64.6	0.657	0.646	0.634	0.623	0.611	0.599	0.586	0.573	0.559	0.544	0.527

Note 1. This table shows the factors used for modifying the output under the standard conditions (atmospheric pressure 100 kPa {750 mmHg} : atmospheric temperature 25 °C (77 °F) relative humidity 30% to that under specific environmental conditions.
The applicable standards are ISO 3046-1, JIS 8002. The factors are calculated according to the expressions specified in the standards.
2. This table is applicable to the turbocharged diesel engine.
3. Relative humidity isn't taken into consideration.

Table 2 Conversion Factors under Mechanical Efficiency of 85% — Turbocharged diesel engine

Altitude	Atmospheric pressure		Intake air temperature (℃)										
m	**mmHg**	**kPa**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
0	760	101.3	1.237	1.189	1.143	1.099	1.058	1.018	0.981	0.945	0.912	0.879	0.848
100	751	100.1	1.225	1.177	1.132	1.088	1.047	1.008	0.971	0.936	0.903	0.871	0.840
200	741	98.8	1.214	1.166	1.121	1.078	1.037	0.999	0.962	0.927	0.894	0.862	0.832
300	732	97.6	1.202	1.155	1.110	1.067	1.027	0.989	0.952	0.918	0.885	0.853	0.823
400	723	96.4	1.190	1.143	1.099	1.057	1.017	0.979	0.943	0.909	0.876	0.845	0.815
500	714	95.2	1.179	1.132	1.088	1.047	1.007	0.969	0.934	0.900	0.867	0.836	0.807
600	705	94.0	1.167	1.121	1.078	1.037	0.997	0.960	0.925	0.891	0.859	0.828	0.799
700	696	92.8	1.156	1.111	1.067	1.026	0.987	0.951	0.915	0.882	0.850	0.820	0.791
800	688	91.7	1.145	1.100	1.057	1.016	0.978	0.941	0.906	0.873	0.842	0.811	0.783
900	679	90.5	1.134	1.089	1.047	1.006	0.968	0.932	0.897	0.864	0.833	0.803	0.775
1000	671	89.4	1.123	1.079	1.037	0.997	0.959	0.923	0.888	0.856	0.825	0.795	0.767
1100	662	88.3	1.112	1.068	1.026	0.987	0.949	0.914	0.880	0.847	0.817	0.787	0.759
1200	654	87.2	1.101	1.058	1.016	0.977	0.940	0.905	0.871	0.839	0.808	0.779	0.752
1300	646	86.1	1.091	1.047	1.006	0.968	0.931	0.896	0.862	0.830	0.800	0.771	0.744
1400	638	85.0	1.080	1.037	0.997	0.958	0.921	0.887	0.854	0.822	0.792	0.764	0.736
1500	630	84.0	1.070	1.027	0.987	0.949	0.912	0.878	0.845	0.814	0.784	0.756	0.729
1600	622	82.9	1.059	1.017	0.977	0.939	0.903	0.869	0.837	0.806	0.776	0.748	0.721
1700	614	81.9	1.049	1.007	0.968	0.930	0.894	0.860	0.828	0.798	0.768	0.741	0.714
1800	607	80.9	1.039	0.997	0.958	0.921	0.885	0.852	0.820	0.790	0.761	0.733	0.707
1900	599	79.9	1.029	0.988	0.949	0.912	0.877	0.843	0.812	0.782	0.753	0.726	0.700
2000	592	78.9	1.019	0.978	0.939	0.903	0.868	0.835	0.804	0.774	0.745	0.718	0.692
2100	584	77.9	1.009	0.968	0.930	0.894	0.859	0.827	0.796	0.766	0.738	0.711	0.685
2200	577	77.0	0.999	0.959	0.921	0.885	0.851	0.818	0.788	0.758	0.730	0.704	0.678
2300	570	76.0	0.989	0.949	0.912	0.876	0.842	0.810	0.780	0.750	0.723	0.696	0.671
2400	563	75.1	0.979	0.940	0.903	0.867	0.834	0.802	0.772	0.743	0.715	0.689	0.664
2500	556	74.1	0.970	0.931	0.894	0.859	0.826	0.794	0.764	0.735	0.708	0.682	0.657
2600	549	73.2	0.960	0.921	0.885	0.850	0.817	0.786	0.756	0.728	0.701	0.675	0.651
2700	542	72.3	0.951	0.912	0.876	0.842	0.809	0.778	0.748	0.720	0.694	0.668	0.644
2800	535	71.4	0.941	0.903	0.867	0.833	0.801	0.770	0.741	0.713	0.687	0.661	0.637
2900	529	70.5	0.932	0.894	0.859	0.825	0.793	0.762	0.733	0.706	0.679	0.654	0.631
3000	522	69.6	0.923	0.886	0.850	0.817	0.785	0.755	0.726	0.699	0.672	0.648	0.624
3100	516	68.8	0.914	0.877	0.842	0.808	0.777	0.747	0.718	0.691	0.666	0.641	0.617
3200	509	67.9	0.905	0.868	0.833	0.800	0.769	0.739	0.711	0.684	0.659	0.634	0.611
3300	503	67.1	0.896	0.859	0.825	0.792	0.761	0.732	0.704	0.677	0.652	0.628	0.605
3400	497	66.2	0.887	0.851	0.817	0.784	0.754	0.724	0.697	0.670	0.645	0.621	0.598
3500	491	65.4	0.878	0.842	0.808	0.776	0.746	0.717	0.690	0.663	0.638	0.615	0.592
3600	484	64.6	0.869	0.834	0.800	0.769	0.738	0.710	0.682	0.656	0.632	0.608	0.586

Conversion Factors of Output



3. COLD STARTING AND OPERATION

[1] GENERAL

As explained in the preceding section regarding engines used in cold weather, a standard KUBOTA engine without external load can be started in temperatures as low as -15 °C (5 °F).
When the engine is mounted on a machine, cold starting performance is subject to various conditions, so very careful checks are necessary.
Points regarding fuel, lubricating oil, cooling water, starter, battery and glow plug are covered below.

[2] FUEL

The fuels of a high fluid point (viscosity) do not flow smoothly at an extremely cold temperature.
Such fuels should not be used. The table below shows the recommended fuels.

Standard / Temp. range	JAPAN	U.S.A.
	JIS K2204	ASTM D975-94
-5 °C (23 °F) and over	Diesel Fuel No.2 (or its equivalent)	No.2-D
-5 °C to -15 °C (23 °F to 5 °F)	Diesel Fuel No.3 (or its equivalent) or Diesel Fuel Special No.3 (or its equivalent)	No.1-D
Under -15 °C (5 °F)	Diesel Fuel Special No.3 (or its equivalent)	

For the diesel fuels, each nation has used a standard specified by a nationally authorized organization. In accordance with such a standard, a diesel fuel suitable to each season or region is selected to use.
This is in addition to the standards of JAPAN and U.S.A. shown in the above table.

Note :
Do not allow water to be mixed with the fuel.
Water in the fuel may freeze and prevent fuel flow.

[3] LUBRICANT

Oil viscosity changes in cold temperature as crystallization of the wax element contained in oil proceeds, and fluidity is finally lost. Wrong selection of oil cannot only increase resistance for cold starting but also affect lubrication of each part. Oils for low temperature, containing additives for lowering the pour point, should be used.

Note :
The use of synthetic oil is not recommended.

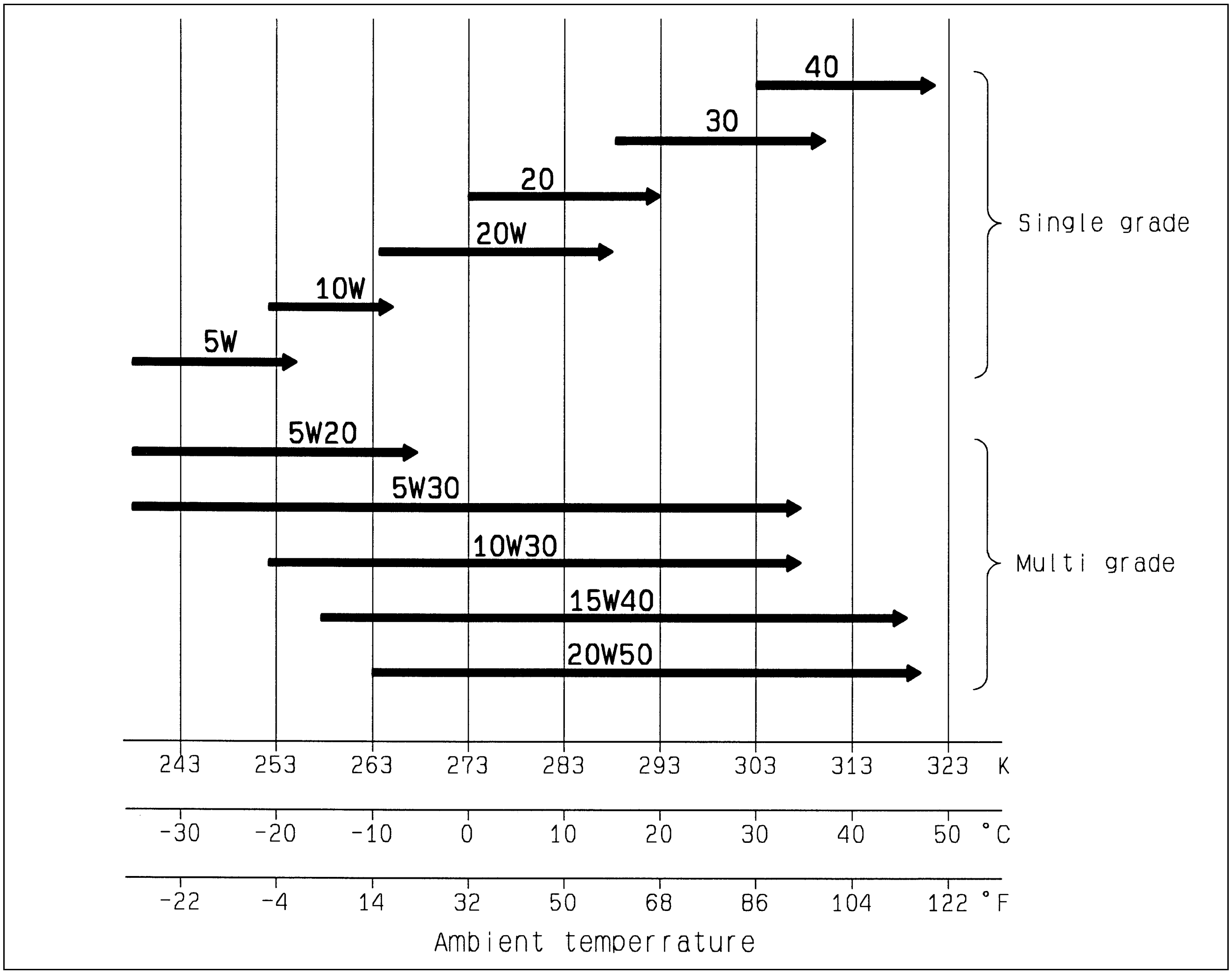


Fig. 3-15 Suitable oil viscosity chart

[4] COOLANT

High quality antifreeze must be used at all times.
1) Mix antifreeze with soft distilled water to use.
2) Premix the H_2O and antifreeze thoroughly before adding to the engine
3) Use only a 50/50 mix of H_2O and ethylene glycol (antifreeze) at all times.
4) Change antifreeze mix once a year.

[5] STARTER

Starters used in KUBOTA engines have the following standard capacities ;

Engine size Total displacement cc (cu.in.)	Starter capacity (kW) [More than -15 °C (5 °F)-BB Spec.]
Less than 700 (Less than 42.72)	0.8 to 1.0
700 to 1500 (42.72 to 91.54)	1.0 to 1.4
1500 to 3000 (91.54 to 183.06)	1.4 to 2.0
Over 3000 (Over 183.06)	2.0 to 2.5

Cold starting difficulty depends on the ambient temperature (intense cold or extreme cold) and resistance of transmission.

1) When an ON/OFF clutch is used between the engine and the power transmission, it can be set to OFF during starting and engine can be started as if starting an isolated engine.
2) Even though an ON/OFF clutch is not used, when resistance of the transmission is small, or when resistance is not small but the ambient temperature is not very cold, a standard starter may be sufficient.
3) On the contrary, as resistance increases, or as the ambient temperature becomes extremely cold, a large capacity starter and battery must be used.
4) As the displacement per cylinder increases, a larger capacity starter and battery must be used.

[6] BATTERY

From the viewpoint of startability, the battery capacity should be as high as possible. The capacity however is regulated by the assigned installation space and the balance between battery capacity and charging capacity. The table below is used as the standard in accordance with the description in the starter section.
Too much battery capacity imposes too much load on the starter. In the worst case, the starter may be burned up. Therefore, it is necessary to sufficiently examine and decide the battery capacity in accordance with the ambient conditions at starting.
As a principle, however, the battery is prepared and set by the manufacturer of machine to which the battery will be installed.

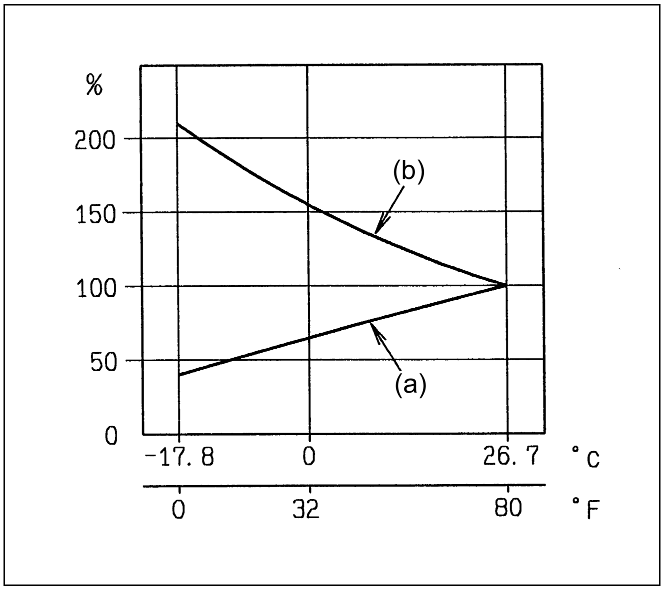
Battery capacity (AH)

Engine size Total displacement cc (cu.in.)	Battery capacity (AH)	
	20hr Ratio	5hr Ratio
Less than 800 (Less than 48.82)	35 ~ 50	28~40
800 to 1900 (48.82 to 115.95)	65~75	53~62
1900 to 3000 (115.95 to 183.06)	100~120	80~96
Over 3000 (Over 183.06)	150~180	120~144

Cold Cranking Amperage

Engine size Total displacement cc (cu.in.)	Cold Cranking Amperage [C.C.A (A)]
Less than 800 (Less than 48.82)	350~400
800 to 1900 (48.82 to 115.95)	450~540
1900 to 3000 (115.95 to 183.06)	580~670
Over 3000 (Over 183.06)	1050~1200

Discharging capacity is reduced by temperature change. The battery discharging capacity varies with the ambient temperature change.
Especially at a low temperature, the decrease of discharging capacity poses a problem. As for the equipment used at an extremely cold temperature, if the load of its hydraulic pump, torque converter, etc. is estimated to increase, it is necessary to increase the battery capacity together with that of the starter. When further increase is required, use of 24 V specification starters and glow plugs should be considered.



(a) Comparison of cranking power available from fully charged battery at various temperature.
(b) Comparison of power required to crank engine with S.A.E. 10W-30 oil at various temperature.

Fig. 3-16

[7] BATTERY CABLE

The battery cable size (cross-sectional area) largely influences the starting performance of engine (especially at an extremely cold temperature).
It is necessary to select a cable of appropriate size. The following summarizes the procedures for specifying the battery cable size area.

Current (A)	Cable size (mm^2)	AWG size
380	15	6
440	20	4
550	30	2
630	40	1
710	50	0
800	60	2/0
960	85	3/0
1170	100	4/0

[Ambient temperature : 40 °C (104 °F)]

Procedures for specifying battery cable size

1. Obtain the rated current of starter.
   To obtain the rated current (A), divide the rated output of starter (kW) by the battery voltage (V).

   Ex.
   When a 2.2 kW starter is driven by a
   12 V battery : 2200 (W) / 12 (V) = 183.3 (A)

   When a 2.2 kW starter is driven by a
   24 V battery : 2200 (W) / 24 (V) = 91.7 (A)

2. Multiply the obtained rated current by three (since the current flow at starting is about three times the rated current).

   Rated current × 3
   Ex. 183.3 × 3 = 549.9 (A)

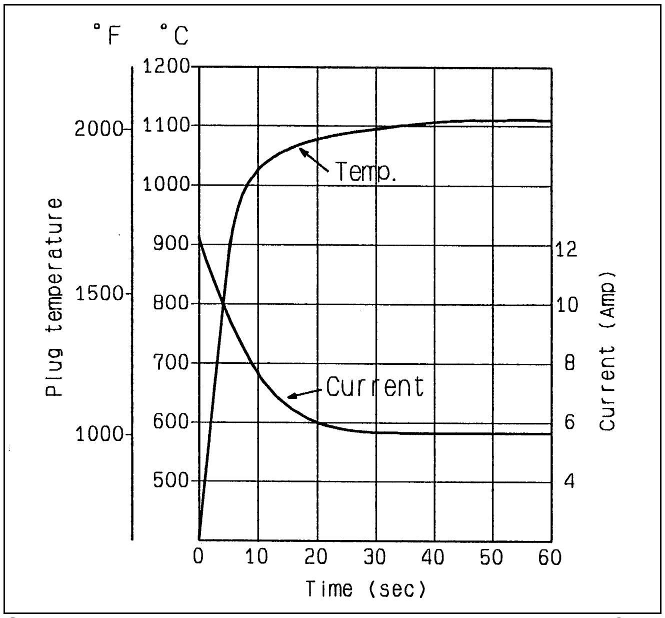
3. In accordance with the obtained starting current value and above table (Table of maximum current for each cable size in short time operation), select the minimum cable size to withstand the starting current value.

   Ex.
   The above table shows a cable of 30 or 40 mm^2 cross sectional area (low voltage cable for automobiles) must be used.

4. For 24 V special applications, the above guide-lines can also be used.

[8] GLOW PLUG

The temperature and current and period of time of glowing plug are as shown in Fig. 3-17.
With the S.M., 05, 03-M, 07 and V3 series, the Super Glow Plug (Quick Glow Plug) system is supplied as a standard component to reduce the preheating period. When preheating is too short, the combustion chamber does not become sufficiently warm and the operator must repeat starting operation.
In this case the battery is also discharged.
Note : Refer to 9-7, "[4] GLOW PLUG".



Glowing current time period and glow plug surface temperature and current.

Fig. 3-17

Atmospheric temperature °C (°F)	Time required * for red heat sec	Time required ** for preheating sec
Above 10 (50)	—	NO NEED
10 (50) to -5 (23)	Approx. 6	Approx. 5
Below -5 (23)		Approx. 10

* The above values are shown only as reference values and vary with engine types.
* Time required for red heat:
  Time required for (raising the tube surface temperature to approx. 800 °C (1472 °F) at the glow terminal voltage of 12 V.

**Limit of continuous use is 20 seconds.

[9] AUXILIARY STARTING DEVICES

Auxiliary devices are required when the engine is started at extremely cold temperature, or when it must be started in a short period (in approx. 10 seconds) in severe cold temperatures.

1) Coolant heater
   A coolant heater is installed in the coolant circuit to preheat coolant to 10 to 30 °C (50 to 86 °F).
2) Oil pan heater
   Oil pan may be heated from the bottom with a heater, or oil in oil pans may be heated directly by sheathed heaters.
3) With stationary engines, engine room can be heated, or engine covered and heated with infrared heaters.
4) Regular pre-heating
   About 50% of the rated voltage is applied to the glow plug to prepare for the emergency start. (Effective for reducing the starting time of emergency generator).

Time that a 50% of rated voltage could be applied. : Continuous

【WARNING】
Don't use starting aids such as ether.