UDC 621. 311. 23 : 621. 436

TOTAL OUTPUT 12,000 kW DIESEL POWER PLANT FOR YAKUSHIMA WORKS, YAKUSHIMA DENKO CO., LTD.

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I. FOREWORD

Power plants in recent industries are required to have sufficient capability and controllableness in order to fully meet demands in quality of electric power required by various loads as well as to secure safety preservation power of factories. When the power plants are expanded, the same considerations have to be taken so as to fulfill the obove mentioned requirements as a whole plant. Based on these needs, attention has recently become focussed on low grade oil, high unit capacity diesel power plants. The major reason for this being the performance and construction of medium speed supercharging high output diesel power plant corresponding to the heavy load of diesel engines, together with economical, highly efficient operation on low grade fuels.

The 6,300 kW diesel power plant delivered to the Yakushima Works of the Yakushima Denko Co. has been operating satisfactorily ever since being placed on commercial operation in 1971. An outline of this plant is given in this article.

II. OUTLINE OF DIESEL POWER PLANT

This plant is run in parallel with the existing hydraulic power plant and shares the fluctating load of various utilities and is operated as the base load. Since the output of the hydraulic power plant differs in accordance with the generated power during the wet and dry seasons, the plant has been designed to supply power to various utilities by making the output of the diesel power plant the base, and ample power is thus supplied even during the dry season. The 1st plant employs a single 5,700 kW unit while the 2nd plant employs a single 6,300 kW unit. Both plants employ exhaust gas boilers which utilize the exhaust gas heat of the diesel engine. The viscosity of the low grade oil is adjusted by heating the oil with the steam generated in this manner and the heated oil is then used as the diesel engine fuel. The outputs of the No. 1 unit and No. 2 unit differ. This has been done to improve the diesel engine of the No. 2 unit as compared with the No. 1 unit. However, the external dimensions of the diesel engine and generator are the same (Refer to *Figs. 1, 2* and *Table 1*).

III. LAYOUT

An exterior view and layout of the overall plant are shown in *Figs. 3* and *4*. The new plant is

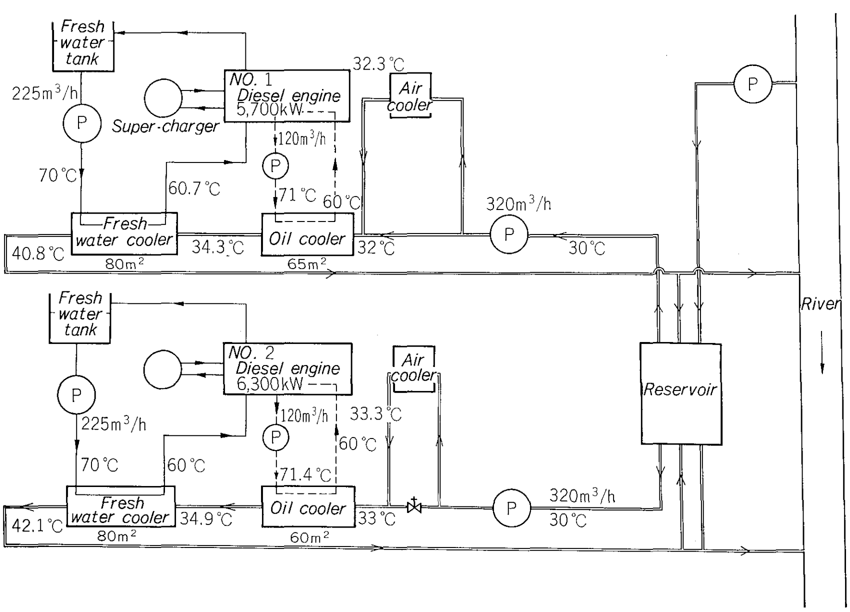

Fig. 1 Heat balance diagram of diesel engine

Table 1 **Diesel engine, generator and auxiliary**

	No. 1	No. 2
Type of diesel engine	18PC2V	18PC2V
No. of cylinder	18	18
Cylinder bore	400 mm	400 mm
Stroke	460 mm	460 mm
Max. continuous output	8,100 ps	9,000 ps
No. of rotation	514 rpm	514 rpm
Mean effective pressure	13.7 kg/cm^2	15.14 kg/cm^2
Max. explosion pressure	90 kg/cm^2	90 kg/cm^2
Weight (dry)	75,800 kg	75,800 kg
Generator	3 phase synchronous generator	Same as left
Rating	Continuous	Same as left
Output	6,710 kVA (5,700 kW)	7,500 kVA (6,300 kW)
Voltage	3,300 V	3,300 V
Current	1,175 A	1,310 A
Frequency	60 Hz	60 Hz
No. of rotation	514 rpm	514 rpm
No. of pole	14 poles	14 poles
Power factor	85% (lag)	84% (lag)
Insulation class	B class	B class
Excitation system	Thyristor exciting	Thyristor exciting
Weight	28,000 kg	28,000 kg
Fuel oil system		
Banker C storage tank	1,200 k*l*	
Banker C settling tank	20 k*l*	
Banker C service tank	10 k*l*	10 k*l*
Banker A storage tank	300 k*l*	
Banker A service tank	10 k*l*	
Banker C transfer pump	87 *l*/min.	
Banker A transfer pump	87 *l*/min.	
FO purifier	2,800 *l*/h, 5.5 kW	2,850 *l*/h, 5.5 kW
Banker C filter	30 mesh	
FO filter No. 1	60 mesh	60 mesh
FO filter No. 2	10 μ	10 μ
FO pump	3,000 *l*/h, 3 kg/cm^2 1.5 kW	3,000 *l*/h, 3 kg/cm^2 1.5 kW
FO heater	12 kW	12 kW
Lub. oil system		
LO sump tank	8,000 *l*	9,000 *l*
LO purifier	3,000 *l*/h	3,000 *l*/h
LO pump	120,000 *l*/h, 7 kg/cm^2, 55 kW	120,000 *l*/h, 7 kg/cm^2, 55 kW
LO cooler	65 m^2	65 m^2
Cooling water system		
Cooling water pump	225,000 *l*/h, 3 kg/cm^2, 30 kW	225,000 *l*/h, 3 kg/cm^2, 30 kW
Fresh water cooler	80 m^2	80 m^2
Fresh water explosion tank	450 *l*	450 *l*
Raw water pump	320,000 *l*/h, 2 kg/cm^2, 30 kW	320,000 *l*/h, 2 kg/cm^2, 30 kW
Fuel valve cooling water tank	60 *l*	60 *l*
Fuel valve cooling water pump	2,700 *l*/h, 3 kg/cm^2, 1.5 kW	2,700 *l*/h, 3 kg/cm^2, 1.5 kW
Fuel valve cooling water cooler	1 m^2	1 m^2
Starting air system		
Air compressor	30 m^3/h, 30 kg/cm^2, 7.5 kW	
Air tank	750 *l*, 30 kg/cm^2×2	
Exhaust gas device		
Steam boiler	400 kg/h, 4 kg/cm^2	400 kg/h, 4 kg/cm^2
Soft water tank	3,000 *l*	
Boiler feed water pump	28 *l*/min. 6.3 kg/cm^2, 1.5 kW	28 *l*/min. 6.3 kg/cm^2, 1.5 kW
Suction device		
Oil bath filter	3,240 m^3/min.	2,980 m^3/min
Vent fan	1,320 m^3/min.	2,000 m^3/min
Roll o. pack	672 m^3/min.	765 m^3/min

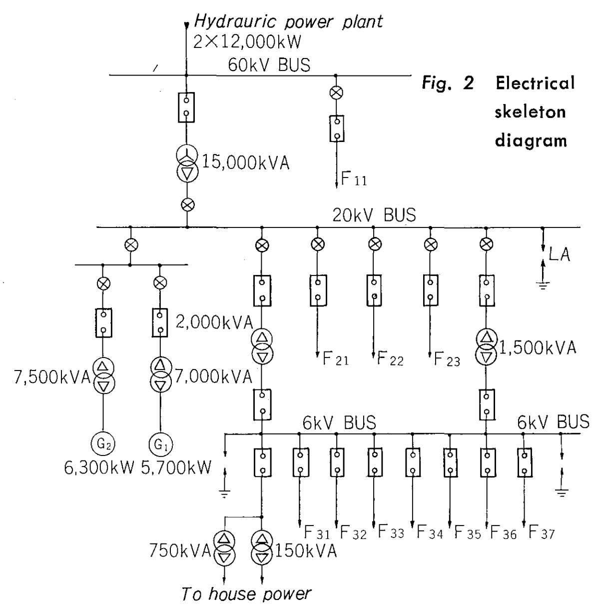

Fig. 2 **Electrical skeleton diagram**

installed to the right side of the 5,700 kW diesel power plant previously delivered. The major points considered in the layout of this plant were high operating performance, ease and safety of operational control and supervision, convenient maintenance and inspection, reduction in the length of piping and cabling, ease of installation and wiring work, clear distinction between fuel, lubricating oil, cooling water, and electrical systems, and the avoidance of mutual error.

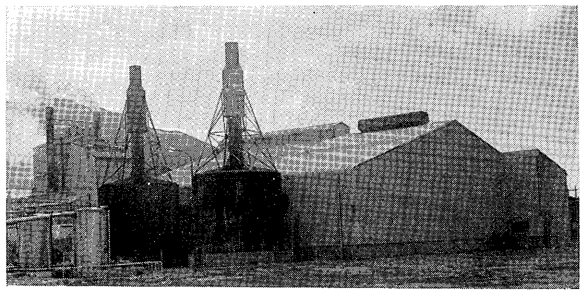

Fig. 3 Outerview of diesel electric power plant

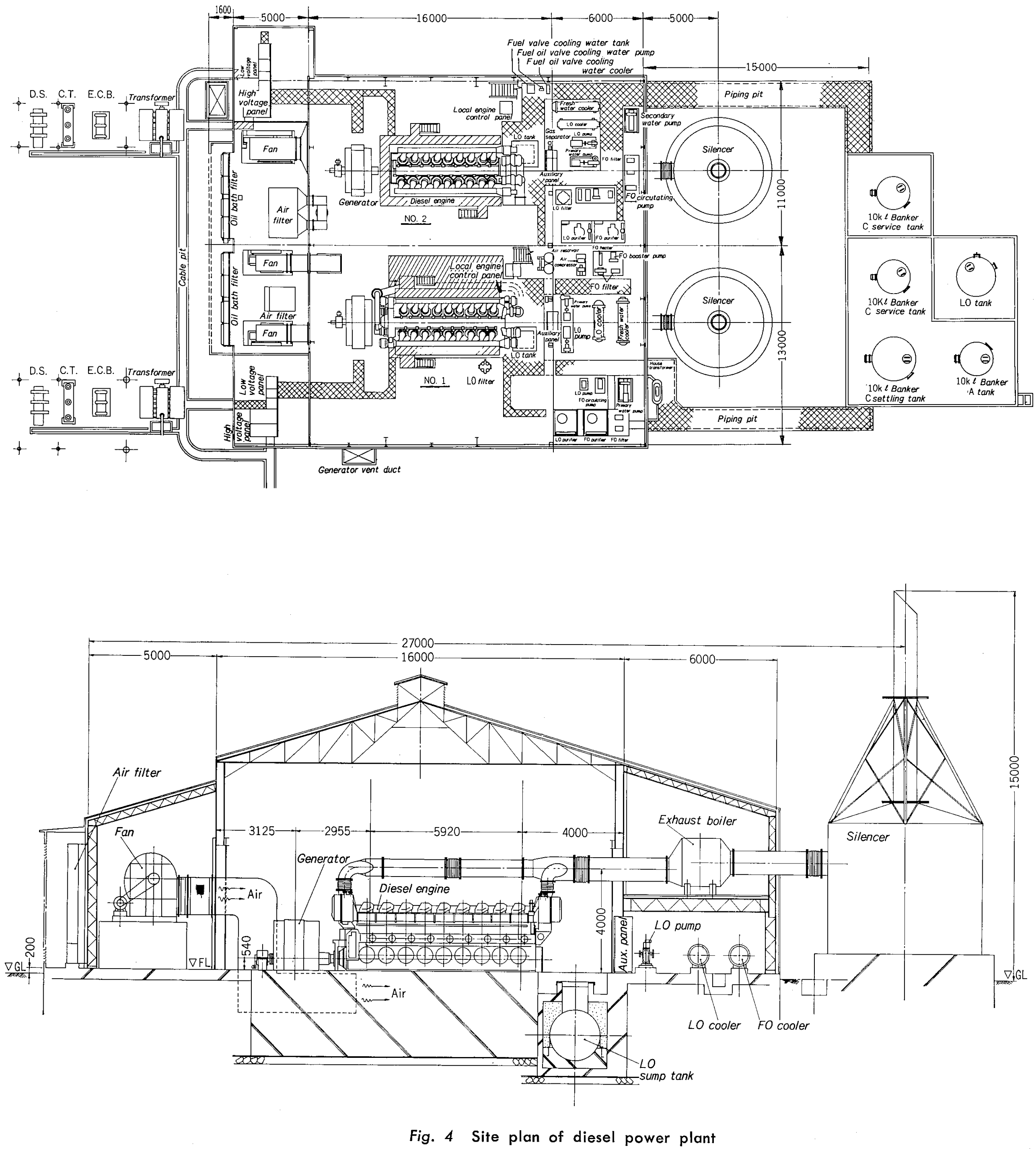

Fig. 4 Site plan of diesel power plant

IV. DIEREL ENGINE AND AUXILIARY EQUIPMENT

1. Diesel Engine (*Fig. 5*)

A cross section view of the PC2V diesel engine is shown in *Fig. 6*. Both the No. 1 unit and No. 2 unit are the supercharger type and are identical except for the number and part of the construction of the pistons. Major particulars are given in para. II " Outline of the Diesel Power Plant ".

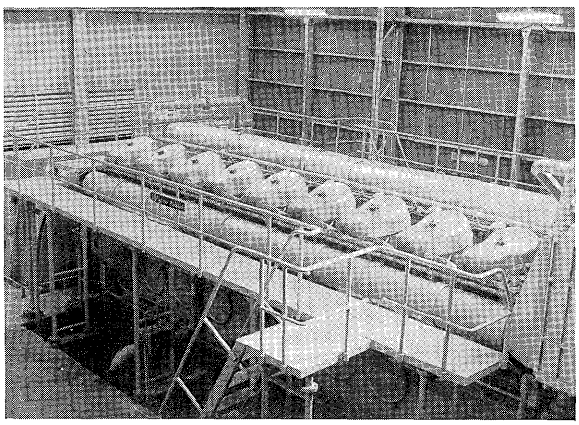

Fig. 5 Outerview of 6,300 kW diesel engine

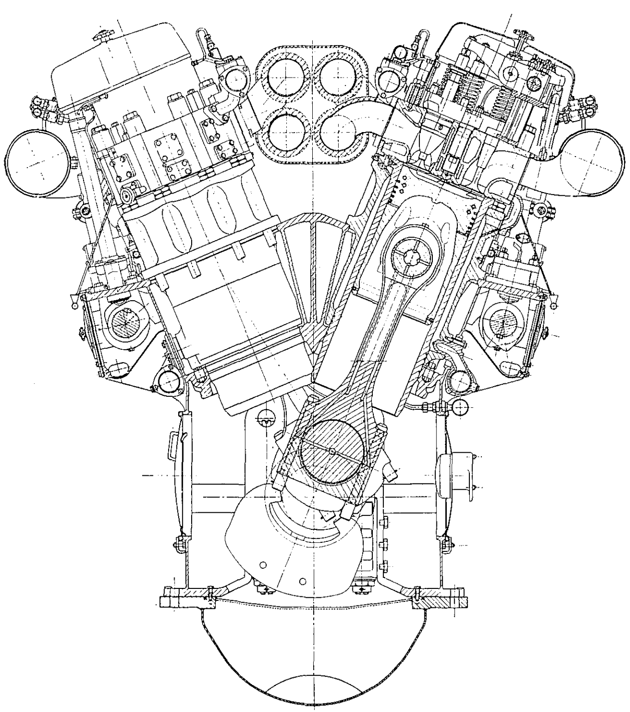

Fig. 6 Cross sectional view of engine

As can be seen from the cross section view, a V-type construction is employed. The features of this type of construction being :

(1) Small size, light weight

Fabricated construction utilizing a cast steel member and steel plate frame (crank chamber) making its final weight extremely light compared to other steel plate unit type constructions. Its strength and rigidity are also superb. Since this permits correct support of the rotating crank shaft, the life of the shaft bearings is long. Furthermore, its light weight permits a reduction in the size of the mounting foundation, thus facilitating installation. The parts handled during maintenance are also light weight. Since a rotating speed of 514 rpm is utilized, its output is high despite of its small size. For this reason, its cost is lower than that of even low speed direct coupled generators. Building construction costs are also low because of the low height required by the power plant building.

(2) Low grade fuel (Banker C) can be used

The use of Banker C oil poses such problems as dispersion of the fuel injected into the cylinder by thermal adjustment of the viscosity of the fuel oil. Moreover, corrosion due to the sulfur component and vanadium inherent to the fuel oil must also be prevented. In addition, since the fuel oil also large amounts of such difficult to born components as residual carbon, ash, asphalt, etc., a construction which provides good combustion of such components is required.

High temperature cooling of the cylinder head and cylinder liner is performed by fresh water. Therefore, the sulfurous acid in the combustible gas is not changed to corrosive sulphate and wear is inhibited. The fuel injection valve is located at the middle of the cylinder head and two exhaust valves and intake valves are installed at both ends of the head. The exhaust valves are incorporated in a valve box and stellite alloy is deposited on the valve rod seat and valve seat. Moreover, the intake valve rod is coated with brightlay. Since it is heat resistant alloy processed, it will amply withstand long operation under high temperature, high pressure combustion chamber conditions. Moreover, a rotocap which is gradually rotated at each operation is installed to the exhaust valve rod, and since the rod isn't seated at the same point at all times, leakage at the seat due to carbon, etc. is prevented. This is one of the most important factors involved in the use of low grade oil. The fuel injection valve is cooled with fresh water to maintain the end of the nozzle at a low temperature at all times and to prevent the accumulation of combustion carbon. For this reason, an excellent mist is obtained and together with the shape of the combustion chamber, the fuel is completely combusted and the exhaust temperature is low.

(3) Pulse converter supercharging system

The major difference between the No. 1 unit and No. 2 unit is that the former employs a dynamic pressure supercharging system while the latter employs a pulse converter system.

The conventional dynamic pressure supercharging system performs drive and scavenging of the supercharger utilizing the exhaust gas pressure pulsations. The pulse converter system also utilizes the exhaust gas pressure, but a converter is installed at the gas inlet of the supercharger and the fluctuating gas pressure waves are converted to a constant pressure and then sent to the supercharger. The high efficiency of this system gives it the following advantages:

Improving the engine performance in high efficiency of the supercharger

Reduction of

- No. of supercharger installation units
- about 2～3% fuel consumption
- the temperature of exhaust gas

(4) Increased air supply cooling capacity

Since the density of the air from the supercharger is low due to its high temperature of 100°C or greater, a large amount of fuel is combusted, and the density of the air must therefore be increased by cooling the air in order to increase the output. In the case of the No. 2 unit, the cooling performance and output have been increased by increasing the cooling area by improving the construction of the air cooler.

(5) Starting, stopping, and no-load characteristics

One of the major features of the diesel engine is its extremely simple and smooth starting and stopping. When the starting button is depressed, compressed air from the air tank is fed to the starting valve of each cylinder through the engine starting air line control valve, the compressed air then enters the successive cylinders in accordance with the opening of the line control valve, the crank shaft is rotated by the force of the air, and fuel operation is started from the cylinder nearest the fuel tank. When the stop button is depressed, compressed air enters the fuel cut-off device the flow of fuel is interrupted, and the engine stops.

When started at normal room temperature, about 20 minutes is required from starting to the full load. The engine raises to full load within 3 minutes when the temperatures of the cooling water and lubricating oil are sufficiently high.

(6) Speed variations and vibration

Since the diesel engine employs a crank mechanism, speed variations are severe. However, since the amount of variation is extremely small in the case of a multicylinder engine, high quality power can be actually obtained. A Woodward Model UG40D hydraulic governor is employed for speed control.

The shaft system of the diesel engine and generator poses torsional vibration problems, but torsional vibration has been avoided by installing a special balance weight to the crankshaft and installing a damper at the end.

With respect to vibration of the foundation, the weights of the reciprocating parts of the engine have been combined through a detailed study to reduce vibration produced during operation. Therefore, no vibration appears at the surface of the foundation.

2. Auxiliary Equipment

1) Fuel oil system

The fuel oil system is shown in *Fig. 7*. A 1,200 k*l* storage tank is provided in the Banker C oil system. The oil is sent to the settling tank by means of a feed pump and passed through a cleaner. The clean fuel oil enters the service tank, reaches the heater through a fuel oil supply pump and filter and the fuel oil whose viscosity is adjusted here by heating to a suitable temperature is then combusted by injecting it into the cylinder. The Banker C oil system tank is equipped with a heater and the piping system is insulated. The Banker A oil system is equipped with a 300 k*l* storage tank and is connected to the Banker C oil system through the Banker A oil service tank and Banker A, C fuel oil change over valve.

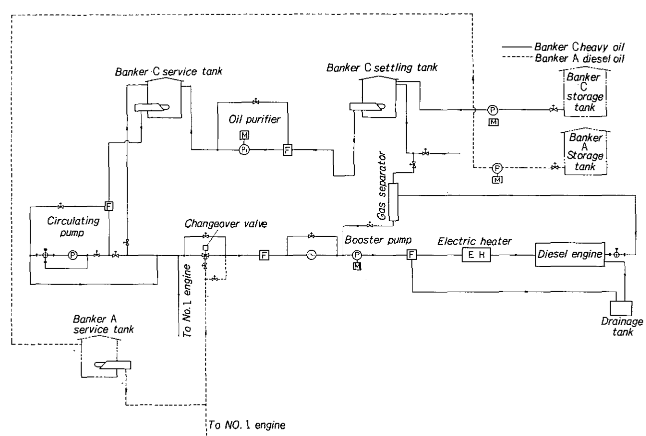

Fig. 7 Fuel oil flow diagram

2) Lubricating oil system

The lubricating oil system diagram is given in *Fig. 8*. The oil sucked in from the 9,000 *l* underground sump tank by the lubricating oil pump is cooled by a cooler and is forced fed to all parts of the engine and to the generator bearings through a filter. The oil which lubricates and cools all parts is collected directly or at the oil pan of the engine and sent back to the lubricating oil sump tank. The oil inside the lubricating oil sump tank is cleaned by a special cleaner so that sludge included in the oil is always removed. Oil is supplied to the lubricating sump tank from the storage tank by a transfer pump.

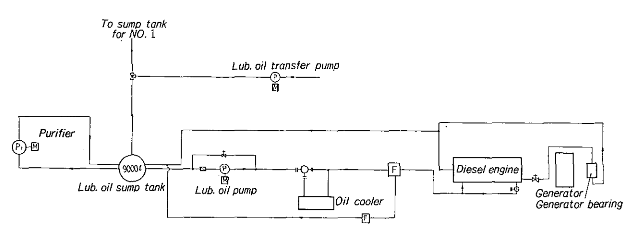

Fig. 8 Lubricating oil flow diagram

3) Cooling water system

The cooling water system diagram is shown in *Fig. 9*. There are two systems, a primary and a secondary cooling water system. The primary cooling water (fresh water) is filled in the system and is forced fed to the engine and supercharger for cooling by a pump. After cooling, the hot water is fed to the fresh water cooler where it is cooled and then recirculated. The system is replenished automatically from the expansion tank. The fuel injection valve is cooled by an independent system as shown in the figure to increase the cooling effect. River water is used in the secondary cooling system.

The water is first sucked up to the storage pond by a pump and passed through each of the coolers. After performing heat exchange the water is sent to the discharge water canal.

To prevent corrosion inside the piping, the fresh water system is water processed using a water processing agent.

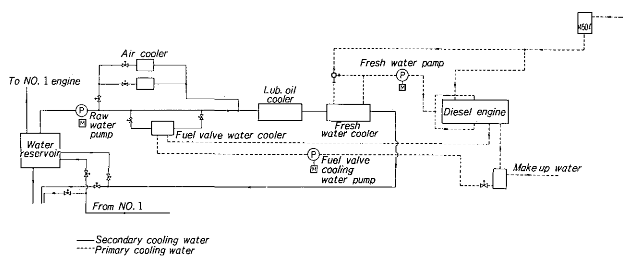

Fig. 9 Cooling water flow diagram

4) Starting air system

The starting air system diagram is shown in *Fig. 10*. There are two 750 *l*, 30 kg/cm^2 air tanks. Automatic air filling is performed by an air compressor so that engine starting is possible at all times. The system is constructed of two systems, a 30 kg/cm^2 high pressure circuit and a pressure reduced 10 kg/cm^2 low pressure circuit.

The high pressure system forces air into the cylinders through a starting valve which is directly connected through a drain separator and filter. The low pressure system is divided into a branch which controls the starting valve of the engine through a starting solenoid valve through the same path as described above and a branch which acts on the fuel stop device of the engine through a stop solenoid valve.

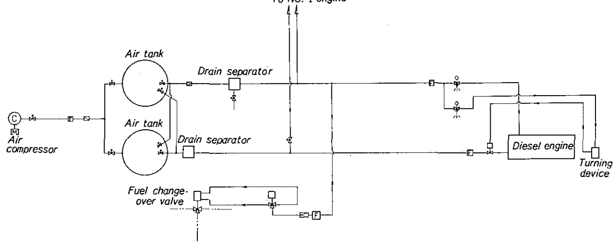

Fig. 10 Strating air flow diagram

5) Intake air, exhaust and steam system

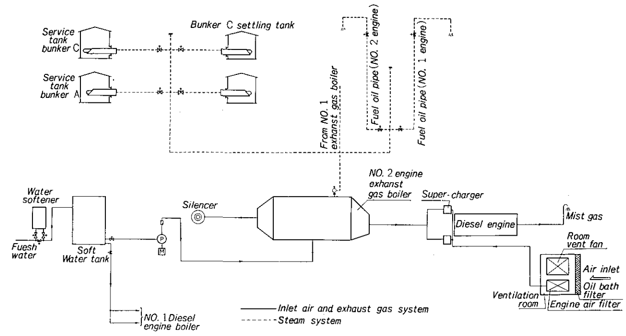

Fig. 11 Intake air, exhaust gas and steam flow diagram

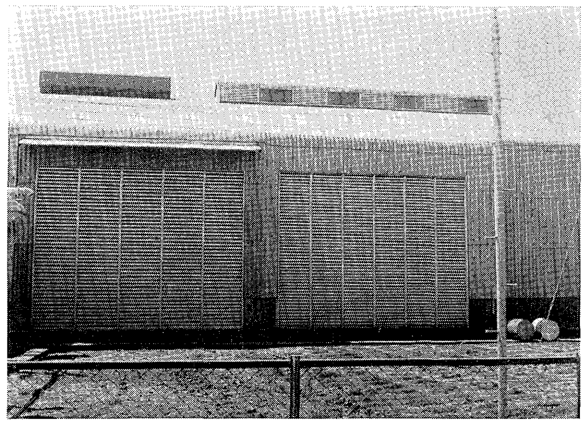

Fig. 12 Outerview of oil bath filter

The intake air, exhaust and steam system diagram is given in *Fig. 11*. This plant has been designed with consideration given to the sufficient removal of dust in the air. When dust is sucked directly into the engine, abnormal wear of the pistons, piston rings, and other sliding parts and rapid deterioration of the lubricating oil will be produced. A ventilating room is provided in one part of the power generating station building and an oil bath filter has been installed to the air intake. The ventilating fan of the building and the engine air filter are installed inside the ventilating room. This air filter and the supercharger air intake are directly connected by a duct. An outerview of the oil bath filter is shown in *Fig. 12*. After driving the supercharger, the exhaust from the engine is sent to the waste heat boiler through an exhaust pipe and then discharged to the atmosphere from the smokestack through a silencer. Ample consideration has been given to the prevention of noise and atmospheric pollution in the design of both the silencer and smokestack. The waste heat boiler utilizes the heat of the engine exhaust to produce saturated steam, which is used to heat the fuel tanks and to maintain the temperature of the fuel lines and is discharged to the atmosphere through a steam trap after use.

A scale inhibitor is added to the make up water which has been softened by water softening equipment and the water is then supplied to the waste boiler.

3. Results of Operation

Machine No. 1 has been operatiing continuously for nearly 19,000 hours without a failure eversinece beeing placed in operation in September, 1969.

Table 2 **Results of starting test**

Times of start	6 times
Air tank pressure before start	30 kg/cm²
Min. starting pressure	10 kg/cm²
Air tank capacity	750 *l*×1
Air temperature	30°C
Lub. oil temp.	40°C
Cooling water temp.	35°C

Table 3 **Performance of engine**

Load (100%)	6,300 kW	Remarks
Fuel oil consumption rate	210~214 gr/kWh	Fuel oil temperature 33~42°C
Exhaust gas temp. at cylinder outlet	440~460°C	
Primary cooling water temp. engine inlet / engine outlet	55~56°C / 63~65°C	
Lub. oil temp. cooler inlet / cooler outlet	64~65°C / 41~44°C	
No. of rotation of supercharger	14,000~14,100 rpm	
Air temp. before cooler / after cooler	117~118°C / 40~43°C	
Room temp.	30~32°C	
Vibration on foundation floor	0 mm	

Yearly fuel consumption is approximately 210~230 gr/kWh (Banker C oil operation). Banker A oil is used during starting and stopping and Banker C oil operation is performed only when the load exceeds 50%.

The engine system lubricating oils are Shell Agena 30 as the system oil and Shell Turbo 33 for the supercharger.

The test results for No. 2 machine are given in *Table 2~5*. As can be seen from these values, good results were obtained.

Table 4 **Performance of governor**

Prime mover 18PCV diesel engine 9,000 ps, 514 rpm
Generator 7,500 kVA 3,300 V pf: 0.84, 60 Hz
Governor UG-40-D
Over speed trip test 585 rpm (13.8%)

Load (100%)	6,300 kW
Rotation speed at	
Loading (rpm)	514
No load (max.) (rpm)	563
Stable (rpm)	531
Instantaneous (%)	9.5
After instantaneous (%)	3.3
Frequency at	
Loading (Hz)	60.3
Stable (Hz)	62.2
Atfer instantaneous (%)	3.2
Time (sec.)	6.5
Voltage at	
Rated load (V)	3,400
No load (V)	3,600
Stable (V)	3,400
Regulation (%)	6.1

Table 5 **SO_2 contained in exhaust gas**

Item	No. 1	No. 2
Rated load (kW)	5,700	6,300
Load measured (kW)	3,500	6,300
Kind of fuel oil	Banker C	Banker A
Quantity (k*l*/h)	1.2	1.51
Sulfer content (wt%)	2.34	0.86
Calorific value (kcal/kg)	9,750	10,300
Specific weight	0.9474	0.8554
Exhaust gas (Nm³/h)	24.200	36,800
Concentration (ppm·vol)	200	10
SO_2 exhaust vol. (Nm³/h)	4.84	0.368
Funnel height		
Gross height (m)	15	15
Effective height (m)	30.3	44.7
K reduced value	5.28	0.184

V. DIESEL GENERATOR

1. Generator

1) Specifications

Generator

The specifications of the generator are given in para. II " Outline of the Diesel Power Plant ". An outerview of the generator is given in *Fig. 13.*

2) Ventilating system

The ventilating system is a self-ventilating type in which the air is sucked in from both sides by a centrifugal fan installed to the center of the rotor and discharged at the bottom of the stator. The cooling air intake port employs a protected construction equipped with a protective metal screen. Careful consideration has been given to its installation

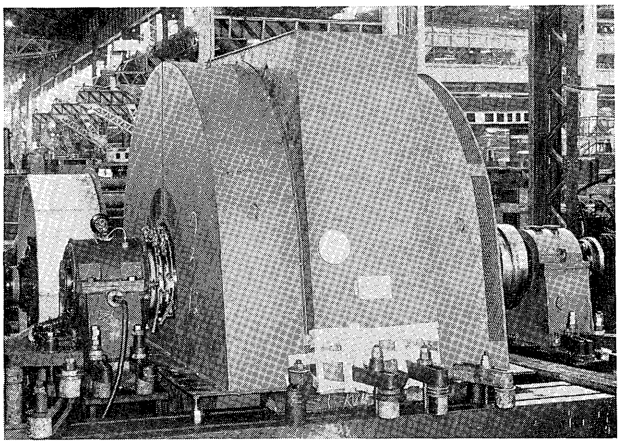

Fig. 13 Outerview of 7,500 kVA diesel generator

position to prevent the entry of oil vapor from the engine.

3) Generator construction

(1) Stator

The stator is composed of a stator frame, core, and winding. These have been rigidly assembled and manufactured to amply withstand the rated operation as well as to be sufficiently rigid with respect to the abnormal torque produced when sudden short circuit faults occur. The stator core is a laminated core of high quality thin silicon steel plates in order to reduce eddy current loss. After being wrapped 1/2 lap at the stator frame and pressed by a dove tail key groove provided around the outer periphery, it is retained by a press ring and tightened by core tightening studs to form a single unit. Moreover, to increase the cooling effect, a number of ducts are provided in the axial direction.

The stator winding conductor construction is several tens of wires. Each wire is insulated by a glass covering and perfectly transpositioned in the groove of the core to reduce the skin effect of the current due to leakage flux.

Spacers are provided between the windings at the ends of the coils, the adjacent wires are bound together, and make a single unit by the coil support rings to increase rigidity so that distortion is not produced in the case of sudden short circuit faults.

The stator frame employs a fabricated construction which possesses ample rigidity to withstand the reaction when the core is tightened, rotational reaction of the rotor, magnetic pull, thermal expansions of the core and its own weight, and so that there is no deviation produced in the air gap and forms the cooling air path for the core and winding.

(2) Rotor

The rotor center is inserted at the main shaft. The salient pole consisting of a magnetic pole core, field winding, and damper winding is installed to this rotor center. The slip ring which carries the excitation current of the rotor winding is provided at the top of the main shaft.

The magnetic pole core is made of laminated thin high quality steel plates having high permeability and mechanical strength. The core supports the field winding and damper winding and amply withstands their centrifugal force, self-weight centrifugal force, magnetic pull, etc.

The field winding is made of flat bar in an edgewise state. After insertion into the insulated core, the molded winding is sufficiently press dryed and retaining plates are welded to the magnetic pole core under the pressed state considering the effects of centrifugal force during rotating. After the poles are installed to the rotor yoke, each rotor winding is connected and leads are connected to the slip rings. The rotor center is shrink fitted to the shaft and attached to the shaft by a tangential key. Moreover, it is strong enough to amply withstand the action of the centrifugal force of the magnetic poles including the winding, centrifugal force due to its own weight, magnetic pull, torsional vibration, etc. The main shaft is a single semi-hard steel forging and is designed to amply withstand torsional stress, vibration ,and shaft deflection. The slips rings are 2 stainless steel rings made a single unit through insulation. To increase the conduction characteristics spiral grooves are machined at the outer periphery of the rings.

(3) Bearing

The bearing is a metal bearing and employs a forced lubricating system using the diesel oil. The bearing metal is high quality white metal deposited on the cast iron backing metal. Since the support face relative to the bearing stand is a spherical seat, it can respond freely to bending of the shaft. The bearing stand employs a welded steel plate construction and supports the weight of the rotor and is strong enough to amply withstand even vibration. The center of the shaft is divided in two and the bearing backing metal is supported at the center. Moreover, to prevent shaft current, an insulating liner is installed at the stand floor mounting surface of the unloaded side bearing stand and the stand is mounted to the floor with insulated bolts. In addition, the positioning pins are insulated taper pins.

2. Exciter

The progress made in thyristor production techniques and the improvements made in their reliability has been accompanied by the conversion of the conventional rotating exciter to thyristors and the practicalization of thyristor exciter equipment. Several hundred of these equipments have already been manufactured and their superb characteristics have been proven by their operating record.

The basic circuitry of this exciter equipment is shown in *Fig. 14*. The power transformer connected to the self-terminal of the generator is made the power source and the field winding of the generator is excited by the current rectified by the thyristor.

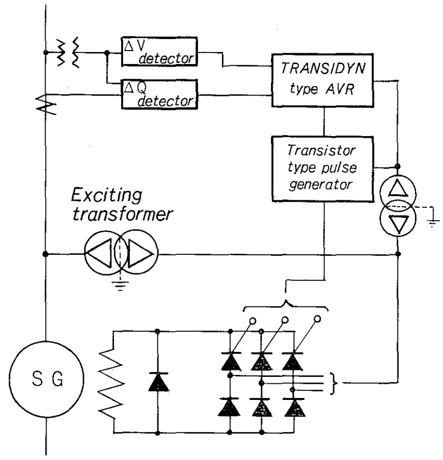

Fig. 14 Thyristor self-excitation system

The field current can be automatically adjusted from maximum to zero by controlling the voltage impressed on the field by changing the firing phase of the thyristor.

VI. OPERATING AND SUPERVISION SYSTEM

1. Operating System

The plan for the operating order of this plant is as follows:

Starting...... Starting preparation (auxiliary equipment operation)→engine starting→rated speed→voltage confirmation→load connection→switching to Banker C oil

Stopping...... Switching to Banker A oil→load interruption→engine stopping→stopping auxiliary equipment

Those operations concerning the engine are performed at the machine side operation desk and those concerning the electrical system are performed at the central control panel. Moreover, parallel operation of both the No. 1 and No. 2 machine is possible.

2. Supervision System

A central control panel and machine side operation desk are installed in this play and a machine side —remote supervision system is employed. One group of processes starting from starting preparation of the diesel generating set through operation and up to stopping are indicated at the machine side operation desk and central control panel by indicator lamps. Moreover, generating set accident indication is only given at the central control panel. Heavy accident indication is performed by bell and light accident indication is performed by buzzer. These are installed in the central control room and power room. As for stopping of the engine, normal stopping is performed by a pushbutton at the machine side operation desk and emergency stopping is performed by pushbutton at the central control panel. Furthermore, emergency stopping is also possible by means of the stop lever installed at the diesel engine.

VII. CONCLUSION

A simple outline of the 6,300 kW diesel power plant recently delivered and the existing 5,700 kW diesel power plant has been given above. It is felt that this type of power plant will gradually increase in size in the future. In this respect, we plan the early completion of the Model PC2–5V engine having a 20% greater output (600 horsepower per cylinder) at the same speed as compared with the existing Model PC2V by modifying the major internal parts without changing the external dimensions and weight. Furthermore, the 950 horsepower Model PC3V engine is currently being planned.

In this introduction, details could not be amply described, but we would be happy if the facility outline given here is found useful as a source of reference in later planning in the currently increasing demand for economical diesel power plants.

Finally we wish to express our deep gratitude to all those at Yakushima Denko Co. for their cooperation in the planning, design, and manufacture of this plant.