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30,000 KW DIESEL POWER PLANT FOR THE KOREA ELECTRIC COMPANY

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I. INTRODUCTION

For several years, diesel generator equipment has been used widely in power supply plants and has been accepted by all users.

Since this type of equipment is cheap, easy to install and simple to operate, etc., it is suitable for use in both regional power plants and factories or buildings (as private generators), as either stationary or movable equipment.

Previously, however, the actual output of a single diesel engine was only about 2500 kw in general and applicable fuel was limited to high quality oil. These conditions made it difficult to employ diesel equipment in large scale plants and consequently its popularity had not been developed.

Recently highly reliable, medium speed large output diesel engines which can utilize low quality oil formerly used only in boilers and large low speed engines for ships have been developed in various places. Many reports of actual use of this equipment indicate that it is now possible to construct large scale diesel power plants which supply cheap power using these new type engines.

The advantages which diesel generator plants have over plants using other types of prime movers can be outlined as follows.

1. Thermal efficiency is high and remains almost constant in respect to partial loads.
2. Handling is simple and high speed starting and stopping are possible.
3. Housing, foundation and other construction fees are all low.
4. Construction can be completed quickly.
5. Expansion in stages is simple.
6. The ratio of machines in use to back-up machines is improved.

(In other words, plant operating efficiency is high) In other words, the same advantages found in small-scale diesel generator equipment can all be incorporated in large scale power stations.

Recently, Fuji Electric supplied a full scale commercial standard power plant with an output of 30,000 kw to the Bupyong Power Station of Korea Electric Co. The equipment for this plant will be outlined in this article.

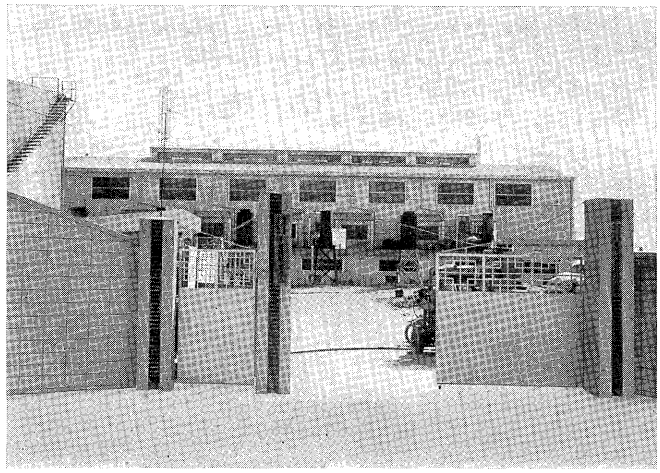


Fig. 1. Front view of power station

II. EQUIPMENT OUTLINE

This power plant is used in the diesel power station newly constructed by the Korea Electric Company in Bupyong to provide electric power for Korea's rapidly expanding industry. The overall capacity of the plant is 30,000 kw (six individual units of 5000 kw each).

The generator voltage is stepped up by a transformer from 6.6 kv to 66 kv and fed to the previously constructed 66 kv bus line.

The principle components of the plant are as follows.

1. Generator Equipment

6250 kva (5000 kw) ac generator	6 units
7200 ps diesel engine	6 units
6.6 kv 1200 amp 350 Mva magnetic blowout circuit breaker	6 units
High voltage (6.6 kv) apparatus	1 set
Control panel and AVR	1 set
Engine accessories	1 set

(fuel equipment, cooling water equipment, lubricating oil equipment, air equipment, smoke exhaust equipment, auxiliary boiler equipment)

Auxiliary devices and control devices in the station	1 set
Dc power source 150 amp•hr, 110 v	1 set

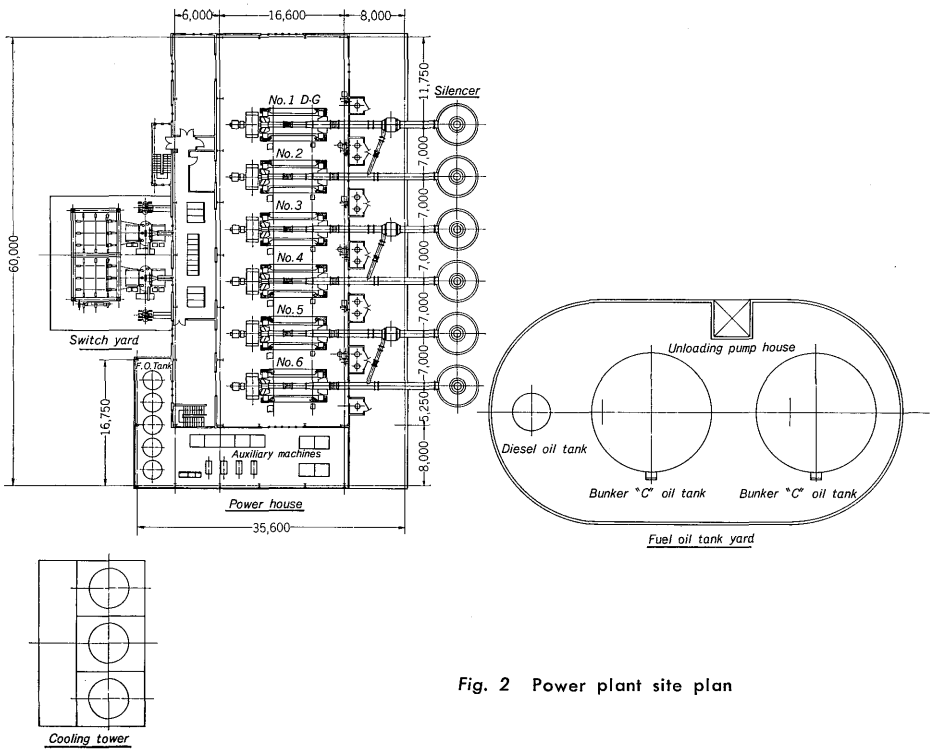


Fig. 2 Power plant site plan

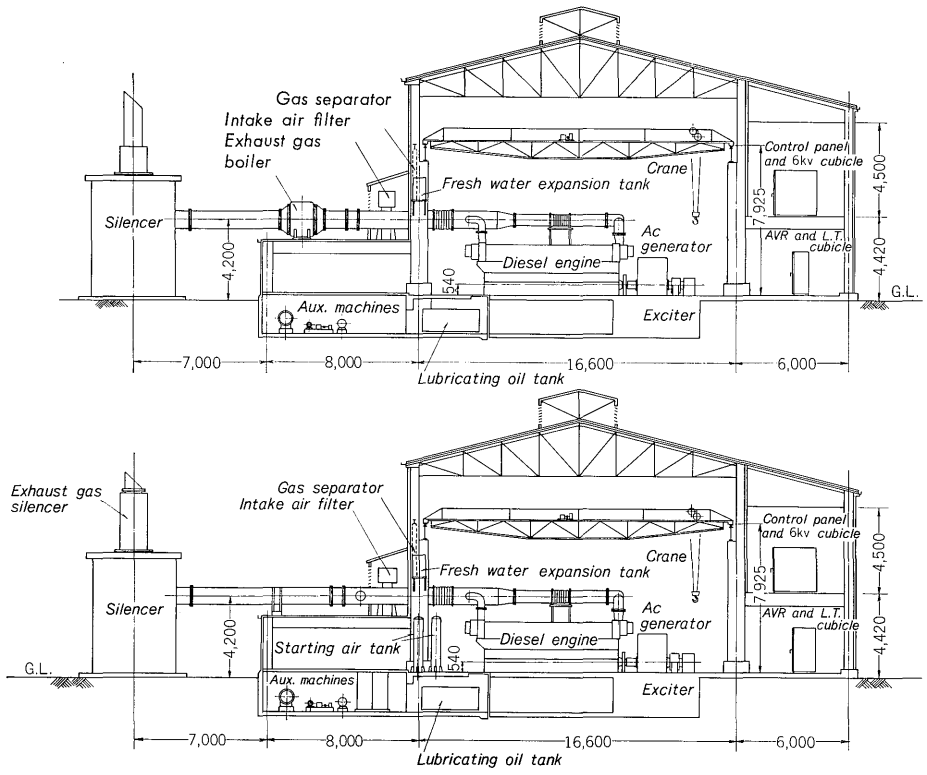


Fig. 3 Section of power plant building

2. Transmission Equipment (for outdoor use)

20,000 kva 6.6/66 kv 3-phase oil-immersed transformer	2 units
72 kv 1200 amp 2500 Mva air circuit breaker	1 unit
69 kv 1200 amp, 800 amp disconnecting switch	4 units
84 kv lightning arrester	3 units
69 kv current transformer (1200–800–600–400/5–5 amp)	3 units

The cooling water tower, fuel storage tanks, and exhaust silencers included in the engine accessories are naturally for outdoor use, as are the 66 kv transmission components. The station building is divided into a main machine section, an auxiliary machine section and an electrical section. Equipment has been arranged in each of the sections so as to facilitate handling and maintenance.

The first floor of the electrical section contains instruments which are not necessary for daily operation supervision, and power distribution panels. On the second floor there is a control room containing the main control and relay panels.

The equipment is all based on the specifications in major Japanese Standards (JIS, JEC, JEM).

III. DIESEL ENGINES

1. Construction and Functions

The diesel engines are Fuji S.E.M.T. Pielstick PC2 Diesel Engines manufactured by the Fuji Diesel Co., Ltd. Specifications are as follows.

Type : 4-cycle single-acting trunk piston, solid direct injection, exhaust gas turbine supercharged type.

Model : 16PC2V

Rated shaft output : 7200 PS

Site conditions

(a) Maximum ambient temperature 40°C

(b) Temperature of cooling water to internal cooler 32°C

(c) Elevation above sea level 1400 m max.

Overload output : 10% an hour in 12 hour

Rating :	Continuous rating
Speed :	514 rpm
Cylinder number :	16
Cylinder alignment :	45° Vee
Cylinder inner diameter :	400 mm
Piston stroke :	460 mm
Average piston speed :	7.88 m/sec
Explosion pressure :	90 kg/cm^2
Brake mean effective pressure :	13.64 kg/cm^2
Compression ratio :	12.5
Starting method :	Compressed air, directly into cylinder
Firing sequency :	Left 1 5 2 6 8 4 7 3 Right 9 13 10 14 16 12 15 11
Fuel :	Bunker C oil
Thermal efficiency :	38.3～40.3%
Fuel oil consumption :	163 g/ps/hr +5% Based on 17,200 BTU/lb. Lower (net) calorific value
Lubricating oil consumption :	1.5 g/ps/hr Based on detergent lubricating oil specification SAE #30
Exhaust gas temperature :	420～460°C at cylinder head outlet (mean value)
Jacket water flow :	185 ton/hr
Lubricating oil circulated :	110 ton/hr
Cyclic irregularity :	1/7100 (Including GD^2 of generator
Dimensions :	Overall length 7151 mm Overall width 3280 mm Overall height 3189 mm (Height above floor surface 2740 mm)
Total weight (dry) :	68,500 kg

Fuji Diesel concluded a technical tie-up with the French Co. S.E.M.T. concerning the internationally known high-capacity large-output Pielstick PC2 type medium speed 4-cycle diesel engine. Since the first engine was completed in February, 1966, a large number of these machines have been delivered and are now operating well. An outline of the construction of the Pielstick engine construction will be given below.

1) Crankcase and main shaft

The essential parts of the engine body are all of welded construction and, because of the hanger type main bearing, stress distribution is ideal and the safety factor is high. The main bearing cap is fixed from the upper part of the crankshaft with jack bolts and the bearing pedestal is fastened securely at equal intervals to the wall of the crankcase with bolts. Therefore, these same precautions as observed with ordinary engines are required when removing the bearing etc. The bearing metal consists of a lead-tin alloy overlaid with kelmet metal.

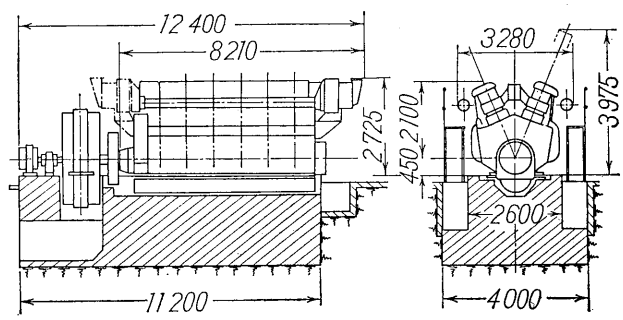


Fig. 4 Basic outline of diesel engine and generator foundation

2) Piston

The trunk type piston is made of a high silicon aluminum alloy and employs the lubricating oil cooling system. The cooling oil is force-circulated in a spiral pipe casted in the piston head. The piston contains 4 compression rings and 2 oil rings.

3) Crankshaft

The crankshaft is made of a single forging of special steel which has excellent fatigue resistance because of the special forging method.

4) Cylinder jacket

The cylinder jackets are made of cast iron. Since the jackets are independent for each cylinder, there is no corrosion problem because the cooling water does not make contact with the main engine unit which is made of steel plates welded together. Even if the cooling water should leak, it can not get into the crankcase because of the gap between the jacket and the main body, and therefore, the lubricating oil will never deteriorate.

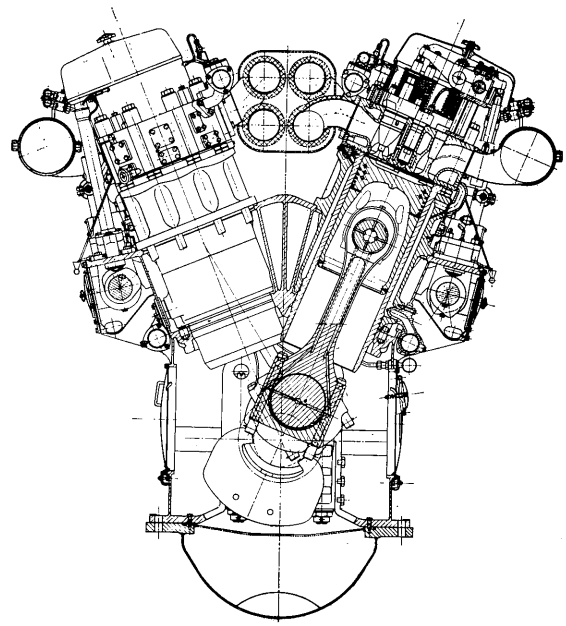


Fig. 5 Cross-section of PC2V type engine

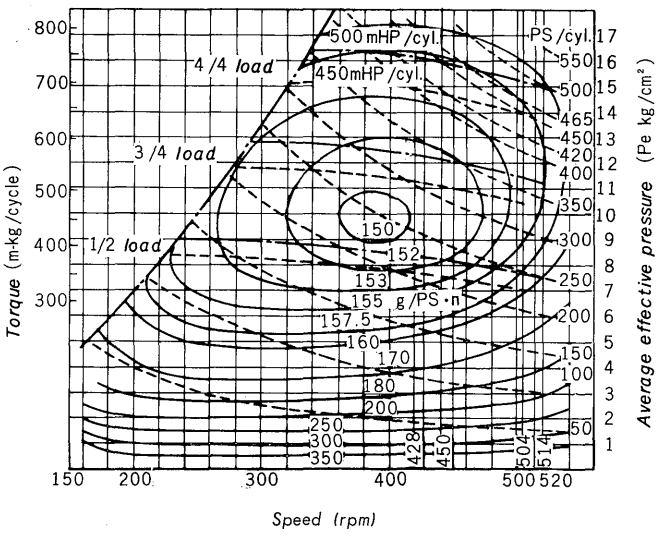
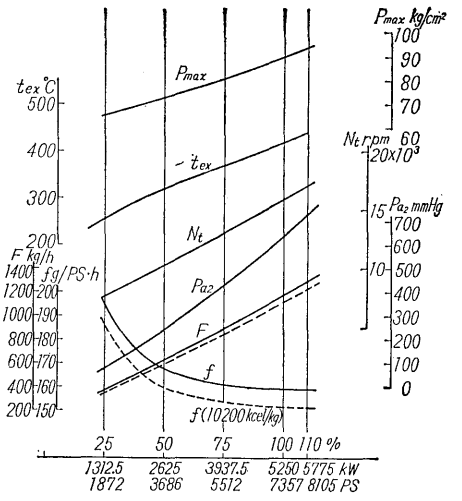


Fig. 6 Equal fuel consumption curves for PC2V engine



F: Fuel consumption
f: Fuel consumption factor
P_{a2}: Air pressure (after air cooler)
P_{max}: Maximum pressure inside cylinder
N_f: Supercharger speed
t_{ex}: Cylinder outlet exhaust temperature
(Broken lines are when low calorific value was changed to 10,200 kcal/kg)

Fig. 7 C-type heavy oil characteristics curves from official factory test on 18 PC2V type engines (500 rpm, 7560 ps, 5250 kw, C-type heavy oil low calorific value 9700 kcal/kg)

5) Cylinder liner

The cylinder liners located in the cylinder jackets are made of high quality cast iron. The cooling water circulates in a cooling chamber formed between the cylinder and jacket.

6) Connecting rod

The connecting rod is made of a stamp forging of special steel, H-shaped in cross-section. The crank pin metal is kelmet with an overlay of lead-tin alloy. The piston pin is of the floating type.

7) Cylinder cover

The cylinder cover is made of cast iron and contains two intake and exhaust valves each, as well as a fuel valve, starting valve, safety valve and injector cock. The exhaust valves are of the water cooled valve casing type, which makes them easy to remove.

8) Fuel injector

Each cylinder has an individual Bosche-type fuel pump and the injection valves are of the water-cooled type. The pipe from the fuel pump to the injection valve is short which insures good injection.

The features of these engines are as follows.

1) These engines are very compact when compared with the former low speed large scale models. Since welded type construction is used throughout, the weight is reduced and reliability increased.

2) The piston speed and shaft mean effective pressure are both high and the output is large. The rated output for each cylinder is 430～500 ps at a rotating speed of 400～520 rpm. The shaft mean effective pressure is 14.95～16.75 kg/cm² and the mean piston speed is 6.14～7.98 m/sec.

3) These are medium-speed large-output 4-cycle diesel engines, and also low quality heavy oil (Bunker C) or gas fuels can be used.

4) Fuel and lubricating oil consumption is low.

Fuel consumption : Using diesel fuels 115 g/ps/hr
Lubricating oil consumption : Using low quality oil 160 g/ps/hr
1.0～1.5 g/ps/hr

5) Since the main operating parts have high reliability and wear is minimum, frequent maintenance is not required. Operation for 8000～10,000 hours without disassembly was experienced.

6) Since the same design as in the V-type and in-line engines is used, most parts can be easily interchanged.

7) Remote control is easy to incorporate and automation is also possible.

8) Excellent reliability is obtained in standard power plants both on land and at sea. Since these engines can use low quality oil, they have a long service life and are easy to handle ; they will lower power costs if used as private generators and thus contribute to an overall reduction of factory costs.

2. Starting and Stopping Methods

In general, an automatic starting system and remote control are employed with standby generating equipment, but in this plant, there is little chance of starting or stopping and emergency starting is not required, so that the engine can be started or stopped manually at the local panel. Emergency stopping can be controlled from the central control room on the second floor.

The auxiliary equipment has a centralized operating panel for each unit so that collective manual operation is possible.

3. Accessories

1) Fuel oil system

This system consists of two 500,000 gallon Bunker

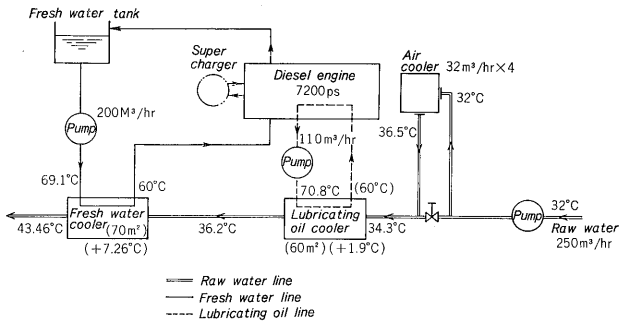


Fig. 8 Heat balance diagram

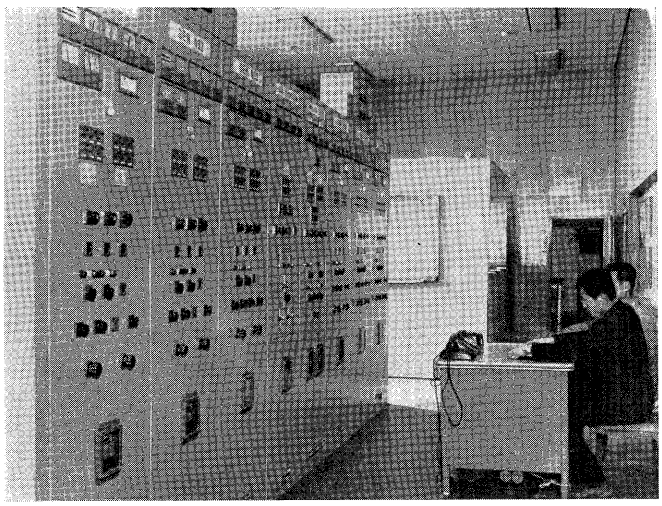


Fig. 9 Central control room

C fuel storage tanks, various types of pumps and a 30,000 gallon diesel fuel storage tank for light load operation or starting. The Bunker C fuel oil system is heated by means of an electric heater or a steam heater operated by the engine heat exhaust boiler, and all distribution pipes are provided with sufficient heat resistant material. The Bunker C temperature at the engine input was planned as 90～100°C.

2) Lubricating oil system

Each engine has an 5000 liter sump tank (optional) in which the lubricating oil can be regenerated. The engine lubricating oil is also used in the generator bearing via a branch line.

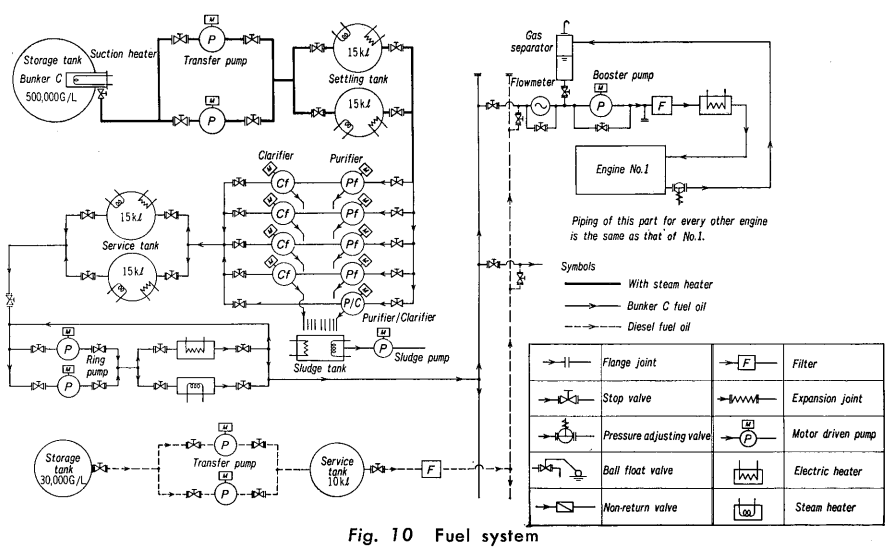


Fig. 10 Fuel system

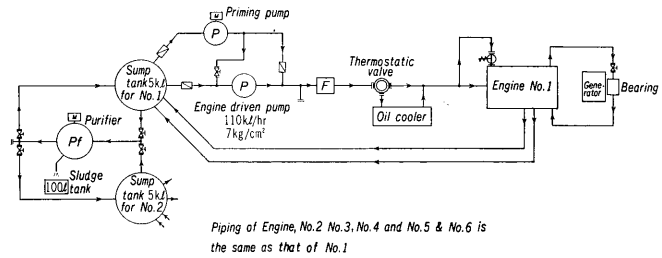


Fig. 11 Lubricating oil system

3) Cooling water system

This system is divided into a primary water (fresh water) system which provides circulation in the main engine unit and supercharger, and a secondary system for cooling of air cooler, fresh water cooler and lubricating oil cooler. The primary system includes an expansion tank and has a closed cycle, so that make-up feed requirements are small. The secondary system provides circulation by means of a cooling tower.

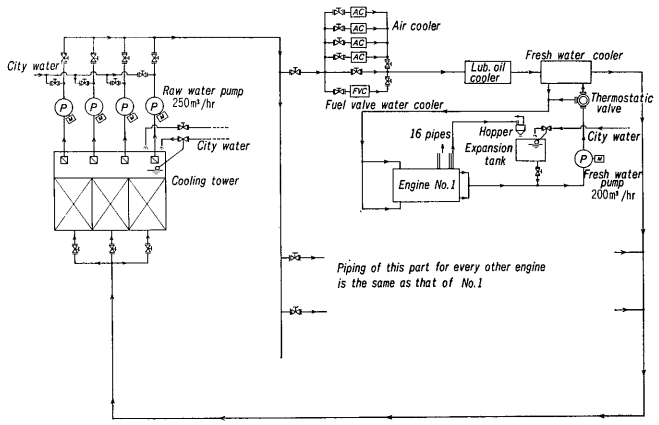


Fig. 12 Cooling water system

4) Air intake and exhaust gas system

Air intake is effected directly from the interior of the room. An air filter which also serves as a silenceris is provided in the air in take port, so that foreign matter is prevented from entering the supercharger or intercooler. The exhaust gas from each engine is exhausted outside the plant building via a large silencer. Three of the six engines have exhaust gas boilers for heating the bunker C fuel.

5) Starting air system

For every two engines, there are two 750 liters air tanks, one for

general use and one for standby use. In all of these air tanks, the pressure is held constant by means of an automatic air charging equipment.

6) Others

A 25-ton overhead crane is provided in the plant for use during periodic inspections.

IV. GENERATOR

Generator specifications are as follows.

Type :	Open horizontal shaft, revolving-field salient-pole-type synchronous generator
Model :	F 505/33–14
Number of phases :	3
Rated output :	6250 kva (5000 kw)
Power factor :	80% (delayed)
Rating :	Continuous
Rated voltage :	6600 v
Rated current :	547 amp
Frequency :	60 Hz
Speed :	514 rpm
Insulation class :	B class
GD^2	23.5 $T\text{–}M^2$ (not including shaft)
With overhang-type dc exciter	
Model :	aGV 280 68 kw 220 v
Dimensions :	Overall length approx. 4000 mm
	Overall width approx. 3440 mm
Total weight :	Approx. 34,200 kg

The generator is directly coupled to the diesel engines and for this reason, sufficient consideration must be given during design to prevent such problems as the occurrence of shaft bending loss due to torsion vibrations from the engines, resonance between the engine irregular torque and electrical oscillations inherent in the generator, and hatching during parallel operation. Precautions must also be taken to assure complete dynamic balance in the rotor.

The points have been investigated in detail and a durable construction was devised to provide complete safety. The bearing is of the one-pedestal type and a forced lubrication system is employed which also supplies lubricating oil to the engines. There is no possiblity of current circulating in the shaft.

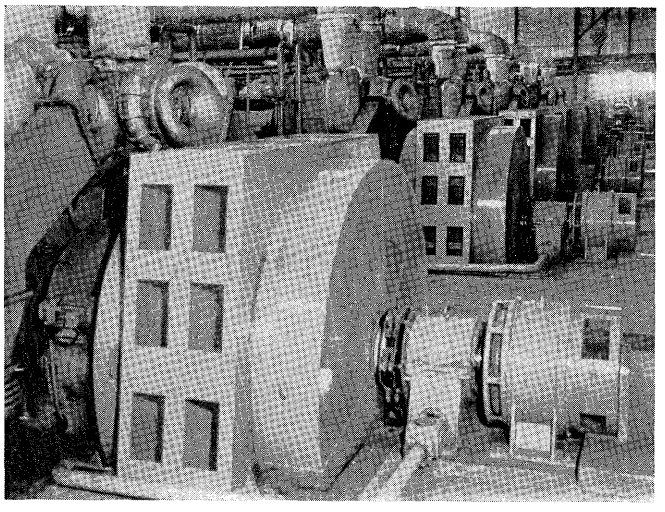


Fig. 13 Interior of power plant

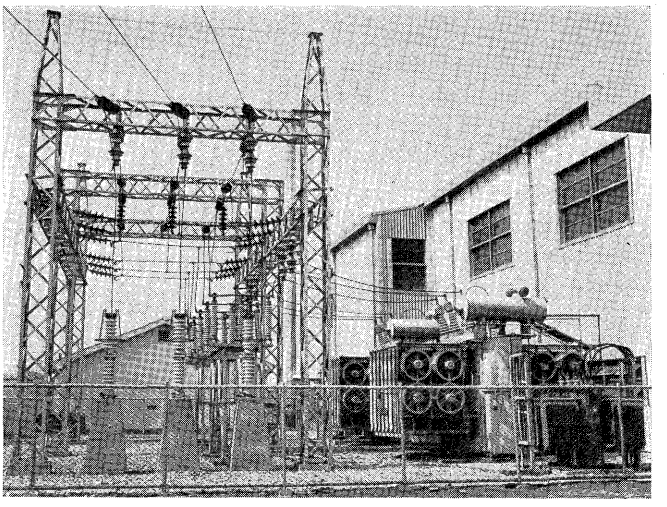


Fig. 14 Outdoor substation

The rotor and stator windings both have B class insulation. The stator winding employs wire with a baked insulation finish made of a special glass resin. Mica tape is baked on this wire to provide complete insulation with respect to ground. The rotor winding is of the edgewise type with asbestos insulation between the layers. All windings have ample resistance to heat.

V. OTHER ELECTRICAL EQUIPMENT

1. The exciter is a dc shunt exciter with isthmus-type magnetic poles developed specially by Fuji Electric, which means that a main field regulator is not necessary. The automatic voltage regulator is a quick-acting static type thyristor system which is highly reliable and ideal for parallel operation. The voltage regulation accuracy static type with a thyristor system which is highly reliable and ideal for parallel operation. The voltage regulation accuracy is $\pm 0.5\%$. When accidents occur in the AVR, the exciter can be switched to self-excited system, from automatic to manual to allow for manual voltage regulation.
2. The generator system is divided into 2 groups of three units each and a transformer for stepping up the voltage is provided for each group. This is planned to limit fault currents when there is an accident in the main internal circuits as well as to prevent complete generator shut-down during faults in the main circuits.
3. At the neutral points of each generator, there is a resistance to ground which limits the current to 100 amp or below, and prevents abnormal voltages from occuring in the 6 kv system.
4. When short-circuits occur in the generators or ground faults arise in the windings, a selective circuit breaking protective system is employed in

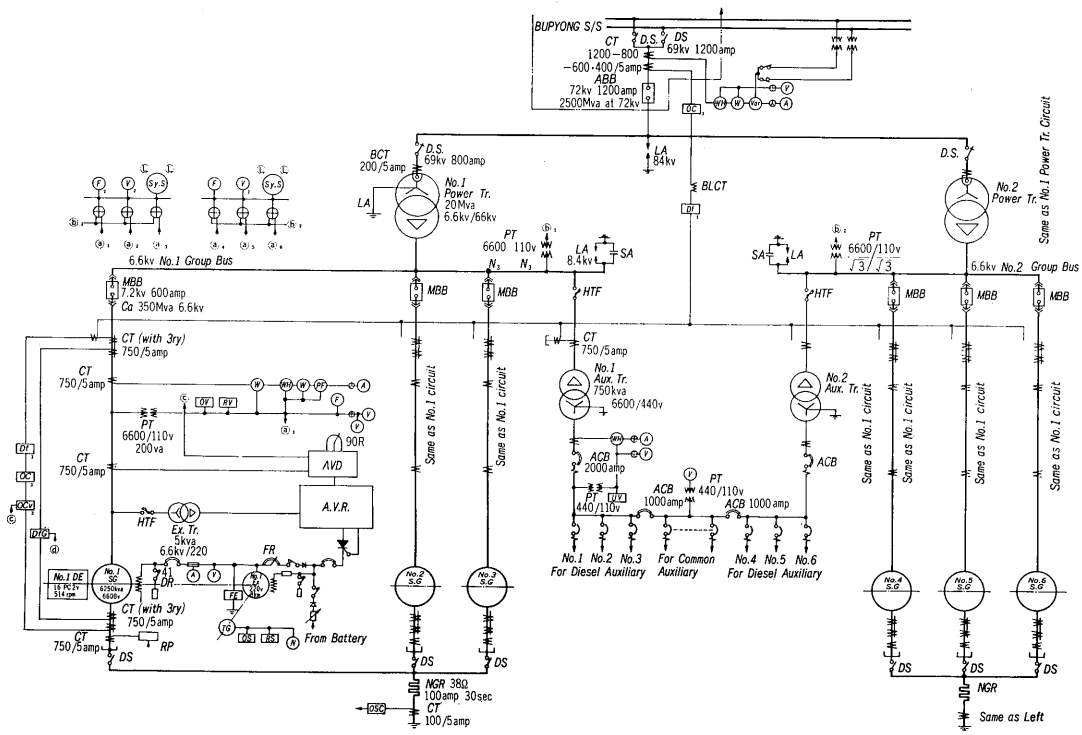


Fig. 15 Electric system

which the faulty equipment is cut-off by tripping the circuit breaker in question.

5. Bus line short-circuit protection is provided as well as lightning arresters for both the 6.6 kv and 66 kv systems.
6. Synchronous making, load distribution operations etc. can be easily carried out manually from the central control panel.
7. The auxiliary power voltage is 440 v. A transformer is provided for each group so that the power can be supplied from either of the groups to any auxiliary equipment.

VI. PROTECTIVE EQUIPMENT

The diesel generator equipment is protected by load interruption and automatic shut-off of the engines when any of the following faults occur.

1) Short-circuits in the generator windings.
2) Grounding of the generator windings.
3) Grounding of the field winding
4) Temperature rise in the generator bearing.
5) Decrease of the engine lubricating oil pressure
6) Temperature rise of the engine fresh water
7) Engine overspeed
8) When the emergency stop button is pressed

Conditions when there will be no load and no excitation of the generator are as follows.

1) Generator over voltage
2) Generator overcurrent
3) Reverse power

Warnings are also given for the following: decrease in engine lubricating oil pressure (first step), temperature rise or flow decrease in the cooling water, fuel temperature rise, pressure decrease, oil level drop, air pressure decrease, boiler water level or pressure irregularities, etc.

In the engines, lubricating oil pressure decreases and overspeed are important factors leading to engine breakdown so that a mechanical back-up protection system is provided in the engines to prevent these two faults. There is also sufficient protection provided for the step-up transformer circuit.

VII. CONCLUSION

An outline has been introduced here of Fuji Electric's standard series of Pielstick engines which have an output of 1500～5700 kw. This series has been designed to meet the needs of all the users. In the near future, engines with unit capacity of 10,000 kw will be realized and someday no doubt there will be standard plants with power outputs of 100,000 kw. By utilizing the many advantages inherent in the diesel engine, Fuji Electric will endeavor to develop still better diesel power plants for the future.