UDC 621. 224. 2+621. 313. 322

FRANCIS TURBINE AND GENERATOR DELIVERED TO SHINSOYAMA POWER STATION, KANSAI ELECTRIC POWER CO., INC.

By Takeshi Kaneda

Technical Dept.

I. FOREWORD

A Francis turbine and generator under manufacture in Fuji Electric's select production lines ever since receipt of the order on March of last year have now been completed. The machines are now in the course of installation at the site with the goal of commissioning early next year. This turbine is of a low head (65.8 m) and a large discharge (124.1 cu.m/s), as a Francis type, with the turbine runner of a maximum diameter of 4350 mm, and a weight of approximately 35 tons, and the direct-coupled generator's stator has an inside diameter of 8 m due to the low speed of 150 rpm. With these features, the machines are considered to be one of the largest machines in Japan.

Fuji Electric takes pride in its top level techniques for manufacturing turbines and generators. It has earned a high reputation exporting a number of turbines and generators. Of all the aims of the Fuji Electric's various manufacturing, most important are not only pursuit of economy, but improvement of efficiency, promotion of machine reliability and also the attention we always give to simplicity and accuracy of operation and maintenance. Also various trials of these points have been applied to these machines, never before seen in the past machines.

The Shinsoyama Power Station is to be installed near the Shokawa River, near the center of Japan. The water for power generation is taken from the Soyama Reservoir (with an effective storage capacity of 3,000,000 cu.m and operating water depth of 25 m) through a pressure tunnel of approximatly 715 m, surge tank, and a penstock of approximately 124 m. The water thus obtained is discharged into the Komaki Reservoir. A total of 11 power stations (with a total output of approximately 600,000 kw) have been already constructed near the Shokawa River by the Kansai Electric Power Co., Inc. and the Electric Power Development Co., Ltd. This new power station is to be installed in addition.

This power station is to be remote-controlled from the Soyama Power Station, together with AFC control by signal from the central power control center of the company. Fuji Electric has delivered also a complete set of control devices, such as transistor type remote control devices, etc. Given in this paper are the explanations only regarding the turbine and generator.

II. SPECIFICATIONS

The specifications of the turbine and generator are as in the following:

1. Turbine

(1) Number of units	1
(2) Type	Vertical shaft Francis type
(3) Output	Max. 72,000 kw Normal 70,800 kw At min. head 68,000 kw
(4) Effective head	Max. 65.8 m Normal 65 m Min. 63.3 m
(5) Max. discharge	124.1 cu. m/s
(6) Speed	150 rpm
(7) Specific speed	216 (m-kw)

2. Generator

(1) Number of units	1
(2) Type	Vertical shaft enclosed ventilation umbrella type with air cooler
(3) Rated output	72,000 kva
(4) Rated voltage	Normal 11,000 v Oprating range 11,500 to 10,500 v
(5) Rated frequency	60 cps
(6) Rated power factor	95% (lagging)
(7) Speed	150 rpm
(8) Excitation system	OH type static excitation system

Since the effective head is 65.8 m, a Kaplan turbine and diagonal flow turbine (Deriaz turbine) were discussed and studied for employment. However, since this power station has only a small variation of head and is to be used for peak load operation, the Francis type has been employed because of its excellent economy and performance characteristics. Inlet valve has been omitted from this turbine after study of the point of its purpose, effect and calculation of profit and cost.

As for the generator terminal voltage, 11 kv and

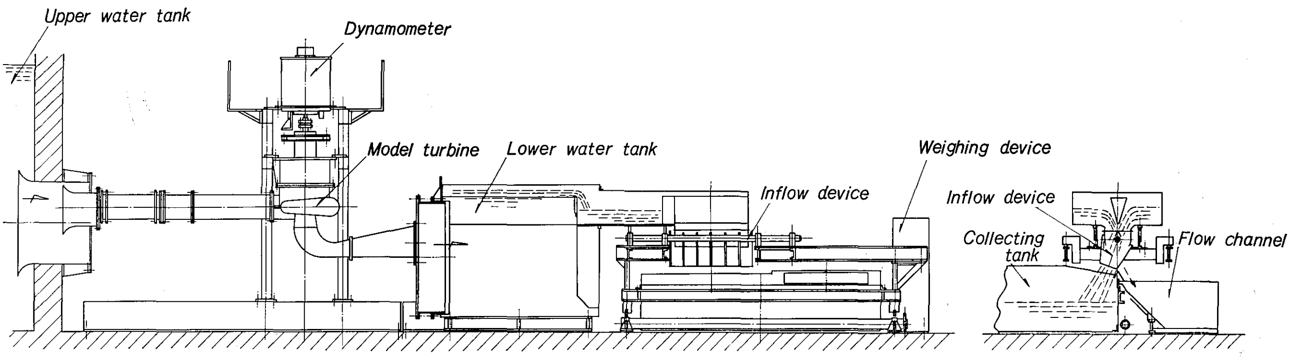


Fig. 1 Model turbine efficiency test rig

13.2kv were discussed for selection. As a result, with consideration given to the generator circuit equipment, 11 kv has been selected for reasons of economy.

Generally, by the standards, operation within a voltage variation of ±5% from the rated voltage is required without no injury. The normal voltage in the case of this generator merely indicates the voltage to be the normal one when expressing the reactance etc., as a "per unit value". A voltage within ±5% of the normal voltage is designated as a rated voltage and various guarantees are required. This is demanded by the actual status of the voltage of the power system in which the generator is involved. Accordingly, the machine is designed with sufficient margin to meet the requirement.

Furthermore, because of the importance of this power station the generator is specified to be able to keep the voltage at 11.5 kv even at the frequency of 90% and the excitation system has been made to meet this requirment.

There have been many cases where the generator is operated as a synchronous condenser so as to absorb the apparent power, thus preventing voltage rise when the power system is on light loading. This generator has also a chance of the synchronous condenser operation, and is specified to undergo continuous operation at power factor of 95% with the rated apparent output.

Discussed first regarding the excitation equipment were both the rotary exciter and the static type self-excitation system. As a result the OH type self-excitation system has been employed because its many records of actual operation demonstrated high reliability and high-quality performance. With the employment of this self-excitation system, the generator has very high response characteristics in a wide range of frequency and voltage fluctuations, simultaneously satisfying the customer's requirement for constant voltage control supporting the power system voltage whenever a fault has occurred.

Given in the following are explanations regarding the features of the turbine and generator.

III. TURBINE

1. Model Test

Prior to manufacture of a prototype turbine, a model was manufactured to a scale size of approximately 1/10 for test for efficiency, cavitation, runaway speed, index, guide vane self-closing and draft tube air admission, thus confirming the respective characteristics. The test was conducted in accordance with the JIS "Model test for hydraulic turbine" (draft). Given below are some of the example of the test results.

1) Efficiency test

The flow measurement in the efficiency test was conducted by the gravimetric method, meeting the IEC international test code for hydraulic turbines; the specifications of the major parts of the flow measuring equipment involved in the gravimetric method of the Fuji Electric's hydraulic research laboratory are as in the following: The measuring error of the flow is less than ±0.1%.

Measuring equipment:

- Maximum measurement: 10 tons
- Minimum scale: 1 kg
- Effective measurement: Approx. 8 tons

Time measuring instrument:

- Minimum measuring time: 1 msec
- Switching device: Switching time 0.1 sec

Shown in *Fig. 1* is the arrangement diagram of the model turbine efficiency test rig. Shown in *Fig. 2* is the efficiency test result for the normal head of 65.0 m.

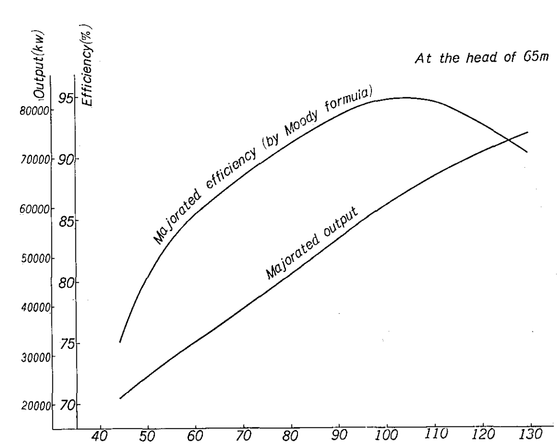


Fig. 2 Model efficiency test result

2) Cavitation test

The cavitation test was conducted at a test head of 40 m.

Shown in *Fig. 3* are the results of the cavitation test at the maximum head of 65.8 m. The critical cavitation coefficient is very low and no cavitation air bubbles are noted inside the runner under the installation conditions at the site. Thus it has been confirmed that there is no need of any concern about cavitation damage.

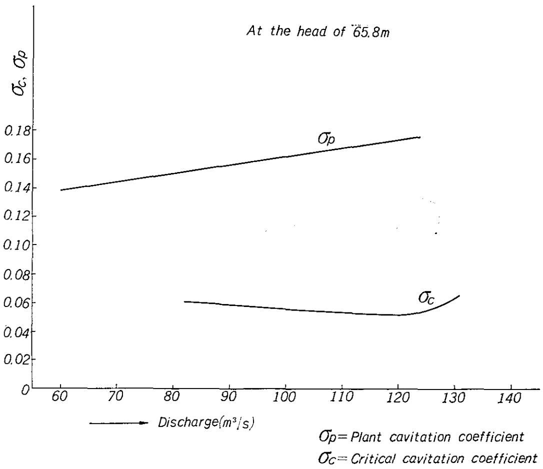


Fig. 3 Model cavitation test result

3) Air admission test

An air admission test was carried out in order to check to see whether or not an air admission pipe into a draft tube is required and sufficient natural air admission is possible under actual operating conditions. Shown in *Fig. 4* is a photograph illustrating the air admission test in progress.

Surging occurs in the range of guide vane opening of about 60 to 30%. However, surging may be completely eliminated by sending air into the draft tube.

It has been confirmed that the required air flow is approximately 2% of the maximum turbine flow and that there is almost no drop in efficiency due to air supply. *Fig. 5* shows the test results which have been converted into the prototype turbine at a normal head of 65 m. The condition permitting natural air admission is found with $H_{ap} + H_L < 0$; however, because the air piping resistance H_L is less than 1 mAq, it is possible to maintain the required air flow sufficiently under the installation condition of the power station at the site, by the natural air admission.

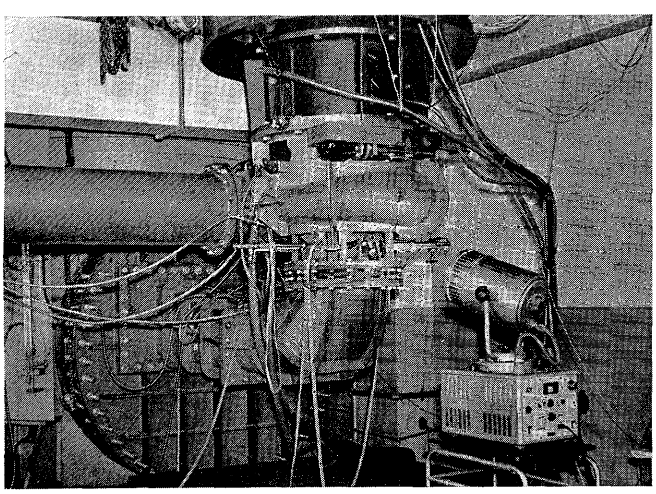


Fig. 4 Air admission test

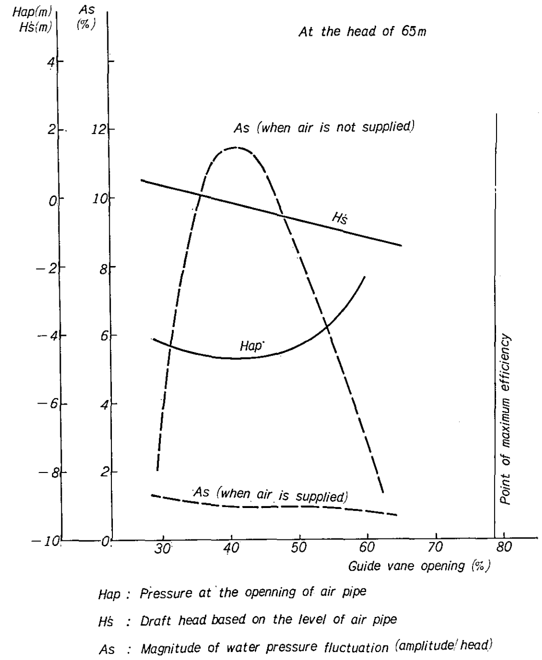


Fig. 5 Air admision test result

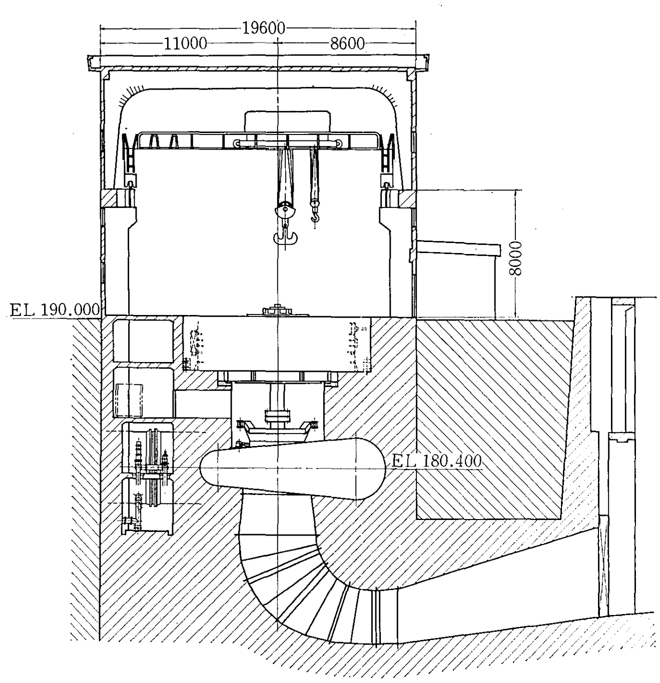


Fig. 6 Cross-section of power station

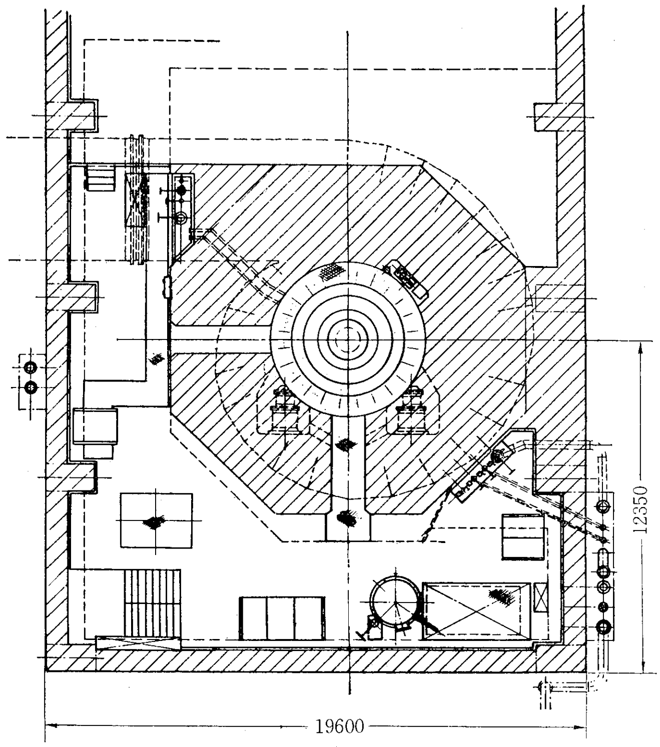


Fig. 7 Floor plan of power station (Part I)

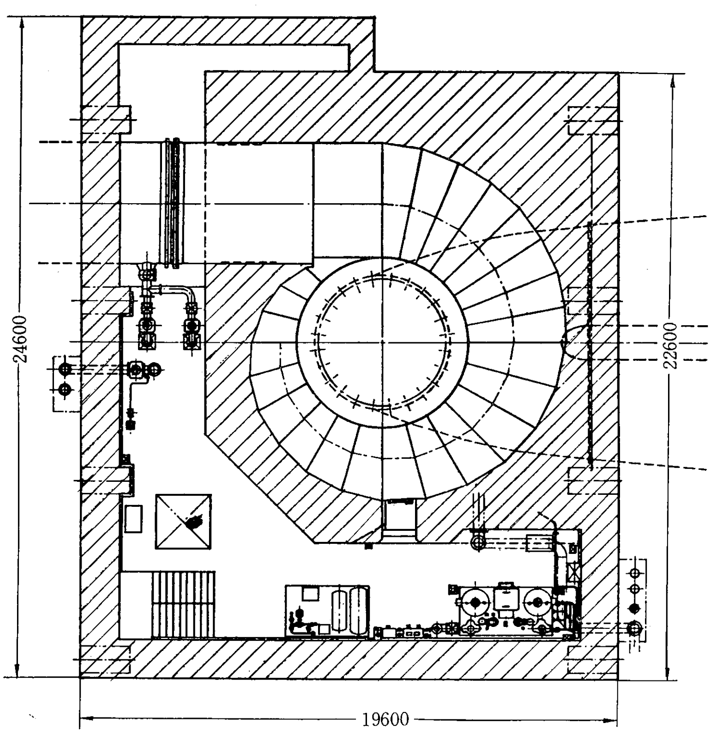


Fig. 8 Floor plan of power station (Part II)

2. Construction

The installation of the turbine and generator is by the concrete barrel system as shown in the arrangement diagrams of *Figs. 6* through *8*.

Fig. 9 shows the condition of the temporary assembling of the turbine at the shop. Because of

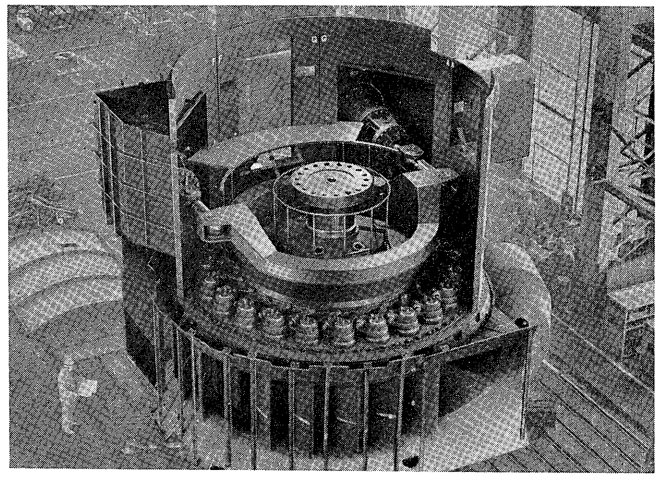


Fig. 9 Shop assembly of turbine

the extreme weight of each part of the large-type turbine, special consideration is given to the method for disassembling and assembling; provided at the bracket at the bottom of the generator are the suspension bolt hole and a rail for a double geared trolley so that a motor-driven chain block can be installed. When requiring to dismantle the turbine bearing metal, a wheeled table may be used in addition to this geared trolley to easily transport the metal to the outside of the passage of the turbine barrel.

Given in the following are details concerning the features:

1) Turbine

The construction of the turbine is as shown in the cross-sectional view of *Fig. 10*, where such major parts as the casing, speed ring, top and bottom covers, are constructed mostly of welded steel plate for maximum economy and reliability.

(1) The speed ring is divided into four sections. The casing is welded to the speed ring at site. The inlet inside diameter of the casing is 4450 mm, while the maximum plate thickness of the cone is 25 mm. Fuji Electric has already manufactured many casings of field weld construction. This type of construction is far more economical. It is furthermore understood that this type of construction is superior in reliability. Used for the material of the casing cone are SM 50 B (JIS-G-3106 "Rolled steel for welded structure", yield point 38 kg/mm^2 min., tensile strength 50$\sim$60 kg/mm^2), with consideration given to the effect of the ring pipe form regarding the same cross-section; thinner plate thickness for the circumference located further away from the speed ring is used, thus permitting the entire

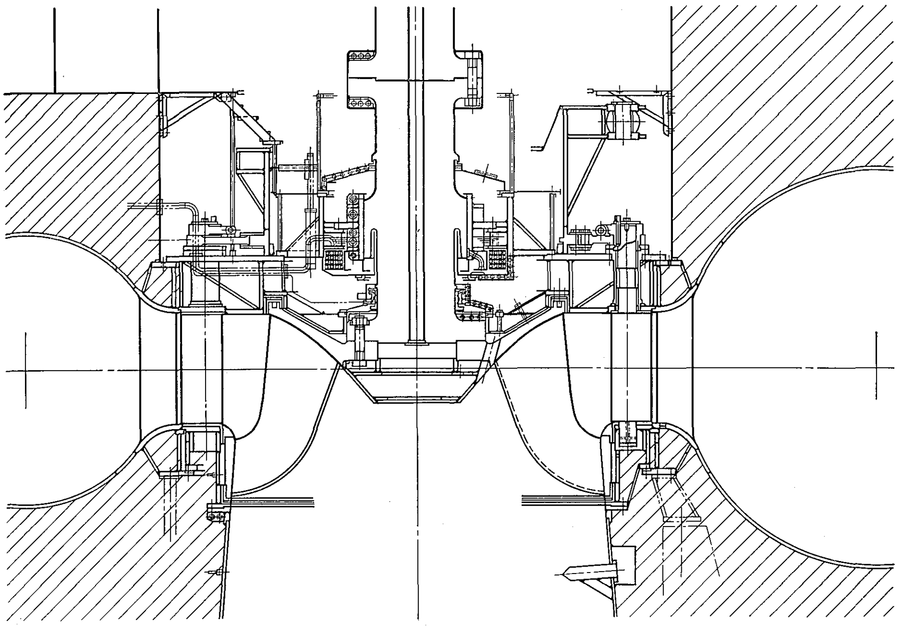


Fig. 10 Cross-section of turbine

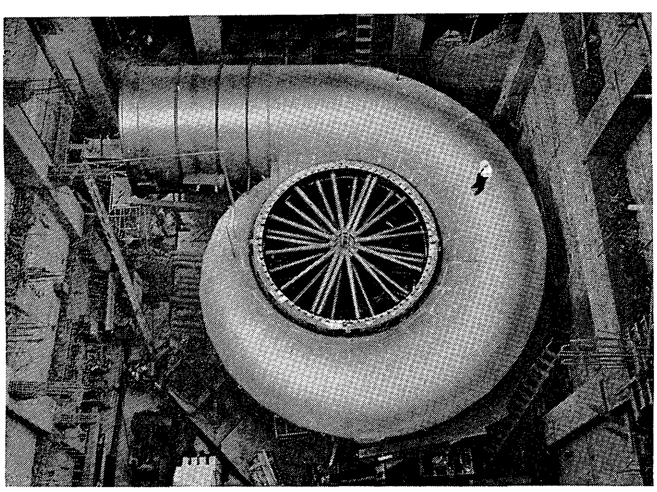


Fig. 11 Spiral casing almost completely welded at site

casing to be strengthened with proper balancing. Regarding the dividing line for transport, such division is set to be made at the point furthermost from the speed ring in order to minimize distortion of the finished surface of the speed ring due to the welding at the site. *Fig. 11* shows the casing welding almost completed at the site.

The following points were taken into consideration and borne in mind during the welding work :

(a) The portion of width 100 mm centering upon the welding line was preheated to approximately 100°C. The electrode used had been previously dried for a period longer than 30 minutes at more than 300°C.

(b) A spider was inserted inside the speed ring for restriction and correction of distortion.

(c) During the welding work, peening was accomplished whenever deemed necessary to alleviate the residual stress and to minimize the deformation.

(d) After completion of the welding work, liquid penetrant inspection was carried out all along the welding line.

(e) The liquid penetrant inspection was conducted all along the line of the gouged surface.

(f) 100% X-ray inspection was conducted of the T-joint and spot examination was done of the other portions.

After field welding annealing was not made but the water pressure test was performed with a pressure of 14.4kg/sq. cm.

For this casing, an equal number of stay vanes and guide vanes are used ; the top cover is not divided into two sections, i.e., inside and outside, but is constructed into one single unit, so that the pitch diameter of the guide vane may be made smaller. This permits the casing to be made smaller in size than the construction with the top cover divided into two sections. Upon manufacture, the casing cone is temporarily assembled at the shop again after the speed ring has been machine processed in order to minimize the requirements at the site for the unit-to-unit setting, thus fitting the dimensions before shipment to the site.

There is no inlet valve in this power station and the penstock and the casing are connected by a loose flange. This serves to permit adjustment by the stud of the loose flange unit even when the relative distance in the water flow direction differs somewhat from the designed value, for the reason that the penstock and the casing are imbedded separately, and also to cope with the elasticity of the exposed portion of the penstock and expansion and contraction due to change in atmospheric temperature.

Generally, in order to prevent local pressure rise on the concrete contacting surface, with resultant cracking of the concrete, often employed is a method in which the concreting is done by applying the water pressure to the casing, or by placing suitable cushioning material between the casing and the concrete. However, this power station employed the former method. The concrete was placed with the water prrssure, kept at half the value of the static water pressure in the casing, as a result of the study.

At the time of the water-pressure test of the casing, the stress and displacement of each part were measured, resulting in no abnormal values and no water leakage.

(2) A single-unit structure was employed for the top cover. This single-unit structure undergoes minimum distortion and provides sufficient strength. The runner may have to be disassembled only when overhauling. There is scarcely a need for removing the runner: there is no need of dividing the top cover into two sections, The top cover water drainage is done through the stay vanes. The pressure reduction at the top surface of the runner is made only with the runner balancing hole, eliminating the equalizing pipe.

The bottom cover is of the concrete-imbedded type.

(3) The runner is made of one cast 13% chrome stainless steel. *Fig. 12* shows the runner, of weight more than 35 tons, with the maximum outside diameter of 4350 mm. Since it cannot be transported by rail, it was transported by sea from Yokohama Port and arrived at Toyama Port on the Japan Sea for delivery to the site. The water at this power station contains a considerable amount of dirt and sand. In order to minimize resultant wear of the runner, special consideration was given to provide the runner with material quality of a particularly high degree of hardness.

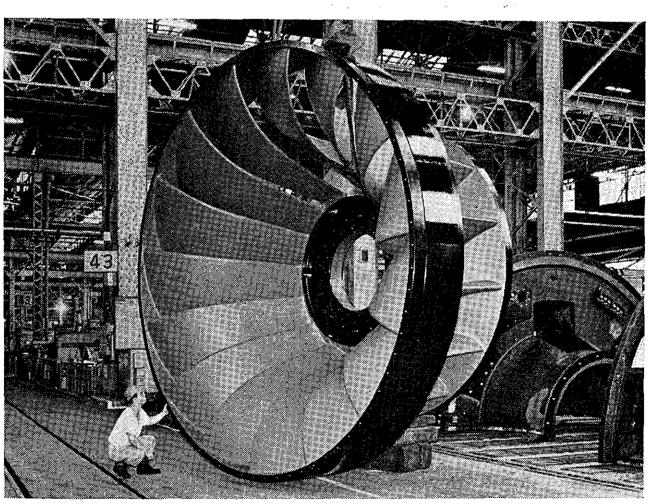


Fig. 12 Turbine runner

(4) For the guide vane, a self closing type was employed, in which the guide vane can be safely closed to less than the non-load opening by its water-pressure closing power when the hydraulic pressure of the servomotor has been lowered during the operation.

(5) The turbine bearing is constructed so as to permit easy disassembling and inspection, employing self lubrication system by the oil immersion type viscosity pump, most accurate in performance for oil circulation. In this lubrication type, a special type of oil groove is provided inside the bearing and the viscosity of the oil is utilized for lubrication. This type of lubrication has long been used at Fuji Electric for many years and its superiority has been well demonstrated.

(6) Carbon packing is used for the seal of the turbine shaft. The conventional carbon packing device is of a system to be installed concentrically to the turbine shaft. However, the one employed for this turbine has the carbon ring pressed axially, with the rotation part of the turbine shaft and the carbon in plane contact. This sealing type has the following features:

(a) The type of the carbon ring is simple and permits easy processing.

(b) The pressing force may be adjusted to a certain extent by means of the spring.

(c) Because of the plane contact, uniform pressure over the relevant surface may be obtained.

(d) Wider wear allowance of the carbon ring may be obtained, so that a longer period is allowable before replacement with spare parts.

(e) During operation, the carbon ring may be floated off the seat surface by the sealing water, thus preventing the former from direct contact with the latter and minimizing the wear of the carbon ring. When the turbine has been brought to stop, the carbon ring comes to contact the seat surface, thus almost eliminating water leakage.

2) Guide vane servomotor

Arranged on both sides, left and right, of the access of a width of 1200 mm at the turbine barrel are the servomotors with large cylinder inside diameter of 825 mm, fixed to the foundation plate at the side wall of the pit liner. The connecting rod which conveys the power of the servomotor is constructed in the turnbuckle type permitting adjustment. When the turbine is not in operation, the oil pressure of the pressure receiver is applied directly to the servomotor closing side for locking and mechanical lock is not provided. For this purpose, there is installed a hydraulic changeover valve. Also, with the customer's requirement arrangement has been made so that the piping of the return oil pump device can be connected as a manual type open/close device in the case of no water to operate the turbine; this permits free opening of the servomotor to any required opening by changeover valve even when there is no pressure oil in the pressure receivor.

3) Others

The governor is a cabinet type electro-hydraulic governor using the magnetic amplifier of Fuji Electric's standard type. The governor requires only simple maintenance, featuring high sensitivity (0.01% or lesss).

Provided are two oil pumps, one for normal use and another for stand-by use.

IV. GENERATOR

1. Construction

Figs. 13 and *14* are photographs of the shop assembled generator and sectional view, respectively. Since the generator is of low speed and a large capacity, the outside diameter of the rotor is extremely large and the outside diameter of the air ventilation hood ranges to 11.7 m. Consequently, a perfect umbrella type is employed.

Given in the following are the explanations regarding the constructions and features of the major parts:

1) Stator

The air duct is of concrete and octagonal in shape with a distance of 11.7 m between opposite sides. The top surface meeting in height the floor level of the generator permits wider utilization of the generator room. The generator is imbedded in the concrete air duct. The stator frame is divided into four section consistent with the transportation convenience, and is installed on the ring base which is also of divided construction.

The stator is shown in *Fig. 15.* The stator core is built up with a fan-shaped silicon steel plate lapped and laminated, while for tightening to the stator frame a new Laschen system is employed where features are combined of the conventional Laschen system and the dovetail system.

By this system, the magnetic utilization of the core is improved and easy retightening is possible as in the case of the ordinary dovetail system even when there is effected an aging of the iron core due to heat cycle after a long period of operation of the generator. Looseness of the iron core causes vibration and may in the worst case develop into breakage of the coil. In order to prevent this a special varnish (to minimize the eddy current of the core) has been developed which does not change in thickness even after long use. In order to make sure that there is no abnormal vibration caused, even locally, by resonance with the magnetic force power after the core lamination, an induction test was conducted with the magnetic flux passing through the iron core as in the actual operation. In this test, the local resonance frequency was measured confirming that there is no portion which is tuned with the power source frequency and its multiple frequency.

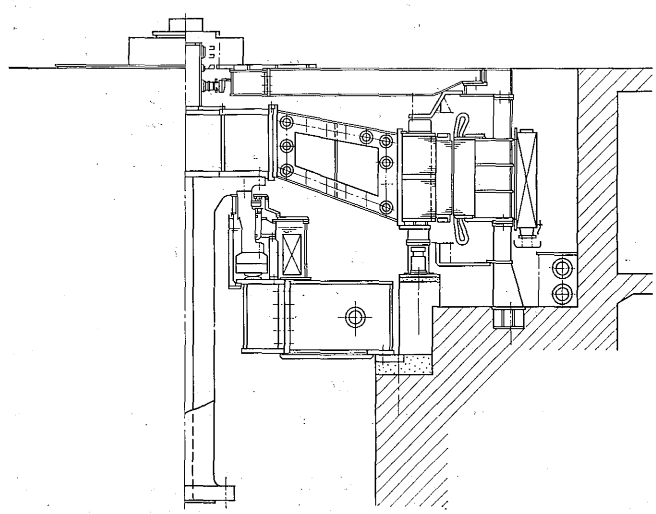


Fig. 14 Cross-section of generator

The stator coil, (using the epoxy-family resin which has been often introduced before for its main part) is an F-resin insulating one turn coil, superior in both corona resistivity and heat resistivity, with minimum corona occurrence.

2) Rotor

For the pole, a laminated steel plate of high tension-resistance with a thickness of 1.6 mm is firmly tightened by rivets through the special steel-made end plate.

Its connection with the yoke is made in the dovetail system; it is fixed by means of the struck-in tapered key. Since stator slots are cardinal numbers, the pole piece is skewed in order to prevent the waveform from being distorted due to the slot

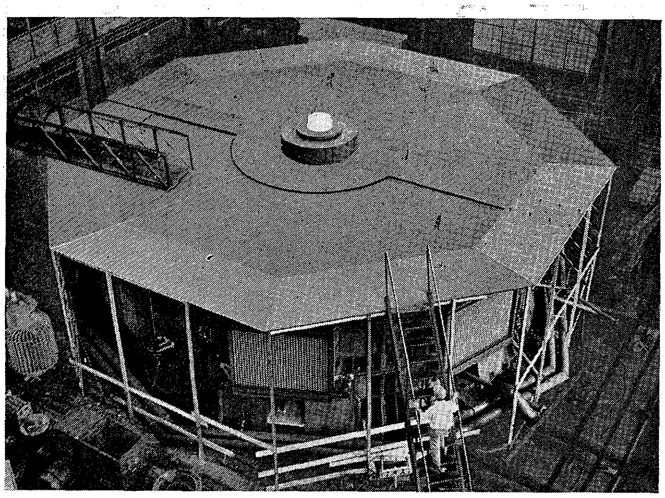


Fig. 13 Shop assembly of generator

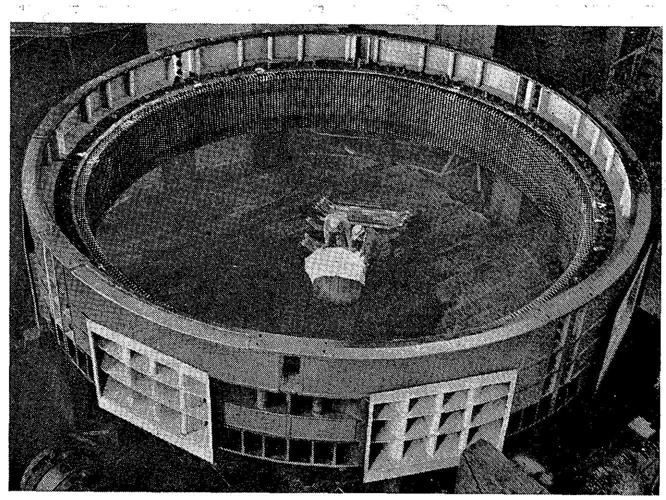


Fig. 15 Stator

harmonic wave. Inserted between the winding and the pole piece is a non-magnetic supporting plate for perfect winding support. The pole winding is heated and compressed at a temperature and pressure determined in consideration of the temperatnre difference between the magnetic pole and winding and also the centrifugal force, and is fixed to the magnetic pole. Used for the layer-to-layer insulation of the winding is a special insulating material having no effect of size change due to aging, while used for both the top and bottom insulating flanges are the epoxy-family insulating plates, superior particularly in mechnical strength and heat resistivity, so that the change due to aging may be small and can be ignored.

This eliminates the need for providing of spring at the bottom end of the winding after long use, thus fully meeting the change in the winding due to thermal expansion and centrifugal force during operation.

The yoke is the part most severely affected by stress, since it rotates supporting the magnetic pole and occupies the greater part of the rotor. It requires dismantling for transportation ; for this reason, the high tension steel plate, pressed into fan type, is lapped and laminated. For efficient cooling of the center portion of the iron core, an air duct is provided in the center portion.

For the rotor center, a welded construction type is employed having two cone type disks, one each for top and bottom for its main part, and is divided into two sections, center boss and outer circumference center portion for transportation convenience ; the center portion is further divided into two semicircular sections. As for the umbrella type, it is necessary that the guide bearing be inserted into the inside diameter of the center in order to lower the center of gravity of the rotor, thus increasing the stability of the machine. For this reason, the center portion becomes cone-shaped. In the conventional spider-shaped center, a considerable bending moment is caused to the base portion of the arm during operation due to the centrifugal force.

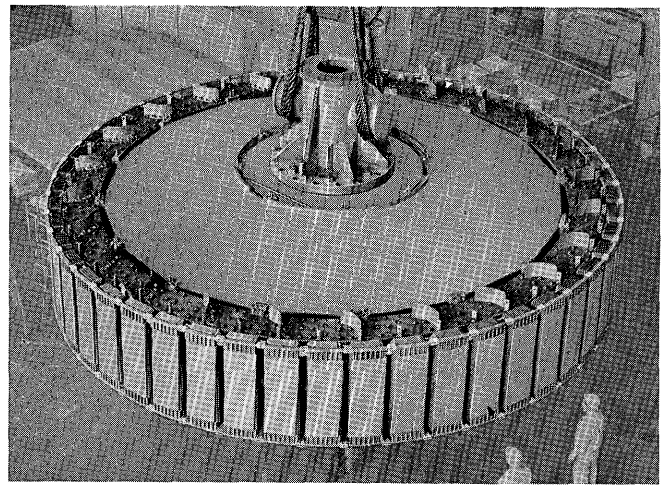


Fig. 17 Rotor

As for the center of the cone plate type shown in *Fig. 17*, which is employed in this generator, rigidity is considerably increased, so that this considerable bending moment is extremely effective to the construction supporting the bending moment ; furthermore it is advantageous to the strength for the torque conveyance. It has been proven that this construction has high rigidity of structure and minimum displacement. In the conventional spider-type center a few arms serve to work as a fan of extremely poor efficiency, so that the air flow loss is considerable and also noise is often caused. Accordingly there is a method often employed in which a shielding plate is installed between the arms to prevent this defect. In this consruction, the top and bottom cone-shaped plate, used as a strengthening member, also serves as a shielding plate. *Fig. 17* shows the rotor.

3) Bearing

The thrust bearing plays a vital role in the umbrella type construction ; furthermore it receives a considerable thrust load, while maintaining a well-lubricated condition. The total thrust load of this

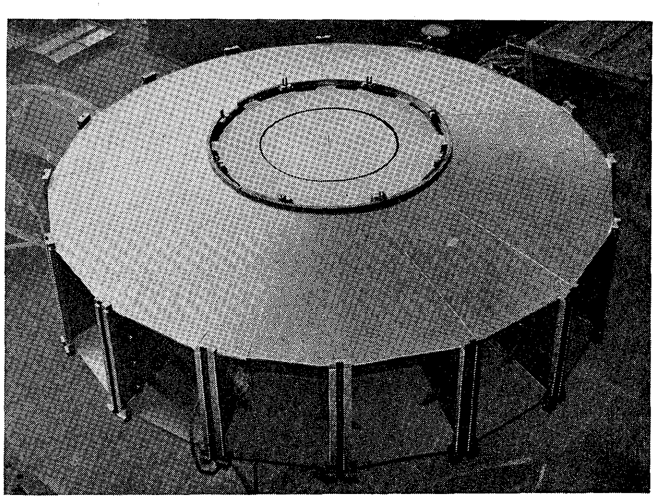


Fig. 16 Rotor center

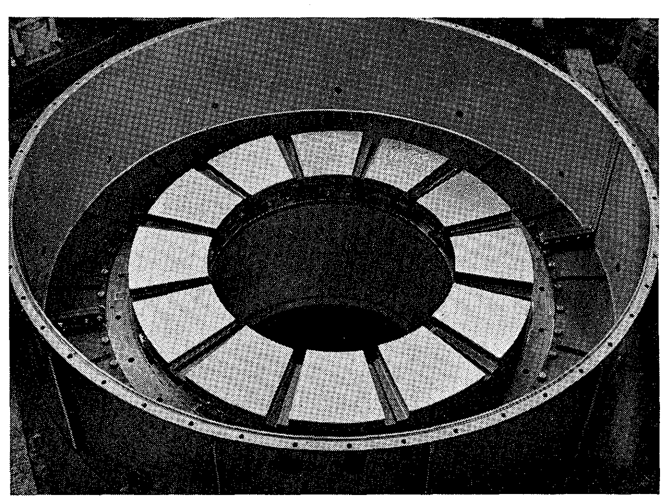


Fig. 18 Thrust bearing

generator ranges to approximately 650 tons. For a large load, a very effective Fuji Michel type thrust bearing is used. *Fig. 18* shows the construction of the thrust bearing. The features of the Fuji Michel type bearing are that a pivot is provided in the center portion of the pressure distribution of the segment thus permitting the inclination of the sliding to be freely changed in accordance with the operating conditions, that since slight manufacturing error can be automatically compensated for because of the elasticity support so that the load can be equally distributed even when there is no close initial adjustment made upon assembling, and that lubrication can be well accomplished because of the elasticity support in accordance with the inclination of the thrust bearing surface due to magnetic and mechanical unbalancing force of the rotor. The uneven load upon installation and during operation is merely several percent of the average load even in the case of the worst operation condition. In designing the whitemetal, the supporting elasticity and reduction of oil film due to increase of the surface pressure, the worst possible operating condition is considered.

The guide bearing is divided into 16 sections for easier disassembling and inspection; it is fixed to the bearing support, so that it hardly differs functionally from the one ring construction. The guide bearing of the one ring construction has been demonstrated in the past in the actual machines to be usable in the case of a considerable diameter and high peripheral speed, so that this type of construction is employed as much as possible in order to simplify assembling and maintenance.

For cooling of the lubricant, the oil inside the oil tank is circulated by the pumping action of the hole radially bored in the thrust collar, and cooled by means of the oil cooler installed inside the oil tank. This is the self cooled oil immersed type bearing. The bearing is confirmed to be safe upon the shop test under special operating conditions of an overspeed of 140% for a one minute, low speed of 15% for a 30 minutes and cooling water interruption for 30 minutes.

For the oil leakage prevention of the run-through portion of the bearing cover, a labyrinth structure has been employed with multiplexity in the diametric direction, as shown in *Fig. 14*. The oil leakage preventing device at the shaft side is of a double-wall structure providing satisfactory results as employed in all other generators.

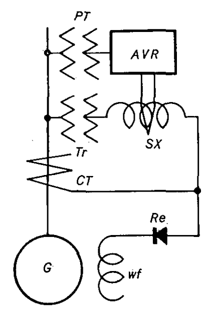
4) Ventilation cooling

Radial fan is installed both on the top and bottom ends for circulation of cooling air. A partition plate is installed in the fan shield at the peripheral portion of the fan, thus permitting effective passing of the cooling air through the heat source. Through the adjustment of the cooling air adjusting hole of the stator frame and provision of the partition plate permit optimum setting of the ventilation. The rotor coil is effectively cooled by the cooling air blown in the shaft direction from through the clearance between the poles and by the air flow blown in the outside diameteric direction by the self fan action from the ventilation duct at the center of the rotor yoke, and this resulted in better cooling effect than first expected.

A total of eight air coolers are installed along the outer circumference of the stator frame at equal intervals.

2. Excitation Device

This generator is record-breaking for the self-excited compound type ac generator, having the largest capacity of all of them. Generally, in low-speed and large-capacity machine such as this, the rotating exciter output is bound to be greater, so that the machine size has to be remarkably great. For this reason, it is often true that in the case of a comparatively high-speed machine, the self-excitation system is less economical than the rotating excitation machine. However, in a low-speed machine, the self-excitation system often becomes less costly. Particularly in the case of this machine, where speed response characteristics of more than 2.0 is required in the excitation system, and where the excitation machine size is to be determined by the excitation machine output at 90% speed in order to maintain the rated output at 90% frequency, this tendency is outstanding. For reference, the output of the excitation device of this generator is 400 kw.



G : Generator
Tr : Exciter transformer
CT : Exciter current transformer
SX : Saturable reactor
Re : Rectifier
wf : Field winding

Fig. 19 Principle diagram of series reactor system ac compound generator

A number of various systems for the self-excited type ac generator have been announced and used practically. The OH system employed in this generator is a typical series reactor system, being one of the systems having the highest response characteristics. The principle of the series reactor system, shown in *Fig. 19*, is to control the series reactor current which supplies the excitation component being independent of the load. A saturable reactor is adopted as the series reactor. As long as the terminal voltage is within given limits, the saturable reactor maintains constant current characteristics, so that there is no case that a part of the secondary current of the current transformer passes through the series reactor to return to the power source. For this reason, the most outstanding feature of the series reactor system is that the field current responds extremely quickly to a change in the load current. Although the OH type circuit shown in *Fig 23* is seen to be slightly different

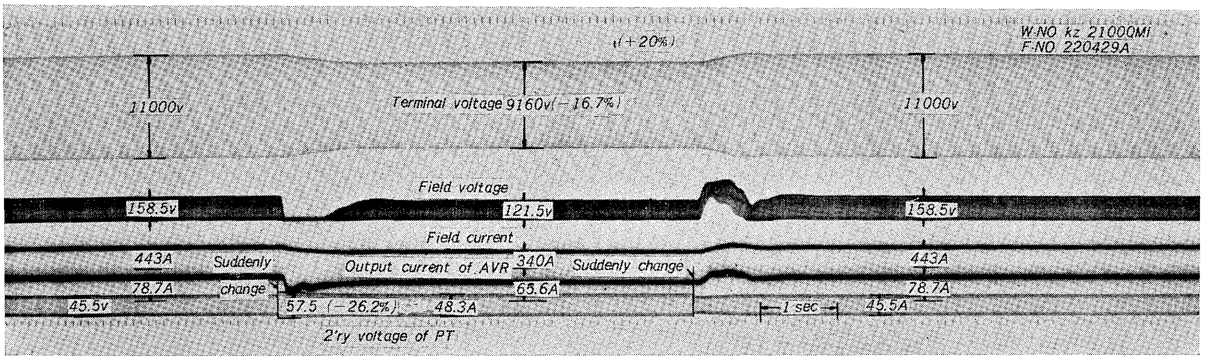


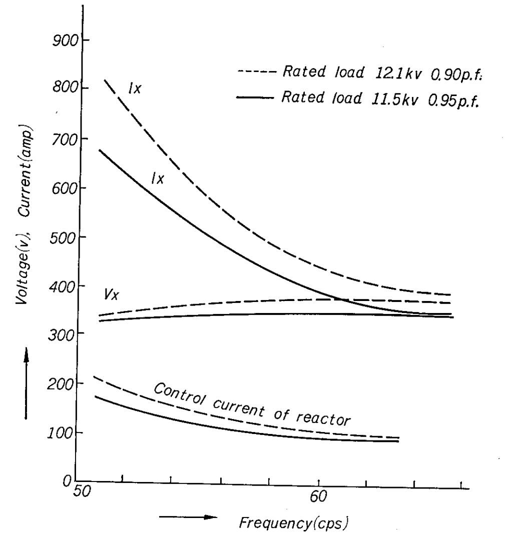
Fig. 20 Oscillogram of indicial response test

from the one shown in *Fig. 19*, both are the same in principle.

In the case of load rejection or sudden reduction of the load, it is necessary that the field current be quickly decreased. It is a matter of course that reverse excitation is generally impossible in the rectifier system excitation. In this system, however, the ac and dc circuits are short circuitted at the position of the rectifier simultaneously with the sudden load reduction and made into separate circuits, so that the applied field voltage becomes zero instantaneously. Even when the reverse excitation is impossible, if the voltage can be reduced to zero instantaneously, the quick response characteristics in the direction of reducing the magnetism is not at all inferior to that of the rotating excitation machine, often being superior. This is clearly seen from the comparison of the voltage rise value upon load rejection, in which the applied field voltage does not necessarily become zero only in the case of the sudden load reduction. *Fig. 20* shows an oscillogram of the indicial response test in which the set voltage value is suddenly reduced in the non-load condition, with the field voltage seen reduced to zero. *Fig. 21* shows the characteristics involved in operation at frequencies and power factors other than the rated values. In this system, which must be operated either at the maximum voltage or voltage of higher value even when the frequency has been lowered to 54 cps, the flat compensation is adopted, and the equipment is made larger than that which corresponds to the rated condition.

Shifted to the excitation circuit is the impulse voltage through the exciter transformer, exciter current transformer or stator winding. The impulse withstanding voltage of the excitation circuit is planned to be 4.5 kv. *Fig. 22* shows the actual measurement value of the shifted voltage.

The exciter transformer has a static shield between the primary and secondary windings, so that shifting to the secondary side is prevented the greater part being that shifted from the stator winding and the exciter current transformer, as is known from the result that the applied point are *B* and *C* points. The maximum value of the shifting voltage is 7.3%,



V_X: Terminal voltage of reactor
I_X: Current of reactor

Fig. 21 Required reactor-current and voltage given as function of operating frequency

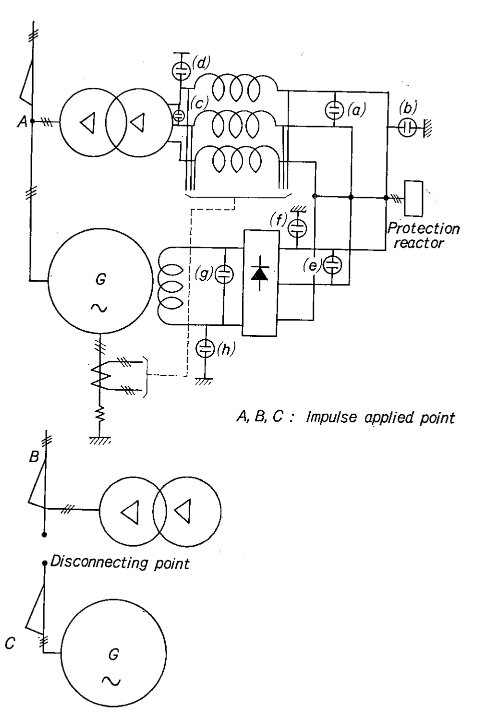


Fig. 22 Surge analyzer test circuit

Table 1 **Surge Voltage in Excitation Circuit (% to the applied voltage)**

Applied Point \ Measured Point	a	b	c	d	e	f	g	h
A (U phase)	3.8	5.5	7.3	4.9	3.8	5.8	3.0	5.0
A (3 phase)	0.45	6.8	2.1	3.2	0.53	6.8	1.3	6.6
B (U phase)	—	—	—	—	—	—	0.07	0.46
B (3 phase)	—	—	—	—	—	—	0.09	0.92
C (U phase)	—	—	—	—	—	—	1.6	5.1
C (3phase)	—	—	—	—	—	—	1.5	7.3

4 kv, being less than the insulating level of the excitation circuit 4.5 kv. *Fig. 23* shows a detailed connection diagram of the excitation equipment.

3. Test Results

The shop tests were conducted over the widest possible range of items. Tests which cannot be performed at the factory are to be performed after the installation has been completed at the site. Given below is the explanation regarding some of the test results conducted at the shop:

1) Efficiency test

In the efficiency test, the efficiency was obtained from the input of the dc driving motor. Since the guaranteed efficiency is to include the loss of the excitation equipment, being different from JEC 114, the voltage and current of the excitation equipment were obtained at various load conditions, checking it with the result of the each test of the excitation equipment, thus obtaining the loss of the excitation equipment. The armature current which corresponds to 72.5 Mva is set at 100%. *Fig. 24* shows the test results.

2) Characteristics test

This is a large-capacity generator, but is not specified as a line-charging generator. Since there was no particular demand for larger charging capacity, the short-circuiting ratio is guaranteed to be 1.0 with a tolerance and the measured value was 1.0.

Table 2 shows the measured results of various reactances and time constants.

The three-phase short-circuitting test was conducted at a 25% voltage, so that it is a nonsaturable value. GD^2 of the generator was obtained as 9180 t-m^2 through the retardation method; This value corresponds to the accelerating constant T_S of 7.8 seconds.

V. CONCLUSION

The completion of Japan's leading large-size turbine and generator at the shop with satisfactory results has cleared the way for manufacture of a super-large capacity turbine and generator expected in the future.

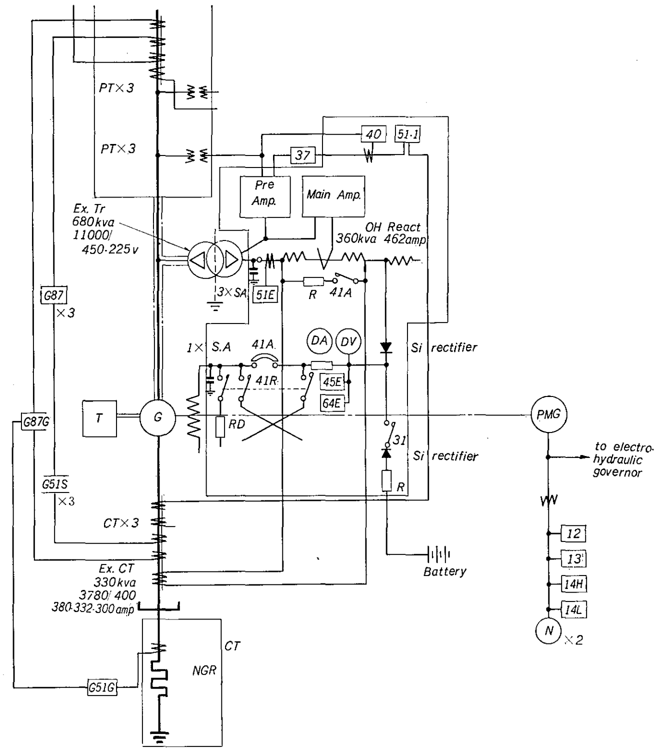


Fig. 23 Connection diagram of excitation system

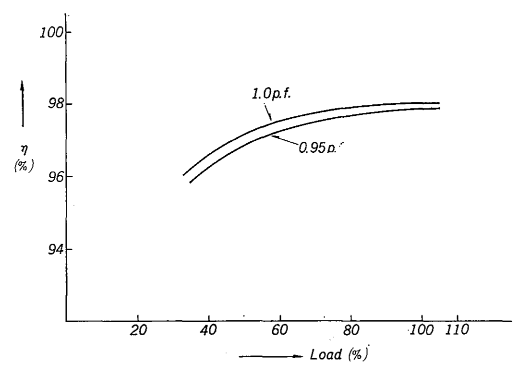


Fig. 24 Efficiency test result

The machines may soon be installed completely at the site and test operation is to be conducted. The records of the site test may be given at a later date.

Table 2 **Reactances and Time Constants**

x_d	100%
x_q	76.4%
x_z	25.1%
x_0	14.3%
x_d'	36.0%
x_d''	23.6%
x_q''	25.6%
T_a	0.144 sec
T_d''	0.047 sec
T_{d0}'	5.39 sec
T_d'	1.84 sec