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FRANCIS TURBINE AND GENERATOR FOR TEDORIGAWA NO.1 POWER STATION, ELECTRIC POWER DEVELOPMENT CO., LTD.

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I. FOREWORD

The design and manufacture of the Francis turbines and generators for the Tedorigawa No. 1 power station were begun in 1975. These equipment are scheduled for installation and completion in June 1979.

Since the 2 x 129MW vertical Francis turbines and 2 x 132MVA vertical synchronous generators for this power station are the largest capacity machine in Japan except for pumped storage power station. It is required to have high reliability from the stand points of performance and construction of the machines, and high rationality in operation, and various new techniques and constructions were adopted, in addition to exhaustive studies, in their design and manufacture.

This paper introduces the main features, and new technology and construction of this turbine and generator.

II. OUTLINE OF POWER STATION

This power station comprises a 153m high center core type rock fill dam constructed at the upper stream of the Tedorigawa. power station in Ishikawa prefecture and a Tedorigawa reservoir having an effective storage capacity of $190 \times 10^6 m^3$. A maximum output of 250MW is generated by the flow through the waterway with a 1,526.98m long pressure tunnel, a surge tank and one line penstock. Annual power production will be 426×10^6 kWh.

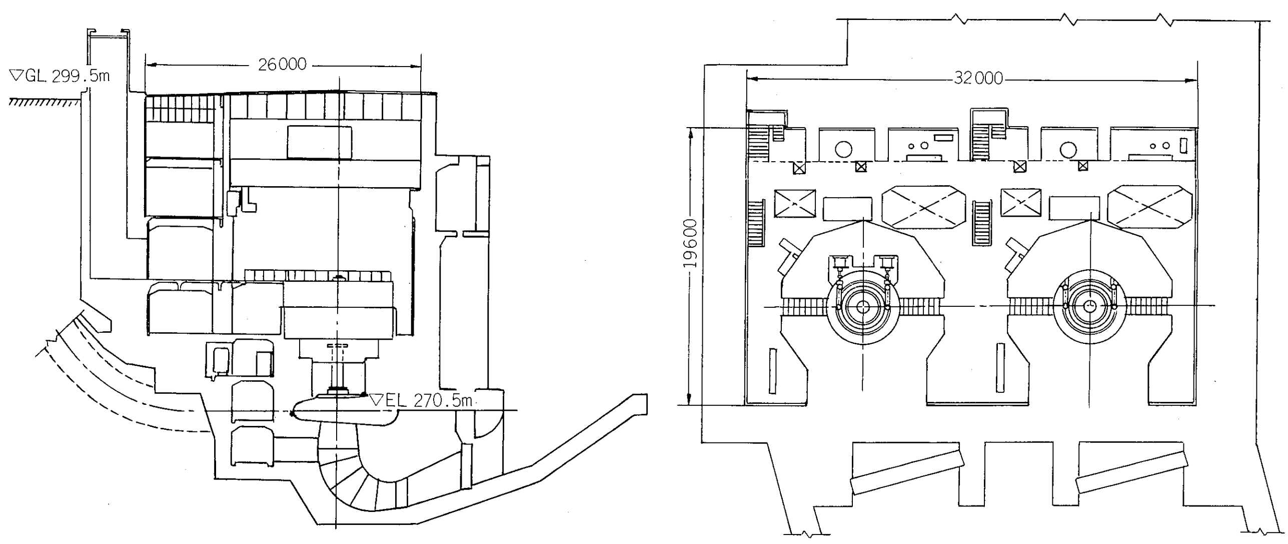
1) Name of river: Tedorigawa river
2) Power station type: Semi-underground power station
3) Operation system of power station: Fully remote control system with automatic frequency control operation from a central control station.

The machine hall general arrangement is shown in *Fig. 1*.

III. SPECIFICATIONS

1. Turbine

Nos. of unit:	Two (2)
Type:	Vertical Francis turbine
Maximum output:	129, 000 kW
Net head:	Maximum; 188.5m
	Minimum; 113.0m



(a) Side view (b) Plane view

Fig. 1 Machine hall general arrangement

Maximum discharge: $89.3m^3/s$
Rated speed: 240rpm
Specific speed: 149 (m-kW)

2. Generator

Nos. of unit:	Two (2)
Type:	Vertical totally-enclosed internal cooling synchronous generator (semi-umbrella type)
Output:	132, 000kVA
Speed:	240rpm
Frequency	60Hz
Number of poles:	30
Voltage:	16, 500V
Current:	4, 620A
Power factor:	0.95 (lagging)
GD^2:	$6{,}200t{\cdot}m^2$
Exciting system:	Thyristor type static exciting system

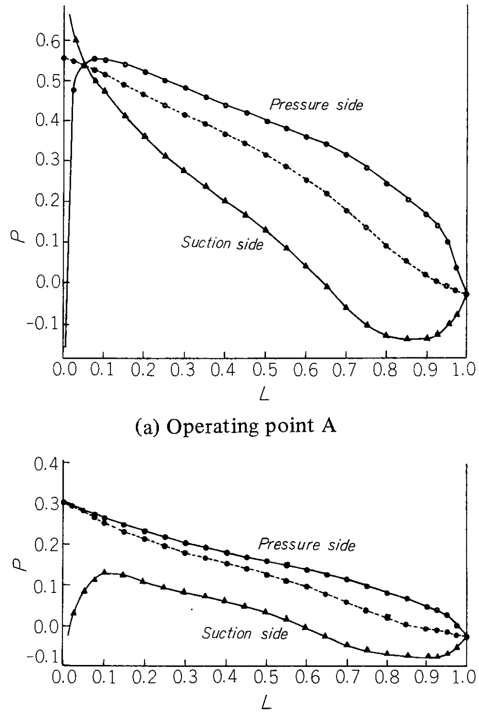
IV. TURBINE

1. Performances

1) Development of runner

Since the turbine has a high specific speed, the variations of net head are large (the minimum net head comes to 66 percent of the maximum net head), and moreover, operation under automatic frequency control is to be performed up to partial load, the runner is required to have suitable characteristics for large variable range of net head and discharge.

At the time of development of the runner, considering this operation range mentioned above, computer studies were conducted on the flow pattern by flow analysis computer program "RUNFLAS" to develope a runner with the feature to prevent cavitation occurence at the suction side of the runner inlet under pertial load operation at the maximum head, and to restrict the water flow separation from blade surface at the high pressure side of the runner inlet under full load operation at the minimum head. The pressure distribution around the runner blade for two typical operating points is given in *Fig. 2*.



(b) Operating point B

Fig. 2 Pressure distribution around the blade

Operating point A corresponds to about half load operation at maximum head. The local pressure drop at the suction side of the runner inlet and the negative pressure gradient following it can be seen. This shows that flow separation and cavitation at inlet of the runner blade easily generated from this portion.

Operating point B is for maximum guide vane opening at minimum head. The negative pressure gradient at the pressure side of the runner inlet and occurence of flow separation of runner inlet are evident. To widen the range at which this occurence of flow separation of runner inlet and cavitation are restricted, an adequate runner inlet profile is employed relative to changes in the flow direction.

Runner design was based on the results of this flow analysis, and the cavitation characteristics were confirmed by model tests. At the model tests, the lower head cover and runner band were made of acryl resin so that the appearance of generation and growth of inlet cavitation could be observed in detail. The cavitation generated at the negative pressure side of the runner inlet is shown in *Fig. 3*. A runner that adequately satisfied the specifications of the prototype turbine was developed and desinged, based on the results of careful observation during model tests.

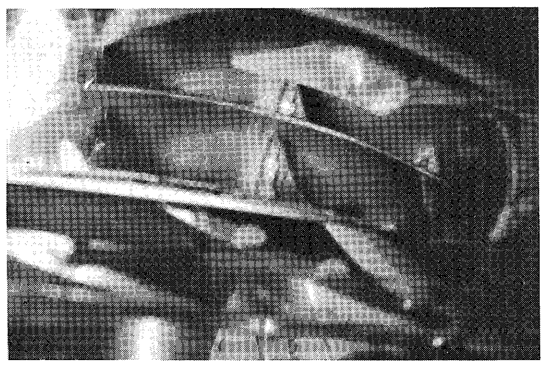


Fig. 3 Cavitation phenomena of runner inlet blade

2. Turbine Construction

A sectional view of the water turbine is shown in *Fig.4*, and the spiral casing and upper head cover assembled at factory are shown in *Fig. 5*.

1) Stay ring

The stay ring employs a rational new construction having a higher reliability than that of the conventional water

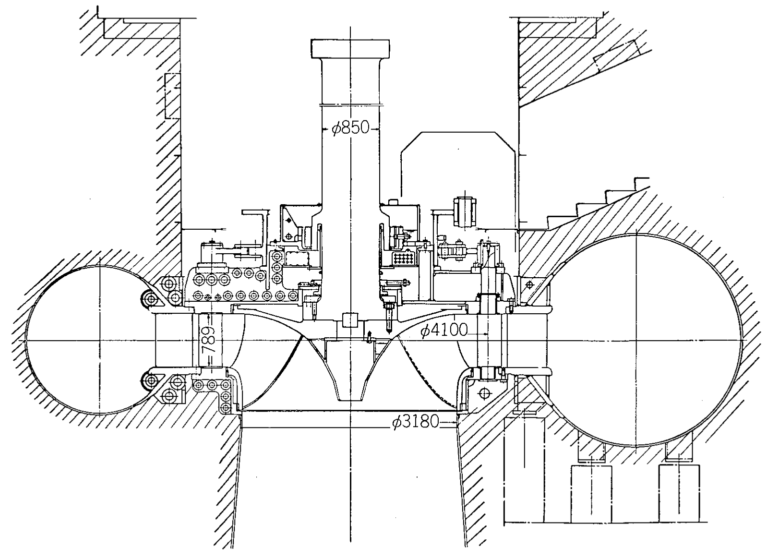


Fig. 4 Section of water turbine

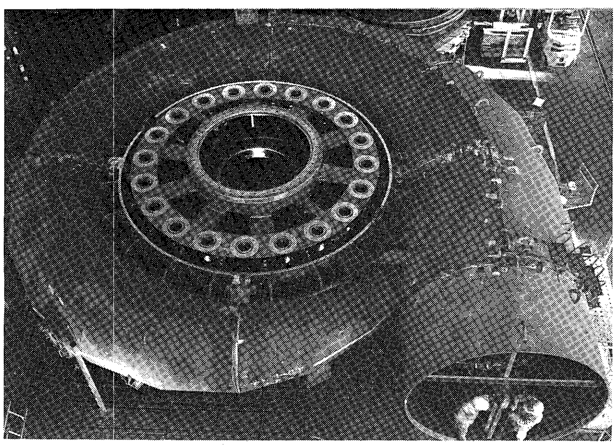
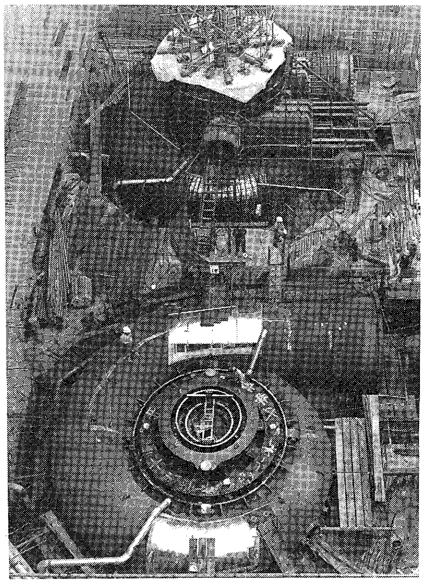


Fig. 5 Casing and upper head cover assembled at factory



Remarks:

Unit No. 1 turbine (front side) has been finished the field welding of spiral casing.

Unit No. 2 turbine (behind the unit No. 1) has been completed the installation works before concreting.

Fig. 6 Installed turbines at site

turbine from the standpoint of strength.

The stress concentration produced at the conventional stay vane and crown plate has been eliminated, and the stress has been uniformly distributed by selecting the minimum torsional moment produced at the stay ring due to hydraulic pressure by means of designing a rational arrangement of the load action points caused the tension of the sprial casing and upper head cover, and the other external force that act on the stay ring. This allowed minimization of the stress on the joint portion of the stay vane and casing corn plates, and increased reliability.

2) Upper head cover and bottom ring

A new construction simplier and more reliable than the conventional construction is employed at the head cover and bottom ring.

Stress and deflection were analyzed by axial symmetric program of the finite element method to simplify the transmission path of the water pressure applied to the upper head cover and bottom ring, and to apply the thick plate block construction employed with our standardized small capacity turbines to a large capacity turbine. As a result, deflection value of the upper head cover and bottom ring which effects the performances of the main parts of the water turbine, was minimized, and the stress produced at the radial ribs was reduced substantially, thus making the adoption of the block construction at a large capacity machine possible. *Fig. 6* shows the turbines under installation at site.

3) Runner

Even though this machine is a large capacity and high speed machine, a fabricating welded construction of carbon steel casting was employed for the runner. The fabricating welded runner is a partial casting having a better finishing profile of the runner blades than the whole carbon steel casting runner. Since there are few internal defects at the high strees portions of the runner blades where jointed with crown plate and band, it is possible to be manufactured a high quality runner by welded construction. The electro-slag welding method was employed for the runner. When the electro-slag welding method was employed, stress analysis of the runner was performed by the finite element method. The thickness of runner blades was selected so that the concentrated stress was small, the quality of the welding portion and welding deformation were studied by means of a mockup, and a welding plan and inspection procedure were established to improve quality. Moreover, since the runner is for a wide range of operation, the area to be applied 18-8 stainless welded overlay having good anti-cavitation characteristics was selected from the results of careful observation during the model cavitation test. No movable liner for the runner seal portion is employed.

4) Turbine shaft

The turbine shaft is a common shaft with the generator shaft, and is directly connected to the roter center of the generator through the thrust support.

5) Bearings for guide vanes and guide vane operating mechanism.

Because of the requirements to reduce man power for operating and maintenance of the power station and to prevent water pollution of the downstream of the river, oil-less lubricating system is employed for the bearings of guide vanes and guide vane operating mechanism of this machine, instead of the conventional grease lubrication system.

We have already employed this bearing system for several numbers of power station, including Toyomi No. 2 power station, Tohoku Power Co., Japan, which has a 61 MW Kaplan turbine placed in operation in 1975. However, since the Tedorigawa No. 1 power station machine is a large capacity machine, and automatic frequency control operation is also performed, and the load frequently varies, its reliability was confirmed by conducting characteristic with a test model.

6) Inlet valve

The inlet valve is a 3.5 m diameter butterfly valve, and is a record making 200m class head butterfly valve. Conventionally, this type of inlet valve is disadvantageous because water leakage easily occurs from the shaft at both sides of the valve disc. Since it has a high head and large diameter, as previously mentioned, a new construction having a higher sealing effect than the conventional construction was employed at the valve disc shaft seal.

Moreover, a new loop line rib type construction with small deflection is employed at the valve body.

The safetyness and reliability of this prototype valve have been confirmed and deflections under maximum hydraulic pressure was measured by pressure and leakage tests at factory. The inlet valve under factory assembling is shown in *Fig. 7*.

V. GENERATOR

This machine is a semi-umbrella type. As previously mentioned, the generator and turbine shaft are consisted from common shaft and connected directly to the rotor center through the thrust block and is the maximum class of hydraulic turbine generator in Japan. A sectional view of the generator is shown in *Fig. 8*.

In recent years, factory assembly and testing have been frequently omitted because of improvement of design accuracy by means of usage of computer, establishment of efficiency test carried out at site and from the view point of economy and shortening manufacturing period. In this case of Tedorigawa No. 1, the factory test will be carried out one of two generators.

The construction of this generator is outlined below.

1. Stator

The stator is divided into four parts for transportation. The stator core is of S class silicon steel plates which have low iron loss, laminated to a stator frame through stud bolts. An increase in capacity is accompanied by a need for design countermeasures against thermal expansion of the core. Special consideration has been given to this thermal expansion in this machine especially at the mounting portion between stator frame and base blocks and core tightening stud bolts.

The stator coils are of one turn coil with robel transposition, and the wave winding with double star connection, and no jamper of inter pole connection is employed. Strands with different dimensions are employed at the top and bottom coils, considering of increasing space factor and reducing eddy current loss by skin effect. The main insulation is epoxy resin based F-resin/F insulation.

Generally, the use of a one turn coil in large capacity machines has various advantages, but the constitution of

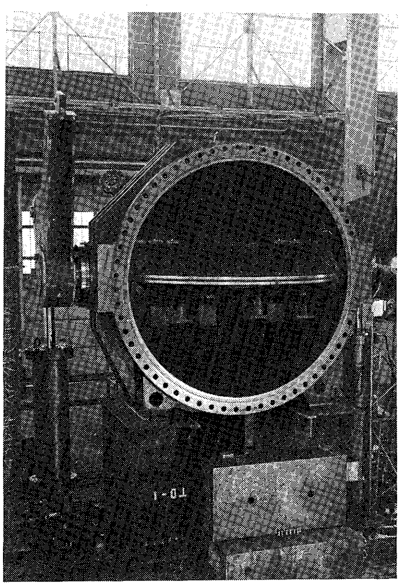


Fig. 7 Inlet valve under factory assembling

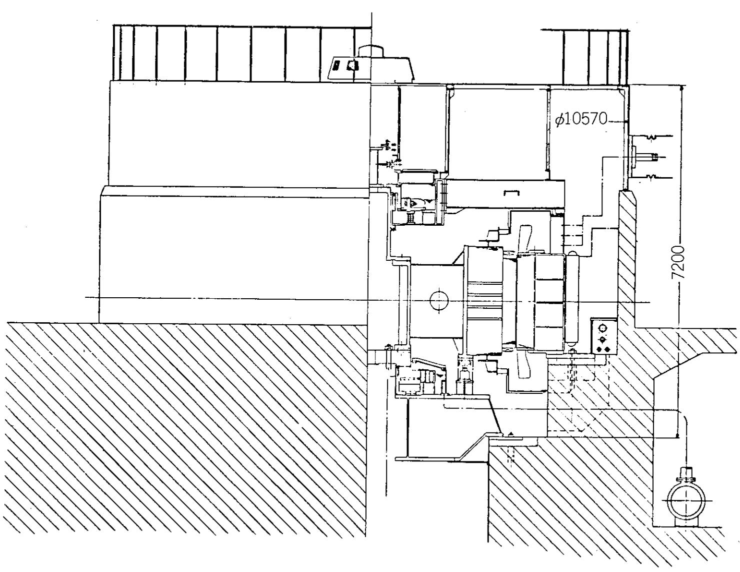


Fig. 8 Section of generator

the coil is closely related to selection of the slot pitch, cooling techniques and various other factors. For the machine employed one turn coil, in general, the relation between, the product values of rated voltage and parallel circuit numbers, and the generator output, have an almost simple relationship such as that shown in *Fig. 9*. At a rated voltage of 16.5kV, the one turn coil can be employed for the machine of more than about 50MVA in output. However, even if for such class machine, the use of a one turn coil is difficult in case of certain number of poles because of the relation with the number of parallel circuits. This machine for Tedorigawa No. 1 employs two parallel circuits with fractional slots.

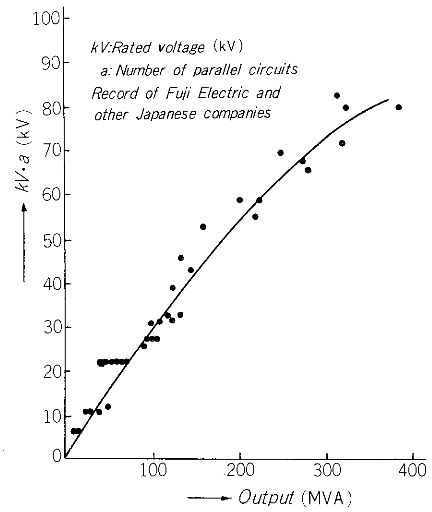


Fig. 9 Output vs. voltage X number of parallel circuits

Since this machine has a high rated voltage of 16.5kV, especially considering to prevent occurence of corona phenomena on coil ends, paint is applied in three coats to obtain a suitable potential gradient. The number of coats and the painted length were decided by computer so as to obtain the ideal potential gradient.

At site assemble and installation of the stator, each split section of the stator frame will be assembled just on the generator foundation without hanging a complete stator frame assembled. This prevents harmful deformation of the stator frame.

2. Rotor

The rotor consists of a thrust block, rotor center, laminated rotor rim, polepieces and upper shaft.

The thrust block is coupled to the turbine shaft by four shear pins and eight studs. The rotor center is installed to the thrust block through radial torque pins. The upper shaft is constructed of welded steel plate. Shaft current preventing insulation is provided at the top of upper shaft, and an upper guide collar is heat shrunk to the upper shaft through the insulation. Upper guide collar is supported by an upper guide bearing.

The poles consist of a laminated core and tightened by the rivets through the steel endplates at both ends. The field coil is cured at a suitable temperature and pressure to adequately adapt to the centrifugal force and repeated thermal expansion that occur during running operation, and is unitized and installed to the pole core. Teflon lubricant is provided between the insulation collar installed to the core and coil so as to minimize the thermal stress generated at the coil by reducing the friction seizing force caused by the coil centrifugal force and thermal expansion during operation. Moreover, coil bracing is provided to prevent deformation of side surface of the coil by tangential component of the centrifugal force. The creeping characteristic at high coil temperatures was also considered, and the number of coil bracings was selected so that there is no harmful deformation under all operating conditions.

Ventilation is provided by efficient axial fans mounted on the top and bottom of the rotor rim. Equalizing the axial direction air flow distribution of core duct is extremely important with generators having a long core. Consideration has been given so that a small pressure drop though the interpoles, and a rational air flow are obtained with this machine by providing air ducts at several points at the center of the rim and having space notches in outer edge of the rim. Ventilation analysis of these complex circuits was performed by computer, and the ventilation area required each circuits were selected so that an air flow distribution adapt adequately to a loss distribution of coils and core.

3. Bearing

The thrust bearing is our standard Mitchell type bearing capable of safely supporting a thrust load of approximately 600 tons. The thickness, temperature and pressure distribution of the oil film on the pads during operation were calculated by computer, and the pad shape is so as to be suitable over all. Bearing characteristics analysis is discussed in detail in the descriptive paper "Application·of Computer for Hydraulic Turbine Generator Design" on page 19. The computed oil film temperature distrubution of the thrust pad of this machine is given in *Fig. 10*.

The lubricating oil for the thrust bearing combined with the lower guide bearing is cooled by a separate type oil

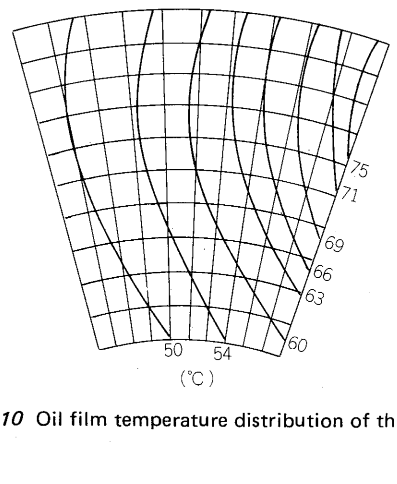


Fig. 10 Oil film temperature distribution of thrust pad

cooler installed outside the air housing. The oil is circulated by the self-pumping action of pump holes drilled in the thrust collar. Since this cooling system is simple to maintenance and has a high cooling efficiency, it is employed as the standard cooling system for the thrust bearings of our generators. We already have more than ten years experience with this system, and its reliability has been proved by the delivery of more than 30 units, both domestically and overseas.

The upper and lower guide bearings are both the segmental type. The bearing gaps can be easily adjusted by adjusting bolt.

The lower bracket supporting the thrust bearing employs a rectangular box type construction. The upper bracket is the parallel beam type.

For the large capacity generator, the effect of the spring constant of the stationaly parts including bearings is very important in the natural frequency of the machine. Since this machine has a high runaway speed of 480 rpm, this point was considered, and not only the rigidity of the rotating part, but the rigidity of the brackets and other supporting parts were made amply high to assure safe operation even at the runaway speed.

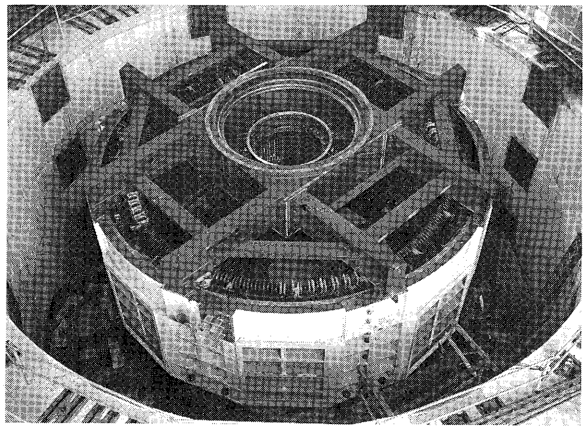


Fig. 11 Generator stator under shop assembly

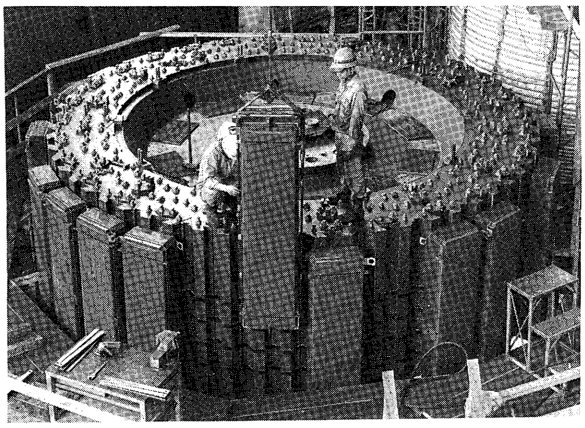


Fig. 12 Generator rotor under shop assembly

4. Others

Shaft current preventing insulation is provided at two different points of this machine in series. One of these points provided at the shrink fitting part of the upper shaft and upper guide collar as previously mentioned, and the other is provided between the upper bearing support part and upper bracket. This insulation provides adequate reliability against bearing damage due to shorting of the insulated parts.

A brake dust collecting device consisting of a suction blower is provided. This collector is operated automatically when the brake is applied.

VI. CONCLUSION

The Francis turbines and generators for the Tedorigawa No. 1 power station have been outlined and their features discussed. We are happy to have had the opportunity to manufacture these large capacity turbines and generator incorporating numerous new techniques, and added ample studies up to detailed design and manufacture and secured high reliability.