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EQUIPMENT FOR UIAM POWER STATION, KOREA ELECTRIC COMPANY

By Rikio Okano

Electric Power Engineering Dept.

I. INTRODUCTION

Uiam Power Station of Korea Electric Co., is situated along the North Han River at a location beyond Chunchon city. Overall equipment includes two 23,500 kw vertical shaft Kaplan turbines, two 25,000 kva synchronous generator, two 25,000 kva transformer, switchgears with 168 kv air circuit breakers, and an emergency diesel engine generator set supplied by Fuji Electric Co. Construction is now underway at the site.

The river is one of the largest hydroelectric power sources in Korea and the plant is a low-head large-discharge type with a gated dam which utilizes residual head between existing Chunchon Power Station and Chongpyon Power Station of the Korea Electric Company. The turbine runner diameter is 5000 mm which is one of the largest size of Kaplan runner ever produced in Japan. The casing is a semi-spiral concrete type, with main parts designed to provide unique features. The overall generator system is economical and practical construction drastically reduces maintenance requirements.

The generator is an umbrella-type. The thrust bearing is mounted on turbine head cover. The lower guide bearing of the generator located just below the rotor also serves as a pressurized oil feed device for runner blade operation, and the runner blade servomotor is housed in the rotor center. Thus, turbines and generators are coupled to form an integrated machine. Not only is the machine economical, but numerous advantages such as the decreases of crane lift and capacity which facilitates civil and construction works are found.

The 168 kv air circuit breakers used in the outdoor switchyard are a unique type developed by Fuji Electric. The performance of the circuit breaker has been fully proven by High Voltage Research Laboratory at Takeyama.

Electric power generated at this station will be boosted to 154 kv and fed through the switchyard of Chongyong Power Station located downstream on North Han River to the main transmission lines of the Korea Electric Company and distributed into Seoul and other principal cities. Fuji Electric was also awarded a contract for switchgears and control equipment of Chongpyong Switchyard at the same time and the equipment was delivered together with that for the Uiam Power Station.

II. TURBINES

1. Turbine Specifications

Number of unit : Two

Type : Vertical-shaft semi-spiral Kaplan turbine

Turbine output :

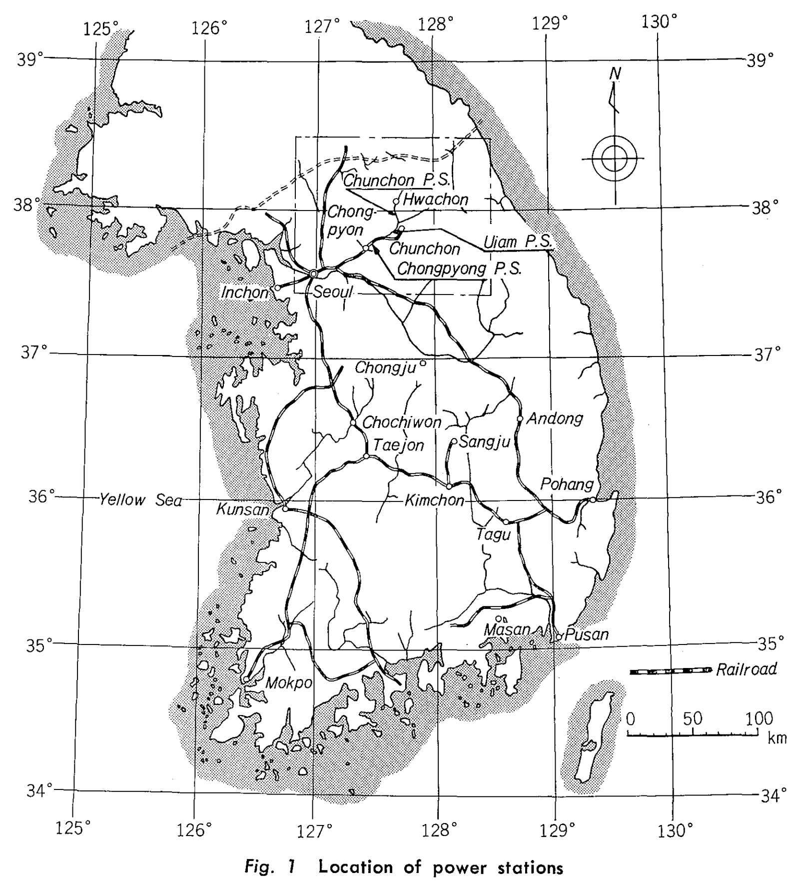

Fig. 1 Location of power stations

Under maximum effective head ......23,500 kw
Under normal effective head ....23,500 kw
Under minimum effective head ......15,200 kw

Head :

Maximum effective head ....17.2 meters
Normal effective head ....15.9 meters
Minimum effective head ....12.0 meters

Discharge :

Under maximum effective head ......150 cu m/sec
Under normal effective head ....163 cu m/sec
Under minimum effective head ......141 cu m/sec

Speed : 112.5 rpm

Specific speed : 545 (m-kw)

2. Turbine Characteristics

To verify turbine characteristics, a $^1/_{12}$ model was prepared and tested according to Japanese Industrial Standard (JIS) " Model Tests of Hydraulic Turbines (Provisional) " as follows :

1) Efficiency Test

As the acceptance test, a model test for turbine efficiency was carried out in Fuji hydraulic research laboratory. The discharge measurement in this test was made by the gravimetric method. Efficiency conversion from the model to the prototype turbine was made by the Moody $^1/_5$ power formula. Results are shown in *Fig. 2,* indicating that guaranteed values were met with large margins for the full range of discharge at each head.

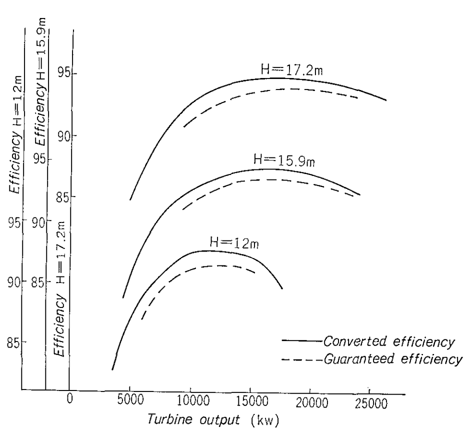

Fig. 2 **Model efficiency test results**

2) Cavitation Test

Cavitation characteristics under the maximum effective head (17.2 meters) is shown in *Fig. 3.* The critical cavitation coefficient is very low. Excluding bubbles caused by gap cavitation at the runner, no other bubbles were found and verification that the runner is not subject to damage by cavitation was made. *Fig. 4* shows a model cavitation test, under a running condition which is equivalent to that of prototype turbine under the maximum effective head and at the maximum output.

3) Runaway Speed Test

A maximum runaway speed of the turbine established by model test has been confirmed to be within the guaranteed value.

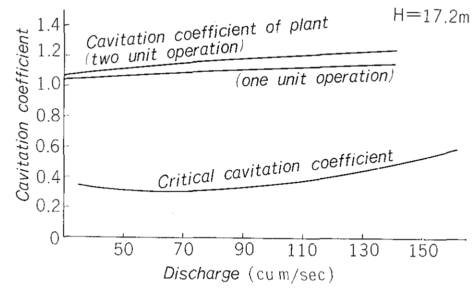

Fig. 3 **Model cavitation test results**

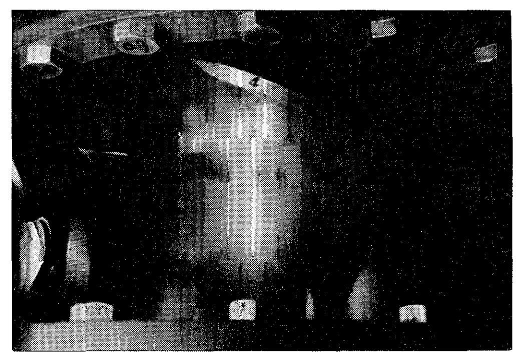

Fig. 4 **Model runner under cavitation test**

3. Turbine Construction

The turbines are vertical shaft, semi-spiral, Kaplan types. The capacity is classified as medium, but physical dimensions are notable. A great effort has been paid on design to reduce the cost of low-head large-discharge turbines, which are generally expensive, and full consideration and attention to operational stability and ease of maintenance were included, making full use of profound Fuji Electric experience and integrated technology.

Most parts of the turbine unit, excluding the casing, are made of welded plate steel for improvement in strength and simplification of construction. A pair of unique Fuji ring type servomotors is used as the guide vane servomotor, and are mounted on the turbine head cover together with the thrust bearing.

The runner blade servomotor is housed in the generator rotor center, and pressurized oil for controlling the servomotor is fed through the pressurized oil feed device which also serves as the lower guide bearing of the generator. This is one of the unique features in Fuji Kaplan turbines. With this construction, overall equipment length is substantially reduced, resulting in decreased construction costs for the equipment itself and the building. At the same time, simplification of maintenance and operation is realized. *Fig. 7* is a cross-section of a turbine and generator, and *Fig. 8* the shop assembly of a turbine.

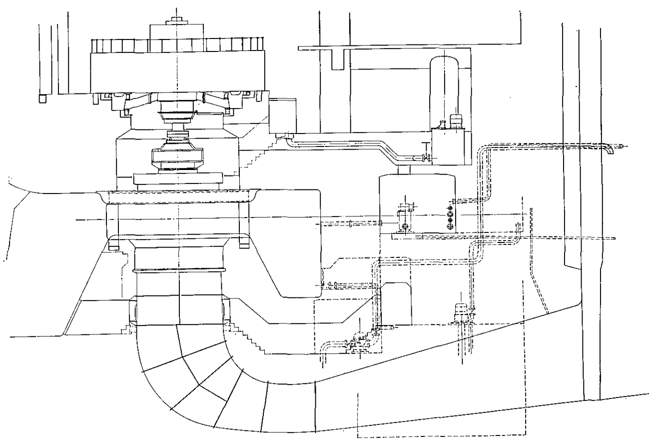

Fig. 5 Section of power station

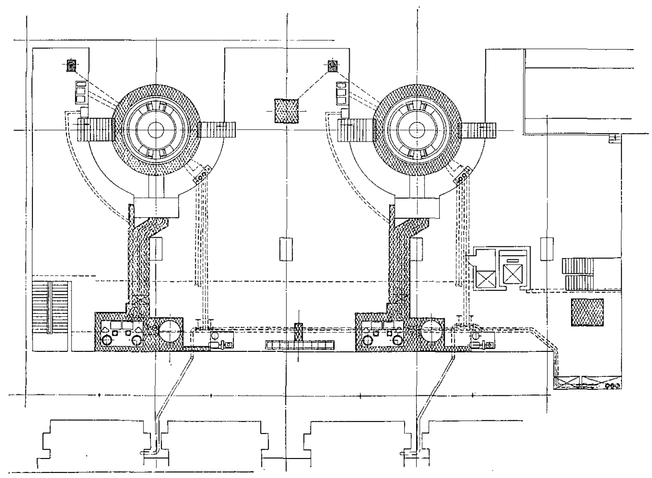

Fig. 6 Plan of generator room

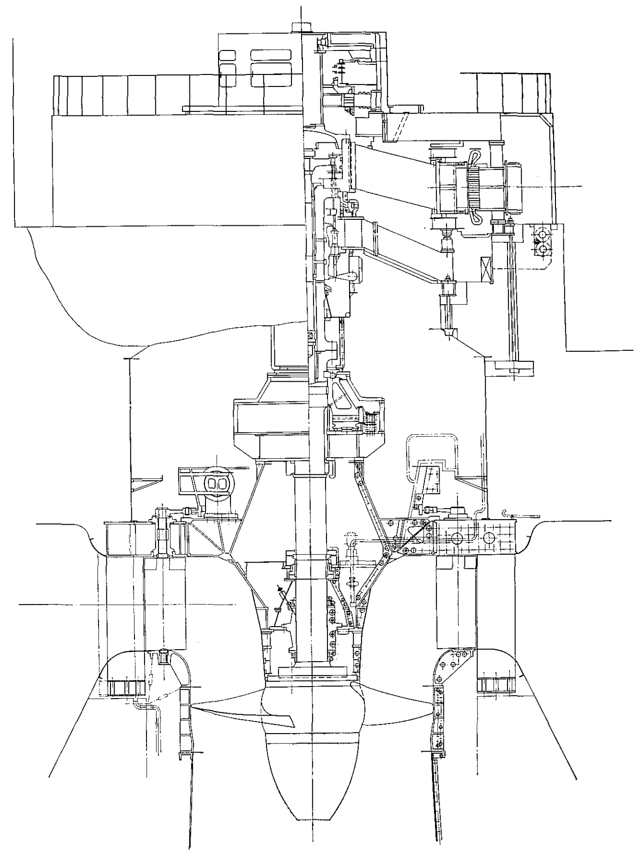

Fig. 7 Section of turbine and generator

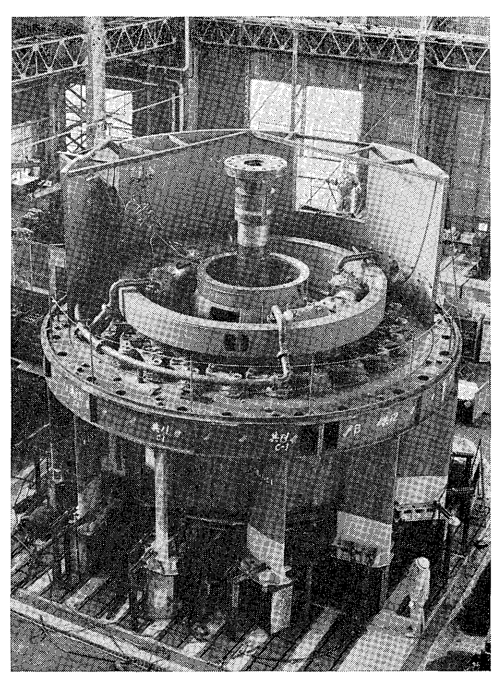

Fig. 8 Shop assembly of turbine

1) Casing and speed ring

The casing is semi-spiral concrete type. The speed ring consists of an head cover and stay vanes. The stay vane has no lower ring. The bottom of each stay vane is directly fixed to the concrete casing with anchor bolts, and the lower quarter of the overall length is buried in concrete. The top of stay vane is secured by bolts to the head cover. The head cover is fabricated with steel plate and consists of the outer head cover as an upper ring of the speed ring and the inner head cover. One third of the outside of the outer head cover is buried in concrete. Thus, the speed ring, including the head cover, is very rigid despite simple and lightweight construction. This construction is especially advantageous when the transportation capacity is limited. Since the outer head cover is buried in concrete, special guide vanes described later are used to facilitate disassembling and removal.

2) Head and bottom covers

The head cover consists of the outer cover combined with the upper ring of the speed ring and the inner cover. Both parts are made of welded plate steel. The generator thrust bearing is mounted on the top of the inner cover. The guide ring and ring type servomotor are also mounted on it and the main turbine shaft bearing is mounted on the inside lower part. The bottom cover is made of cast steel, supported by a discharge ring made of welded plate steel.

3) Runner

The runner diameter is 5000 mm and the runner has five movable blades. The runner blade is made of 13% chrome cast steel and is rimed with a corrosion-resistant tip on outside circumference to prevent pitting by gap cavitation. The link mechanism in the boss is simplified construction and full attention has been paid during design, so that the mechanism withstands centrifugal force produced during runaway. *Fig. 9* shows a runner assembly at the factory.

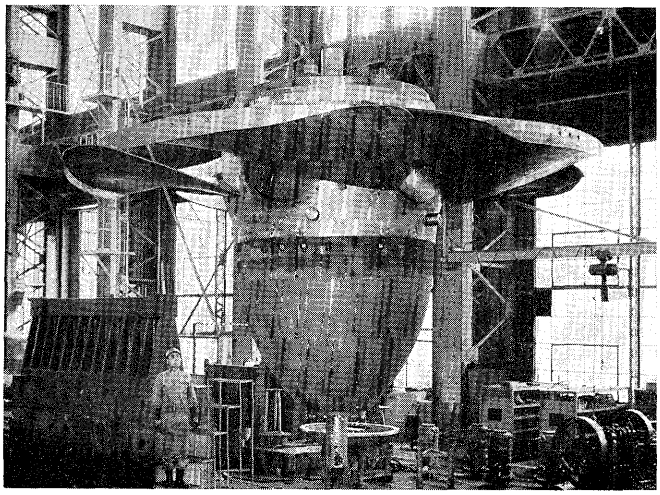

Fig. 9 Runner

4) Guide vane and guide vane servomotor

Since the top cover is buried in concrete, the guide vane has special construction which permits removal from the covers. On the upper end of the guide vane, two detachable pieces with a height corresponding to the length of the lower guide vane spindle are provided. For the dismantling of guide vane, the following procedure is observed. The upper guide vane bearing is removed, along with the detachable pieces of the guide vane. The guide vane is pulled upward until the lower guide vane spindle comes out of the bottom cover, and is pulled out along the lower cover toward the inside lower direction.

The guide vane regulating mechanism has simple construction: Single guide vane arm connected to the guide ring with two links (upper and lower).

The shear pin is designed so that it is essentially not affected by the torsional moment acting on the pin due to frictional force. The guide vane servomotor is a ring type. The cylinder is connected to the inner cover, and the piston is secured to the guide ring.

Use of this servomotor is advantageous, due to compactness, easy installation, and smooth operation and easy maintenance. As the large cutout hole through the concrete barrel for placing of servomotor rods is not required and reaction force of the servomotor is not applied to concrete, additional advantages are found on the civil and construction works.

5) Packing Box

For the main shaft water sealing system, the end seal type carbon packing is employed. Water sealing action is performed by two carbon rings (inner and outer) forced against the collar fitted on the main shaft in the direction of the shaft. Clean water is injected through a strainer into the space between the carbon rings to maintain constant pressure during operation, irrespective of head variations for turbine. This system is advantageous, due to simple construction, low leakage, and low carbon ring wear.

6) Runner blade servomotor and pressurized oil feed system

The runner blade servomotor is mounted in the generator rotor center, and pressurized oil for the servomotor is fed through grooves in the generator lower guide bearing and bores in the turbine shaft.

Pressurized oil from the guide bearing passes through the inside or outside of the oil feed tube placed concentrically between the generator shaft and the piston rod and is led to the upper or lower side of the servomotor piston.

At the upper part of the servomotor, air can be separated from oil and hence an automatic air vent is included. The vertical movement of the servomotor piston is fed back to the governor. An oil pressure tracking system is used between the turning ring (connected to piston and moves up and down together with servomotor cylinder) and the return rod (mounted on the generator bracket). Since the rod and the ring are not in metal contact (rod is following the ring through an oil film caused by oiljet on the rod head), there is no danger of wear and therefore motion is transmitted reliably.

4. Water Supply System

Since the effective head is small and there is not a sufficient head for the carbon packing system, two systems were designed separately, one with water fed from the casing and the other with water pumped to the water supply tank from the water supply pit connected to the reservoir. The former supplies water through the strainer to the air cooling system of the generator and the thrust bearing cooler. The latter which has a sufficient head supplies water to the carbon packing, oil cooler of pressurized oil system, and diesel engine. For the prevention of wear of carbon rings caused by a large amount of sediment in the water in flood season, special strainers are provided.

III. GENERATORS

1. Specifications

1) Main generator

Number of unit:	Two
Type:	Vertical shaft, rotating field, enclosed ventilation umbrella type (with air cooler)
Output:	25,000 kva
Voltage:	11,000 v
Frequency:	60 cps

Power factor:	0.9 (lag)
Speed:	112.5 rpm
Flywheel effect:	3450 t-m^2 (guaranteed value)
Standards:	JEC-114

2) Exciters (directly coupled to main generators)

Number of units:	Two
Type:	Vertical shaft, open type
Output:	270 kw
Voltage:	440 v

3) Permanent magnet generator (coupled to main generator)

Number of units:	Two
Output:	0.7 kva
Voltage:	110 v

2. Generator Characteristics

When a generators is a very low speed machine and has as many as 64 poles, difficult technical problems are encountered in the design. For generators such as these where GD^2 demanded by the turbine is nearly identical to natural generator GD^2, a "copper machine" (electrical loading of stator increased and mechanical dimensions made small) should be selected for cost reduction and efficiency improvement. If electrical loading is too large, however, the temperature of the stator winding may rise abnormally and Potier reactance due to the increase of leakage reactance of the stator winding and the rotor winding may increase. As a result, the electrical loading of the rotor should be large in order to obtain the required short-circuit ratio. However in such a multiple pole machine, the distance between poles is small, and there fore field winding design is difficult. Furthermore, as the air gap length is small compared to the inside diameter of the stator, a difficult technical problem is encountered in manufacturing and assembling equipment so that eccentricity is not produced.

Full consideration and attention have been paid to design of the stator winding, and the field winding in considering ventilation. As a result, electrical loading could be as large as that of largecapacity high-speed generators. Thus, confidence in low-speed high-capacity generators has improved.

3. Generator Construction

As shown in *Fig. 7,* there is no bearing at the top of the generator and the permanent magnet generator and the d-c exciter are mounted directly on top of the rotor center. The runner blade servomotor is housed in the rotor center boss and the pressureized oil feed device also serves as the lower guide bearing. Therefore, as compared to the ordinary Kaplan turbine with the pressureized oil feed device mounted on the top of generator, the overall height of this particular generator is less. Also no return rod passing through the upper shaft of generator simplifies construction of generator. As no circulating circuit for the shaft current is formed across the guide bearing, insulation which prevents shaft current is not required. The thrust bearing is mounted on the top of the turbine head separated from the guide bearing. Thus, the average diameter of the thrust bearing is reduced and bearing loss is decreased. At the same time, the span of the bracket is greatly reduced, decreasing bracket weight. The thrust bearing is located separately from the generator where adequate space is available. Therefore, it can be easily and conveniently disassembled and inspected without disturbing the generator and the turbine. Through full utilization of Fuji experience related to umbrella type generators including the 72,000 kva 150 rpm generator delivered to Shinsoyama Power Station last year, this particular generator was designed to provide efficient cooling at speeds as low as 112.5 rpm and increased weight due to larger dimensions is held to a minimum while adequate mechanical strength is maintained. Construction of individual components is described in the following.

The stator frame is welded construction and split into four parts for transportation. Eight water-cooled air coolers are mounted on the exterior of stator frame. The conventional Laschen system is used for securing stator cores to the stator frame. In clamping laminated layers, the heat drying process was repeated several times so that there would be no shrinkage or looseness of the core due to aging. The stator winding is a one-turn, "Roebel" transposed type and is wave winding system. For generators with a large number of poles, the wave winding system is also advantageous from the viewpoint of omitting crossovers which connectedbetween poles of stator winding. Although this generator is a fractional slot, the wave winding system was employed from the special viewpoint as above.

The coil insulation is F-resin (epoxy resin) which was developed by Fuji Electric and has proven excellent characteristics through ten years of actual application. Magnetic pole cores are made of laminated high tensile-strength steel sheets and are attached to the rotor yoke by dovetail system.

As mentioned above, the dimensions of rotor poles and field winding are carefully designed since the machine dimensions are affected by them on a machine with a large numbers of poles.

For the umbrella type generator in general, distance between center of gravity of the rotor and the position of the guide bearing must be short in order to improve mechanical stability. For this particular generator, welded construction with two cone shaped steel plates (upper and lower) was employed. The cone shaped center provides good rigidity and is therefore very effective against bending moments which could be produced when the machine is in operation. Furthermore, the cone shaped construction reduces a windage which occured by rotor center loss to a minimum, in contrast with ordinary spider type

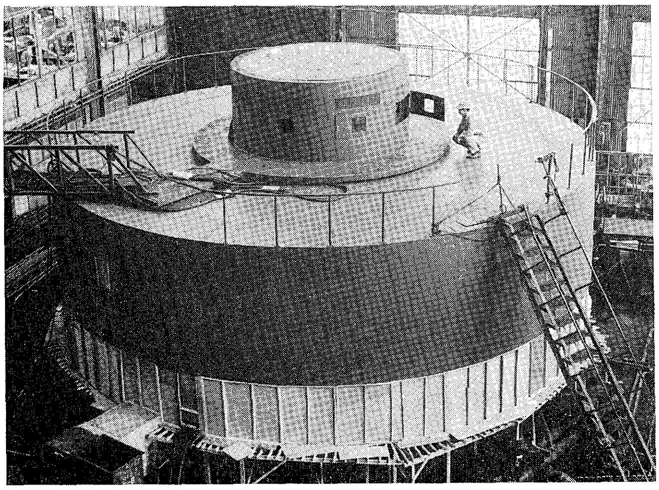

Fig. 10 Shop assembly of generator

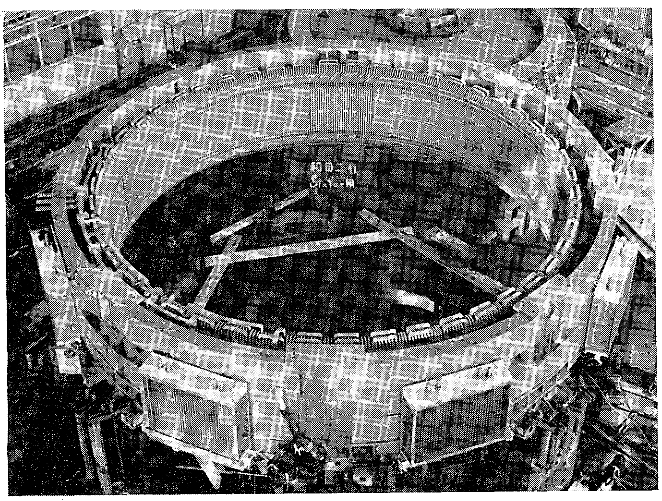

Fig. 11 Stator

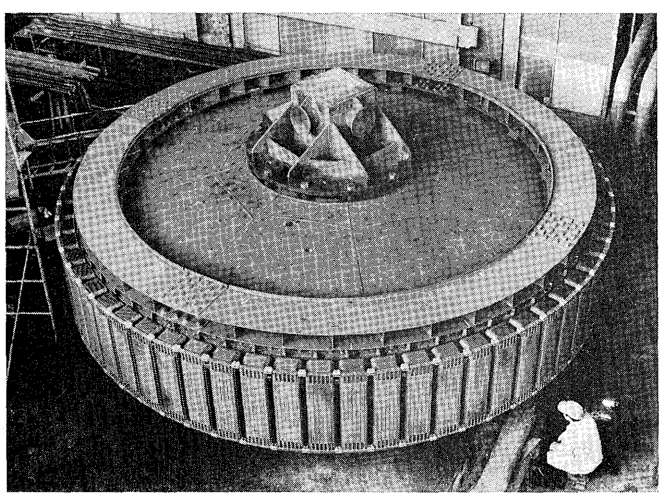

Fig. 12 Rotor

construction. In considering with a low speed, an efficient fan for the required cooling air flow was designed, and effective circulation of cooling air was examined during factory testing, and suitability of this aspect was confirmed.

Fuji-Michell thrust bearing with a capacity of 530 tons was employed. This type of bearing was used for 850-ton thrust of the 45,000 kva generator at the Oyodogawa No. 1 Power Station and 770-ton thrust of the 38,000 kva generator at the Akiba No. 2 Power Station, and the performance has been well proven. The thrust collar can be split into two parts and therefore can be disassembled independently from the turbine.

4. Factory Test Results

The factory tests were carried out in accordance with the standard of JEC-114. The temperature rise test proved that there were sufficient margins for both the stator and rotor, verifying that careful consideration and attention had been given. Efficiency shown in *Fig. 13* was obtained, proving that the equipment is highly efficient and economical. Waveform distortion was as low as 1.4%, due to that consideration and attention paid to winding and other items. Reactances and time constants are shown in *Table 1.*

IV. OTHER EQUIPMENT

Fig. 14 is a skeleton diagram for the Uiam Power Station. The main transformers are 3-phase oil-filled self-cooling type. The main part was shipped in the assembled state, with a temporary cover.

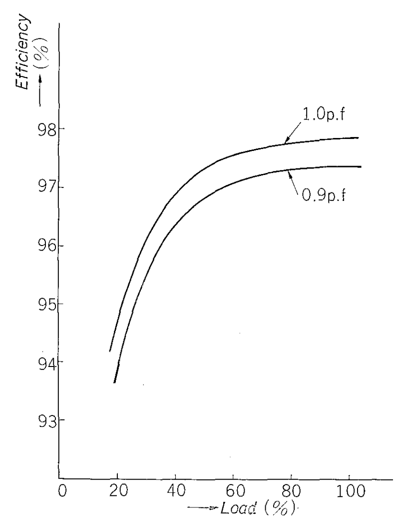

Fig. 13 Efficiency curves

Table 1 **Reactances and Time Constants**

x_d	95.2%	x_d'	47%
x_d''	32.5%	x_q''	32%
x_2	32.5%	x_0	16.3%
$T_{d'0}$	4.16 sec	T_d'	1.84 sec
T_a	0.101 sec	T_d''	0.041 sec

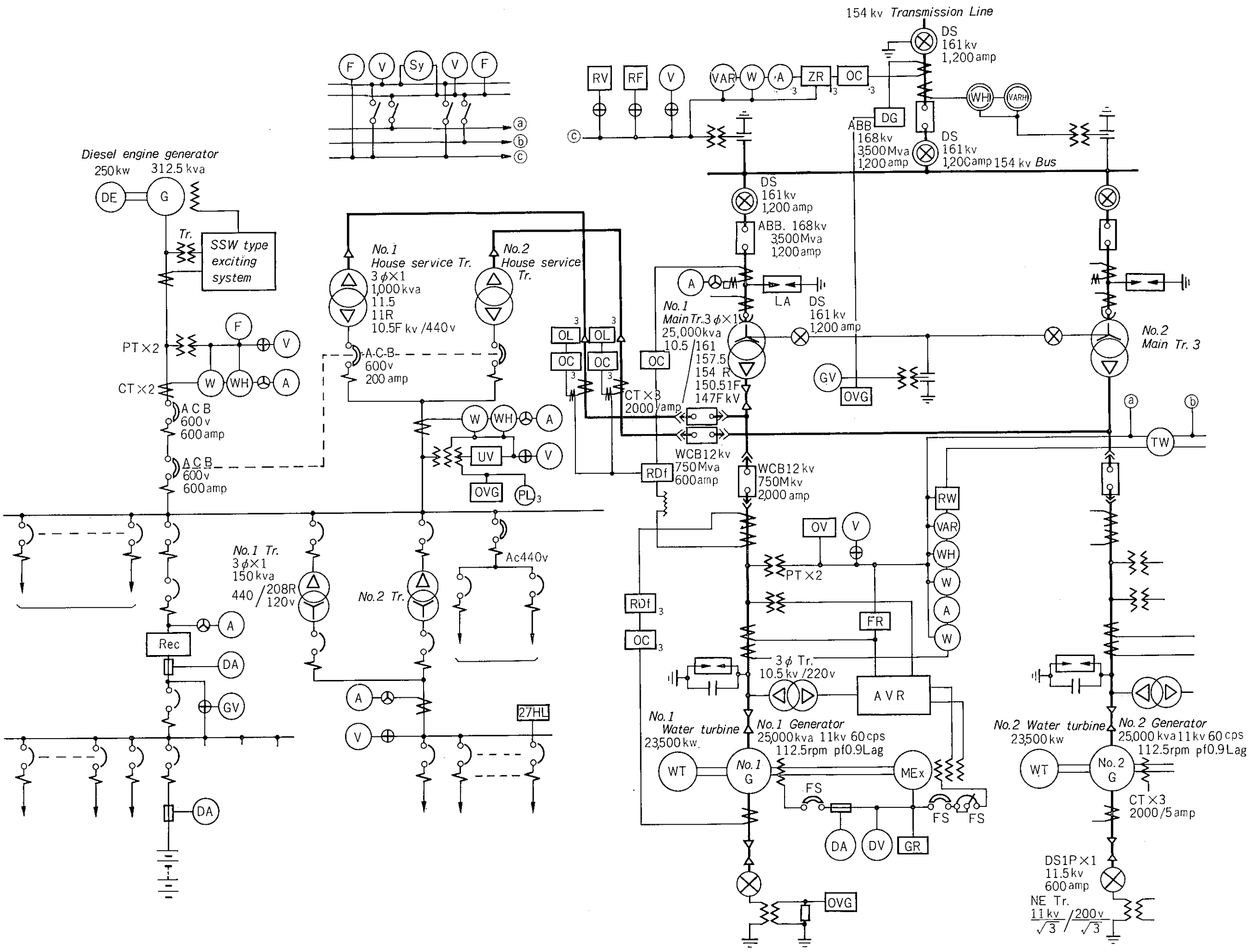

Fig. 14 Skeleton diagram

The transmission line circuit breakers are Model RF 720, 168 kv 1200 amp, 3500 Mva air blast type, one of a series of 72∼168 kv use introduced by Fuji Electric. These circuit breakers are based on unique Fuji system of a continuous pressurized nozzle packing system employed for improvemnet of breaking action, reduction of contact wear, and ease of handling. A view of the 168 kv air circuit breaker appears in *Fig. 15*. In this contract, a total of four units including that for Chongpyong Power Station were included. Details of other equipment cannot be included due to the lack of space, Advanced technology of Fuji Electric is also applied to this equipment.

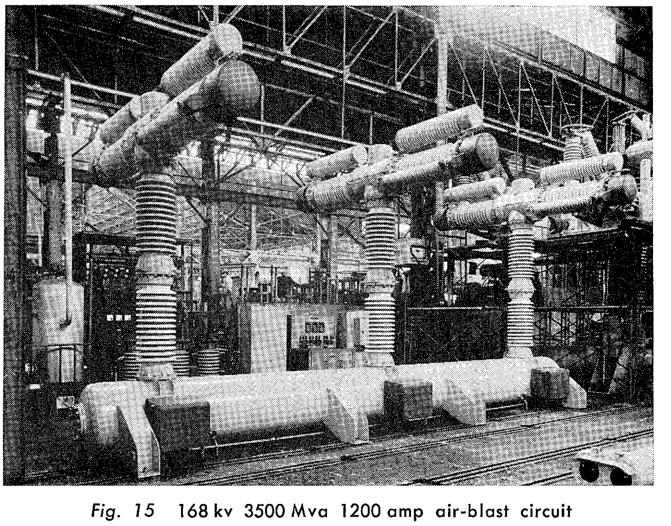

Fig. 15 168 kv 3500 Mva 1200 amp air-blast circuit breaker (Type RF 720 J/140/1200 D)

V. CONCLUSION

An outline of equipment delivered to the Uiam Power Station has been given. The author sincerely hopes that this report will provide at least a small amount of information for further improvement and development of low-head large-discharge turbine and generator.

The author gratefully acknowledges the kind cooperation and guidance rendered by concerned parties in the Korea Electric Company and Nihon Koei Co., Ltd., and is looking forward to the time when this equipment will be placed into service operation as an energy source in Korea.