JINTSUGAWA THIRD POWER STATION WITH LOW-HEAD LARGE WATER QUANTITY KAPLAN TURBINES

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Synopsis

Last year, the Kaplan turbines for the Jintsugawa Second Power Station were built by us as the first set after resuming technical corporation with the Voith Co. (Germany), and revolutionalizing construction of the Kaplan turbine in Japan withits up-to-date style and high efficiency.

Subsequently, the order was placed with us for the water turbine and generator in Jintsugawa Third Power Station and their main parts have recently, been completed.

They have more marked features in the design of turbines than that of the Second Power Station such as hydraulic return mechanism of runner servomotor, completely welded construction, etc.

I. INTRODUCTION

The Jintsugawa Third Power Station of the Hokuriku Electric Power Co., is a dam type power station constructed two miles downstream from the Jintsugawa Second Power Station, where the water turbines and generators built by our company have been successfully operating since the beginning of 1954.

In order to ready the servicing by the power-shortage season ;—winter, a great effort was made to complete the Jintsugawa Third Power Station, both during the manufacturing in our factory and the assembling at the site.

Then, in the end of Dec. 1954—it was ten months since the order was accepted, commercial power generating was successfully began.

The turbine of this power plant is a distinguished Kaplan turbine in respect of low-head large water quantity in this country, and its up-to-date structure attracting the attention of the circles.

II. SPECIFICATIONS OF EQUIPMENT

Vertical Shaft Movable Runner Blade Propeller Turbine .....1 set.

of Head 8.22 m	Maximum 9.72 m
	Minimum 8.72 m
Water quantity	120 m^3/s.
Maximum output	10,200 kW
Revolutions	100 r.p.m.

Three Phase A.C. Synchronous Generator ..1 set

Output	11,000 kVA
Voltage	11,000 V
Frequency	60 c

Oil Immersed-Self-Cooled Three-Phase Transformer .....1 set

Output	11,000 kVA
Voltage	10.5/77 kV

Expansion Circuit Breaker .....1 set
80.5 kV 800 A 1,500 MVA

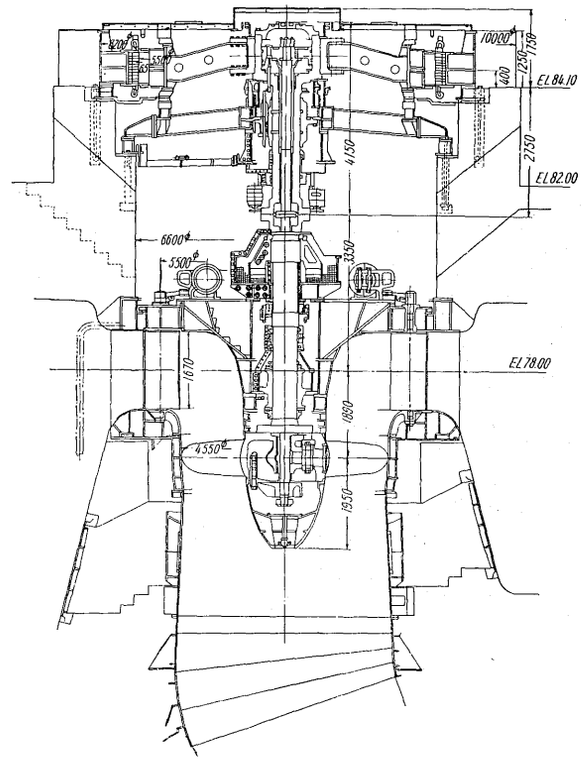

Fig. 1. Sectional drawing of Kaplan turbine and generator

III. TURBINE

As can be seen in the sectional drawing of Fig. 1, the construction is radically different from the concept of ordinary Kaplan turbines.

Namely :—

1. The structure was simplified by placing the thrust bearing on the upper cover of the turbine which makes possible the lowering of the building.

2. The runner servo motor is contained in the generator rotor center, cutting down the shaft length greatly.
3. By placing the Kaplan device (device of employing a pressure oil to the runner servo motor) on the generator guide bearing, the construction of the upper side of the generator can be simplified and this structure prevents the generator coil from being spoiled or damaged in case of leakage oil from the Kaplan device, in comparison with the usual type Kaplan device which is placed on the top of the generator shaft. And furthermore the lubrication of the generator guide bearing is made by this pressure oil, when the special lubrication device of generator guide bearing become useless.
4. With the employment of the above mentioned new type Kaplan device, the return mechanism adopts the latest oil pressure type.
5. A ring servo motor is installed on top of the turbine cover as a guide vane servo-motor preventing the generator barrel from being affected by this strong force. This also frees the power station building from any restrictions in the design.

Such important characteristics as mentioned above

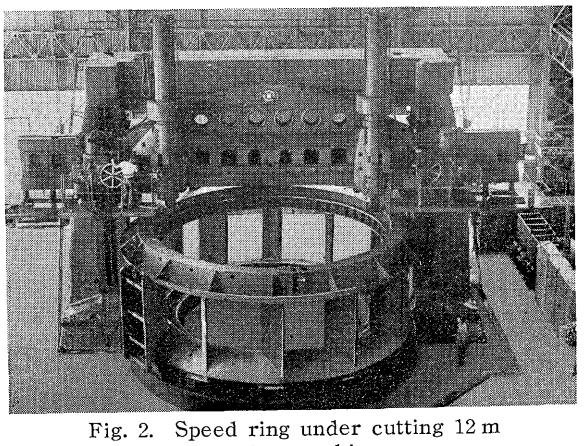

Fig. 2. Speed ring under cutting 12 m turning machine

can be seen, and an explanation on the structure of each of the main parts follows.

Turbine Body

It is of a semi-spiral casing type built of concrete and is provided with a concrete barrel for installation.

Welded steel sheet is used extensively for all parts, reducing weights and carrying out economical design by rationalizing the construction.

Runner

It is a more vital requisite in Kaplan turbines than for any other type to increase turbine speed by taking high specific speed for the sake of economical

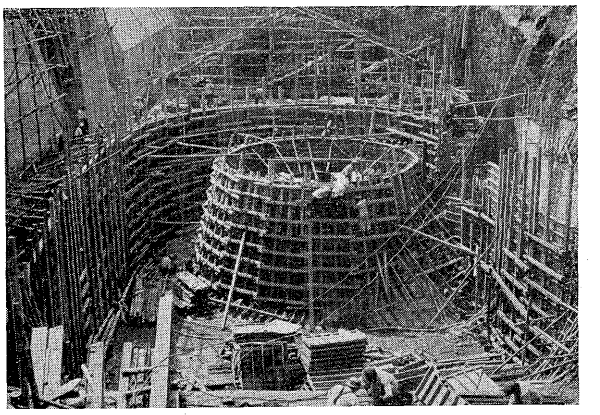

Fig. 3. Semi-spiral type concrete casing under construction

design; therefore the runner construction and the workmanship on the vane are the most important deciding points. The outer diameter of this runner is 4.55 m, and the number of blades is five. Our company is using a special copying lathe to plane the surfaces of the work with high accuracy. Its cutting speed is extremely high as compared with conventional one, achieving excellent results. As to the accuracy of work, the runner is finished with 1 mm. tolerance for each side, and $^{1}/_{1000}$ for its length. Fig. 4 shows the runner blade under finishing.

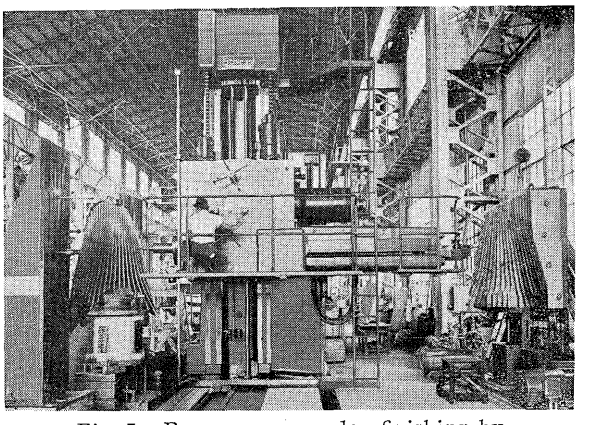

Fig. 5. Runner vane under finishing by special boring machine

For the runner blade packing, oil resistant synthetic rubber packing superior to leather in flexibility and durability is used and is kept always in contact with the blade's shaft by means of springs.

This is a very excellent construction which not only stops oil leakage completely from the interior of the boss, and water seepage from outside of the runner, but it makes possible replacement of the packing without removing the runner blade.

Runner Blade Servo-Motor and Pressure Oil Device.

The system in which the runner servo motor is contained within the generator rotor center is adopted.

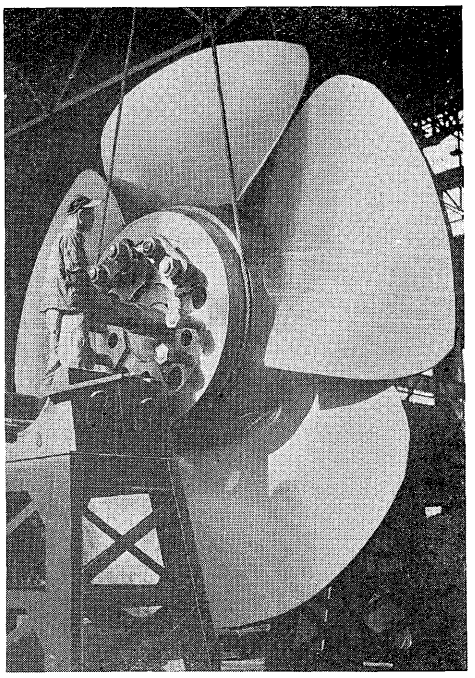

Fig. 5. Completed runner

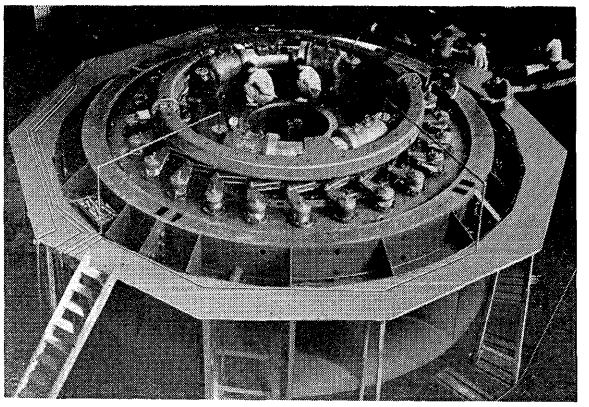

Fig. 6. 10,200 kW Kaplan turbine proper

This made possible shortening the generator and turbine shafts, which, together with the runner blade operating rods at the turbine shaft flange, helps to reduce the height to the crane hook greatly.

In ordinary Kaplan turbines the pressure oil device is installed on top of the generator and the return mechanism is led from the top of the generator to the governor, on building design. However, as to the turbine for this power station, a system which combines the generator guide bearing and the pressure oil device is adopted. This system is especially effective for umbrella type generators, as shown in the assembly drawing the entire construction is extremely simplified. Furthermore, as shown in Fig. 5, the system employed for the return mechanism consists of a disc attached to the bottom of the runner servo-motor, and moving up and down, and oil pressure type return mechanism controlled by this disc. By using this system the friction is negligible and a powerful return force is available by means of oil pressure.

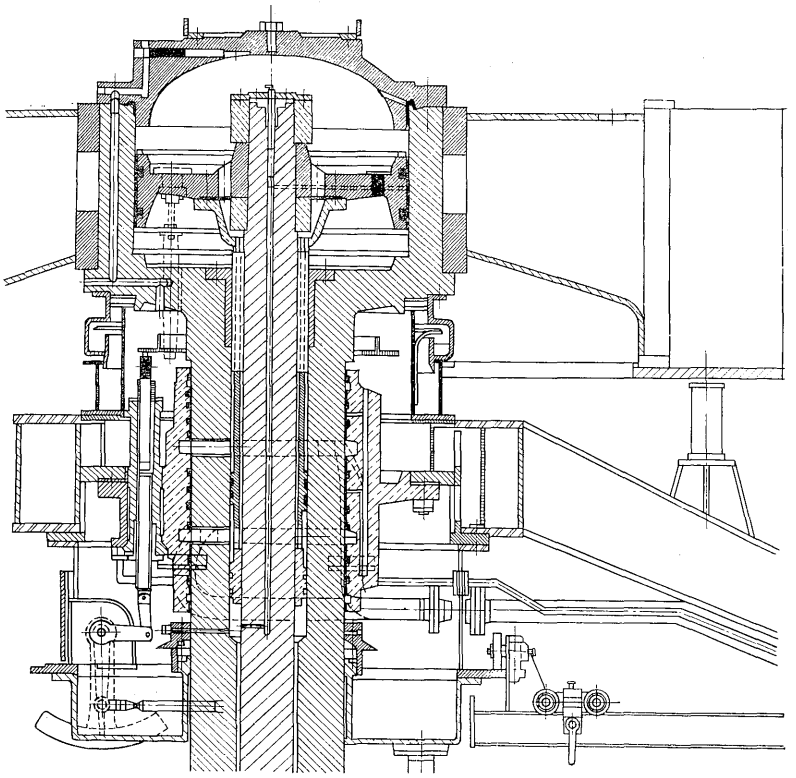

Fig. 7. Pressure-oil leading device of runner servo motor

Guide Vane Servo Motor

A ring servo motor is used for the guide vane servo motor. This consists of a ring piston, cylinder and packing of a special construction. The piston is attached directly to the guide ring and the cylinders are arranged symmetrically on the turbine cover. In general when the turbine becomes so large as to require separate installation of the servo motor and actuator parts of the governor, the guide vane servo motor is rather mounted on the generator barrel, or installed at a suitable location by the spiral casing. But finding a proper position is difficult in the case of a concrete casing such as used in this power station, it involves a very difficult problem. This ring servo motor does away with this problem completely. In this construction, the oil pressure on the piston affects on the guide ring as a couple and causes no torque in the generator barrel or other concrete parts by the servo motor. It can be pre-adjusted perfectly during the assembly work at the factory and made installation guide simple. Fig. 6 shows the turbine under assembling and testing at the factory, where the ring servo motor was operated by the pressure oil device to open and close the guide vanes, to attain perfect adjustment. Then, it was shipped after being disassembled.

Runner Ring

The runner ring is made of steel sheet, welded together, with its outside cast in concrete. As to the runner ring, the concentrated stress generated in the parts corresponding to the runner blade due to the pressure difference of its both sides receives repeated stress rotating with the blade, and often results in vibrations. This is perfectly avoided by casting casing in concrete.

However, in the cast-in casing as this the replacement of the worn out parts is impossible, and if left as it is its will lead to poor efficiency and gap cavitation. In order to overcome the disadvantage there has been such uneconomical practice as casting the whole runner ring of 13% chrome steel. In this power station, novel design was adopted that the main body of the runner ring is of welded steel sheets, and to the runner center section subject especially to wear is welded 18–8 nickel chrome steel sheet.

As it is well known, the runner ring forms a part of a spherical surface maintaining a 2 mm gap from the runner vane, and a very high degree of accuracy is required. It is a very difficult task to weld stainless steel sheets to a body which is liable to cause welding strain from its structural standpoint but the careful study of the welding rod, welding order and heat treatment made this difficult work successful.

Governer

A cabinet type governor is used, with an actuator of the latest motor operated totally enclosed sheet spring pendulum type which is highly sensitive and stable. A magneto generator friction-coupled to the main shaft in used for the power source of pendulum motor.

The Kaplan turbines are controlled to constantly obtain the highest efficiency by changing the opening of the runner blade according to the guide vane opening. For the purpose of the maintaining their relative positions a cam in a shape determined as a result of model testing is used.

However, even though such a cam is used as to maintain the most desirable relative opening at a certain head and speed will fail to meet the requirements when there is a change in head or frequency. In order to have automatic compensation for this and to maintain the best relative opening, a " high efficiency operating device " is provided to this turbine. In Kaplan turbines, when the unit head r.p.m. n_1' changes, the relation between the runner and guide vanes makes an approximately parallel shift with the change of n_1', the head becomes high as n_1' becomes small, vice versa and if the frequency becomes greater n_1' increases accordingly, and vice versa. In other words, when head and frequency change, this is converted to the change of n_1'. Therefore cams should be prepared for varing n_1' in response to the changes in frequency and head, and be piled up to form a solid cam to answer the purpose.

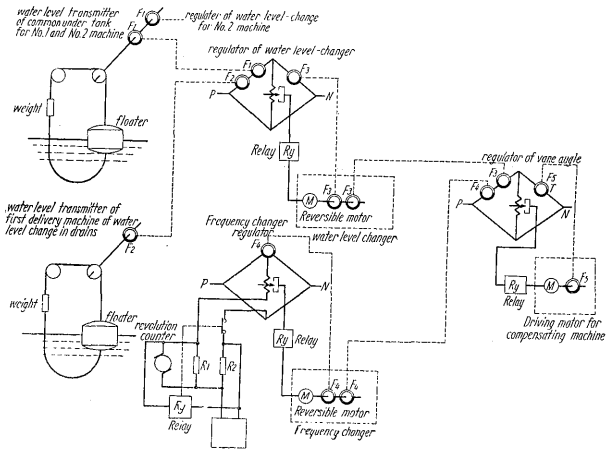

Fig. 8. High efficiency control device for Kaplan turbine

As a device for converting the head and frequency change into a change of n_1', a " high

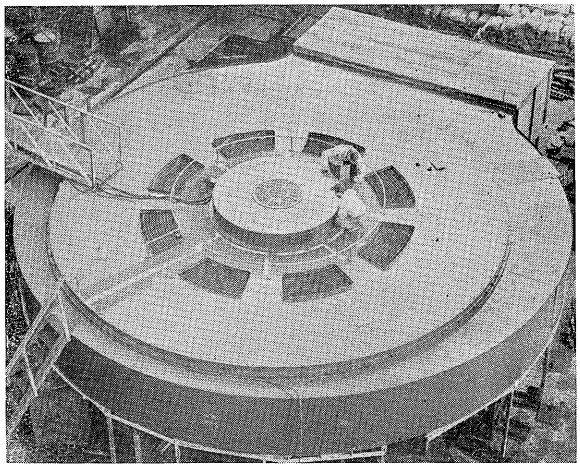

Fig. 9. 11,000 kVA generator

efficiency operating device " consisting of ring tube, bridge relay, operating electric motor and magnetic amplifier etc. as shown in the block diagram in Fig. 7 in the diagrams. As seen, for changes in the head, the ring tube is operated by floats placed in the head tank and the tail race, the change in water level being transmitted to the water level converter as a change in resistance of the ring tube. On the other hand, for changes in frequency, the difference between the output voltage variation of the highly sensitive tachometer dynamo and the voltage of the magnetic amplifier type constant voltage apparatus is transmitted to the frequency converter bridge. The quantity of difference voltage drives the ring tube of frequency converter breaking the bridge relay balance of the runner blade angle adjuster, causing the compensation mechanism operating motor to rotate until a balanced is resumed. If adjustment is made to have this stable position at a place of the cam corresponding n_1' of that time, this will meet the requirements.

Damping and braking of each part of this device has been considerately determined to assure stable and reliable operation.

Pressure Oil Device

As the pressure oil chamber, pressure oil pump and pressure oil cooler are neatly arranged on top of the oil sump tank, the installation and examination can be very easily. Both the main and auxiliary pressure oil pumps are of motor driver type. The pumps are of vertical shaft screw type rated 25 kg/cm^2. 900 l/min. and 1,750 r.p.m.

The pumps are of high efficiency and 75 HP motor is enough for driving, having little vibration and noise.

IV. GENERATOR

This is rare example of a low speed generator in Japan-11,000 kVA, 100 r.p.m. and 72 poles. Because of this low speed, the huge Kaplan turbine runner capability of being pulled up without dismantling the stator, and also 2,300 t-m^2 GD^2 required by the turbine, the dimensions of the generator have greately increased. Consequently, the design-

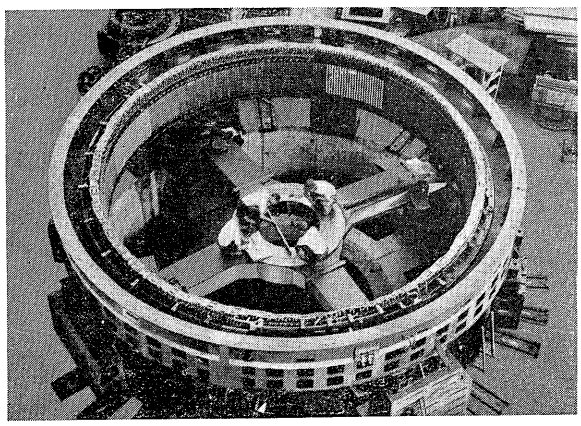

Fig. 10. Stator of 11,000 kVA generator

ing and manufacture was carried out by all out efforts of the company's technical staff to attain economical design and reduced weight as well as restricted size to meet the traffic requirements. The appearance, as shown in Fig. 9, is very smart.

Umbrella Type Structure

As mentioned in the chapter of on turbines, the structure is of the umbrella type, in which the thrust bearing is placed on top of the turbines upper cover, which makes the lower bracket free from vertical load, only supporting the rotor not to tilt. If the thrust bearing is installed in the lower bracket as in the case of the ordinary umbrella type unit, and is supposed to support the weight of the turbine and generator's rotating parts and a water thrust of 285 t, a very sturdy bracket is called for because of almost 7 meter span, causing a great increase in weight. As concrete barrel will also be subjected to the thrust, it will give serious problems on the civil engineering. The methods adopted by the company has overcomes these difficulties completely.

Separately Installed Exciter

Because of low rated speed, direct couple of the exciter will result in a considerable increase in the size and weight. Consequently a separate exciter driven by an induction motor of 900 r.p.m. is employed. As a result, not only the saving in weight of the exciter but also the elimination of exciter load on the generator's upper brackets results in only a simple beam to support the weight of the generator deck being required. Therefore the upper bracket and the stator frame supporting it become

simpler in construction and light in weight as compared with ordinary generators.

Stator Construction

The stator frame is built of welded steel sheet and is divisible into four sections for the sake of transporting. The stator core is composed of T class silicon steel sheets laminated half overlapping each other and with several ventilation ducts provided in the axial direction to increase cooling surface.

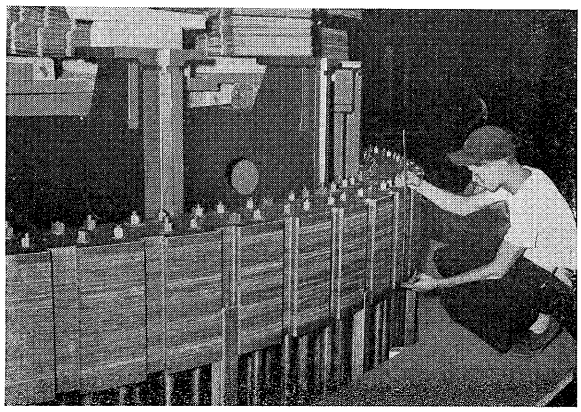

Fig. 11. Rotor yoke under laminating work

They are also tightened with studs so as to avoid getting loose by shocks and vibrations. To prevent the increase of iron loss by strain due to the pinching iron core sheets, are annealed in vacuum after punching and a special varnish has been applied to inter layer insulations. Non-magnetic steel is used for the finger holding the core teeth preventing the increase of iron loss due to the leakage flux.

Rotor Construction

As the outer diameter of the rotor is 6.5 m, its gravity of the center is placed as close as possible to the guide bearing, and the spider is made of the umbrella type for greater stability. The spider consists of 16 arms of welded steel plates and is fastened by reamer bolts to the spider boss containing the runner servo-motor.

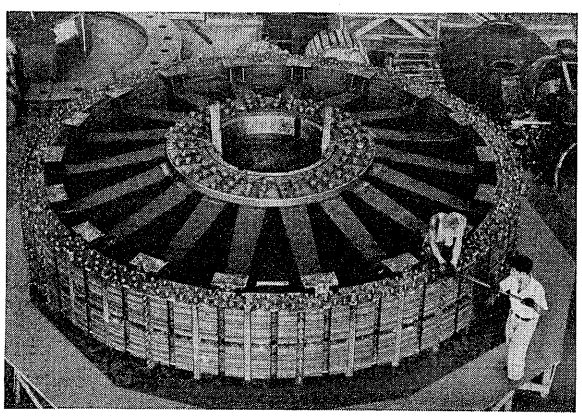

Fig. 12. Assembling of rotor

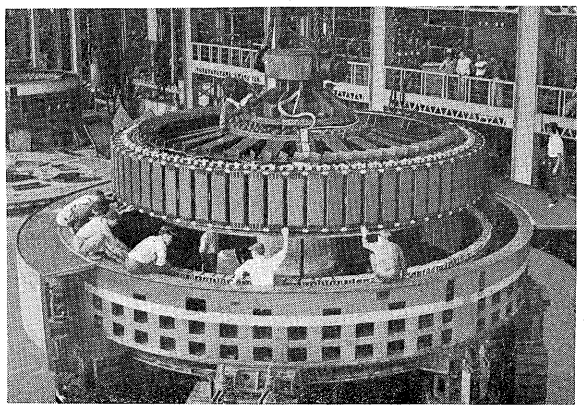

Fig. 13. Assembling of generator

Because that it must be shipped disassembled, the yoke is formed by lamination of 3,600 pieces of twelve segment of thin steel sector plates with one third overlapping over each other and firmly fastened by reamer bolts ; then shrunk fit to the spider and coupled with a guide key.

The magnet pole built of pole pieces of laminated steel sheets, made one body to a forged steel magnet pole core by welding and this is fitted to the yoke by a dovetail key. The damper winding is provided on the magnetic pole to prevent hunting and generation of abnormal voltage. The field coil is edge wise winding having asbestos paper treated with adhesive varnish inserted for inter layer insulation ; this is sufficiently heated and pressed after being pressed into a strong iron bobbin insulated with micanite.

Thrust Bearing

The Mitchell type bearing is used with two pins on the segment metal to prevend moving toward its rotating direction. The disc type springs made of special spring steel are used for the supporting elastic material, and at their center a special projection on the lower end of the segment metal is supported. The center of spherical projection is off the segment metal center of gravity in the direction of rotation so as to facilitate the adjustment of the segment metal offering a most ideal lubricating surface to fully support its load. The thrust collar is made of forged steel rings and is fixed to the main shaft by a cast steel thrust collar supporter.

The oil immersion system is used for cooling wtih copper cooling pipes arranged in the oil tank. In disassembling the thrust bearing, there is no need of removing the rotor, and the rotating type crane attached to the lower backets, is used for it.

Tachometer Dynamo

A pendulum driving generator which also serves as a magneto A. C. generator for a tachometer and highly sensitive D. C. generator, for a hand high cycle conpensating high efficiency operating device are suspended from the lower bracket by means of a hinge bolt and are driven through a rubber ring by friction from the surface of the coupling flange between the generator and turbine shaft.

Magnet Amplifier Type Automatic Voltage Regulator

The automatic voltage regulator for this generator is of the magnet amplifier type. In this type, the generator output voltage is taken out through a potential transformer, and compared with standard voltage of the output voltage of the constant voltage device utilizing the magnetic amplifier: its minute difference is amplified in two stages by a magnetic amplifier and supplied to the magnetic field of the main exciter. For example, if the generator output voltage is too high, the balance of the voltage between this and the standard voltage will effect the first stage of the magnetic amplifier and consequently the second stage amplifier controlled by this produces the output, current to the exciter's backward coil, then the exciter's output is reduced. If the generator output voltage is too low it produces the boostward output current to the exciter.

Exciters using this type of automatic voltage regulator are of a special type, the sub-exciter being omitted and a self exciting "Isthmus Pole" attached, besides a self exciting coil there are coils superposing additional separate excitation of boost and back.

The exciter with Isthmus pole can stably generate a rated output voltage by self excitation alone. Only when the generator voltage has changed from its standard value it is controlled by receiving to the magnetic amplifier's output current of the back or boost coil.

Besides the automatic voltage regulator, consideration has been given to make automatic current limitter and power factor regulator in this power station. The automatic voltage regulator of this system has the following merit ;—

1. It is a completely static type, the moving parts are absent making it durable and not requiring nothing, maintenance.
2. Being of a zero type control system, its degree of stability is high, and control speed is also high.
3. High accuracy due to a high degree of amplification factor.
4. Extremely simple operation.
5. Sub-exciter not required.
6. Power factor control possible.

Results of Generator Tests

This generator has adopted a new construction possessing varied characteristics as mentioned above and its completion was drawing attention of the circles. It was completed early in October 1955. and post plant as the factory tests were carried out with satesfactory results, test results is given as information to those interested in. In spite of an extremely economical design to reduce the weight, the limit of temperature rise and efficiency were above the guaranteed valve, which demonstrates the superiority of their novel design.

The no load saturation characteristic curve and the short circuit characteristic are as shown below. The short circuit ratio is 1.15, voltage regulation is 20.9% at p.f. 83%.

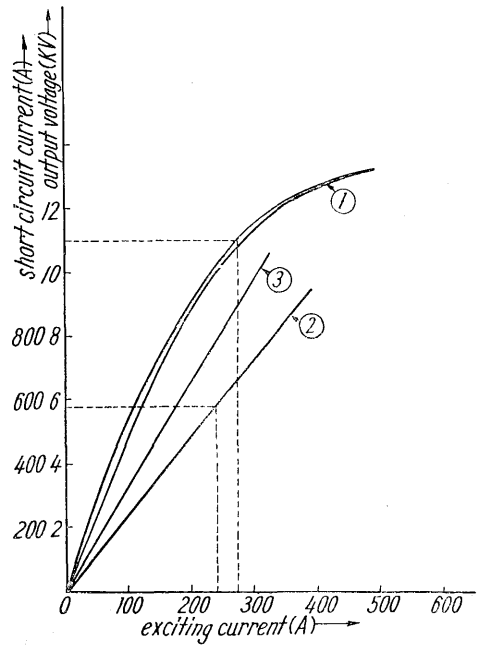

Fig. 14. Characteristic curve of 11,000 kVA 1,000 V 578 A 60 c generator

The efficiency was so good that it is 0.2% above guaranteed valve.

The results of no load and short circuit temperature rise are as shown is the table 1, and are highly above JEC standards.

Table 1. Temperature rise

Temperature rise	Stator winding		Rotor winding	
	Thermometer method	Resistance method	Thermometer method	Resistance method
No load	19.5 °C	1 6 °C	1 5 °C	1 8 °C
Short circuit	1 9 °C	3 6 °C	1 2 °C	1 4 °C

CONCLUSION

The above is a brief description of the Kaplan turbine and directly connected generator in Jintsugawa No. 3 power station. This turbine and generator are record products for low head large water quantity Kaplan Turbine, and its latest construction has been drawing attention of all concerned in the electric power industry in Japan. Commercial operations was started in the middle of December, having completed the installation work in such a short time of 80 days.

Introduction of Products

MAGNETIC MATERIALS WITH RECTANGULAR HYSTERESIS LOOP

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I. INTRODUCTION

Attention was focused on the magnetic materials with rectangular hysteresis loop after a success by Koppelman of the Siemens Co., in using it for a contact converter in 1941. Since then it has come into use for magnetic amplifiers etc., and the like with considerable expansion of its field of application. After the end of the world war II, inspired by the development in Germany of the application of magnetic materials with rectangular hysteresis loop, researches more undertaken in U.S.A., Great Britain and other countries, resulting in the production of Deltamax, HCR etc. with similar charactristics to Permenor Z 5,000 Z of schmetz Vacuumschmelze A. G.

Research in this field was taken up by many investigators in Japan, too. Our Company made a plan of producing contact converter in 1950 and simultaneously launched research work on magnetic materials with rectangular hysteresis loop. In August 1951 a trial core was completed, for the first time being successful in the industrial production in Japan. Thenceforth our Company has been self-supporting iron cores, to be used for our contact converter and magnetic amplifier and turning out products of superior quality.

Those magnetic materials utilizing the rectangularity of hysteresis loop are, as is well known, oriented 50% iron nickel alloy, Permalloy and Perminver annealed in a magnetic field and oriented silicon steel, but oriented 50% iron nickel alloy is most extensively used because of its good rectangularity and high saturation induction.

Our Company has conducted research on various magnetic materials and put them to practical use, but oriented 50% iron nickel alloy is predominating among them. The following is a brief account for it.

II. MANUFACTURING

Oriented 50% iron nickel alloy is that produced by combining the processes of severe cold rolling and heat treatment at high temperature, and having