MAIN ELECTRIC APPARATUS DELIVERED TO THE HOKURIKU ELECTRIC POWER CO., WADAGAWA NO. 2 POWER STATION

By

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I. INTRODUCTION

The Wadagawa No. 2 Power Station constitutes a main and essential part of the Joganji-Arimine Power Resources Development Project (J.A.P.) with a magnificent total output of some 261,400 kW which is now put under progress by the Hokuriku Electric Power Co. This Power Station, with its output of 122,000 kW, is to be among those of the largest output in Japan. In itself, the Joganji Riverhead zone has a big rainfall with annual total of 3,300 mm, a half of which is made from snowfall in winter season. These snowdrifts on the mountain area begin thawing at every spring, almost all of which flow down as the melted snow towards the Japan Sea by June. The J.A.P. has therefore been set about with the purpose of reservoiring this melted snow in a dam in order to use it effectively for various aims during the drought season.

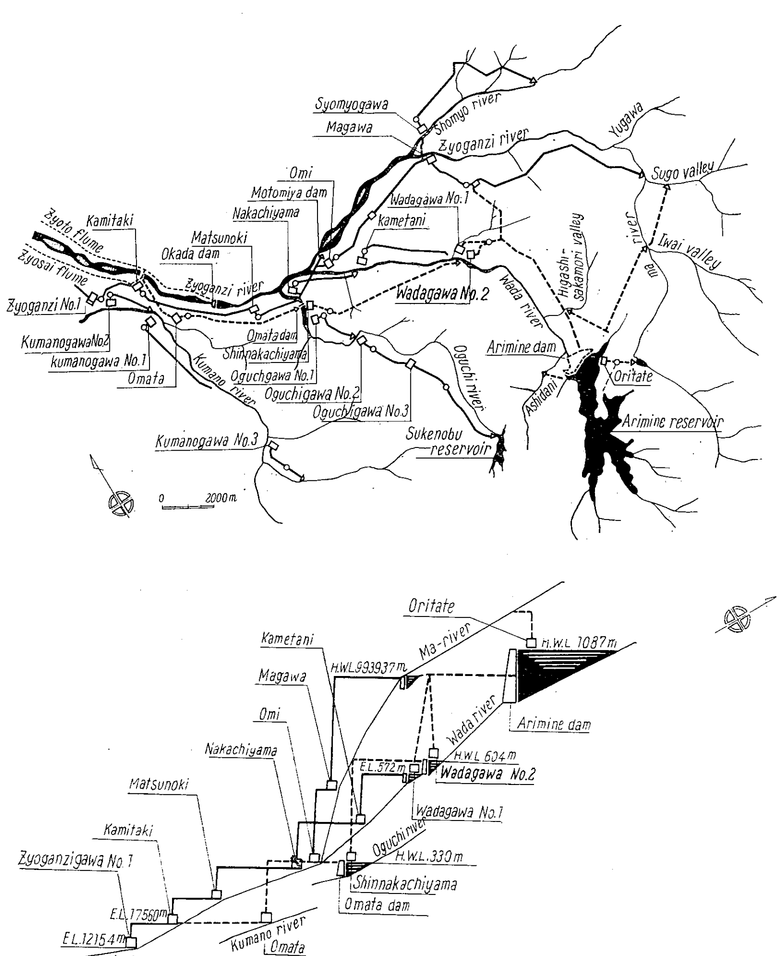

Fig. 1. Drawing of the J.A.P.

As illustrated by Fig. 1, the Wadagawa No. 2 Power Station is of a dam type construction, being planned to be established at the extremely upper waters of the J.A.P.; of which dam is a gravity type concrete dam with the height of 140 m and the reservoiring volume of 217,730,000 m^3. The storage of water at this dam site is to be once utilized altogether up to the drought season of July and August, and then those heavy rainfalls of a rainy season of September are to be again collected at this dam in order to keep the flowing condition of the downstreams satisfactory and to use these reservoired waters effectively during the winter drought season.

As the Power Station is established on the very narrow valley, our Company has decided to adopt the vertical Pelton turbine with the special attention being paid to those points of making the speed of turbine higher and making the area of their installation narrower. Among a great many vertical Pelton turbines, this is of course not only the larg-

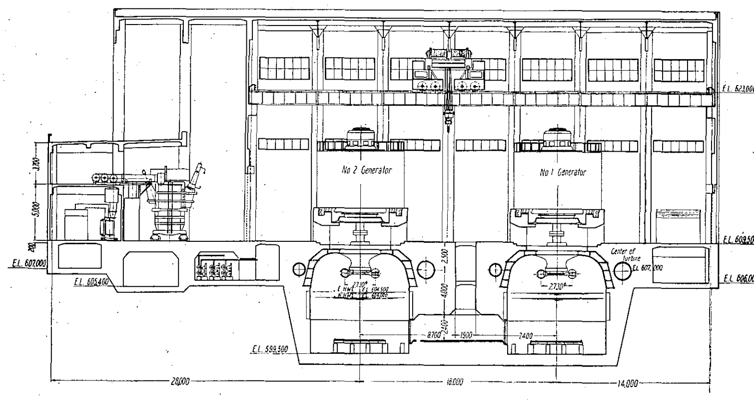

Fig. 2. Cross section of Power Station building

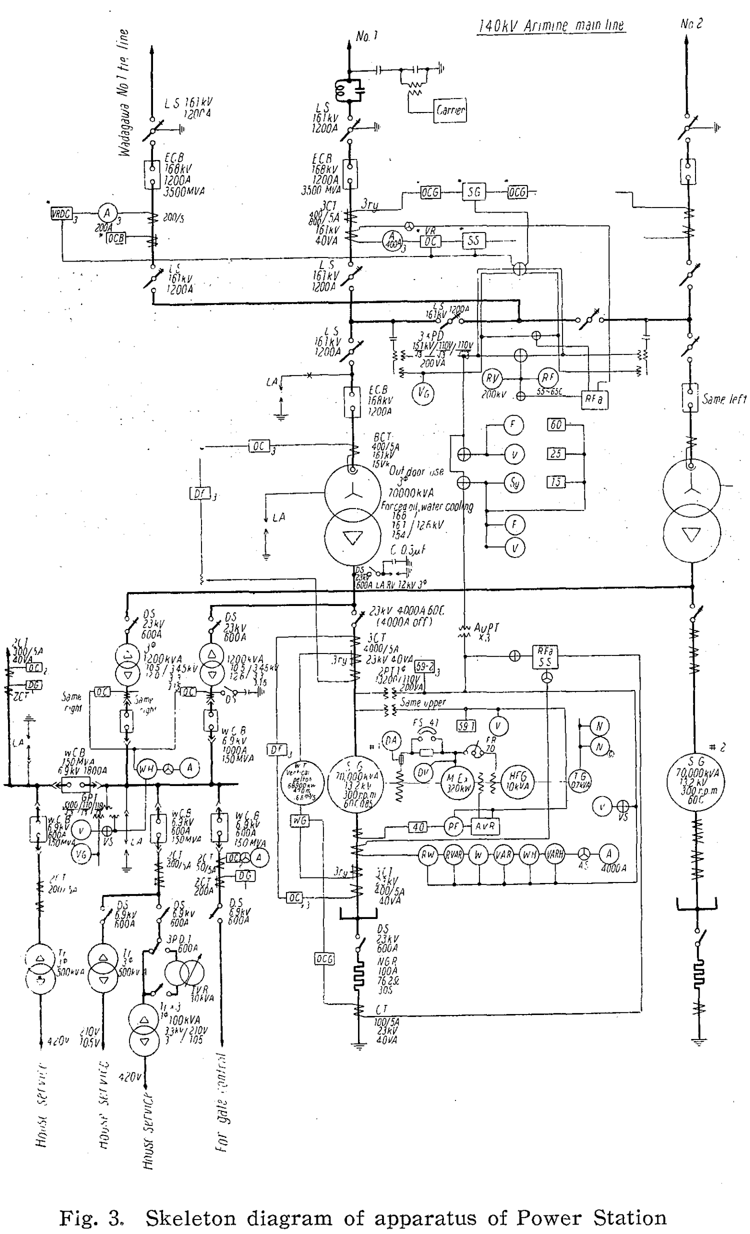

Fig. 3. Skeleton diagram of apparatus of Power Station

est one in the Orient but also with the outstanding big output throughout the world.

The main transformer is to be located inside the building of the Power Station, taking into account a heavy snowfall during the winter; while the circuit breaker, the disconnecting switch and so forth are to be installed on the roof of the Power Station building, because proper building site for the Power Station could not be found at any other place from the view point of its geographical features.

All readers may refer to the skeleton diagram illustrated by Fig. 3 for the composition of various equipments and apparatus of the Power Station. The so-called unit system has been applied for all main circuits, and the electric power generated by the two generators is to be boosted with each main transformer up to 154 kW, before it is to be transmitted through the two parallel lines.

As this power station is the most important among those stations established under the J.A.P. abovementioned, the special consideration has been paid to secure the driving power required to this station itself, so that the necessary driving power is to be supplied through the two 1,200 kVA transformers for the power generation which are put in branch circuits from the main circuit; further precautious consideration has been paid for emergency case, so that the required driving power for this station might be obtained from the adjacent power station at a rate of 3 kV; and any one of these driving powers of three resources are interlocked among each other to prevent them from mutual interference at receiving time.

As for the very important 400 V circuit among the low voltage ones for driving powers, in which the oil pump and the cooling water feed pump are to be connected, we have equipped an induction regulator with the automatic voltage regulating device in order to provide these motors with a constant voltage of 400 V to keep a positive operation.

As known quite well, our Company has long since tied up in the technical aspects with both the J.M. Voith Company of West Germany (in the field of water turbine) and the S.S.W. Company (in the field of such electric apparatus as generator, transformer and so forth), respectively ; so that we have completed such apparatus as of ultra-modern types to deliver them to this Power Station, by introducing extensively these highly qualified technics of these two Companies and by concentrating unique technics of our Company onto these apparatus.

Now, the brief explanation will be given in the following lines on the construction and features of these apparatus.

II. TURBINE

1. Ratings

A summarized specification of the turbine is as follows :

Number of turbine :	2 turbines	
Type :	4-nozzle vertical pelton turbine	
Effective head :	Maximum	470 m
	Normal	430 m
	Minimum	380 m
Maximum volume of water utilized :		16.6 m^3/s
Maximum output :		68,900 kW
Speed :		300 rpm
Specific speed (n_s) :		19.6 (m–kW)

2. Application of the vertical Pelton turbine

The effective head of this Power Station stands 470 m high at most, so that it may be easily understood that the Pelton turbine is to be applied within this range of the head. However, careful model test and consideration have been made by our staff prior to the final decision of applying the vertical type Pelton turbine.

Generally speaking, the Pelton turbine of the latest type is said to display the highest efficiency within the range of its specific speed per jet $\left(n_s = n\frac{P^{\frac{1}{2}}}{H^{\frac{5}{4}}}\right)$ of 18∼20 (m–kW). It is preferable for us to set the speed of the turbine as high as possible within the above-mentioned range of n_s and, at the same time, within such range as imposing no excessive load on the rotor of the generator from standpoint of its strength. If we increase the number of nozzle, as above-mentioned, and lessen such output (p) as being borne with a single nozzle ; we can increase the speed of the turbine, even with the same value of n_s, in proportion to a square root of the number of its nozzle.

As for the horizontal type Pelton turbine, the only two nozzles have at most been able to be provided for each runner from standpoint of its construction. As for the vertical type Pelton turbine, the number of nozzle could be increased without difficulty, so that the latter might have the following advantageous point :

1) Its installation area is narrower.
2) The number of nozzle may be freely decided at any of two, three, four, five, or six ; so that both the speed of the turbine and the number of its nozzle can be set to secure both the possibly highest speed within the limitation of the design of the generator and such value of n_s as giving the highest efficiency to the turbine.
3) The horizontal shaft double nozzle double overhang type turbine, is to require two runners and two main valves which costs the most of all turbines. In comparison with this type, the vertical shaft type ones require only one runner and one main valve, so that the latter is more economical than the former.
4) As the vertical shaft type turbine needs only one runner, the windage loss of its runner part becomes a half of that of the horizontal shaft type one. Therefore, the vertical type turbine is of more efficient than the horizontal type.

Having been mentioned in the foregoing lines, the vertical shaft type turbine has the prominently advantageous points than the horizontal shaft type ones. However, we must take note of the following problems from viewpoint of its design :

1) To decide the form of the housing so that the water may drop along through the inner surface of the housing wall without crashing against the runner or the jet, when the water discharged from the runner is to drop down after crashing towards the top surface of the housing.
2) To decided both the distance between the runner and the tail race level, and the depth of the drainage pit with properness, so that the spray of water dropped into the drainage pit may not crash against the runner again.

Our Company has been studying over these problems long since and has completed lots of examples as shown in Table 1 with excellent results of their operation.

Notwithstanding these rich experiences, we had carried out a series of the further attentive experiments for the purpose of completion of the turbine for this Power Station and attained to the satisfactory results prior to our starting of its manufacture.

Table 1. Actual records of the vertical shaft type Pelton turbine

Power station	Countries	No. of generator	Head (m)	Quantity of water (m^3/s)	Output (kW)	No. of revolution (rpm)	No. of nozzle	Specific speed (m-kW)	Maker	Delivered year
Kemano	Canada	3	760	15.6	106,000	327	4	13.4	D. E. A.C. V.E.W.	1954
Kurobegawa IV	Japan	3	580	18.5	95,000	-	-	-		-
		-	540	17.8	85,900	360	6	16.6	**Voith**	1959
		-	500	17.2	76,100	-	-	-	**(Fuji)**	-
Roseland	France	6	1,200	-	86,000	428	2	12.3	Hitachi N.	1957
Wadagawa II	Japan	2	470	16.6	68,900	-	-	-		-
		-	430	16.1	61,400	300	4	19.6	**Fuji**	1959
		-	380	16.1	53,200	-	-	-		-
Pedras	Brazil	4	670	-	65,600	450	4	16.5	D.E.	1954
Koyna	India	4	475	-	65,000	300	4	17.2	N.	1956
Wohleach Lake	Canada	1	573	12.1	61,200	360	6	13.0	B.L.	1950
Bridge River II	British Columbia	2	340	-	60,000	300	5	22.3	N.	1958
Bridge River	Canada	3	340	15.5	46,300	300	6	18.1	B.L.	1949
Lünersee	Austria	5	970	5.42	46,200	750	4	15.5	Voith	1957
		-	900	5.23	41,500	-	-	-	E. W.	-
Guadalape	Columbia	2	535	-	45,000	450	4	18.5	N.	1958
Innerkirchen	Switzerland	5	670	7.6	43,000	-	-	-		-
		-	635	7.4	39,700	428	2	19.0	E. W.	1942
		-	600	7.2	36,400	-	-	-		-
Bear River	U. S. A.	1	597	5.79	29,800	400	3	13.2	B.L.	1950
San Bartoro	Mexico	-	376	8.8	29,000	428.6	6	18.0	A.C.	1955
Han. Deck II	Switzerland	2	430	7.55	29,000	300	2	18.5	E. W.	1950
Shin-Otagiri	Japan	1	317	6.1	16,700	$^{450}/_{375}$	4	-	Toshiba	1958
Tochio	Japan	1	292	6.43	16,000	$^{400}/_{333}$	4	$^{21.0}/_{17.5}$	**Fuji**	1957
Motosu	Japan	1	450.3	3.2	12,500	720	4	19.2	**Fuji**	1956
Shirane	Japan	1	204	6.66	12,000	300	4	21.3	Hitachi	1953
Nakazaki	Japan	1	253	5.0	10,800	$^{400}/_{333}$	4	$^{20.6}/_{17.1}$	**Fuji**	1957
Ishii	Japan	1	161	2.0	2,750	450	4	20.5	Mitsu-bishi	1954

(N. B.) D. E. Dominion Engineering Co., Ltd.
A. C. Allis-Chalmers Mfg. Co.
V.E.W. Vancouve Engineering Works
N. Etablissments Neyrpic
B. L; Baldwin Lima Hamilton
Voith; J. M. Voith
E. W.; Escher Wyss.

3. Decision of the number of nozzle

In regard to the vertical shaft type Pelton turbine, as described above, the decision of the nozzle has very important meaning. For this reason, we have carried out the earnest examinations for the turbine of this Power Station, as to whether 4-nozzle type or 6-nozzle type is to be employed. Speaking of it in detail, we may decide the speed of the turbine at 300 rpm in case of the four nozzles and at 360 rpm in case of the six nozzles, respectively, under the equal value of n_s (19.6 m-kW) for both cases; and the six nozzles appear to be apparently preferable. In spite of this favourable point, there is some fear of loss of hydraulic efficiency by the interference between adjacent jets at the minimum head, because the variation in the head of this Power Station is comparatively larger with the greatest difference of 90 m between the maximum head and the minimum head.

Fixing our eyes upon a particular bucket, this bucket turns by the degrees of the jet angle after it receives any jet and before it comes to the next jet. If the bucket could not discharge all waters given by the preceding jet within the period of time when the bucket turns as large as the degrees of this angle, the next jet comes up to the bucket and the waters of the two jets crash with each other in the bucket to bring out the result of the confused lines of the flow and to cause the decline in the efficiency.

As it is well known that the flow speed of the jet varies in proportion to a square root of the head, the flow speed of the jet comes down with the drop of the head. As a result of it, the water in the bucket can not entirely be discharged within the period of time when the runner turns by the degrees of the jet angle, so that the interference between the adjacent jets may occur.

The jet angles of the multi-nozzle type turbine are shown as follows:

Number of Nozzle	Degree of Angle
2	180°
3	120°
4	90°
5	72°
6	60°

As clearly understood by the above-mentioned table, the jet angle of the 4-nozzle type turbine is larger by 50% than that of the 6-nozzle type, so that the time length of discharging the water in the bucket may be prolonged to that extent and that the interference may not occur very easily even with the fall of the head.

Even in case of the 6-nozzle type turbine, the time length of revolution of the runner as large as the jet angle may be prolonged with decline of the speed of the turbine, so that we may avoid the interference of the jet. In spite of it, the value of n_s becomes lower than that of the range which giving the highest efficiency to the turbine. So that we can not expect any high efficiency altogether even with no interference, farther its mechanism may become more complicated than that of the 4-nozzle type turbine. By that reason the 6-nozzle type turbine is more uneconomical than that of the 4-nozzle type.

As an example showing concretely the interference of these jets, the result of a model test of the 6-nozzle type pelton turbine which has been carried out by our Company is to be given by Fig. 4.

Various efficiencies of the turbine are shown in this figure corresponding to the fluctuation of the water head both as to the case where the six nozzles are used altogether and as to the other

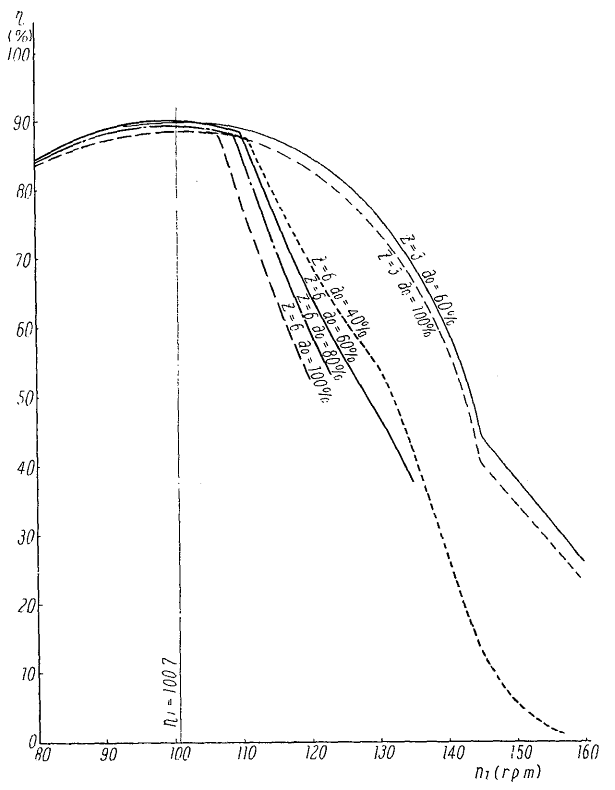

Fig. 4. Model efficiency of the 6-nozzle type Pelton turbine

case where one nozzle for every two is used in their due turn (with each jet angle of 120°) with the rest of nozzles closed, and the different values of $n_1 \left(=\frac{n}{\sqrt{H}}\right)$ in inverse proportion to the square root of the head values are marked on the axis of abscissa in this figure.

As may be understood by the result of this measurement, the interference of jets occurs and the efficiency falls abruptly in case of the six nozzles, when the value of n_1 becomes larger (in other words, the value of the head becomes smaller); while no interference of the jets is seen in case of the alternate three nozzles because the jet angle is larger than that of the six nozzles. As far as the turbine for this Power Station was concerned, positive and sufficient experiments of the model test were carried out as to the two kinds of the model, namely with the six nozzles and the four nozzles, in order to make observation about interference of the jets with use of the stroboscope. As a result of the experiments, it has been made clear that the turbine of applied six nozzles can not accept any rise of its speed with interference of jets at the time of the minimum head, and it has been finally decided to employ the turbine of 4-nozzle type as an applicable one for this Power Station. In addition to the jet angle as above-mentioned, both the number and form of the bucket might be taken into account in order to prevent the probable interference of the jets. We have found the turbine with the bucket of 19 runners to be the most excellent, after various experiments of this turbine as to these issues of the problem.

4. Construction of the turbine proper

Almost all parts of the turbine proper are made of the welded steel plate, just as shown in the cross section of Fig. 5, in order to lessen its weight. The curved surface within the housing to be touched to the flow of water requires the closest application in the course of completion of the vertical type Pelton turbine. Therefore, the most

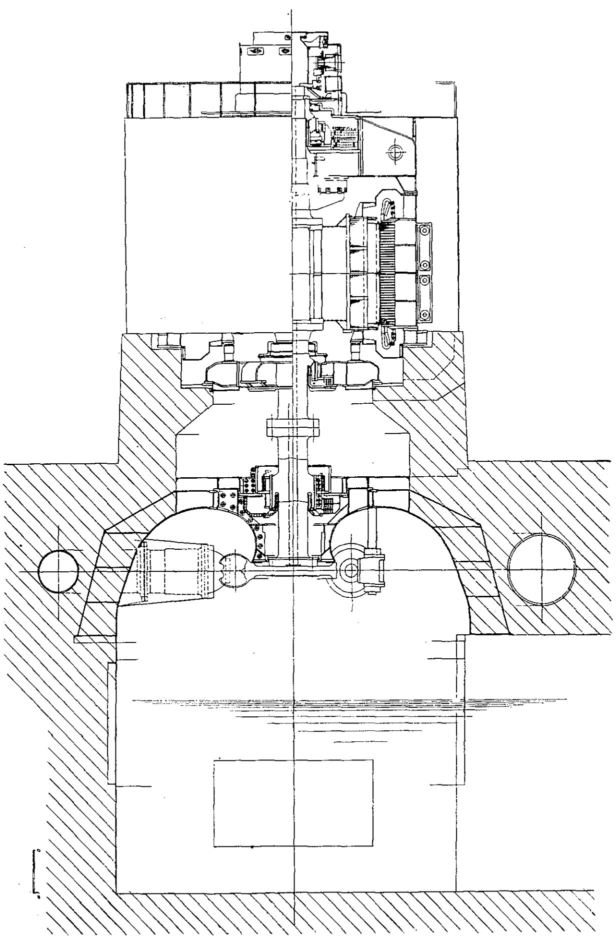

Fig. 5. Cross section of the turbine generator

adequate and proper curve surface has been applied for the turbine with the model test to pay such special consideration that the water discharged from the bucket may not pour into either runner or jet again. The housing is made of the double walls with sufficient strength to stand both the load to be imposed on the casing and the repulsion of jet by the water pressure. In case of the installation at the construction site, the housing shall be embeded in the concrete and, at the same time, the space between the double walls shall be filled up with the concrete cement. By doing so, the strength of the housing can be increased to stand the total load of the turbine generator. Furthermore, the installation work can be easily carried out at the site of construction, as a complete preparatory assembling may be possible at the factory of manufacture by mounting the nozzle and casing or other fittings onto the doublewall structure applied.

Except for the nozzle pipe, the casing is made of the welded steel sheet. As a result of the hydraulic test at the 80 kg/cm^2 pressure, these parts to be imposed upon with the water pressure were found to be with no abnormality even under the assembled state of condition.

Because the runner turns with a high specific speed and the strength of the bucket root comes into question, the method of clamping the bucket onto the runner disk with the bolts and nuts has been rejected but this bucket and runner have been made of a 13% *Ni-Cr* steel by the mono-casting method. The number of bucket runner, the size of the pitch circle, and the maximum outer diameter are made 19, 2,780 mmϕ, and 3,530 mmϕ, respectively.

After the installation of the turbine, the replacement of the runner can be carried out quite simply by putting the rope through the hole of 200 mmϕ penetrating the shaft of turbine and generator and by hanging them with the crane.

Fig. 7 shows the turbine proper in the course of its preparatory assembling at the factory.

The disk jig with the same pitch circle was used in order that the nozzle points with preciseness

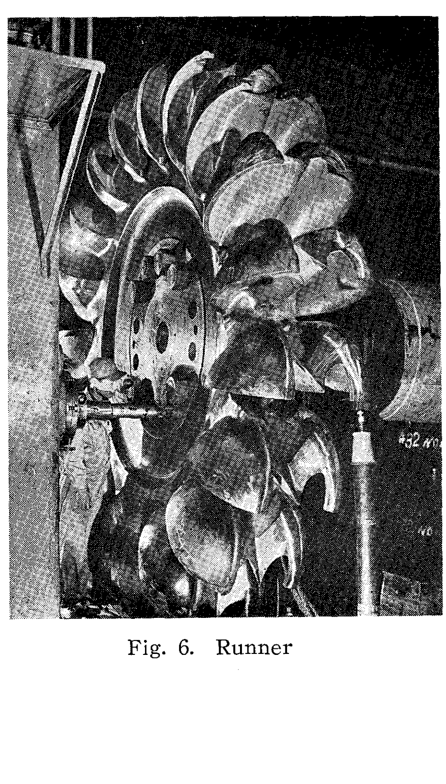

Fig. 6. Runner

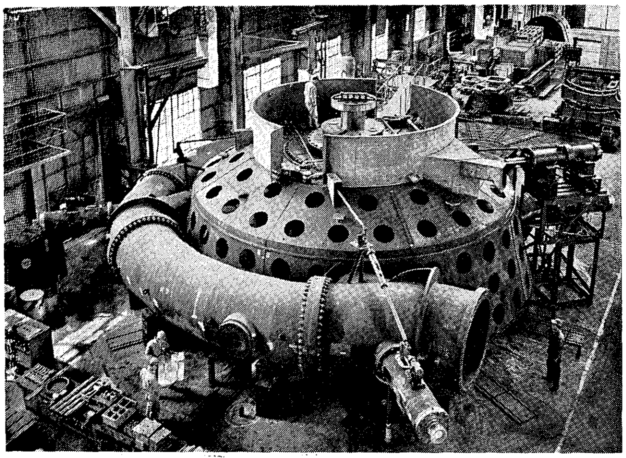

Fig. 7. Turbine proper

into the direction of the tangent of the runner pitch circle and it is located on the same level with the runner center. The delivery of the turbine proper was made after the knock pin was provided for the machine so as to carry out the installation work at the site of construction in an easy way.

5. Main valve

The sphere valve is applied for the main valve of the turbine.

As illustrated in Fig. 8, this type of the sphere valve has such a mechanism that a spherical valve body touches to the valve casing on a circle at its closing time, that the hydraulic pressure in the pressing pipe side is automatically to press the choking plate onto the valve seat to keep it water-tight satisfactorily when it comes to the entirely closed position, and that the spherical valve body turns by 90° to open a cylindrical water path, when it is opened, without any agitation in the flow of water.

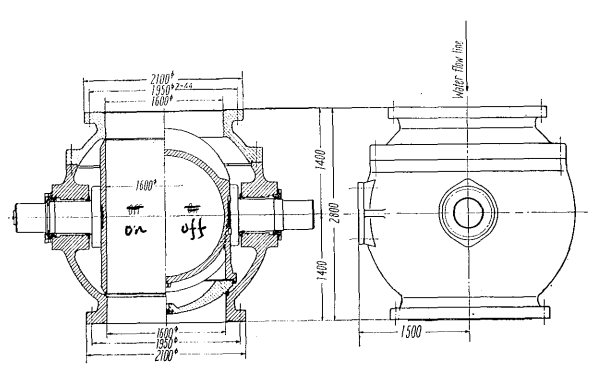

Fig. 8. Cross section of main valve

In comparison with other types of the valves, the most favourable points of the sphere valve will be made such that it will not require so large space as the sluice valve for its fixing, that the water-tight state may be kept more completely than that of any other valves, and that any head loss, as seen in the butterfly valve, will not result at the valve-opening time. The operation of this valve is to be made by a high oil pressure of 60 kg/~~m^2~~ cm^2 in order to make smaller the servo-motor, etc. Separate from that for the governor, the oil pressure device is provided for every two turbines to apply for the normal, the primary reserve, and the secondary reserve purposes, respectively, with the motor driving screw pump of 150 l / m and 3,500 rpm capacity. Because it is to be used only for the main valve and there is little consumption of oil for it while the turbine is put in its operation, the unloader is not be provided but the pressure switch is used for starting and stopping this pump.

6. Electric governor

The electric type governor of particularily high sensibility is employed for the apparatus of this Power Station, because the Station plays very important role to keep a frequency precisely constant through the all power systems connected to the Station. Our Company has already completed many excellent electric governors together with the necessary equipments for the power station, all of which are now put on operation with excellent records of working. They are not provided with the electronic tube because of difficulty in its maintenance, but with the magnetic amplifier at all.

The detection of the turbine speed is made by measuring the frequency, generated by the permanent magnet type sine-wave generator directly connected to the turbine shaft, with the highly sensible and accurate frequency-bridge to obtain such current as in proportion to the deviation value for the setting reference frequency and by amplifying this current at the following amplification device. Particularily, the frequency-bridge is the most important and indispensable part of this governor, so that the double T type RC bridge consisting of the resistor and condenser is applied for this part to avoid any effect by change of temperature or humidity. Therefore, the error of setting the frequency for the temperature fluctuation of ± 10°C is limited within only $\pm 0.04\%$. The output current from the detection bridge is converted by the special magnetic amplifier of the convertor part to the direct current which changes its polerity either to positive or to negative, corresponding to the leading or lagging from the reference value of the turbine speed, and then impressed upon the following magnetic amplifier.

The output of magnetic amplifier is impressed upon the magnet solenoid providing the permanent magnet for the primary pressure distribution valve. This is of an oil pressure amplification type and its magnet solenoid drives only the pilot valve of a small weight to minimize its time lag.

The float valve is turned by the small size motor to move up-and-downward along with the functioning of the pilot valve, so that the friction between the pilot valve and the float valve is limited within a very small extent and that they can work in a very sensible way. As for the returning device for the various controlling valves, the Selsyn type electro-magnetic convertor is applied; which has such a mechanical system as turning the rotor in proportion to the movement of the auxiliary servo-motor, as making the straight line part of the voltage in proportion to the sine value of the turning angle in the stator side correspond to the entire length of the servo-motor stroke, and as getting this voltage to make a negative-feedback into the preceding magnetic amplifier. Therefore, this type of convertor may be said to be of excellent reliability and of long durability.

Fig. 9 illustrates an example of an oscillograph of the governor test carried out at the installation site, and by this result of the test, the governor is found to be of an excellent capacity.

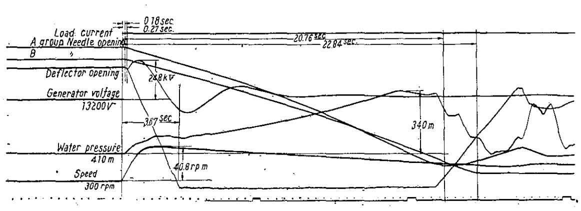

Fig. 9. Oscillograph of the governor test

III. GENERATOR

Having been already described under the preceding paragraph of the turbine, the vertical type Pelton turbine has been applied to increase its speed so that the generator of this Station may be worthy of special mention for a large capacity and a high speed of it. Such a generator as of a large capacity and of a high speed inevitably requires a small diameter and a long core length, so that special consideration must be taken as into the points of cooling and ventilation, of vibration, of insulation system against elongation of the stator coil by thermal expansion and so forth. Our Company has an experience of having completed a vertical type synchronous condenser of 30 MVA and 1,000 rpm capacity, similar to this generator, as one of the vertical type apparatus of a large capacity and a high speed, and has also other excellent records of completing a great many vertical type generators of a large size. Thus, this generator may be said to have been completed by utilizing sufficiently these invaluable experiences and by referring the results of various tests and experiments to a satisfactory extents. The features of this generator, to special mention, consist in the magnetic thrust bearing being provided in order to minimize the thrust bearing loss.

1. Ratings

The ratings of this generator are as follows:

Description:	3-phase AC synchronous generator
Type:	Vertical shaft, revolving field, enclosed air duct circulation type
Cooling system:	Water cooling
Output:	70,000 kVA
Voltage:	13,200 V
Frequency:	60 c/s
Speed:	300 rpm
Power factor:	85% laging

2. Structure

As understood by the preceding Fig. 5, the construction is a so-called ordinary type that the thrust bearing is mounted together with the upper guide bering onto the upper part of the rotor and that the lower guide bearing is fixed to the lower part of the rotor. Above the thrust bearing; the exciter, the high frequency generator for the automatic

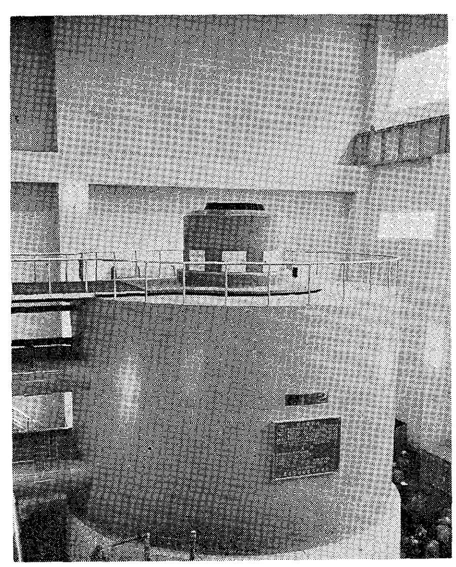

Fig. 10. Appearance of generator

voltage regulator (AVR), and the permanent magnet type generator for the tachometer are directly connected to the same shaft altogether.

The stator frame has an outer diameter of 6 m and a height of 3.1 m, which may be devided in six separate parts due to the limitation of delivery or transportation.

These parts of the frame are made of the steel pipes and steel plate with box construction in a skillful combination, and are of such strong structure with a light weight that the properly bent rims may display a role of the guide which collects the wind to the air cooler efficiently and lessens the ventilating resistance.

The stator core is made of high class silicon steel plate, Class T, which has been stamped out with the slot in a fan-shape prior to eliminating its distortion in the hydrogen annealing furnace and baked with a special varnish on its surface for the purpose of layer insulation.

As shown in Fig. 11, the consideration has been taken to secure a uniform press of the core by putting the oil pressure jack on its circle.

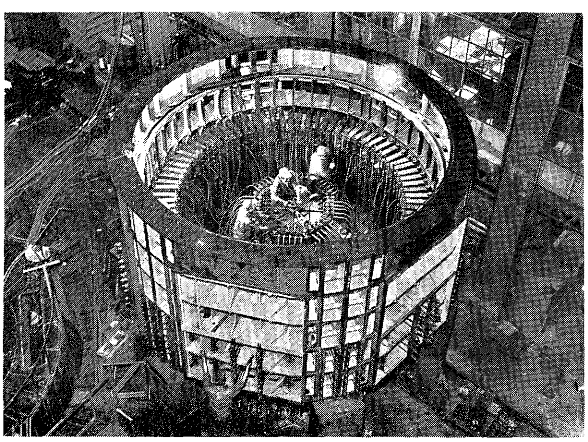

Fig. 11. Press work of the stator core

The stator coil is made by a wave winding, of which conductor is devided in 38 elements and every element of the conductor is insulated with the glass fiber; and employes a so-called "Gitter Stab" system, which completely makes the conductor element transpose in the slot, so as to minimize its stray loss. In such a case as this apparatus with a long coil, special attention must be paid to the difference of elongation by thermal expansion among the copper and insulators, mainly composed of the mica. As for the coil of this generator, a special semi-conductor is fixed to its copper material and the graphite paper, one of the semi-conductors, is wound on the inner surface of the sheath of the insulator, in order that the insulator and its copper part are in contact each other through the semi-conductor.

Even when the copper part becomes longer through the difference in the thermal expansion within the sheath of the insulator, the above-mentioned structure enables the cupper part of the coil to slide in the sheath keeping contact with inner surface of insulator through the semi-conductor, so that there is no fear of causing corona because of an equal potenciality with each other part even when any gap comes to exist in these parts.

In order to confirm satisfactorily the effects of this insulation system, the insulation deterioration test has been carried out to measure those values of tan δ and the corona-pulse with very excellent results. This test was made by impressing repeatedly, upon the sample coil and core of the same size with that of the real materials for a considerably long period of time, such a heat cycle as heating it up to 120°C or the maximum allowable temperature of the B class insulation and cooling it to the normal temperature respectively with impression of the rated voltage.

When the coil was actually made, the strict control of its quality was made by measuring a tan δ characteristic of every one coil. Descrimination of its quality is made with the degree of an inclined angle being composed of the two measured values of tan δ at the points of 13,200 V and 13,200/ $\sqrt{3}$ V.

Fig. 12 is to show an example of this method.

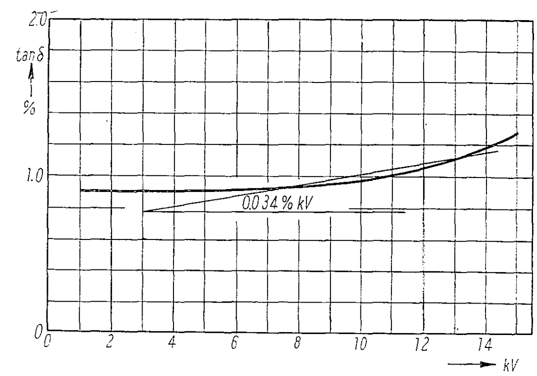

Fig. 12. Characteristic of coil (tan δ/kV curve)

We may speak proudly of the result that all of the actually completed coils have shown the value of tan δ/kV less than 0.1%/kV.

As the customer of this generator requires the rotor to stand against the runaway speed of the turbine upto 565 rpm for 30 consecutive minutes, we have paid special attention to design it to have a sufficient mechanical tolerance or margin not only for the mechanical strength of every part but also for the thermal stress and the bearing temperature. The pole core is made of the 1.6 mm thick *Mn-Si* steel sheet with a high tensile strength, laminated together with the total thickness of 2,300 mm, compressed and formed with the end plate of forged steel made. After the formation of the pole core, a reinforcement plate is welded through the total length of both sides of the core. By doing so, the pole core is united in a strong condition, so that the stress to be imposed upon the yoke fitting part may be balanced throughout the length of the core.

Therefore, the fitting part to the yoke has a sufficient strength even with only one dove tail, in the case of this generator.

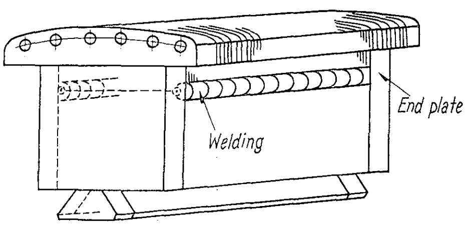

Fig. 13. Pole core

The yoke is made of the 2.3 mm thick steel sheets of a high stress-resisting force, punched out in a shape of the fan, laminated together with three intermittent ventilation holes, and united into a single form by strongly clamping with the reamer bolts.

The mechanical safety factor of this yoke at its runaway speed is more than 1.5 for the yield point of the materials in case of disregarding the friction between these sheets and computing its value by regarding the connection with only the reamer bolts. These yokes of a ring shape are shrunk and fitted to the spiders by induction heating.

The eight spiders are made of thin steel sheet being bent into a shape of boxes and welded with each other, which are also welded to connect with the boss of the welded steel sheet. This boss has the flanges on both ends to be connected with the upper and lower shafts, respectively, so as to display the role of the intermediate shaft.

As this generator has a long core length, so the special attention must be paid to the ventilation of cooling air. As a result of various examination, the axial fan has been employed for this apparatus, of which variable pitch structure was finally decided after the factory test in order to produce sufficient flow of the ventilation and to provide with such a blade angle the most adequate as to minimize its windage loss. It is preferable to locate the fan guide at the possibly nearest point to the coil itself for utilizing the cooling air as effectively as possible, but it has not be able to locate this guide so nearly to the coil as desired, because the old conventional guide of the steel plate made has an increased stray loss by the leakage flux. Taking into account this problem, the glass-polyestel materials have been applied for both upper and lower fan guides of this generator, and, as a result of it, an effective ventilation of cooling air has been secured without any increase of stray loss. This material has the stress-resisting force of 25.7 kg/mm^2, the elastic modulus of 2,400 kg/mm^3, and the thermal expansion coefficient of 19×10^{-6}. When the fan was manufactured, special consideration was taken in the course of its finishing and processing so as to stand sufficiently against any state of condition during its operation.

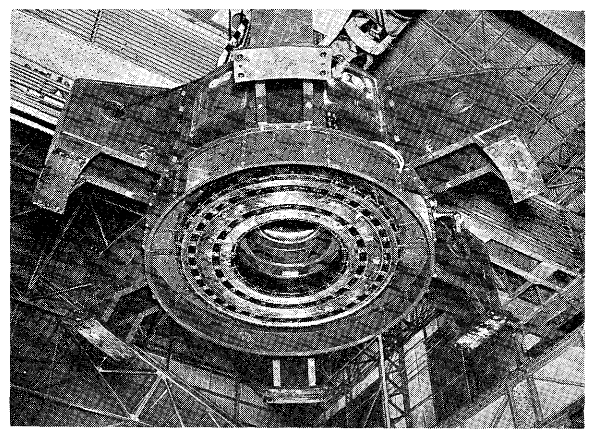

Fig. 14. Magnetic thrust bearing

The most prominent feature of this generator lies in the application of the magnetic thrust bearing. This device consists of the electric magnet fixed to the upper bracket and the attractive plate mounted on the main shaft. In some sense, this device may be of an epoch-making, as it makes the load imposed upon the thrust bearing lessen to a considerable extent by overhanging the revolving rotor with the electromagnet and minimizes the thrust bearing loss. As the electromagnet must attract the revolving attractive plate, it is of such ring shape as completely symmetrical to the center of the shaft in order to prevent any loss of the eddy current.

In order to avoid occurance of any shaft current by interlinking of the leakage flux from the electromagnet together with the rotor, the compensating coil is provided in both the outside and inside of the main magnetic solenoid to eliminate this leakage flux.

The DC source to excite this electromagnet is taken out in the 200 V circuit for the station itself and supplied with rectification of the selenium rectifier. Weight of the generator to be overhung by the electromagnet is made at 202 tons of the total weight of the revolving parts of the generator as much as 207 tons, with consideration of its stability. In other words, the gravity load to be imposed upon the thrust bearing is as little as 5 tons. With this device of overhanging, the thrust bearing loss can be lessened as much as 89 kW. Besides, the employment of the magnetic bearing economizes the power as much as 84.4 kW even with deduction of the power source (23 V, 200 A) of 4.6 kW required for exciting the magnetic bearing. Fig. 15 shows a result of its measurement.

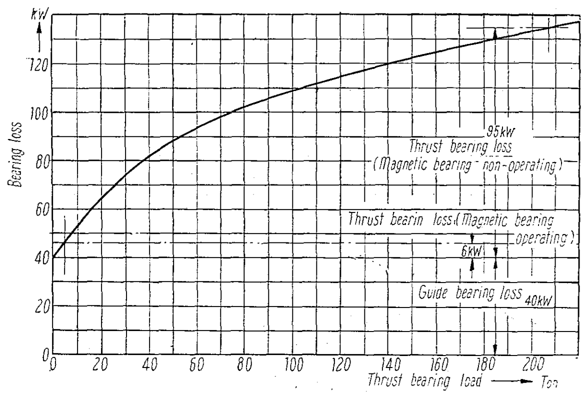

Fig. 15. Curve of bearing loss, measured

This device has been already mounted to the vertical shaft type synchronous condenser of 30 MVA and 1,000 rpm and to each of the vertical shaft type turbine generators of 17 MVA and 333～400 rpm and of 13 MVA 720 rpm and is now put to operation with an excellent record.

The thrust bearing is of the Fuji-mitchell type and is designed to stand satisfactorily against the total weight of the revolving parts of this generator without help of the magnetic bearing and against its runaway speed for 15 consective minutes in accordance with the request of its customer. Every 14 segments of a fan shape are supported by one special disk type spring at the suspending point slightly slid in the direction of its revolution from the segment's center in order that it may be inclined adequately during its operation to form an oil film. The lubrication system is such that the lubricating oil circulates by using the pumping action of the hole in the thrust runner in direction of its radius. This oil may be cooled by the water flowing in the meandering pipe fitted to the thrust tank. The self-circulated type of the cooling system is also applied for the upper and lower guide bearing parts. These bearings are provided with the dial thermometer with a contact warning at the time of bearing temperature rise and the thermal relay of the fuse metal type in order to stop the turbine immediately at the bearing temperature of 75°C. Furthermore, a special device is provided to detect at once and warn the water leakage from the cooling water meandering pipe pouring into the oil.

As for the CO_2 fire extinguisher to cope with the fire of the generator, the smoke detector using the thermostat and the photoelectric tube is employed as a fire detecting device which is designed not to spray the carbon dioxide until the differential relay functions for detection of the inner troubles of the generator and any one of the preceding fire detecting device comes to act for preventing the erroneous function.

A special humidity protection device is provided in order to prevent the coil from condensing of dew-drops through increase of the humidity in the air duct at the time of stopping the generator. This device is to lead the air in the air duct into the cooler using the freon gas, to get rid of humidity by cooling the air within this cooler and condensing the water vapour in the air, and then to feed again into the duct such air as being heated and dryed. This device is quite different, in the sense of positively taking away humidity, from such an old conventional space heater as lowering only the relative humidity of the air by heating it. Thus, we have a firm belief in this device to be of excellent effects, if it is mounted to such a generator as to be installed in the high humidity district.

As for the automatic voltage regulator (A.V.R.), the magnetic amplifier type is employed. The exciter is a dynamo of a self-excited type with the Ithmus Pole and does not provide any sub-exciter. This exciter provides not only the self-excited field coil but also the separate controlled field coil of both forward and reverse directions being controlled by the magnetic amplifier. In ordinary case, this produces the rated voltage only with the self-excited field coil; while, in such a case as of the generator voltage being deviated from the setting range, it immediately supply the positive or negative controlled field coil with the controlling current from the automatic voltage regulator in order to keep the generator voltage constant. Thus, this device is of quick response and has such a structure of entirely static type as having no movable part, so that it may be maintained with quite easiness.

In order to get the large gain of the magnetic amplifier without the sacrifice of its time constant, a high frequency voltage of 400 c/s is supplied from the high frequency generator, directly connected to the main shaft, for the power source of the magnetic amplifier.

IV. TRANSFORMER

The specification of the two main transformers applied for this Power Station is as follows:

Rated output: 70,000 kVA
Rated voltage: 12.6/154–161–168 kV
Frequency: 60 c/s
Connection: delta/star
Cooling system: forced oil, water cooling system

As for the coil of this transformer, the cylindrical coil is employed with consideration of completely holding back the inner potential oscillation in case of invasion of surge. The structure of this coil, just as shown in Fig. 16, is made such that the cylindrically wound coil is arranged in a concentric form and that the shielding plate compensating the earth capacitance is provided in the outer high tension terminal side.

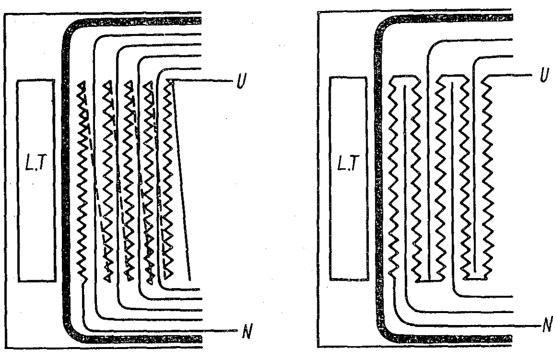

Fig. 16. Illustration of cylindrical coil

The connection among cylinders with one another is made in such a way as connecting the lower end of an outer coil with the upper end of the next or adjacent coil (N form connection). In comparison with the U form connection system of connecting every adjacent coil at each upper end or at each lower end, the voltage imposed upon the layer in the N form case is only a half of that of the U form and it is uniformed through the entire length of the cylinder. Thus, the layer insulation is sufficient only with a half of that of the U form connection. Besides, the cylindrical coil has a comparatively large corresponding area between each layer and a large series layer capacity, so that it may have a high reliability of insulation along with the effects of the shielding plate by retaining completely the inner potential oscillation in case of invading surge.

Fig. 17 shows the oscillograph representing the potential of the taps which is provided between the terminal side and the neutral side in order to measure the distribution of potential inside the coil

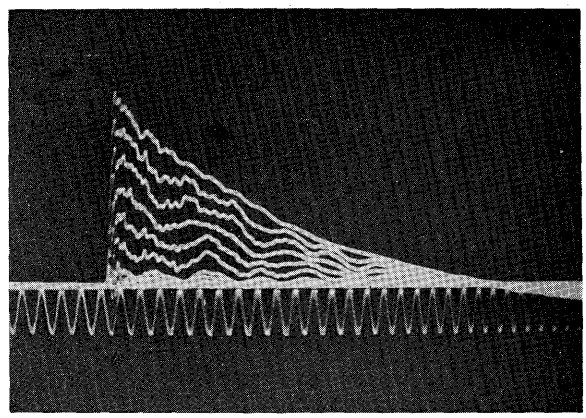
Fig. 17. Oscillograph of the inner potential oscillation

when the impulse is impressed in the high pressure side. According to this oscillograph, the potential of each tap be completely in proportion to the winding number. As clearly understood by this fact, the potential in the neutral side does not rise even when the surge invades, so that it may be possible to apply in safety the graded insulation system and to make its manufacturing cost economize. Our Company has made the neutral insulation fall down to the 100 kV level.

As the cooling oil flows from the bottom to the top of the oil duct which is provided in a vertical direction among the cylinder layers, the head loss of this oil is much smaller and the required output of the oil feed pump is sufficient with much smaller than those of the disk coil where the oil flows in a zigzag way among the coils.

The T–93 class material is applied for the core and the baked carite is employed for the layer insulation.

The tank is devided in three parts, namely, the tank bed, lower cover and upper cover, in accordance with the limitation of its transportation, applying the system of welding these parts altogether after their assembling at the installation site. As the size and weight of transporting various apparatus to the Power Station is limited within a

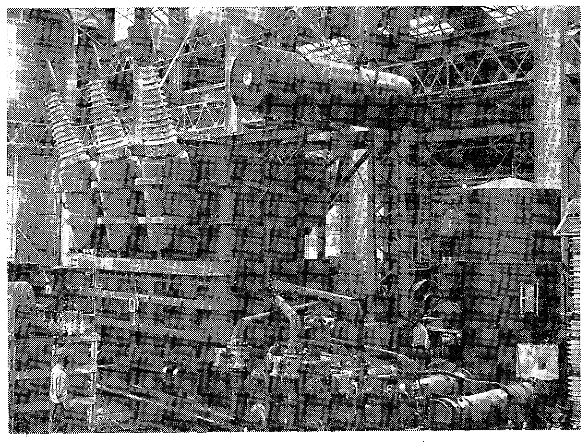
Fig. 18. Appearance of transformer

comparatively small quantity; the tank, coil and core parts of this transformer are separately transported to the installation site where they are to be assembled up to a complete set of the transformer.

The cooling device has every six coolers of water cooling type for each transformer, feeding the oil in the tank into the cooler through the oil feed pump for its cooling. The consideration is taken to each unit cooler, so that any number or set of coolers may be put to operation in accordance with the output of the transformer.

V. SWITCHBOARD AND SWITCHGEAR

Fig. 19 shows the inside view of the switchboard room. The required meters are mounted on the upper part of the vertical surface of the main switchboard. On the other hand, all of the controlling switches are fitted on its inclined surface. Thus, the starting, stopping and any other control of the turbine generator can be carried out within this switchboard room, without troubles of going into the turbine room.

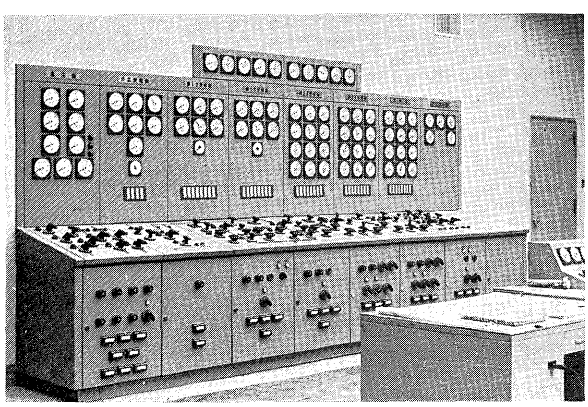

Fig. 19. Appearance of switchboard

All of the protection relays are mounted on the relay board altogether which is installed in the separate room. Furthermore, the contactless type remote supervisory control equipment applying the transistor is provided at this station for the purpose of remote control over the Pelton turbine and two generators installed at the adjacent Wadagawa No. 1 Power Station (13,900 kW).

This system of the control equipment has such prominent features, as of a very long durability of the equipment itself, as of a small size being able to compose the equipment itself with an economical expenditure of its cost, and as of quick response time in comparison with that of the relay type, etc.

The breaker in the 154 kV side is the modernized type of our expansion circuit breakers (E.C.B.), with the rapturing capacity of 3,500 MVA.

The breaker in the 13.2 kV side has a small rapturing capacity of cutting off the rated current of the generator up to 4,000 A, and the accidental breaking may be carried out only by the expansion type circuit breaker in the 154 kV side. Thus the smaller breaker is used only for synchronizing the generator to the transmission system. As this breaker has not large rapturing capacity, so it has been completed only with the small sum of its cost in spite of using for such a large current as 4,000A.

The water circuit breaker is employed for the 3 kV circuit within the Station in order to prevent the danger of fire caused by the ignition to oil. Also, all apparatus for the 3 kV circuit are skillfully united to be put in a cubicle of the steel plate made in good order.

All preceding circuit breakers are operated by the compressed air to be fed by a common compressed air generating device.