30,000 kVA HYDROGEN-COOLED VERTICAL TYPE SYNCHRONOUS CONDENSER WITH MAGNETIC BEARING

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I. INTRODUCTION

A 30,000 kVA Synchronous Condenser, for which Our company spent 18 months to complete with its excellent technique and careful design, is a hydrogen-cooled vertical type machine for outdoor use, being the world's record as a machine with a magnetic bearing.

Vertical type synchronous condensers, so far, have not been manufactured because of large bearing friction loss compared with horizontal machines (the only record is a 25,000 kVA air-cooled synchronous condenser of 13,200 V 25 c/s 500 r.p.m. 6 poles built by Canadian Westinghouse in 1929). This machine, as a vertical type, is successful in minimizing friction loss of the thrust bearing, and achieved higher efficiency than horizontal machine by suspending the rotor by means of a magnetic bearing.

In Japan, synchronous condensers of this class have been usually operated at a speed of 750 r.p.m. but this unit is built to run at 1000 r.p.m. with 6 poles. It saves the materials and increases the efficiency to a considerable extent. Minimum floor space, easy and quick assembly and disassembly by using the crane may also count as an advantage of this vertical condenser.

This machine is designed to be installed at the Shin Sapporo Substation which is on the receiving end of supper high voltage Tokachi transmission line and connected to the tertially side of the main transformers (built by our Company). It is designed not only for power factor correction and voltage regulation, but also for charging one circuit of about 196 km long up to Nukabira. The charging capacity is 15,800 kVA. An induction type starting motor of 1,900 kW, 30 min. rating is used in consideration of rainy weather and for sharing transformer and line losses. The design and manufacturing of the machine are based on technical data obtained from various experiments. The test run at factory was carried out in last November and the machine has been operating successfully since January at the site.

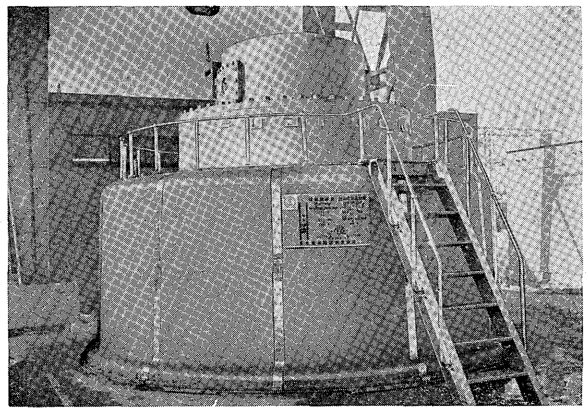

Fig. 1. 30,000 kVA rotary condenser at Shin-Sapporo S. S.

II. PRINCIPAL SPECIFICATION

II-1. Synchronous condenser

Outdoor use, 3 phase, a-c synchronous condenser Vertical, revolving field type with damper winding, hydrogen cooled system

Capacity :	Leading 30,000 kVA (hydrogen pressure 0.035 kg/cm^2 gauge)
	Lagging 20,000 kVA (hydrogen pressure 0.035 kg/cm^2 gauge)
	Leading 34,500 kVA (hydrogen pressure 1 kg/cm^2 gauge)
	Leading 24,000 kVA (in air)
Voltage :	11,000 V
Frequency :	50 c/s
No. of poles :	6
Speed :	1,000 r.p.m.
Power factor :	0 (both leading and lagging)
Rating :	Continuous

II-2. Starting motor

Vertical type induction synchronous motor (directly connected to the synchronous condenser)

1900 kW 30 min. rating (as an induction motor)

500 kW continuous rating (as a synchronous motor)
3000 V 50 c/s, 6 p, 1000 r.p.m.

II-3. Main exciter

Indoor use, horizontal, open type, separate excited d-c generator.
175 kW 220 V 1,470 r.p.m.
The exciter is driven by a 275 HP induction motor. The exciter and a directly coupled high frequency generator for AVR are mounted on a common base and installed in a switch house.

II-4. Single phase high frequency generator for AVR

12.5 kVA, 200 V, 350 c/s, 1,470 r.p.m.
The generator is a power source of a magnetic amplifier type AVR, unique product of the company. It is a permanent magnet generator with excellent electrical characteristics, its rotor being constructed on special design.

III. CONSTRUCTION OF SYNCHRONOUS CONDENSER

A starting motor is located on the upper part of the condenser. A slip ring compartment is placed on the highest top of the condenser; a tachometer generator is equipped on the lower part of the condenser. The stator frame of the condenser and starting motor, side plates and slip ring cover etc. are all made in one compact explosion proof and hermetically sealed construction. A gas cooler is arranged laterally around the stator core, as an ideal place within an allowable limit of transportation condition, expecting the best possible cooling effect. Guide bearings are placed on upper and lower part of the condenser rotor like an ordinary vertical type generator. The thrust bearing and magnetic bearing are placed on the upper bracket (Fig. 2)

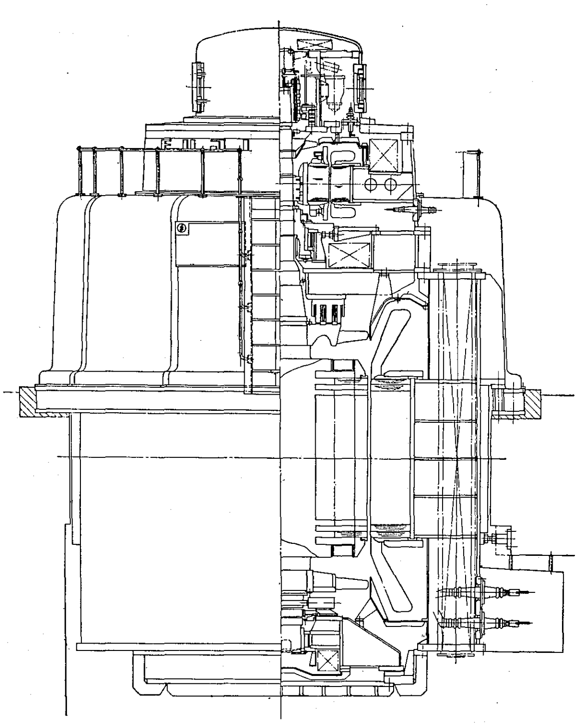

Fig. 2. Longitudinal section of 30,000 kVA rotary condenser

III-1. Stator

a) Stator frame

The stator frame has to be built sturdy enough to withstand all vibrating forces generated by magnetic unbalance, thrust load, rotation, short circuit torque and unbalanced mass of the rotor. In consideration of being hydrogen cooled, it is also required to be built gas tight with satisfactory strength to withstand against gas explosion. Outer plates of stator frame, upper and lower side plates and all parts forming the explosion proof construction are made of good weldable rolled steel boiler plates. These plates are annealed at 650°C after welding to remove stresses. Side plates are 25 m/m thick. The feet of the stator frame which support the whole condenser are sturdily welded at the periphery of the stator frame where the center of gravity falls on. The machine stability is assured by holding the whole machine on the ring shaped base plate. Speciality of this machine is also attained by selecting its feet most adequate position whereby the crane is available.

b) Stator core and coils

Core plates are 0.35 m/m thick and 1.2 w/kg silicon steel, fully annealed after punched to minimize iron loss. They are laminated along with dovetail keys after baking-on with insulation varnish. Press rings are of segment construction with non-magnetic fingers welded, and carefully worked for comparatively large thickness of the laminated core. Stator coils are so-called "Gitter" coils which are completely transpositioned inside the slot. With an insulation method unique to the company the coils are given treatment to perfectly protect them from heat strain and corona effect. Coils are also given enough distance to the ground in consideration of operation in hydrogen.

c) Explosion proof case

As shown in Fig. 2 the upper bracket, stator frame of the starting motor, slip ring cover, lower bracket holder, and lower side plate are assembled

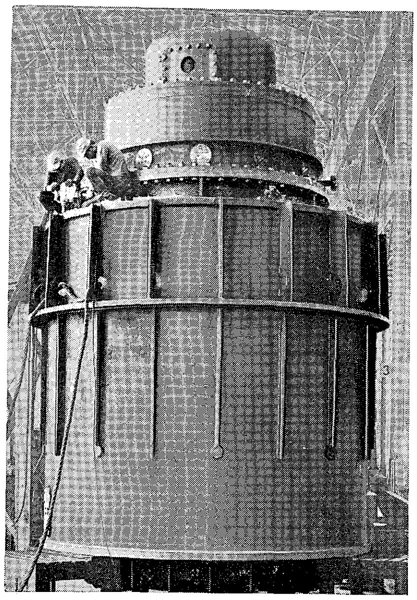

Fig. 3. Explosion-proof casing completely assembled

around the condenser stator frame to form explosion proof construction. It is so designed that, unless it gives trouble for assembly and disassembly of the machine and its transportation, joints that may cause gas leakage are reduced to the minimum (Fig. 3). As is well known, the mixture of air and hydrogen gas exerts highest blasting power when hydrogen content is 35%. The blasting power will be 7 kg/cm^2 when gas pressure is 0.035 kg/cm^2 gauge; 14 kg/cm^2 when 1 kg/cm^2 gauge. However, the protective device has been greatly improved lately and no outside air is allowed to enter under the gas pressure 1 kg/cm^2 gauge; so no consideration may be necessary to explosion under gas pressure of 1 kg/cm^2 gauge. In view of the above, applying the test pressure 7 kg/cm^2 is the usual practice. Though there is no objection to the above conception for this condenser, the test is conducted with pressure of 10 kg/cm^2. Firstly, all parts made explosion proof are assembled after machined and are given test with hydraulic pressure of 10 kg/cm^2. Strain gauge resistance wires are placed as many as possible on various parts to measure tendency of strain, and amount of deformation are also carefully read to confirm the safety.

III-2. Rotor

In view of the size and peripheral speed, the strain at all points of rotating parts is considerably large, especially at over-speed. This is one of the most difficult part of the design and construction of the machine. In relation to this transmission system with which the synchronous condenser is connected, over-speed may be estimated 30%, i.e., 1,300 r.p.m., at which speed every parts of the rotor is designed

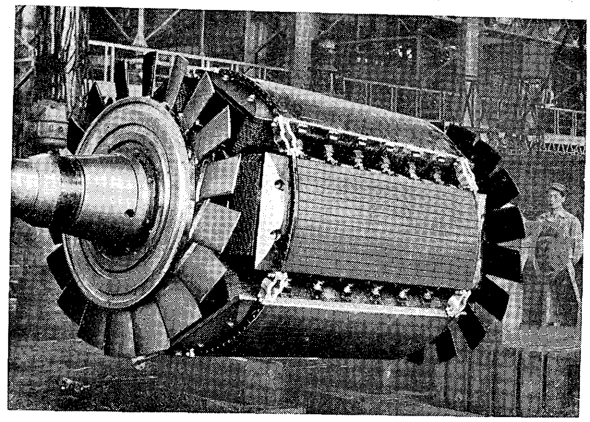

Fig. 4. Complete rotor

to stand with ample safety factor (Fig. 4).

a) Pole core

Thin steel sheets of high tensile strength with one side baked with insulation varnish are laminated and riveted to form large and small blocks. These blocks are then piled alternatively and formed into one body with several pins and strong pole piece end plates. The pole core is made into one integral beam by welding a bracing plate along the entire length, and thus any extra centrifugal forces working on the pole piece are distributed to all core plates. The pole core is fixed into the yoke according to unique comb shape construction. Lower parts of each pole which are comb shaped are made to fit to the grooves of the yoke. Three reamer pins fit in the axial direction make the poles one body with the main shaft rigid enough against full centrifugal forces. The size of reamer pins and the thickness of core blocks can be adjusted properly to share the forces working on them. In comparison with the conventional dovetail construction of fastening poles to the yoke, this method is far preferable for high speed salient pole machine, as there is no initial stress by driving in cotter pins nor increase of forces by wedging.

b) Damper winding

To the pole faces are fitted low resistance copper bars as damping bars. They are brazed to a end ring segment which are then connected to adjacent segments by a connector between the poles. There are a number of styles in the construction of damper winding for high speed machines. The end ring piece of this damper winding is contained between the core and pole face, and a light weight, low resistance duralumin plate is used as a connector. In this new method, it is so devised that large forces are not applied to connectors the yielding point of which has been lowered by brazing. Special precaution is taken to protect oxidation and overheat of the duralumin plate contact surface.

c) Main shaft

The main shaft forms one integral body with yoke. It is made similar to the main shaft of the turbo generator. The reason of making the shaft and yoke in one body is to take into consideration the mechanical strength of shaft and its critical speed. It is obvious to set the critical speed of shaft at above 1,600 r.p.m. in consideration of the over-speed. The determination of shaft material is made in conference with the shaft maker. Mainly due to mass effect and crystal front line it has been decided to take a shaft of S. Cr. Mo 90. After the shaft is heat-treated and roughly machined, several test pieces are taken out of various important parts of the shaft. Overall strength test, supersonic test and mirror test have all shown satisfactory results with the machine in question. Then finaly the shaft is given low temperature annealing at approximately 500°C, and is finished precisely to size (Fig. 5).

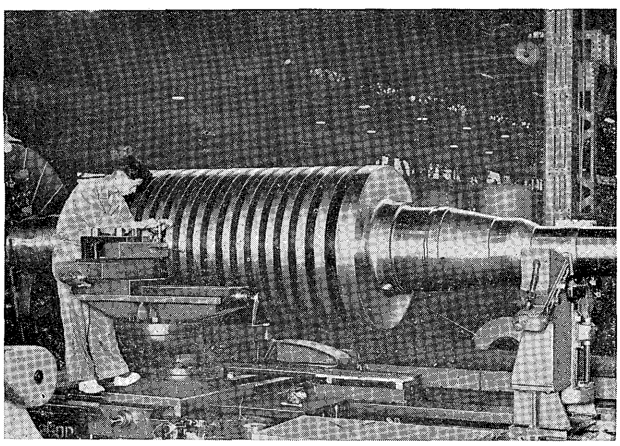

Fig. 5. Main shaft under finish machining

d) Collector rings

For easy inspection, the collector rings of synchronous condenser are placed on top of the machine together with collector ring of starting motor and housed under a cover. A well forged gun-metal of uniform hardness is used for the collector rings. Thread-grooves are cut on the sliding surface to prevent sparking and over-heat. An axial flow fan and cooling pipes with U fins are placed on the utmost top of the shaft for avoiding over-heat in summer. Then between the sliding surface, cooler, and fan, and inside of collector ring cover, a group of removable glass fibre filters is installed to prevent the scattering of brush powder that causes trouble. The collector ring cover form itself a part of explosion proof case and is made rigidly. It is also made possible for inspection or removal of brushes through inspection doors provides at 2 position having peek-in holes covered with organic glass.

III-3. Cooling

Two cooling fans of high efficiency, each of axial flow type, are provided, vanes of the upper fans are welded to rotating part of the magnetic bearing; vanes of the lower fans are made push-fit to the main shaft after welding the vanes to a boss of steel plate. They are made of cast steel, shaped so as to get sufficient static pressure. From the principle of fluid dynamics, the sectional area of vanes are made aerofoil and the surfaces are polished to insure high efficiency. The cooling air, its pressure raised by the upper and lower fans, is actuated by fan action of the rotor poles, partially passes between the poles, enters the stator core ducts and cools its back. Then passing through gas cooler contained in the stator frame, it gathers at the upper and lower end of stator frame, and reaches the fan inlet through the outside of the fan guide. Another part of cooling air cools the end of stator coils; then passing through the gas cooler, joins with the above mentioned air flow. Ventilation holes are provided on the yoke of the main shaft, enabling the cooling air to reach the central part of the core. The gas cooler is arranged longitudinally along the external surface of the stator core. The cooling pipe flanges, the same as used in other generator, are of U fins having good cooling efficiency. The cooling pipes are of brass tube, the same as used in steam condenser. The cooler is fitted to the stator frame in such a way that to the lower-side-plates of stator frame are bolted header-covers, with a good synthetic rubber plate inserted between header and cover; the rubber plate is bolted to the stator upper-sideplate so that expansion and contraction due to tem perature difference of the stator frame nad gas cooler is absorbed by the rubber. On the other hand, it is designed to protect the cooler from any gas leak- age, and pipe cleaning is made possible making no interference to the machine operation. The cooling water temperature in the field is expected to rise 30°C in summer, but the results of factory and field tests have proved that the hydrogen leaving at cooler outlet is cooled under 40°C, provided that inlet water temperature is 30°C.

III-4. Bearing

a) Guide bearing

Lubrication of guide bearings and thrust bearing are of self contained type. In this system, it needs no circulation of lubricant in and out of bearings; needs no gas extraction from lubricant, which are needed in the ordinary hydrogen cooled unit, facilitating the maintenance of the machine. However, the sliding speed of guide bearing in this machine is remarkably high. For this reason, two methods of lubrications is adopted, namely, direct cooling and lubricant cooling. As a result, it has been confirmed that metal temperature is kept always lower than 55°C. It has satisfied the specification which calls "not over 65°C with 10 minutes run without cooling".

b) Thrust bearing

This machine is equipped with a magnetic bearing, but for emergency an ordinery thrust bearing is also provided. An oil cooler of sufficient cooling capacity is contained in the tank. The thrust collar is made detachable from the main shaft in disassembling, but it has a slight margin of tightening so that the assembling or disassembling can be made with ease by induction heating. A special fibre under the segment is usually used for the thrust bearing to the extent of 40 tons. But this machine must withstand fully against the shock when the magnetic bearing is de-energized, so specially designed metal plates are used instead of fibre. This is proved very satisfactory. Turbine oil No. 140 has been used as a lubricant, but to reduce friction loss in case of high speed and also from the standpoint of the value of Z_1n/p, turbine oil No. 110 is used for all bearings including the thrust bearing. It has been proved effective.

c) Magnetic bearing

The magnetic bearing is a device really worthy of pride in the circles, demonstrating its ability in the world to the fullest extent for the first time. It consists of a cast steel stator with exciting winding and compensating winding, and a forged steel rotor which is firmly fitted to the main shaft. It is placed between the upper bracket and condenser rotor. When the machine is operating, approximately 38 tons of rotor weight of 41 tons is supported by this bearing with magnetizing current of 290A; the remaining 3 tons is loaded on the thrust bearing, thus the friction loss of thrust bearing being greatly minimized. The result of test operation has shown an excellent record as described later. Our Company has been experimenting this bearing since the period before the acceptance of this order with a number of experimental equipment, and has collected all sort of data. The magnetic bearing of the condenser then has been designed and built on the basis of various data (Fig. 6). It is found that vibration of condenser has no relation to magnetic effect of the bearing and is seen no change even when the electric source of the bearing is suddenly cut off. Guessed from the condition of segment lining, it is found that the impact value is a good deal less than the theoretical value. This may probably be caused by resistance of air and lubricants. For a protecting device not to lift the rotor too much above predetermined height by abnormal rise of voltage, a downward thrust bearing is provided underneath the upper guide bearing.

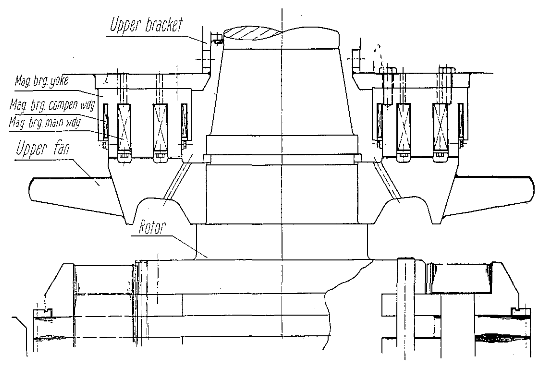

Fig. 6. Construction of magnetic bearing

III-5. Starting motor

The starting motor is designed to work as an induction motor when starting the condenser and charging the transmission line; it works as a synchronous machine for synchronizing to parallel operation. After synchronizing, the motor runs idle. When the machine stops, it works as a d-c braking generator and brakes the rotor with a flywheel effect of GD^2—42 t-m^2. No mechanical brake is provided. A unique axial flow and a ring cooler with U fins are provided for the motor to satisfy a rating of 1,900 kW at 30 min. or 500 kW at continuous rating. A brush lifting device is of magnet operating type and assures accurate operation (Fig. 7).

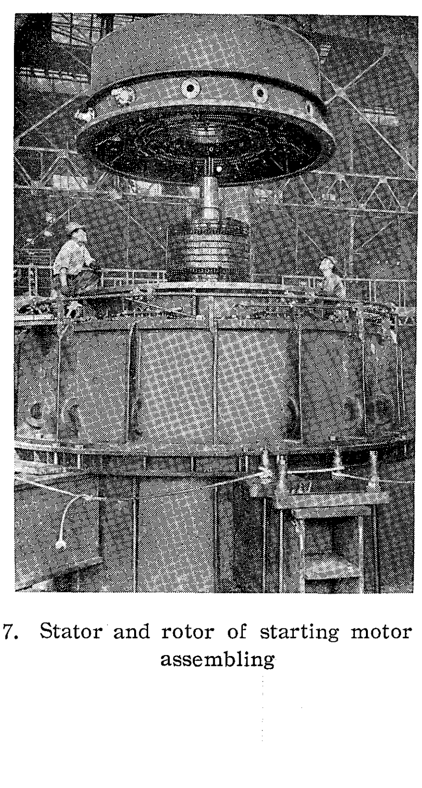

Fig. 7. Stator and rotor of starting motor under assembling

III–6. Terminals and bushings

Main terminals of the stator and rotor of the condenser and of starting motor, and lead wire of the magnetic bearing, tachometer and thermometer, are guided to the pit of the main body by making use of pipes that are penetrating axially through the stator frame, making no interference to assembly and disassembly of the machine ; not being exposed to weather, and all assuring high reliability. Method of passing rotor coil lead through the main shaft is a point that needs careful construction, relating with the gas sealing system then the collector ring cover is to be opened. Heat resistant rubber covered copper wires are used as conductors inside the main shaft, and conductor joints are made with no threadings. The sealing is made at the shaft end. In order to avoid temperature rise of rubber covered copper wires, hydrogen gas is made to pass freely through penetrating holes by the pressure difference in the machine. A part of conductor and the thermometer leads that come out through explosion proof case are enclosed in the high class bushings with a sufficient distance to ground. The mounting part of high voltage bushings are made of non-magnetizing metal to avoid heating.

III–7. Assembly and disassembly

It has been a usual practice to install no cranes for assembly and disassembly of outdoor synchronous condenser. This, however, may not be a good practice even in the case of horizontal machines. Without the crane it takes a considerable time in the initial erection and also it will be of no small trouble for overhauling the machine. It is then a specific feature to have provided a 40 tons portable crane for this condenser.

A further consideration has been given also to make the crane capacity as small as possible by an ingenious operation of shieves and an auxiliary hook. Then the weight of stator 64 tons is succesfully lifted by the crane of 40 tons capacity at the site, which has never been tried before. It may be noted that the horizontal travel of hook is made long enough to facilitate the disassembly and assembly of the gas cooler.

IV. GAS CONTROL EQUIPMENT

There are a number of advantages on the one hand in the electric machine cooled by hydrogen. On the other hand, it needs gas control equipment, operation becomes more complicated, hydrogen and air become explosive at a certain rate of mixture. Hence, it needs extra heavy construction. An extra care has been given to the design of this machine as to rigidity against gas pressure, gas leakage, maintenance of high degree of gas purity, and dependability of control etc, all being attained successfully (Fig. 8).

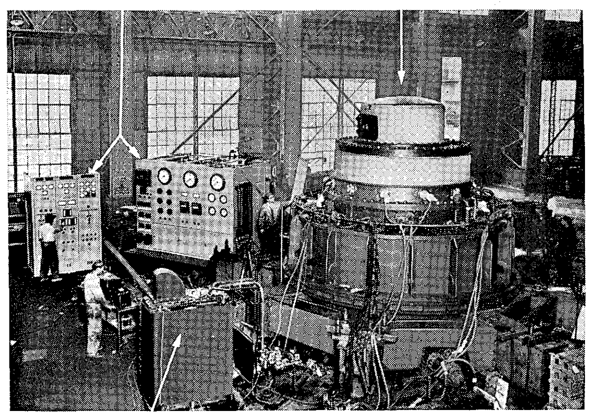

Fig. 8. 30,000 kVA synchronous condenser under testing in shop

IV–1. Gas control system

An initial feed, additional supply and exhaust of gas are made by hand operated valve at the pressure of 0.035 kg/cm^2–the basic pressure of hydrogen gas. (by changing a range of a part of apparatus, it can be operated under 1 kg/cm^2)

a) Initial charge of gas

A vacuum replacement method is adopted. By using a rotary vacuum pump of 3,000 l/min, the interior of the machine is evacuated and is filled with hydrogen. Compared with the CO_2 gas replacement method, quantity of hydrogen gas needed in the initial charge is much less ; it may be equal to the interior volume of machine at the basic pressure, which is very economical. Unlike the CO_2 replacement method, the vacuum attained has a direct relation with the hydrogen purity, thus making possible the filling of high purity gas with ease and quickness. With vacuum at 5.5 mmHg. and by using bombs with hydrogen purity at 99.7%, if the machine is filled with hydrogen up to the pressure of 0.035 kg/cm^2 (25.8 mmHg), the calculated purity of filled gas may be 99%. At the site the hydrogen charging is started when vacuum is 5.5 mm Hg. Measured by an explosion type H_2 analysis apparatus, interior hydrogen purity was found 98.9%. By heat conductive type H_2 purity meter, the reading was 98.7%. Time required to exhaust one H_2 bomb is approximately 7 min., and the number of bombs used for initial filling is little less than 8. This method of gas filling is simultaneously the vacuum drying of coils. It needs an installation of vacuum pump but it saves CO_2 gas bombs, and as a whole, this

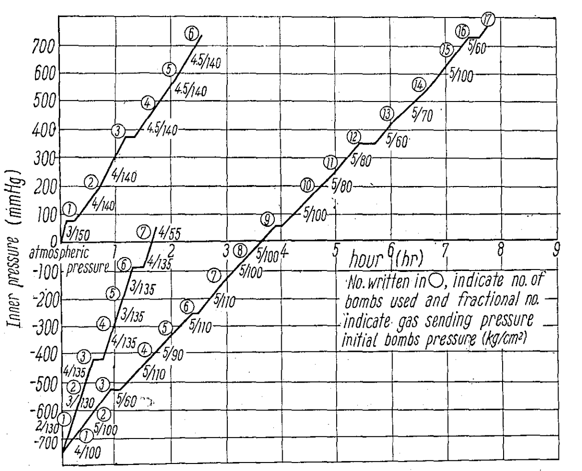

Fig. 9. Record of hydrogen gas charging at factory

method is prefered to the CO_2 gas replacement method.

b) Supplementing gas

When interior gas pressure lowers or gas purity becomes low by the leakage of hydrogen gas from the machine in operation, this is adjusted to a predetermined pressure and purity by operating a hand operated valve. The operating valve is located in the compartment together with pressure and purity meter at the lower part of H_2 control panel. It is easily accessible by opening a door, and is operated by turning the valve with watch on the pressure gauge and purity meter. As synchronous condenser can be built completely enclosed, unlike turbine generator, leakage of H_2 gas is minimized and frequency of gas supplementing is quite reduced. This is why the valve is made hand control.

c) Exhaust of gas

In case of overhauling or inspection, the gas may have to be exhausted, which is accomplished quickly by the vacuum pump. It takes approximately 110 min. to draw gas from basic pressure to vacuum 4.5 mm Hg.

d) CO_2 gas replacement of slip ring compartment

To the slip ring compartment has been adopted the CO_2 gas replacement method specially. When the inspection door of the slip ring compartment has to be opened for changing brushes, after a shaft sealing mechanism has been operated, hydrogen gas is driven out to the atmosphere while CO_2 gas is being sealed into the slip ring compartment till it attains purity over 90%. It will be sufficient to prepare only one CO_2 gas bomb for this purpose. Opening the inspection door or removing the whole slip ring cover by the vacuum replacement method has been proved possible because of a powerful shaft sealing mechanism. By this method, there will be no use of CO_2 gas bomb, CO_2 gas purity meter, CO_2 gas vaporizing apparatus. It is firmly believed that the vacuum replacement method only will be adopted in future. Time required for replacing CO_2 gas replacement from the slip ring compartment at the site is as described below.

Replacement of air by CO_2 gas: 22 min. (CO_2 purity 0–90%)

Replacement of CO_2 gas by H_2 gas: 88 min. (H_2 purity 0–96%)

IV-2. Leakage test of hydrogen gas

Hydrogen sealing pressure in the hydrogen cooled machine is the atmospheric pressure $+0.035$ kg/cm², which prevents air entering inside. But it is unavoidable that hydrogen leaks out of the machine. In the construction of this condenser, an effort is made to stop leakage of gas from either the machine or pipe lines. It is found practically there is no leakage, so that leaking quantity is hard to measure. The gas leakage test is made on the condenser body only in the factory before hydraulic test. The interior air pressure of the machine is raised to 2 kg/cm² to detect points of leakage by soap water bubbles. After careful mending, a mixture of fleon gas is filled up to 2 kg/cm². The fleon leakage detector of GE Co. made was able to locate leakages not found by the soap water method. All leakages were then carefully stopped. After hydrogen filled at the factory test, a hydrogen gas leakage detector of the Shimazu Seisakusho made, a kind of mass analizer, was used to detect the leakage, but since the leakages were well mended, nothing wrong was found. There are two ways of calculating leakage quantity. One is a pressure method, in which the leakage is measured by means of the degree of pressure drop, and the other is a vacuum method which measures the leakage by means of the drop of vacuum or rising interior pressure. The interior pressure variation is indicated on U tube manometer. Even when there is no gas leakage, the manometer reading varies with temperature variation inside the machine. It is important to give a temperature adjustment to the manometer reading. The same thing can be said on the error of temperature measurement. At the absolute interior pressure of 3 kg/cm², if the temperature rises from 0° to 1°, the pressure varies 8.1 mm Hg. When the absolute interior pressure is 5 mm Hg, the same temperature variation makes only the pressure error of 0.0153 mm Hg. Actually, the pressure variation in question due to leakage during 24 hrs. is only a few mm Hg. The pressure method is then not effective to obtain leakage because of the temperature error. In the case of the vacuum method, 5 mm Hg vacuum mentioned above is applicable and the temperature error is made very little.

A vacuum test made after the installation at the site shows that during 22 hours interior pressure changed from 4.4 mmHg to 5.5 mmHg; temperature remained constant at 5.8°C. From these data, leakage volume is calculated as 0.005 m^3/day.

Hydrogen gas leakage during January was such a small quantity as 0.15 m^3/month. This is because the whole machine and pipings were assembled at the works under similar conditions as at the site and confirm that there was no gas leakage when re-assembled at the site exactly as expected.

IV–3. Hydrogen control panel

Purity meters and pressure gauges for controlling hydrogen and CO_2 gas are mounted on the panel front and control valves on the back.

a) Purity meters

The meters are of heat conduction type manufactured at the company's Toyoda Works, consisting of a transmitter and indicator. The indicator is on panel front and the transmitter is on a separate transmitter panel attached on the back of the control panel.

Three kinds of transmitters are manufactured to measure mixed gasses of H_2–air, H_2–CO_2, CO_2–air. A drop-frame type adjusting meter is provided for the H_2–air transmitter which is always in use during operation or stop so that an alarm or quick stop signal is transmitted when the purity drops.

b) Pressure gauges, vacuum gauges

For controlling gas pressure, Bouldon pressure gauges and ring balance type pressure gauges are provided. The former is used when basic hydrogen pressure is 1 kg/cm^2 and the latter is used when the pressure is 0.035 kg/cm^2. Both are provided with drop-frame adjusting meter so that alarm signals are given for pressure rise or pressure drop of the machine. Balance type vacuum gauges are used for measuring vacuum at a time of initial gas filling. They are also products of our Toyoda Works.

c) Pressure differential gauge.

A ring balance type differential pressure gauge is set to measure pressure difference at the front and back of the rotor fan for reference to find hydrogen purity. Changes of purity affect the density, and as the generated pressure by a fan at a define rotating speed is proportional to the gas density, purity can be learnt by measuring this pressure.

IV–4. Gas control and other equipment

a) Shaft sealing mechanism

This is a mechanism provided at the part of the main shaft between the main body and the slip ring compartment. When it becomes necessary to open the slip ring compartment while the machine is at standstill, this mechanism works to isolate the body and the slip ring compartment to prevent gas leakage. This is a new design, as shown in Fig. 10, based on experimental data and on the result of careful studies, working very successfully. This system is of simple construction and simple theory compared with the conventional type, yet it has many features including no failure of rubber packings.

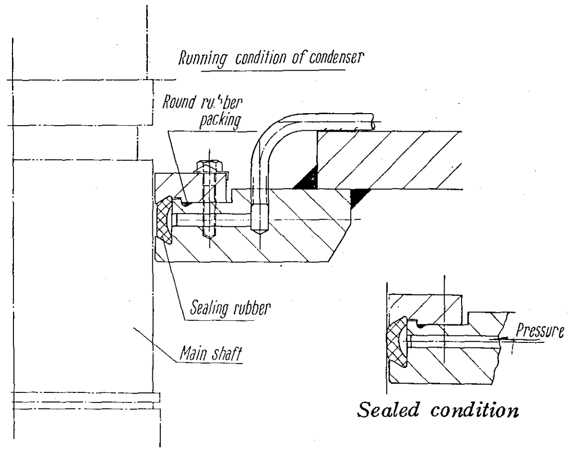

Fig. 10. Construction of shaft sealing for hydrogen gas

b) Hydrogen gas blowers

They are apparatus to circulate hydrogen gas to the transmitter and also to circulate it for drying. Two units—one normal use and the other spare-are provided. They are blowers of revolving vane type (200 l/min.) and so small that they are housed in a hydrogen sealed container together with a motor. By means of this apparatus, the gas purity can be measured continuously even while the synchronous condenser is at standstill.

c) Hydrogen gas drier (silicagel regenerator)

For the purpose of drying hydrogen gas inside the machine 2 driers are installed, one being spare and stand-by unit. The hydrogen that passes into hydrogen purity meter is made to pass through the dryer. It enables the purity meter to indicate always a correct value and thus all gas in the machine is made to be dried little by little. Pink colored silicagel that has absorbed moisture is taken out together with the container from the drier and is regenerated.

d) Mercury releaf valve

Two releaf valves, one to work at basic pressure 0.035 kg/cm^2 and the other to work at 1 kg/cm^2 are provided to control abnormal rise of pressure inside the machine. The former can be adjusted up to the working pressure 0–140 mm Hg. the latter up to 0–956 mm Hg. Adjustment is made possible by adjusting amount of mercury.

e) CO_2 gas vaporizer

If the liquid CO_2 gas in the bomb is discharged to atmosphere directly, it requires much heat and absorb it from the surrounding. As a result the valves and pipes are frozen to clog the passage, a CO_2 gas vaporizer is used to avoid this clogging.

V. COOLING SYSTEM

The condenser cooling water is supplied from a reservoir approximately 60 m apart from the machine by a pump. After passing the cooler, it is returned to the reservoir again where it is cooled of itself and is pumped up again. The pump, strainer, and all valves are installed in the pump room near the reservoir. Following is the specification of the cooling equipment.

Reservoir, 1,200 m^2 (30 m $\times$ 40 m) 2.7 m depth
2–Main vertical pumps, 3,600 1/min. 18 m (one is spare)
2–Induction motors for the above, 25 HP 960 r.p.m.
1–Vertical emergency pump, 300 1/min 15 m
1–D-c motor for the above, 3 HP 1800 r.p.m.
2–Strainers, 3,600 1/min. (one is spare)
1–Strainer, 300 1/min.

The emergency pump is to cool bearings at a time of power failure and is made to run by storage battery. Then, cooling pipe lines between the machine and the reservoir are laid independently from hydrogen cooler lines.

To avoid freezing of the pipe lines of the reservoir in winter when the condenser stops operation, all the lines is made to drain off by using compressed air. Besides the above, instead of exhausting pipe line water into reservoir, a circulating pump is used to circulate water continuously from the pump and condenser and then to the pump. The reservoir is divided into two parts so that only one is used in winter.

VI. TEST RESULTS

The saturation curve at no load and short circuit characteristic curves of this machine are shown in Fig. 11. The short circuit ratio is 0.87 which amply satisfies the guarantee. When thrust bearing temperature by a dial thermometer is being kept constant, the machine losses at various air pressure are shown in Fig. 12. In this case, the pressure of hydrogen in which machine is operated is converted to the equivalent air pressure. Hydrogen pressure 1.035 kg/cm^2 at hydrogen purity 98% is the equivalent air pressure 0.092 kg/cm^2. The windage loss in this case, taken from Fig. 12, is 25 kW. The bearing loss is 80 kW. This figure is the value when no magnetic bearing is used. When the magnetic bearing is used, the bearing loss due to exciting current varies as shown in Fig. 13. The rated exciting current is being set at 290A taking into consideration of voltage variation. The bearing loss decrease in this case is 26 kW. Next, changes of the friction loss due to the oil viscosity with the changes of the thrust bearing oil temperature are given in Fig. 14. The oil viscosity

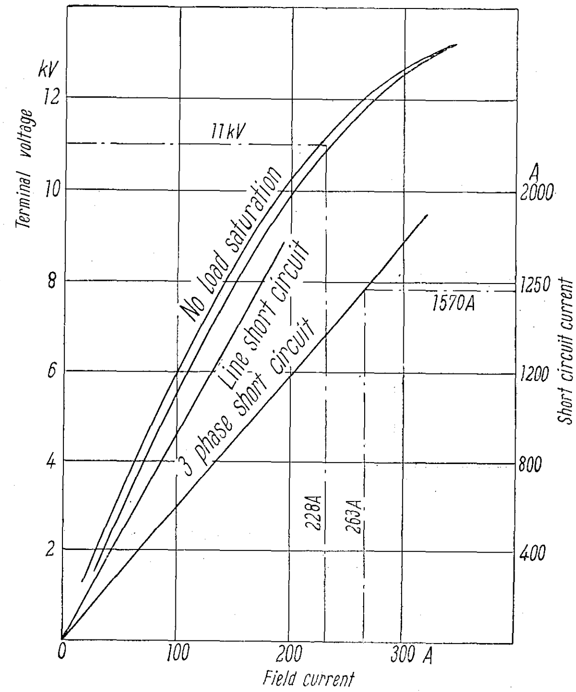

Fig. 11. Characteristic curve of 30,000 kVA synchronous condenser

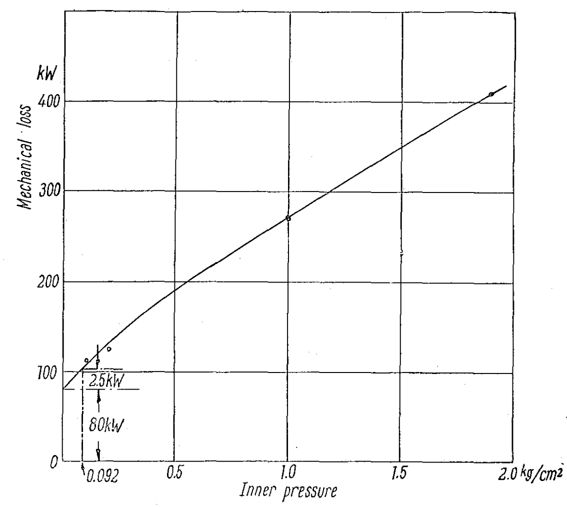

Fig. 12. Relation between mechanical loss and inner pressure

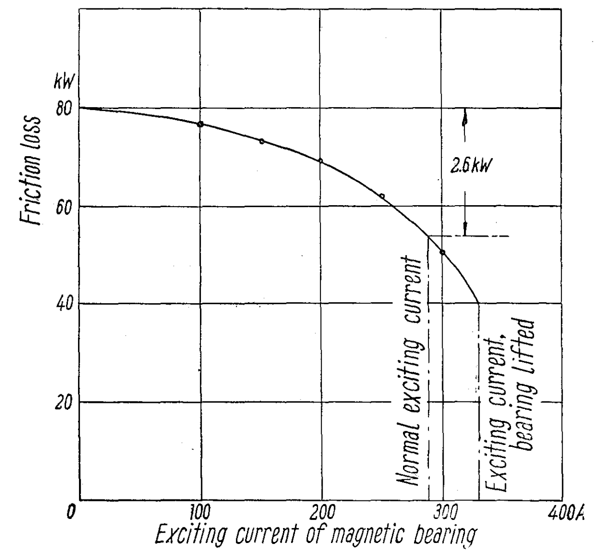

Fig. 13. Relation between friction loss and exciting current of magnetic bearing

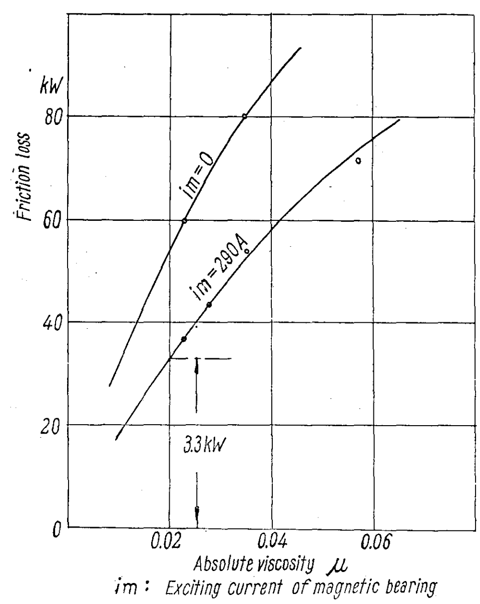

Fig. 14. Relation between friction loss and viscosity of thrust bearing oil

was taken to be equal to the thrust bearing temperature. This may not be altogether correct as an absolute value but can be used as a relative value. When turbine oil No. 110 is used as a lubricant to the bearing, the oil viscosity at 55°C is 0.020, and the friction loss is 33 kW. The excitation loss of magnetic bearing, including losses of power source transformer and rectifier is 5 kW for 290 A. The losses of the machine at rated kVA are summerized as follows.

Core loss	132 kW	431 kW
Stator resistance loss	99.6 ,,	
Additional copper loss	54 ,,	
Rotor resistance loss	82.4 ,,	
Windage loss	25 ,,	
Bearing loss	38 ,,	
Exciter loss	29.8 kW	44.5 kW
Auxiliary machine loss	14.7 ,,	

The total loss 475.5 kW is within the limit of guarantee.

Temperature rises of the machine at various conditions obtained from the result of factory tests based on core loss and copper loss temperature rise tests, are as shown below.

Table 1. Temperature Rise of 30,000 kVA Synchronous Condenser (Factory Test)

		Leading power factor 0		
		24,000 kVA	30,000 kVA	34,500 kVA
In air	ΔT_S ΔT_R	46.5°C 52.5°C	61.5°C 66°C	
In H_2 1,035 kg/cm²	ΔT_S ΔT_R		36.5°C 41.5°C	
In H_2 2.0 kg/cm²	ΔT_S ΔT_R			33°C 45°C

ΔT_S : Stator coil temperature rise (by embedded thermometer method)
ΔT_R : Rotor coil temperature rise (by resistance method)

Cooling water temperature (at the inlet) is 14—16°C, and basic temperature in the machine (temp. at the cooler exit) is 20—25°C. However, when the cooling water temperature is 30°C, the cooler exit temperature shows below 40°C, and the temperature rise at various points is shown as below, which are believed to satisfy the guarantee.

In the air at 24,000 kVA

$\Delta T_S = 47.5°C$ $\Delta T_R = 65°C$

In H_2 1.035 kg/cm² at 30,000 kVA

$\Delta T_S = 40°C$ $\Delta T_R = 51.5°C$

In H_2 2.0 kg/cm² at 34,500 kVA

$\Delta T_S = 36°C$ $\Delta T_R = 56.5°G$

Government witness test at the Shin-Sapporo Substation on temperature rise is as follows :

$\Delta T_S = 31.5°C$ $\Delta T_R = 47°C$

Where voltage is 10,700 V, current 1670 A, H_2 purity 99%, H_2 pressure 1.072 kg/cm², cooling water temperature 6°C, basic temperature in the machine 11.5°C. The voltage wave form of this machine is quite good, and the distortion factor of no load wave form is less than 1.3%. Voltage endurance test by commercial frequency and impulse test with standard wave form have passed successfully.

VII. CONCLUSION

This machine is regarded to be a world record as a machine of 30,000kVA, vertical shaft, 1000r.p.m. and of hydrogen cooled type with magnetic bearing.

The result of all tests at the factorys shows excellent figures ; the government witness tests are also completed with great success. The machine is now operating. Specially to be noted is the magnetic bearing which plays a great part to elevate the efficiency.

Since receiving order for such a record product, Our Company concentrated all the effort in the design and manufacture, based on experimental data as well as thorough investigation, on inexperienced matters ; paying attention to even a piece of bolt, manufacture proceeded with all precautions. The company feel it a great pride to the completion of the machine with great success in operation both electrically and mechanically. The company is still seeking an opportunity to manufacture still higher class of machine based on the valuable experience thus gained.

EQUIVALENT CIRCUIT AND OSCILLATION OF POTENTIAL OF NEUTRAL POINT OF STAR-CONNECTED TRANSFORMER WINDING OF CYLINDRICAL-LAYER TYPE

By

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I. INTRODUCTION

Coils of the transformer winding of cylindrical-layer type[1] can be connected in two ways. Fig. 1a is the single coil connection, using the coils all wound in the same direction and Fig. 1b is the twin coil connection using the coils wound in different directions one by one in pairs. Further, when these windings are connected in star for 3-phase supply, the line terminal U may be located at the end of the outermost coil as shown in Fig. 1a and 1b or be located at the end of the innermost coil as shown in Fig. 1c. The former is called " normal arrangement " and the latter " inverted arrangement ".

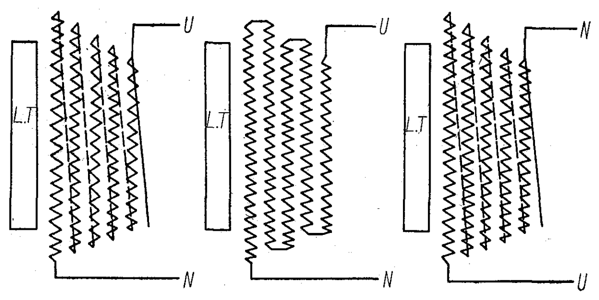

Fig. 1. Varieties of cylindrical-layer-windings

The cylindrical-layer winding is now widely adopted especially for extra high tension transformers with directly earthed neutral point not only in our Fuji Denki Co. (Refer to table 1) but also in E.E. Co. in Canada[2], G.E. Co. in U.S.A.[3] and

Table 1. Examples for Power Transformers with Cylindrical-Layer-Windings Manufactured by Fuji Denki (For BIL 750 kV or over)

Name of Customer	Capacity kVA	Voltage kV	No. of Pcs	Remarks
For Directly-Earthed Neutral System				
Dengen Kaihatsu K.K.	117,000	275/154/11	2	
〃	117,000	275/77/11	1	
Hokkaido Denryku K.K.	78,000	187/66/11	1	Mobile type
〃	78,000	187/66/11	1	〃 (under manufacturing)
Kansai Denryoku K.K.	45,000	275/132	1	
For Non-Directly Earthed Neutral System				
Tohoku Denryoku K.K.	55,750	154/66/11	1	Mobile type (under manufacturing)
Tokyo Denryoku K.K.	81,000	154/11	2	Mobile type
〃	*27,000	154/11	4	*3×1φ bank capacity
〃	*20,000	154/11	4	* 〃 〃
Hokuriku Denryoku K.K.	29.000	154/66/11	1	(under manufacturing)
Kansai Denryku K.K.	13,000	154/11	1	
Kyushu Denryoku K.K.	15,000	66/11	1	BIL 350 kV
Taiwan Power Co.	42,500	154/66/11	2	