# MAGNETIC THRUST BEARINGS

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## I. INTRODUCTION

Recently, the efficiency of electric machines has conspicuously increased. Taking rotary machines as an example, the main reasons for its high efficiency are, without doubt, the improvement made in the construction materials and the reduction in the losses accomplished by every possible means. The use of high grade silicon steel sheets has effected decrease in iron loss, improvements made on insulation materials have greatly increased the space factor of copper wires and the progress made in winding technique has simplified the complicated conductor transposition resulting in the decrease of the copper loss. Moreover, the application of hydrogen cooling method has resulted in minimizing the windage loss of the high-speed turbo-generators.

Among the progress and development made in these various directions, there was one and only blind spot which had not been considered. This blind spot was the friction loss. The magnetic thrust bearing explained here is a device for decreasing this friction loss by lifting the load applied to the thrust bearing with an electromagnet.

In general, no explanation is necessary for the advantages in the use of the vertical type water-wheel generators except for one shortcoming which is the increase in the friction loss. Of the total losses in vertical type generators, the percentage accounted for by the friction loss varies widely according to the type of construction used, the rotational speed and $GD^2$ but is said to be approximately 5 to 25%. In generators directly coupled to Kaplan water-wheels or high-speed Francis water-wheels, the percentage accounted for by the friction loss is considerably large and its effect on the efficiency of the generator is almost disastrous.

The principal aim of this magnetic thrust bearing is to minimize the friction loss in this type of vertical generators and to obtain friction loss characteristic superior to that of the horizontal type generator. Moreover, the utilization of this bearing is not limited only to water-wheel generators. If hydrogen-cooled synchronous condensers, considered practicable in horizontal type only, are altered to a vertical type with a magnetic thrust bearing to reduce the mechanical loss, advantages thus gained in combination with the superior characteristic of the vertical shaft machine will make them unparalled by the horizontal type.

## II. CONSTRUCTION AND CHARACTERISTICS

In high speed or heavy thrust load vertical rotary machine, the support metal of the thrust bearing is generally divided into several sector segments. For instance, the Mitchell type thrust bearing consists of a rotating collar which revolves with the shaft, and sector type support segments lined with Babbit metal on the surface which comes in contact with the collar. The segments rest on steel pins mounted on the bearing housing through an elastic material. When not in motion, this rotating part and the stationary part are in contact throgh an oil film with the sliding surfaces parallel to each other. However, when in rotation, the support segments are freely tiltable up to a certain limit in the direction of rotation, since the pins on the underside are purposely mounted off center towards the direction of rotation.

Consequently, a wedge-shaped oil film is formed between the rotating collar and the support segments permitting smooth lubricating action to effect a large reduction in the coefficient of friction. However, development of considerable amount of friction is still unavoidable.

### 1. Element which Determines Friction Loss

Generally, the friction loss of the vertical shaft thrust bearing is given by the following equation:

$$\mu = k_1\sqrt{\frac{Z\times V_m}{p}} \quad \cdots\cdots (1)$$

$$W_m = \mu V_m P = k_2\sqrt{Z\cdot P\cdot V_m^{\ 3}} \text{ (kW)} \quad \cdots\cdots (2)$$

Where: $W_m$ = Friction loss of thrust bearing (kW)
$\mu$ = Friction coefficient of bearing
$V_m$ = Mean sliding speed of the sliding area of thrust bearing (m/s)
$p$ = Thrust load per unit area of support segment (kg)
$P$ = Total thrust load (kg)
$Z$ = Viscosity of lubricating oil
$k_1$, $k_2$ = Constants determined by the shape of support segment of thrust bearing

By examining each term related to the friction loss in equation (2) it is evident that the term which has the most effect on the friction loss is the sliding speed. Since $W_m$ is proportional to $V_m^{\ 1.5}$, the most effective way of reducing $W_m$ is to decrease

$V_m$. However, it is not feasible to lower the sliding speed below a fixed value. That is, when the thrust load to be applied to the bearing is established, the necessary surface area of the support metal is readily determined from its allowable surface pressure. If the surface pressure is increased above a fixed value, there is a danger of breaking the wedge-shaped oil film causing the metal contact. Also, since this produces objectionable effect on the elastic body which supports the pin on the underside of the segment, it is not feasible to increase the surface pressure to a large extent. When the surface area of the bearing is established, its minimum diameter will naturally be determined and the minimun peripheral speed at a given rotational speed will also be determined.

The primary requisite in the selection of the lubricating oil is to choose a type of oil which produces oil film difficult to break during operation. To satisfy this requirement, mineral oil of good quality and without any impurities and having high viscosity $Z$ must be selected. However, this contradicts with the aim to decrease the value of $W_m$ in the equation (2). Therefore, the condition for the selection relative to the bearing pressure, is to select oil having low viscosity within the range in which the oil film will not break. However, there is a limit in the viscosity of the oil itself so that oil having very low viscosity cannot be selected.

$k_2$ is determined from the dimensions of the support segment and is given by the following equation:

$$k_2 = k_3\sqrt{A\cdot\left(\frac{4}{b}+\frac{1}{l}\right)} \quad \cdots\cdots\cdots\cdots \quad (3)$$

Where : $A$ = Surface area of thrust bearing ($cm^2$)
$b$ = Length of support segment in radial direction (cm)
$l$ = Length of support segment in peripheral direction (cm)
$k_3$ = Constant

From equation (3), it is evident that there is a limit in decreasing the value of $k_2$ by changing the shape of the sector segment. From the above reasoning, the only way to obtain the maximum reduction in the friction loss is to decrease the thrust load $P$. If $P$ is made to decrease, the above-mentioned $V_m$, $Z$, and $k_2$ which are quantities relative to $P$ can be made to decrease. Thus, in the magnetic thrust bearing, the rotor is lifted upward by the use of an electromagnet to reduce the thrust load.

## 2. Construction of Electromagnet

There are various methods in mounting the electromagnet on vertical type rotating machine. Few examples are illustrated in Fig. 1. The type (a) is the method for mounting the electromagnet at the end of the shaft. The construction is very simple and as with type (b) is applicable to machines requiring small magnetic pull. Type (b) and (c) are those mounted in between the ends of the shaft. The magnetic pull of this electromagnet is given by the following equation :

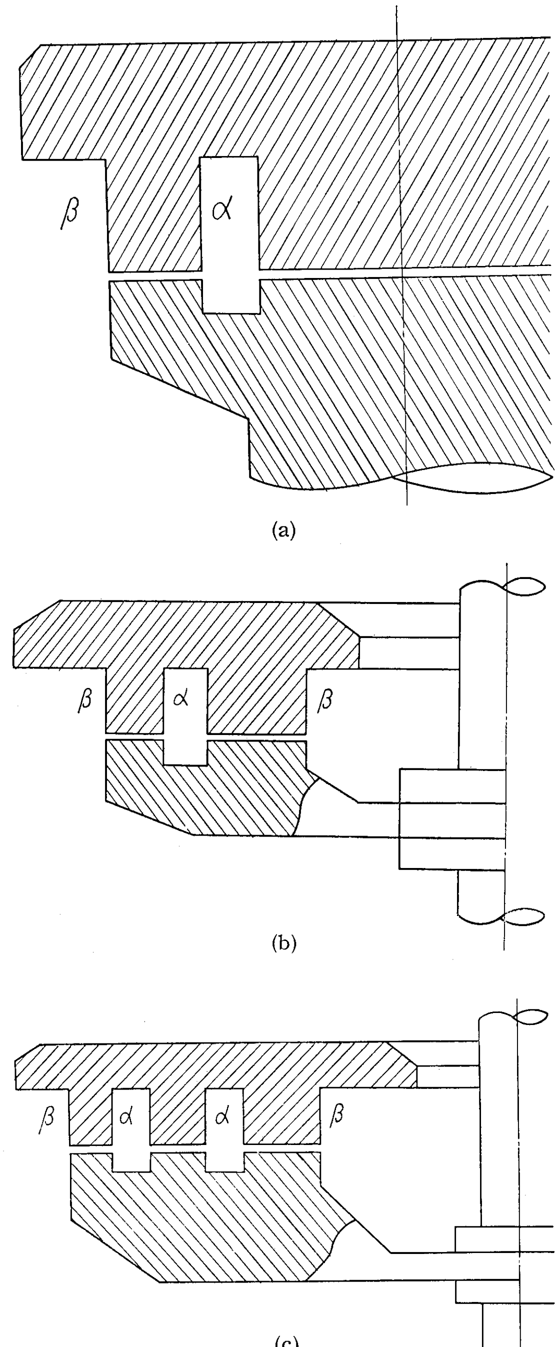

Fig. 1. Electromagnet

$$F = \frac{B^2\cdot A}{8\cdot 981{,}000} \quad \cdots\cdots\cdots\cdots \quad (4)$$

Where : $F$ = Magnetic pull (kg)
$B$ = Magnetic flux density of air gap (Gauss)
$A$ = Effective surface area ($cm^2$)

Let $F$ be a function of the exciting current. At first, the magnetic pull varies proportionally to the square of the exciting current, and as the iron core becomes saturated, the slope of the curve decreases.

To simplify the control of the magnetic pull, the saturated portion and the unsaturated portion of this curve are suitably used according to the method by which the magnetic thrust bearing is to be employed.

There are various types in the construction of the electromagnet depending on the structure of the entire rotary machine and the magnetic pull which is required, as shown in Fig. 1. All are perfectly symmetrical to the axis of the shaft and have circular or ring from magnetic pole faces. The number of magnetic poles increase or decrease according to the strength of the magnetic pull required. That is, when the required magnetic pull is small, two magnet poles are used as shown in Fig. 1. Type (a) and Type (b). However, when the reqired magnetic pull is large, the magnet pole must be divided into three or more sections because of the increased thickness of the yoke. There is an advantage in increasing the number of sections since the cooling surface area of the exciting coil is increased. The exciting winding is a ring form winding inserted into the slot $\alpha$ as shown in Fig. 1. and sectional area of its conductor is determined by the permissible excitation loss. This excitation loss must be held down to a minimum because it is a loss which is subtracted from the gain obtained by the reduction in the friction loss. Also, the necessary ampere-turns for the magnetic path of the electromagnet are determined by the ampere-turns required to send the flux through the air gaps. Theoretically, it means that by increasing only the cross sectional area of the conductor, the excitation loss can be held down to a manimum. In short, although this is a problem which is to be decided finally from the economical standpoint of the rotary machine as a whole, the fact that the excitation loss can be economically decreased to a very small amount as to be negligible as compared with the friction loss, is the reason why outstanding performance is exhibited by the magnetic thrust bearing. Besides the main exciting winding, the electromagnet is provided with a compensating winding.

## 3. Compensating Winding

In mounting the electro-magnet on rotary machines, there are two problems which must be taken into consideration. One is the eddy current loss and the other is the shaft current. The eddy current loss occurs from an electromotive force produced in the direction perpendicular to the direction of flux and the rotation. If all emf's act in the same direction and are balanced, no eddy current will flow. To maintain this balance, the electromagnet is constructed such that each part is perfectly symmetrical to the shaft; thus preventing the flow of circulating current. The more important problem is the prevention of the flow of the shaft current. The following three cases are considered as the causes of shaft current:

1. When there is an electric potential difference between the shaft and the ground.
2. When electric potential difference is produced between the ends of the shaft.
3. When the flux is flowing through the shaft in the direction of its axis.

The case 1 is a very special one occurring when ground failure is produced in the grounded exciting circuit.

In the case 2, the unbalance in the magnetic resistance of the armature is the cause for the existence of the alternating flux which crosses with the shaft, producing an alternating potential difference between the ends of the shaft. The shaft current which flows due to the above cause is generally the most undesirable and needs serious considertion in its elimination.

The shaft current produced due to the above-mentioned causes 1 & 2 is a current which flows through the shaft and the bearing and can be prevented from flowing by inserting insulating material in its circuit. Consequently, insulation materials are generally inserted between the upper bracket and the stator frame and to those parts which may complete a circuit for the shaft current to flow such as water cooling pipes, oil pipes, etc.

On the contrary, the shaft current produced due to the cause 3 is an eddy current flowieg locally in the bearing surface and cannot be prevented from flowing by the insulating materials. Therefore, the cause for producing this current must be eliminated. The shaft current from this cause, when compared with the shaft current in 2, has practically no ill effect and in most cases is beside the question, usually no preventive measures being taken.

However, in this device, perfect preventive measure has been taken lest leakage flux may encourage the flow of this shaft current. When flux flows through the bearing surface in the direction shown in Fig. 2, an electromotive force in the direction shown by $E$ is

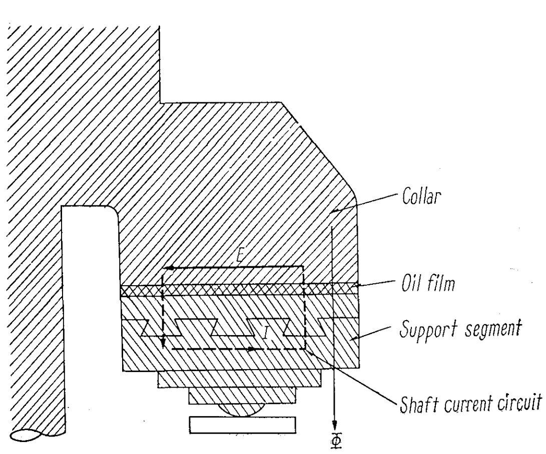


Fig. 2. Shaft current at the thrust bearing

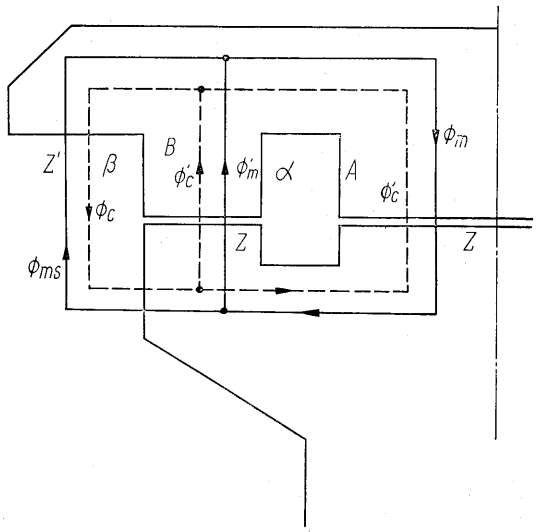


Fig. 3. The effect of the compensating winding

produced. This electromotive force is capable of causing a current to flow through the oil fiilm in the direction of the arrow point. Since the flow of this local current can not be prevented by the insertion of insulation material, the flux, which is the cause of this flow, must be eliminated by all means. In this device, the method used is to cancel out the leakage flux flowing through the surface of the bearing by the excitation of the compensating winding which supplies flux to fully compensate for the leakage flux.

The way to determine the strength of the magnetomotive force of this winding is explained below with Fig. 3. as an example. First, neglect the magnetic resistance of the iron core and the internal leakage flux (leakage which is not a cause for the shaft current to flow) and let the magnetic resistances $Z$ of the two air gaps be equal. When the main winding $\alpha$ is excited, flux $\phi_m$ will be produced by the magnetomotive force $V$ of the winding. This flux is divided into flux $\phi_{ms}'$ through the leakage path (magnetic resistance $Z'$) and flux $\phi_m'$ through the main path. When the compensating winding ($\beta$) is excited in the opposite direction, flux $\phi_c$ will be produced by the magnetomotive force $V_c$. This flux divides into two $\phi_c'$ through the main path as illustrated in the diagram.

These fluxes are given by the following equations:

$$\phi_m = \frac{Z+Z'}{Z(Z+2Z')} V$$

$$\phi_{ms} = \frac{V}{Z+2Z'} \quad \phi_m' = \frac{V}{Z+2Z'} \cdot \frac{Z'}{Z} \quad \cdots\cdots\cdots (5)$$

$$\phi_c = \frac{2V_c}{Z+2Z'} \quad \phi_c' = \frac{V_c}{Z+2Z'} \quad \cdots\cdots\cdots (6)$$

The total flux $\phi_s$, $\phi_A$ & $\phi_B$ of leakage path and the main path $A$ & $B$ are calculated as follows:

$$\phi_s = \phi_{ms} - \phi_c = \frac{V-2V_c}{Z+2Z'}$$

$$\phi_A = \phi_m - \phi_c' = \frac{(Z+Z')V - ZV_c}{Z(Z+2Z')}$$

$$\phi_B = \phi_m' + \phi_c' = \frac{Z'V + ZV_c}{Z(Z+2Z')} \quad \cdots\cdots\cdots (7)$$

Therefore if $V_c = \frac{V}{2}$:

$$\phi_s = 0 \quad \phi_A = \phi_B = \frac{V}{2Z} \quad \cdots\cdots\cdots (8)$$

Thus, if the ampere-turns of the compensating winding are selected as a half of that of the main path, the leakage flux will be completely cancelled out and the flux flowing through the main path will be equal to the flux obtained by calculation with the leakage path and the compensating magnetomotive force neglected. Although the shape of the electromagnet may take various forms as shown in Fig. 1, the necessary magnetomotive force of the compensating winding for completely cancelling out the leakage flux, are always obtainable. The striking fact here is that the relation between $V$ add $V_c$ is always maintained constant regardless of the size of the exciting current. Hence, there is no need for separately controlling the current in the main winding and in the compensating winding if a certain fixed turn ratio is given to the two windings connected in series. The above method is very simple and for any exciting current, satisfies all requirements for cancelling out the leakage flux.

### 4. Power Supply

The power supply is a low voltage d-c source utilizing selenium rectifiers in three phase bridge connection. This rectifier has a minimum of ripples and good efficiency. Since low voltage is most convenient for use in every respect, this power supply can be said the most suitable. In case where there is a large variation in the thrust load, necessitating the control of the exciting current, a M-G set is used or a rectifing device, which has a saturable reactor in the a-c side and controls the d-c output current by controlling its reactance, is utilized. Although there are various applicable methods as noted above, it is the best to select one which will give optimum efficiency for the purpose intended.

## III. CONSTRUCTION OF GENERATOR EQUIPPED WITH MAGNETIC THRUST BEARING

In the application of the magnetic thrust bearing, special attention is paid on the method by which it is mounted in position so that the length of the generator will not increase or result in the unnecessary increase in its weight. From one example of the cross section of generator with the magnetic thrust bearing shown in Fig. 4, it can be clearly seen that a space above the rotor is ingeniously util-

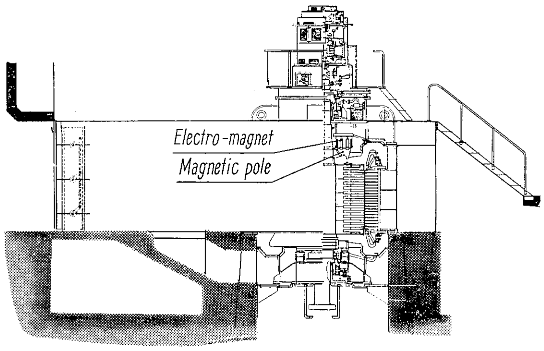


Fig. 4. The section of the generator with magnetic thrust bearing

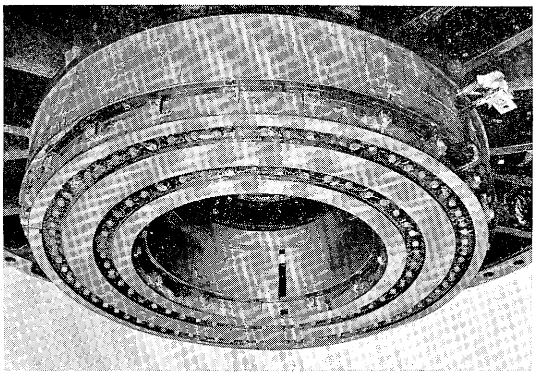

Fig. 6. The electromagnet

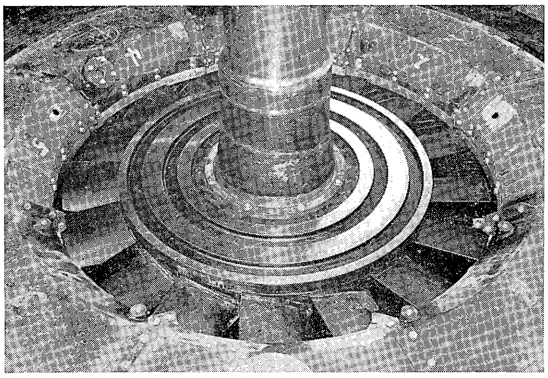

Fig. 7. Fan and magnet pole

ized for mounting the magnetic thrust bearing without causing any appreciable change in the height of the generator. The electromagnet is mounted under the upper bracket which receives the entire thrust of the rotor, thus, eliminating the necessity for any special supports for the magnetic thrust bearing. The upper fan boss is appropriately utilized in the magnet poles with the object of permitting smooth ventilation of the exciting coil and obtaining increased cooling effect. Fig. 5 shows the upper bracket assembling operation of 17 MVA Generator delivered to Tochio Power Plant of the Hokuriku Power Co.

The type "c" electromagnet illustrated in Fig. 1 can be seen below the bracket. Figs. 6 and 7 show the electromagnet and the magnet pole respectively, to be assembled into one unit. The electromagnet is also type "c" having three ring-shaped pole faces with a ring coil inserted between each two rings. The coil supporting plates and the heads of the bolts are only noticeable in the figure.

## IV. RESULTS OF EXPERIMENTS

By using the type "a" model set shown in Fig. 8, experiments were conducted on the relation between the magnetic pull and the exciting current, the problem of eddy current loss, the relation between the compensating winding and the leakage flux, and the relation between the thrust and the friction

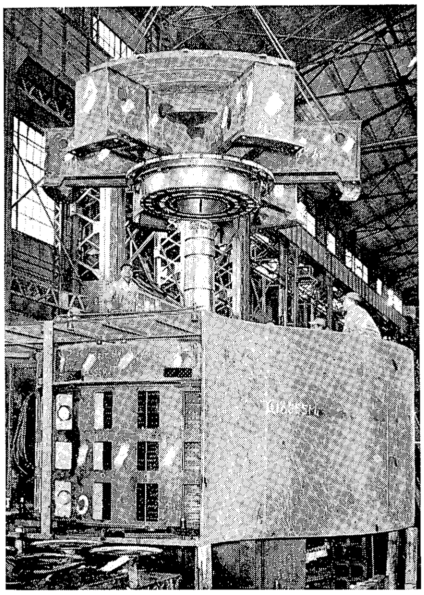

Fig. 5. The upper bracket with electromagnet

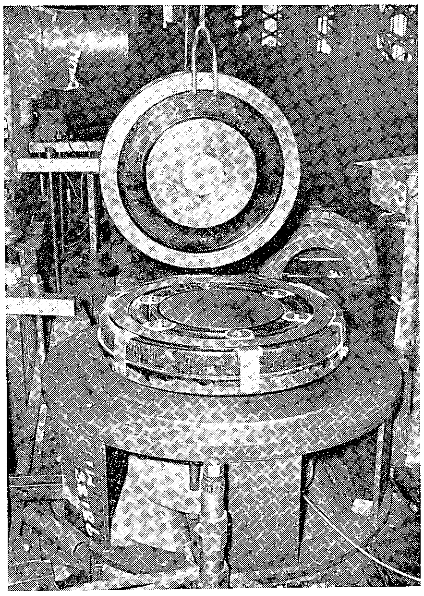

Fig. 8. Model set

loss mentioned in Section II. The results agreed with the afore-mentioned assumptions proving the correctness of our reasoning.

The first application of this thrust bearing was made on 30 MVA synchronous condenser delivered to Shin Sapporo Sub-station of the Hokkaido Power Co., Ltd. This condenser is hydrogen-cooled and would naturally be a horizontal type if the conventional design was used. Even though saving in mounting space and other various gains can be obtained by the use of a vertical type, it could not possibly compete with the horizontal type from the standpoint of friction loss if the conventional thrust bearing were used. However, if the magnetic thrust bearing is used, this defect can natuarally be eliminated. Therefore, the vertical type has been selected. The results showed characteristics superior to those of the horizontal type. In applying the magnetic thrust bearing to the synchronous condenser, since the load on the bearing is its weight only and with no fluctuating thrust as in the water pressure of waterwheel generator, the control system for the synchronous condenser was extremely simplified.

Since then, the magnetic thrust bearings have been applied to Pelton wheel generators having small variation in water thrust against the bearing and practically no variation in the bearing pressure as in the synchronous condenser (generators at Tochio P.S. and Motos P.S. for example), and are at present operating very satisfactorily. The magnetic thrust bearing has also been adopted for the 70 MVA generator under construction for No. 2 Wadagawa P.S.

Actual measurements made on the magnetic thrust bearing equipped on the synchronous condenser at Shin Sapporo Sub-station are taken here for study. The specification of this magnetic thrust bearing is as follows:

Weight of Rotor (Thrust Bearing Load)......41 ton
Type of Electromagnet...........Fig. 1 Type "a"
Capacity of Power Supply.............. 15 V 5 kW
Power Supply.................... 3-phase full-wave, selenium rectifier

Fig. 9 is the curve of the magnetic pull against the exciting current. It can be seen that the mesured values agree extremely well with the theoretical values confirming the fact that the compensating winding is working perfectly and that there are no leakages in the effective flux as had been calculated. In measuring the magnetic pull, an oil-jack provided with oil pressure gauge was used. Before going into the detail of the measurement, let us look at the construction of the bearing.

In the ordinary generator and especially in generator directly coupled to a Kaplan water wheel, a grease lubricated bearing which faces downward is provided for the purpose of limitting the upward floatation of the rotor to within a fixed distance.

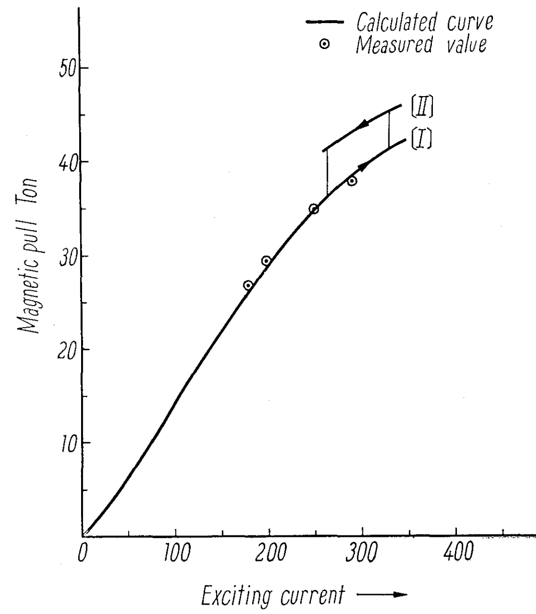


Fig. 9. Exciting current of electromagnet magnetic pull

In the magnetic thrust bearing, the oil surface of the bearing is raised above that of the auxiliary bearing and is designed such that with this bearing continuous operation is made possible.

Now, the measurement of the magnetic pull is accomplished by applying beforehand an upward force ($W_1$) to the rotor with the oil-jack, and gradually increasing the exciting current. The exciting current ($I_1$) is read at the instant the rotor leaves the main bearing and jamps up to the auxiliary bearing.

The magnetic pull $F(I_1)$ corresponding to this exciting current is given by the equation:

$$F(I_1) = W - W_1 \quad \text{.......} \quad (9)$$

Where: $W$ = Weight of rotor

The curve shown in Fig. 9 was obtained by suitably varying the value of this $W_1$. When the rotor slides with the auxiliary bearing, the air gaps become less than at the beginning and the curve (I) of the magnetic pull in Fig. 9 moves over to the curve (II). If the exciting current is increased to more than 330A and then gradually decreased, the magnetic pull will naturally describe a loop in the direction of the arrow point. Since the point on this loop for operation differs according to the amount of voltage fluctuation which may occure in the power supply voltage and to the method by which the exciting current is controlled, the operation should be carried out at the point which is the most effective and also the safest. The explanation concerning the operating point of this synchronous condenser is mentioned later in this section.

This auxiliary bearing has another purpose besides its function as a protective device. In the use of the magnetic thrust bearing, since the main thrust bearing is designed large enough in size to bear the total thrust load so that operation can be continued when failure occurs in the electromagnet, "p" in equation (1) becomes smaller as the electromagnet is operated. Consequently, "$\mu$" increases to disadvantage. When the electromagnet is operated, the necessity of using a smaller bearing other than the main thrust bearing arises for this reason, and hence the auxiliary bearing is to be employed. Especially in the low speed Kaplan wather-wheel generator in which the water thrust is large, the utilization value is still more enhancing. In addition, two and three fold advantages may be obtained by decreasing the size of the support segments and decreasing the peripheral speed at the same time. However, the drawback here is the complications introduced into the control system. Therefore, the most effective use of this auxiliary bearing is in generator having large thrust load.

The relation between the friction loss and the exciting current is as shown in Fig. 10. Without exciting the electromagnet, the total friction loss of the thrust bearing and the guide bearing amounted to 80 kW. With the gradual increase of the exciting current, the friction loss continuously decreased and at 330 A, the rotor was lifted upward to slide with the auxiliary thrust bearing. Therefore, the friction loss of 40 kW on 330 A can be considered as the guide bearing loss. To prevent the rotor from being lifted upward although fluctuations in the exciting current of approximately 10% in magnitude may occure, the exciting current for this experiment was maintained constant on 290 A. This means that during the operation, thrust bearing loss of 14 kW was being produced.

Here, study is again made on the problem of lubricating oil. The above-mentioned experimental data were obtained by using No. 140 turbine oil at the bearing temperature of 45°C. The primary condition for determining the minimum viscosity value of the lubricating oil had been explained as that condition in which the oil film will not be broken by the pressure at the bearing surface. Therefore, with the electromagnet excited, and by using the main bearing, low viscosity oil should naturally be used to reduce the friction loss since the bearing surface pressure will decrease. Also, there is a close relation between the temperature of the oil and the viscosity, that is, when the temperature rises, the viscosity will become considerably low (This change is very large especially for temperature below 60°C).

In cooling the thrust bearing, there is a method in which the oil, supplied from outside, is forced to circulate and a method in which the rotation of the oil itself is utilized for internal circulation. In both methods, cooling water is also used. The energy required to supply this cooling water is not small, and especially in the high head water-wheel generator if water is diverted to the cooling purpose, this loss cannot be neglected. Now, if the electromagnet is excited, the friction loss will decrease and also the temperature of the oil will begin to lower. When this condition is reached, the amount of water for cooling purpose should be adjusted in accordance with the temperature of the oil, so that the oil temperature can be kept constant at a fixed value. This will result in the decrease in the viscosity of the oil and at the same time will reduce the cooling water loss.

From the above standpoint, the lubricating oil was changed to turbine oil No. 110 and the amount of water was adjusted so that the temperature of the bearing would be 55°C with the result that the friction loss was reduced to 33 kW with the exciting current 290 A. This loss is concidered as the true

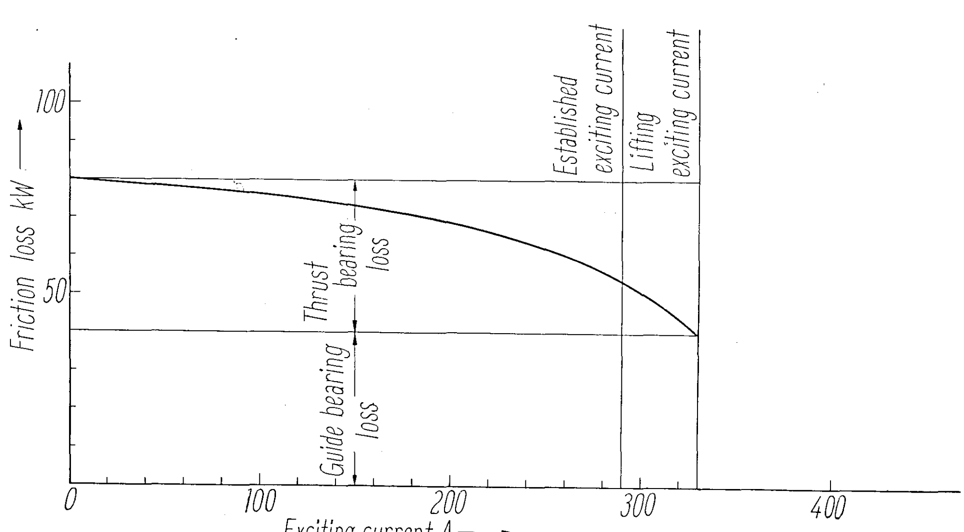


Fig. 10. Exciting current of electromagnet friction loss

friction loss with the magnetic thrust bearing utilized in the most efficient manner. With the excitation loss of the electromagnet as 5 kW, the total loss of the magnetic thrust bearing becomes 38 kW. This value is an indication that the disadvantages of using vertical shaft machines have been completely overcome and the fact that there was a total loss of 475.5 kW in 30 MVA, 1,000 rpm synchronous condenser (1.035 kg/cm$^2$ of hydrogen pressure), is a proof that the total loss is much less than the horizontal type.

Although the first application of the magnetic thrust bearing in Japan for the water-wheel generator, was made on the generator at Motosu P.S., it is reported that an application has been completed on a super-sized low speed Kaplan water-wheel generator in Soviet Russia. The purpose of this application was not only to increase the efficiency but also with the object of decreasing the burden on the thrust bearing since the load including the water pressure which the bearing must sustain, becomes excessively large and with the original design of the bearing, it becomes structurally impracticable. Thus, for large-sized water-wheel generators having large thrust, the magnetic thrust bearing produces secondary usefulness, and at the same time, broadening its utilization range.

Detailed measurements were also made on each characteristics of the magnetic thrust bearing equipped at Motosu P. S. and since the results obtained were as expected as had been the case with the afore-mentioned synchronous condenser, detailed results will not be shown here due to duplication and only the comparison of the efficiencies at unity power factor is shown in Fig. 11.

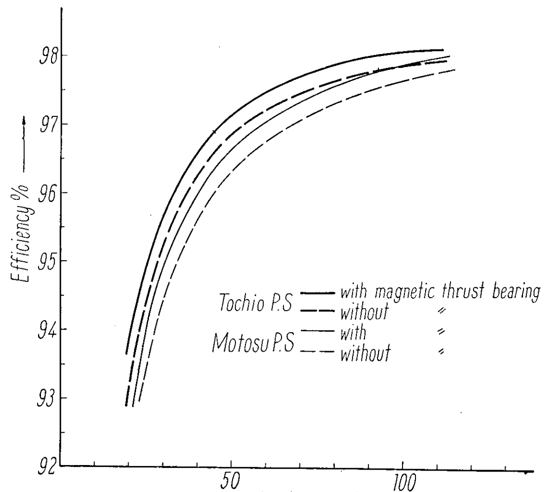


Fig. 11. Efficiency curve

Power station which have this magnetic thrust bearing equipped are Motosu P.S., followed by the completion of Tochio P.S. and Wadagawa No. 2 P.S. which is presently under construction.

The first two power stations are already in operation and the magnetic thrust bearings are playing a very important part in the high efficiency generation of electricity. The specifications for the magnetic thrust bearings of the above-mentioned two generators are as follows:

| | Power Plant | |
|---|---|---|
| | Motosu P.S. | Tochio P.S. |
| Thrust load on generator side (ton) | 32 | 67 |
| Thrust load on water-wheel side (ton) | 4 | 11 |
| Total thrust load (ton) | 36 | 78 |
| Magnetic pull of electromagnet (ton) | 38 | 80 |
| Capacity of excitation power supply | | |
| Exciting voltage (V) | 20 | 20 |
| Exciting current (A) | 280 | 330 |

## V. CONCLUSION

For several years, since the introduction of a new concept of reducing the friction loss in vertical shaft rotary machines by lifting the rotor with electromagnet and decreasing its thrust load, fundamental experiments have been conducted, and, at present, is being actively applied to vertical type synchronous condensers and generators with results far above expectations as explained in the foregoing sections.

However, in anticipation for further development to obtain better results and to widen the range in the application of the magnetic thrust bearings, research and experiments are still being conducted on the method for continuous observation in measuring and controlling the pressure applied to the thrust bearing surface. It is hoped that the magnetic thrust bearing will be effectively utilized on many generators on account of its effectiveness as confirmed by the actual operational data and from experience; it is anticipated that it will play an important part in further improvement of the efficiency of rotary machines.