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THE· LATEST RESEARCH FOR THRUST BEARING

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I. INTRODUCTION

The trend toward hydroelectric power generating equipment having a higher unit capacity and speed is noticeable and the conditions under which the thrust bearings used in such equipment is becoming extremely severe as shown below.

Waterturbine generator: Thrust load 4,500 t, average peripheral speed 15 m/s pumped generator: Thrust load 1,500 t, average peripheral speed 60 m/s.

Experimentation and analysis are necessary for reliability of thrust bearings used under such severe condition and to reduce the bearing losses.

Our ezperimental system for thrust bearings, thrust bearing analysis and experimentation techniques are described and our research on thrust bearings is outlined.

II. HIGH GAPACITY THRUST BEARING EXPERIMENTAL SYSTEM

Al though the analysis technique to be described later is fairly sophisticated, analyisis only is insufficient in thrust bearing research and the analyzed results must be actual proved and supplementary experiments, as needed, are indispensable. Fuji Electric has installed a high capacity thrust bearing experimental system and is conducting experimental research on thrust bearings for this purpose. *Table 1* shows the specifications of the experimental system and *Figs. 1* and *2* show its exterior and sectional views.

Since voluminous data is handled and high precision is required in thrust bearing experiments, this experimental system incorporates various refinements to improve the precision of, and speed-up, experiments.
This system has the following three main features:

Table 1 Specifications of experimental system for thrust bearing

Maximum actual load	1,200 t
Maximum rotating speed	600 rpm
Maximum drive power	2,500 kW
System gross weight	200 t

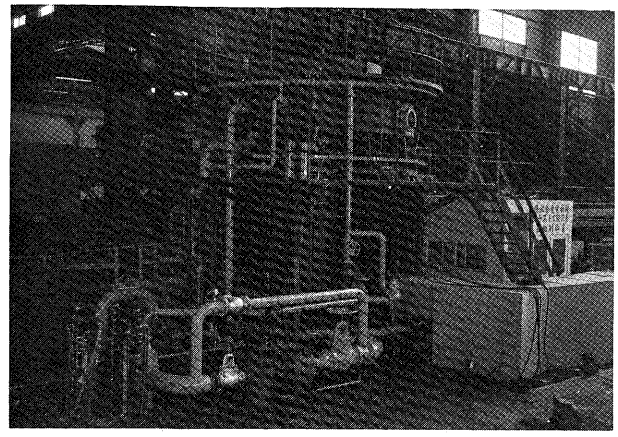

Fig. 1 Exterior view of experimental system for thrust bearing

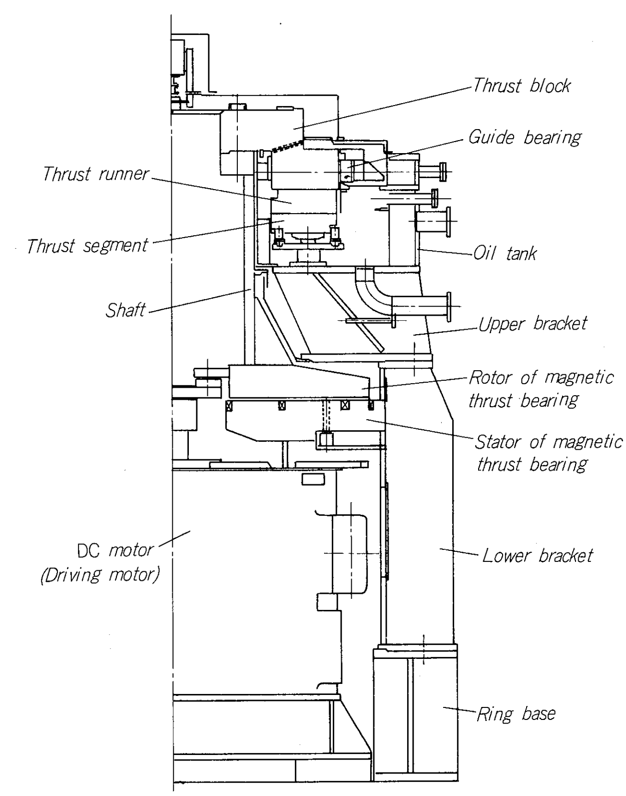

Fig. 2 Sectional view of experimental system for thrust bearing

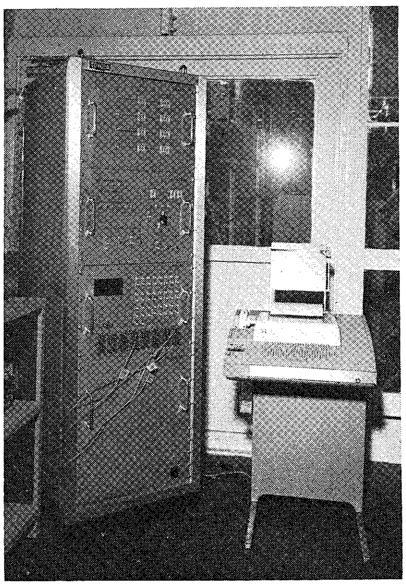

Fig. 3 Exterior view of data processor

(1) Since our uniqe magnetic thrust bearing is used as the load device that acts as the load on the experimental thrust bearing, load setting and control easy.
(2) A load controller and speed controller is furnished. Precise simulation of thrust load and rotating speed changes at starting, stopping, reversing, load rejection, and other operations can be taken.
(3) Data from 80 points that are important to a thrust bearing is processed by an accessory data procesor.

III. THRUST BEARING CHARACTERISTICS CALCULATIONS

Fuji Electric uses a computer to calculate the characteristics of the thrust bearing and detailed studies are made and reliability increased during design. The computer program has the following functions and features:
(1) Lubricating oil viscosity changes due to temperature are taken into account.
(2) Segment thermal distortion, and pressure distortion, and thrust runner thermal distortion are considered.
(3) Since the segment and thrust runner temperature distribution is calculated by the finite elements method, the heat transfer coefficient between the segment/the oil and thrust runner/the oil can be arbitrarily selected for each said face and the calculations are general purpose and calculation accuracy is high.
(4) Since segment and thrust runner distortion is calculated by the finite elements method, the supporting conditions can be arbitrarily selected. Therefore an accurate model of the actual bearing can be made calculation accuracy is high.
(5) Postprocessing of the calculated result has also be refined so the calculated oil film pressure or segmatn thermal distortion can be printed on a line printer and contour lines can be plotted on an XY plotter.

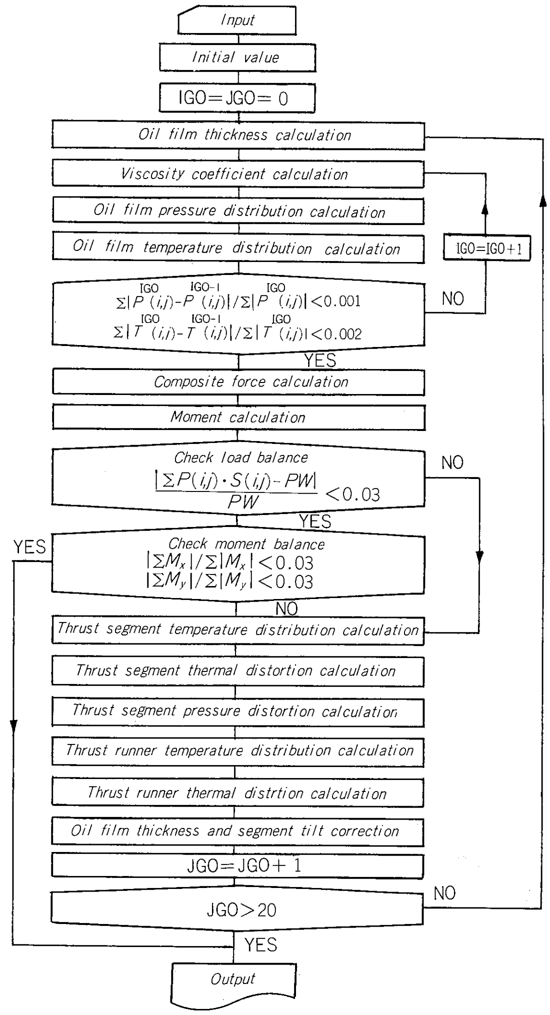

Fig. 4 Flow chart of calculation for thrust bearing characteristics

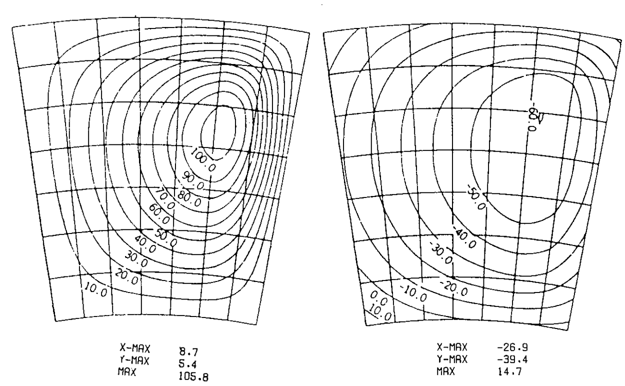

Fig. 5 Contour line of calculated value

The following describes the main calculation contents of this program. *Fig. 5* shows the program flow chart and *Table 5* shows calculation examples for a thrust bearing that is used in a 485 MVA waterwheel generator.

1. Oil film pressure distribution

The base equation for calculating the oil film pressure

Table 2 Influence of segment and thrust collar deflection at characteristics characteristics of thrust bearing

Calculation conditions / Bearing characteristic	When σST, σSP, and σCT considered.	When only σST and σSP considered.	When σST, σSP, and σCT not considered.
Maximum oil film pressure (kg/cm^2)	110.0	91.5	73.3
Maximum segment temperature (°C)	82.9	77.0	71.9
Minimum oil film thickness (μ)	52.0	65.5	71.1

distribution is the Reynold's equation shown below.

where P: oil film pressure, h: oil film thickness, w: rotational engular velocity, o: angle, r: radius

This equation is solved by the calculation of finite difference method.

2. Oil film temperature distribution calculation

The base equation for calculating the oil film temperature distribution is the following energy equation:

where t: oil film temperature, Cp: lubricating oil specific heat, γ: lubricating oil specific weight, J: heat equivalent of work.

This equation is solved by the calculation of finite difference method.

3. Thrust segment temperature distribution calculation

The temperature distribution of the segment slidign face, heat transfer coefficient between the segment and oil, and the ambient oil temperature are given and the segment temperature distribution is calculated by the finite elements method.

4. Thrust segment thermal distortion calculation

The thermal distortion is calculated by the finite element method from the segment temperature distribution and given supporting conditions.

5. Thrust segment pressure distortion calculation

The pressure distortion is calculated by the finite elements method from the oil pressure that acts on the sliding face of the segment and the given supporting conditions.

6. Thrust runner temperature distribution calculation

The temperature distribution of the thrust runner sliding face, heat transfer coefficient between the thrust runner and oil, and ambient oil temperature are given and the temperature distribution is calculated by the finit elements method.

7. Thrust runner thermal distortion calculation

The thermal distortion is calculated by the finite elements method from the thrust runner temperature distribution and given supporting conditions.

Since the segment and thrust runner distortion has a considerable influence on the characteristics of the thrust bearing, high distortion calculation accuracy is a special feature of our program. The influence of distortion is shown in *Table 2*. This table shows that the maximum oil film pressure when the distortion of the segment and thrust runner is not considered is only 67% of that when the distortion is considered.

IV. EXPERIMENT METHOD

1. Measurement method

An extremely large number of measurements were made in the thrust bearing experiments. The main measurements are described below.

1) Thrust load

The thrust spring distortion was measured with a strain gauge fastened to the thrust spring as shown in *Fig. 6* and the thrust load was found from the relation found beforehand between the strain and the load.

2) Oil film pressure

A semiconductor pressure transducer was used to measure the oil film pressure.

Fig. 7 shows how the pressure transducer was installed. Since the span and zero point of the pressure transducer changes with temperature as shown in *Fig. 8*, if the

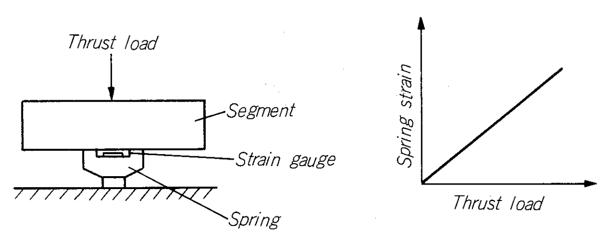

Fig. 6 Measuring of thrust load

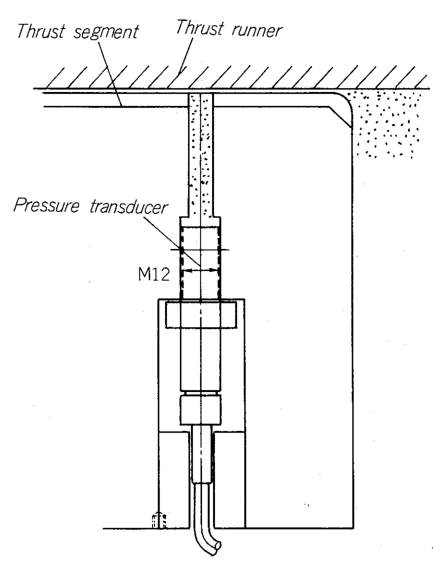

Fig. 7 Installation of pressure transducer

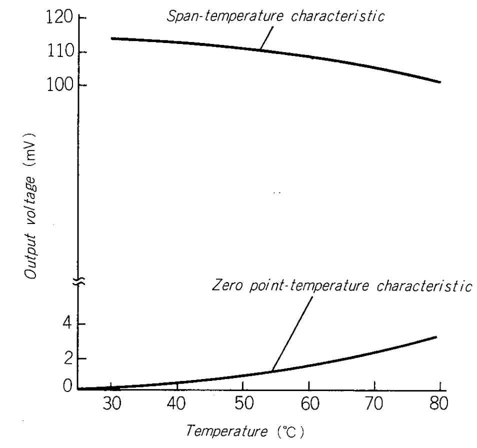

Fig. 8 Influence of temperature at span level and zero level

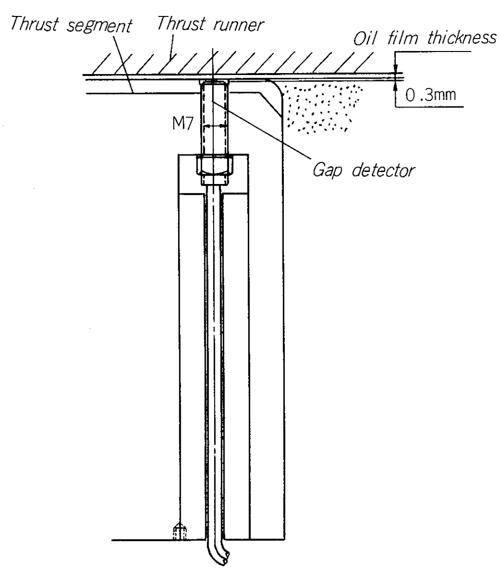

Fig. 9 Installation of gap detector

temperature difference at transducer calibration and at measurement is assumed to be 40°C, a 10 to 20% error will be produced.

Therefore, we held the total error, including that of the amplifier, micro computer etc., to within 2% by measuring the temperature of the transduser during the experiment and performing temperature compensation by means of this temperature and the premeasured transducer span and zero point temperature characteristic.

3) Oil film thickness

An eddy current gap detector was used to measure the oil film thickness. Since the span and zero point of the gap detector also changes with temperature, the same temperature compensation as that for the pressure transducer was performed. *Fig. 9* shows how the gap detector was installed.

4) Oil film temperature, segment temperature, and temperature around segment

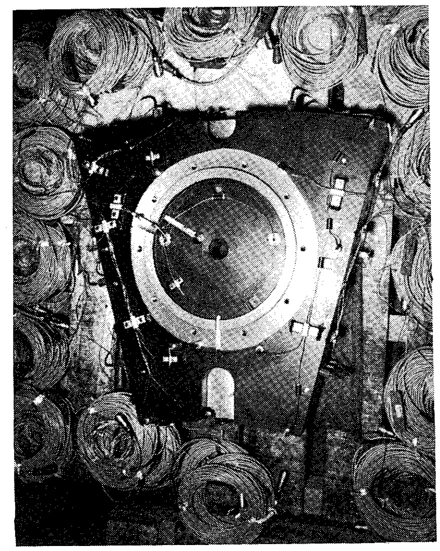

Fig. 10 Installation of thermistor onto segment

A thermistor was used to measure these temperatures. The thermistor is more accurate that a thermocouple and is extremely easy to hadnle. *Fig. 10* shows the thermistor mounted to the segment.

2. Experiment method

There are the two following important points in thrust bearing experiments.

(1) Normal experiments: The bearing characteristics at normal operation are measured.

(2) Transient experiments: The bearing characteristics at starting, stopping, reversing, load rejection, and other transient operations are measured.

Load and speed controller are used to perform these experiments at good precision.

3. Data processing

A computer was used extensively to improve the data processing speed and precision.

Several examples are given below.

1) Oil film pressure, oil film thickness, and segment temperature distribution at normal experiment Contour curves were plotted from the measured data and the maximum value and it postion were calculated to ascertain the normal distribution of the characteristics given above. *Fig. 11* shows the measured oil film pressure distribution as an example.

2) Time change of each bearing characteristic at transient experiment Whether or not there are any abnormal changes in each bearing characteristic must be determined to evaluate the bearing characteristics at the transient experiment.

The time change of all the measured data was plotted on an XY plotter for this purpose.

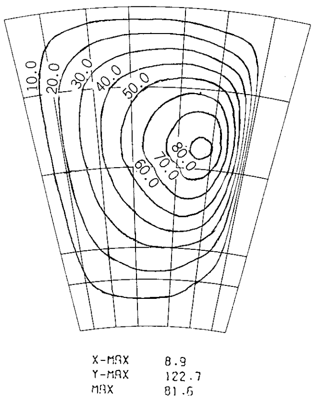

Fig. 11 Example of measured oil film pressure distribution

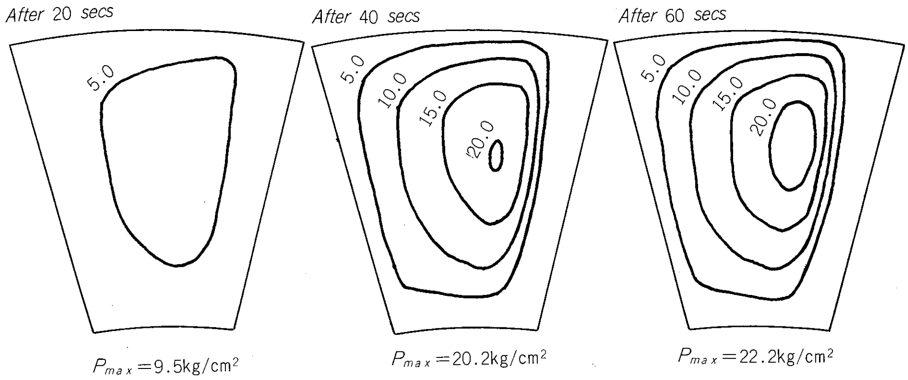

Fig. 12 Transition of oil film pressure distribution measured at transient experiment

3) Time change of the distribution of each bearing characteristic at transient experiment
The time was sectioned at a time interval and the contour curves at each time section were plotted with an XY plotter and the maximum values were calculated for the same purpose as item 2) above.
An example is shown in *Fig. 12*.

IV. CONCLUSION

The development of technology related to high reliability, low loss thrust bearings is an important subject for large capacity waterturbine generator and generator-motor. Fuji Electric is proceeding with earnest research from the standpoints of both experimentation and analysis. The analysis and experimentation methods were outlined. The authors will be happy if this report proves helpful.