The New Development of Measuring EHL Oil Film Thickness for Thrust Bearing

Weimin Zheng Zhaoli Zhang Shenghe Sun
Department of Automatic Test, Measurement and Control
339# Harbin Institute of Technology, Harbin, 150001 CHINA
E-Mail: zhengwm@public.hr.hl.cn

Abstract Through optimizing the electric parameters of the resistance-capacitance (R-C) oscillation, a measuring instrument is developed for measurement of EHL oil film thickness. Actual measurement was made with thrust bearing and actual measurements are in good agreement with theoretical calculations.

Keywords Thrust Bearing, EHL(ElastoHydrodynamic Lubrication), Oil film thickness , measurement, T-C oscillation technique

? INTRODUCTION

Thrust bearings are a key part of large–scale hydro-generators. HEC (Harbin Electric Machinery Company) has a long experience with their manufacturing. They are required to have long service life, high precision, high reliability and lower friction. Therefore, they need good lubrication. It is important to measure the oil film thickness between the runner and the glide segments of the bearings quantitatively for optimization of bearing design and extension of bearing service life. The measurement techniques work for EHL oil film thickness under special conditions only. For example, optical method [1] is well established for measurement of EHL oil film thickness, but it can not be used in practice because it requires one of the contact bodies be transparent. The R-C oscillation technique[2] for EHL oil film thickness measurement has all the advantages of electric resistance method[3] and capacitance method[4]. It is an effective measurement method in practice. The authors research deeply the theory of R-C oscillation technique, from which a measuring instrument is developed for measurement of EHL oil film thickness through optimization of electric parameters. The EHL oil film thickness of space bearings is actually measured with this instrument.

2 DEVELOPMENT OF THE MEASURING INSTRUMENT

2.1 Electric Principle of Test

The electric principle of the R-C oscillation technique used to measure the oil film thickness is shown in Fig.1. The main part of it is the Wien's oscillator as shown in Fig.2, which is composed of an amplifier and a Wien's bridge feedback network. The oscillation condition is determined by the electric parameters of positive and negative feedback circuits. When the amplifier has ideal properties, the transfer function of Wien's oscillator is given by where $k_1=k/(1+ak)$ $a=R_f/(R_F+R_f)$, k is gain factor of amplifier, s is complex variable.

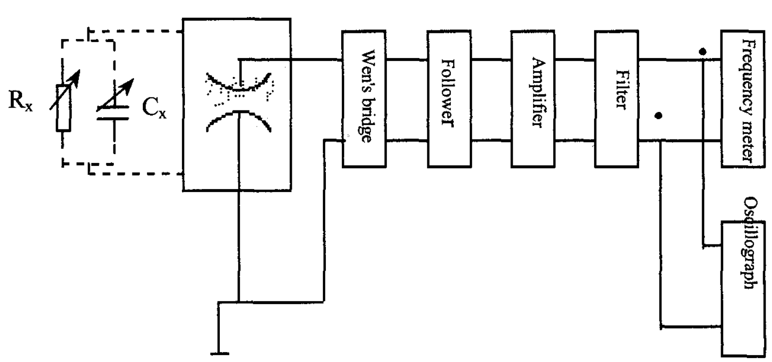


Fig.1 The electric principle of the R-C oscillation technique

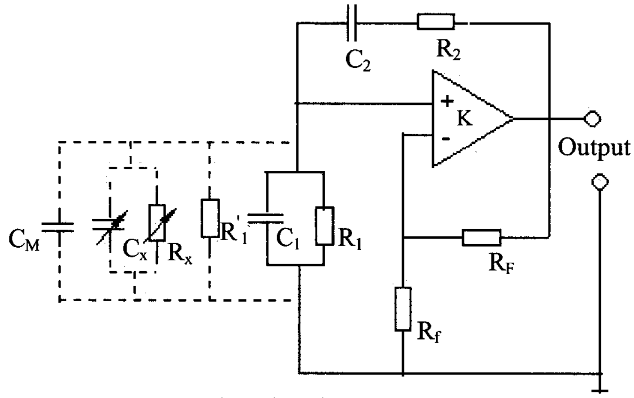


Fig.2 The Wien's oscillator

$$G(s)=\frac{k_1\left(1+R_1C_1s+R_2C_2s+R_2C_1s+R_1R_2C_1C_2s^2\right)}{1+R_1C_1s+R_2C_2S+R_1R_2C_1C_2s^2+R_1C_1s(1-k_1)} \tag{1}$$

The self-sustained oscillation conditions of this Wien's oscillator are where f is the oscillation frequency of the Wien's oscillator.

$$\left.\begin{aligned} f &= 1/\left[2\pi(R_1R_2C_1C_2)^{1/2}\right] \\ C_1/C_2 + R_2/R_1 &= R_F/R_f \end{aligned}\right\} \tag{2}$$

When the Wien's bridge is used to measure the EHL oil film thickness, the lubricated contact is equivalent to the parallel circuit of a variable oil film capacitance C_X and a variable oil film resistance R_X(Fig.1). As shown in Fig. 2, the parallel capacitance of oil film capacitance C_X and distribute capacitance C_M is substituted for C_I, and the parallel resistance of oil film resistance R_X and R'_I is substituted for R_I. In a full EHL state, R_X? 8, when the film thickness changes, C_X also changes, but $R_I(R_I$˜$R'_I)$ is approximately fixed. The oscillation frequency of Wien's bridge changes and reflects the variation of oil film thickness. In a mixed EHL state, there exists metallic contact and R_X? 0, the Wien's oscillator does not oscillate, so we can measure quantitatively the non-metal contact time ratio in a mixed lubrication from oscillation wave-shape. The self-sustained oscillation conditions (Eq.2) of Wien's oscillator are difficult to satisfy in practice, because the oil film capacitance C_X changes obviously. Therefore, the Wien's oscillator works for divergent oscillation with limited amplitude.

2.2 Optimization of Electric Parameters

The measuring properties of the instrument are greatly influenced by the electric parameters of Wien's oscillator. To measure the oil film capacitance C_X accurately in the full EHL state is our purpose of developing the instrument. So we must consider (1) measuring range, (2) resolving power (?f/?C_1). In order to get the optimum electric parameters, we ran optimum tests to determine R_2, C_2, R_1 and R_F/R_f and optimize the resolving power(?f/?C_1) and the range of C_1. The conclusions drawn from the tests are as follows: (1) With measurement in full EHL state, the smaller R'_1 is better. The effect of R_1 on the film thickness measurement decreases with the decrease of R'_1, but the measuring range of the instrument will be decreased when R'_1 is too small. Experiments, proved that R'_1 should be 1~3$k\Omega$. (2)The resolving power of the instrument is high when R_2 is between 4$k\Omega$ and 7$k\Omega$, especially, when R_2 is 5$k\Omega$. (3)The measuring range will increase and the resolving power will decrease with the increase of C_2. The authors recommend C_2 to be 0.01~ 0.03μF. (4)The resolving power of the instrument is high when R_F/R_f is between 1.5and 4. Adjusting R_F/R_f,we can change the initial oscillation frequency of the Wien's oscillator.

The authors select C_2=0.022μF, R_2=5$k\Omega$, R'_1=2$k\Omega$,and develop an instrument for measuring EHL oil film thickness. Adjusting R_F/R_f ,we got an initial oscillation frequency of 11,200kHz when there is no signal input. For divergent oscillation with limited amplitude, it is difficult to establish a relation between oscillation frequency f and capacitance C_1 through calculation. The authors obtain the calibration curve of instrument oscillation frequency f and capacitance C_l by testing (Fig.3).The measuring range of the instrument developed by our own 0~2.2nF, and its resolving power is 3.5Hz/pf.

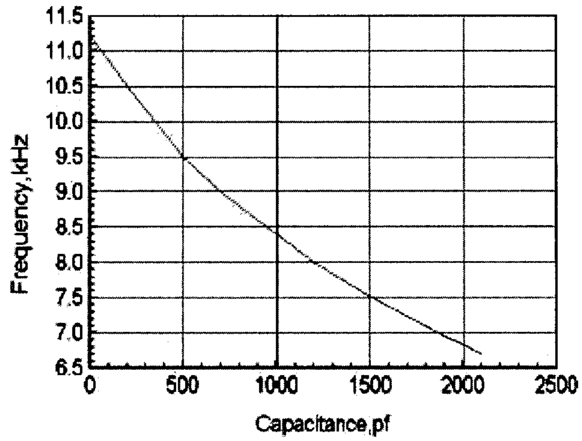


Fig.3 The calibration curve of frequency to capacitance

3.INVESTIGATION OF MEASUREMENT

3.1 Introduction to the Bearings Measured

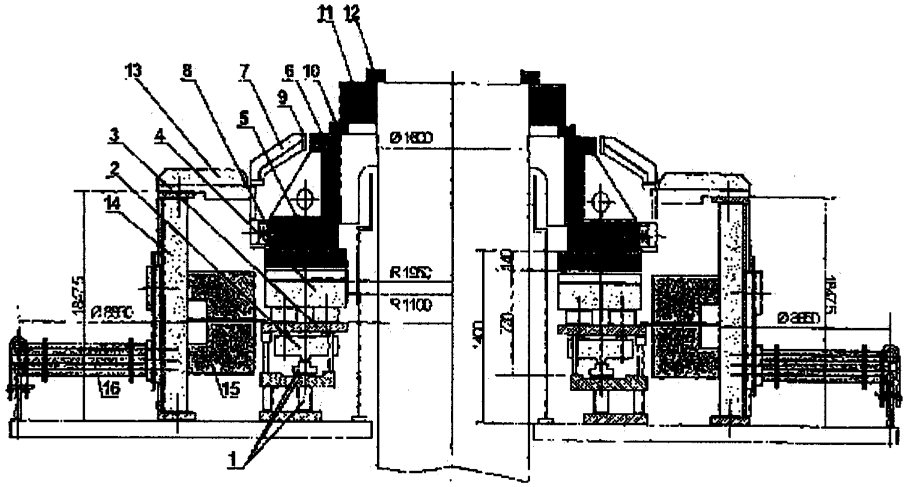
The diagrammatic sketch of the thrust bearings measured is shown in Fig.4. A teflon layered thrust Bearing designed for the future Three Gorges hydro-generators was tested at pressures up to 29.4MN(3000 tons) and rotation speeds up to 107rpm. These conditions allow to predict very accurately the behavior of similar bearings at real operating conditions. Bearing support system and bearing pads were designed by HEC.

3.2 Calibration of Thickness to Capacitance of Oil Film

As shown in Fig.4, we give the calibration curve for oil film thickness h_i to C_X which is the capacitance of oil film of the thrust bearing. It is difficult to establish the calibration curve of h_i to C_X by testing because the thickness h_i of oil film is too thin to measure and the structure of bearing is very complex. So the authors adopt the calculation method to draw the calibration curve of h_i to C_X. When the load is fixed, we can obtain the rolling speed and deformation of working bearing contact point, then the calibration curve of oil film thickness h_i to oil film capacitance C_X.

3.3 Data Processing Method

We can measure in full EHL state the frequency corresponding with $C_l=(C_x+C_M)$ at different speed by using the EHL oil film thickness



1.bearing support
2.load segment support
3.load segment guide ring
4.glide segment/load segment assembly
5.runner
6.thrust block
7.thrust block cover
8.upper guide bearing
9.thrust block seal
10.thrust block bracket
11.rotor shaft
12.rotor shaft bracket
13.oil tank cover (frank)
14.oil tank
15.cooler
16.cooler pipes

Fig.4 Schematic diagram of bearings measured

measuring instrument (as shown in Fig.1) and the frequency meter. Then, we can find the capacitance C_X by using Fig.3. Subtract the C_M from C_l, we can get oil film capacitance C_X for the two bearings. Distributed capacitance C_M can be determined either by actual measurement or statistic method. Finally, we can obtain central film thickness h_i between runner and glider segments of the bearings by using the calibration curve. In partial EHL state, the lubrication condition can be analyzed through oscillation waveshape.

3.4 Results of Measurement

Table1 Measuring results of thrust bearings

Rolling speed Ne, r/min	Results of actual C_M=410.5pf measurement				Oil film Thickness of calculation(μm)	EHL state
	f (kHz)	C_l (pf)	C_X (pf)	hi (μm)		
75 rpm	9.224	630	219.5	0.17	0.14	complete EHL state
80 rpm	9.245	622	211.5	0.18	0.18	complete EHL state
90 rpm	9.285	606	195.5	0.25	0.24	complete EHL state
100 rpm	9.315	592	181.5	0.32	0.32	complete EHL state

Four sets of thrust bearings are measured. And one set of the results is shown in Table 1. In Table 1, *Ne* is the rotational speed of the outer race, hi is the calculated oil film thickness from Eq. (3), which is Hamrock-Dowson equation with thermal and starve influence taken into consideration. where u_i is the rolling speed, Q_i is normal contact load, k_2 is ellipticity, R_b is equivalent radius

$$h_i = 2.69(u_i\eta_0)^{0.67}\alpha^{0.53}Q_i^{-0.067}E'^{-0.037}R_b^{0.464}\left(1-0.61e^{-0.73k_2}\right)C_T C_S \quad (3)$$

along the short axial detection of the contact ellipsoid, u_i, Q_i, k_2 and R_b can be obtained through kinematic and quasi-statistic analyses, $?_0$ is the ambient viscosity of lubricant, a is the pressure-viscosity coefficient, E'is equivalent Young's modulus, C_T is the coefficient for thermal influence on oil film thickness, and C_S is the coefficient for starve influence on oil film thickness.

As shown in Table 1, the measured oil film thickness is in good agreement with the results of calculation. The relative errors are all less than 10 %.

? CONCLUSIONS

1) Using the resistance-capacitance (R-C) oscillation technique, an instrument with high resolution is developed for measurement of EHL oil film thickness.
2) The measured oil film thickness of space bearings is in good agreement with the results of calculation.
3) Cooperating the oil film thickness in measuring instrument with an oscillograph, we can analyze the non-metal contact time ratio through oscillation waveshape in partial EHL state.

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Weimin ZHENG, born in 1971, is a Eng.D candidate directed by Prof. Shenghe SUN in Harbin Institute of Technology. He received his M.S. degree at Harbin University of Science and Technology. His main research field is optical fiber displacement sensor and on-line measurement of oil film thickness.