복합 저어널 베어링 실험장치를 이용한 캐비테이션 연구

Cavitation Experiments Using A Hybrid Journal Bearing Testrig.

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요 약

윤활에서 캐비테이션 문제는 가장 오래된 것중의 하나이며, 현재 많이 사용되고 있는 레이놀즈 경계조건(캐비테이션)은 유막내의 인장력 발생가능성 때문에 그 진실성이 문제되고 있다.

본 논문에서는 복합 저어널 베어링 실험장치를 이용하여 그 가능성이 연구되었다. 이 장치에서 측정된 최저 압력은 −7바 정도였으며 베어링 축회전수에 따라 캐비티가 발생하지 않는 안정영역, 불안정한 음압력 및 캐비티가 존재하는 영역과 두 영역 사이의 천이영역으로 구분할 수 있었다.

1. Introduction

Since the cavitation phenomenon is not clear yet, the cavitation boundary condition for the oil film in bearings has been a controversial question for a long time. The Swift-Stieber boundary condition (often called Reynolds condition) is the most widely used until now. However, the existence of tension in liquids is known for many years; Trevena (1), and many experimentalists have shown the occurance of a sub-cavity pressure loop immediately upstream of the cavity region. There are several papers which permit negative pressures in the oil film; Dowson and Taylor (2). All question lies in the possibility of negative pressure in lubrication, if there is, how much the magnitude of it is. So the aim of this paper is to investigate the controversial question of tensile strength of liquids using a hybrid journal bearing testrig.

2. Experimental Apparatus and Mesurement

For this experimental work we used the hybrid journal bearing testrig which has been made previously by Vermeulen(3). On this testrig the mid section of the bearing showed highly hydrodynamic characteristics for moderate and heavy working conditions (load > and speed >); Fig. 1. Therefore we stated that the testrig can be used for cavitation study. The shaft diameter is 84mm and is driven by a hydraulic motor which can control speed continuously. The load is applied by several dead weights. It is possible

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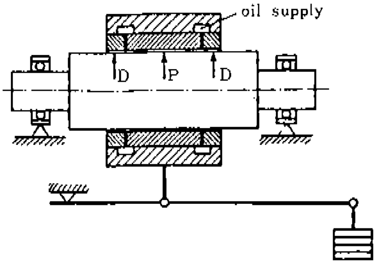

Fig. 1a. A schematic drawing of the hybird bearing testrig.

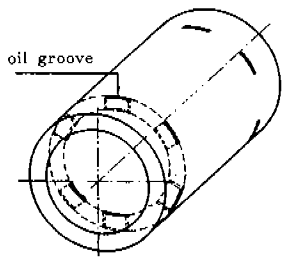

Fig. 1b. Hybrid bearing.

to obtain a fine alignment of the shaft and the bearing using appropriate adjusting devices.

The pressure and the displacements are measured by a quartz pressure trasducer and contactless displacement transducers respectively, which are mounted in the shaft. The problem of rotating coils are solved by using a mercury slipringless transmitter and the signals are amplified, filtered, digitalized and sent to the computer.

All electronic devices are from Vibro Meter Sa, and the models are;

Pressure transducer	6QP500 (piezo-electric type)
Displacement transducer	TW6-100/A (inductive type)
Mercury transmitter	4-MTA/T

A more detailed description can be found in Vermeulen(3).

Meausrement Procedure

1) measure the oil film thickness at both extremities of the bearing. If the values at both sides are not the same, adjust and measure again.
b) Calculate the ecentricity and the attitude angle.
c) Measure the pressure and plot it.

Measurement Programming

The original measurement programming was modified to measure 50 revolutions skipping some revolutions (for example; 1 rev. measurement with an interval of 100 rev.; then 50 rev. measurement; this means 50 rev. measurements on a total of 5000 rev. with each interval of 100 rev.).

Actual measurements were carried out for journal speeds: 800, 1200, 1500, 2100, 2400, 3000 rpm and loads: 4.5, 6.0, 7.5, 9.0, 10.5 KN. This jorunal speed range was chosen because at 1800 rpm the cavity was in transition range, and this load range was selected since 1 dead weight is equivalent to 1500 Newton. We did not use small load range and low speeds because of strong hydrostatic effect in the journal bearing. The lubricant used was Tellus 27. Its viscosity is 0.48 and 0.004 Pa.s at 20 and 100°C respectively. Experimental results are given in Fig.3-6. Figure 2 describes the presenting method of P1, P2, the attitude angle α and the eccentricity ε . For example: (.24,57,11,0) means eccentricity is 0.24, attitude angle is 57°, P1 and P2 are 11 and 0 bar respectively.

Figure 3 shows stable, non-cavity pressure curves for low shaft speeds. The mid section of the curves becomes flat as the load increases. Figure 4 shows unstable pressure curves with cavity for high speeds. The pressure curve, specially negative section, is very unstable and is changing from time to time. The minimum pressure and P2 become high as the load increases, and the P2 becomes

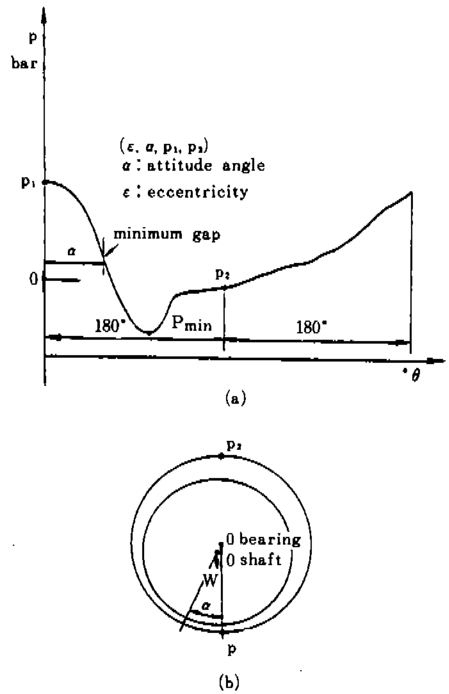

Fig. 2. General interpretation of a pressure curve.

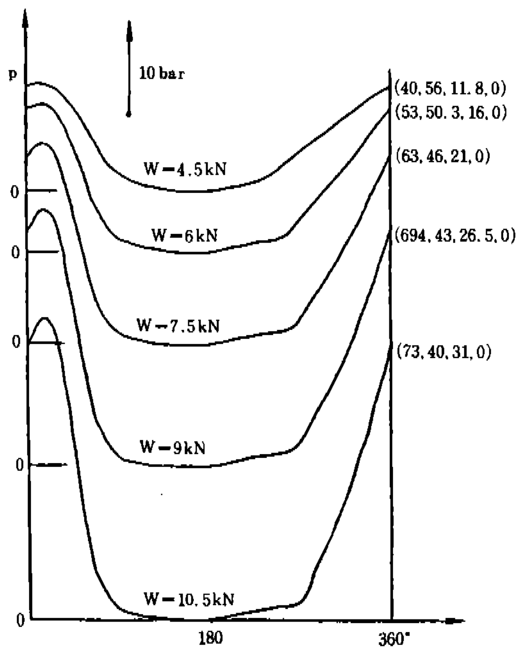

Fig. 3. Stable non-cavity pressure curve. 1200 rpm.

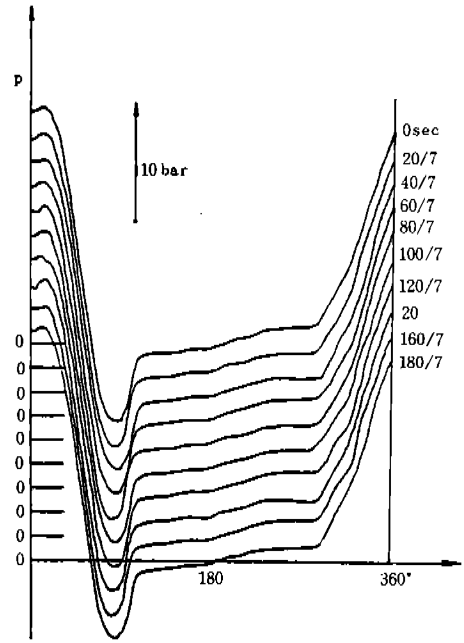

Fig. 4. Unstable curve with cavity 2100 rpm, W=7.5KN, Interval=100 rev. (.425,49,19.4,-0.1), p_{min}=-6.8bar

low as juournal speed increases. In most cases, the minimum pressures are between -6 and -7 bar. There is a small tendency that the negative pressure loop becomes sharp and deep for less load.

Figure 5 shows a transition phenomenon of cavity at 1800 rpm. This is a moderate journal speed, and the cavity appears periodically. When a cavity occurs the minimum pressure is normally higher than -5 bar. The time period depends on the minimum pressure: for low p_{min} the period becomes long, and it is usually about 2 or 3 min. There is a tendency that for high load, the period becomes short.

Figure 6 shows the stability phenomenon of a cavity. There is no cavity for low journal speeds, unless we do not obtain stable conditions. If we change the journal speed suddenly from high to low, there is a cavity and it takes long time to get to the normal state. There is a strong tendency that for high load the time which is required to achive normal state is shorter. It was about 1 hour for 4.5 KN and half an hour for 7.5 KN.

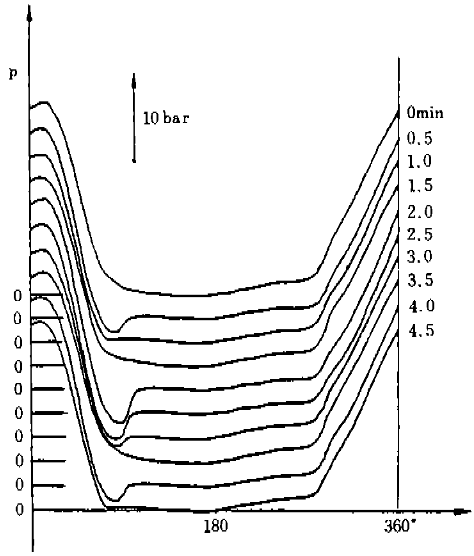

Fig. 5. Transition phenomenon of caivty 1800 rpm, W=7.5KN, Interval=30s (.615,46.4,21,0), $p_{min} \geqq -4.3$ bar

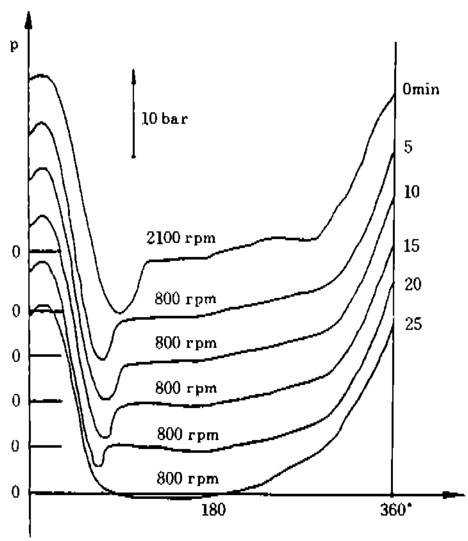

Fig. 6. Stability phenomenon of cavity From 2100 rpm and 7,5KN to 800 rpm and 7,5KN (.53,49.5,19.5,-0.15) to (.724,44.8,20,-0.05) Interval=5 min., p_{min}=-6.9 to -5.5 bar

3. Discussion

As discussed in other papers; Dowson and Taylor(2), Floberg(4), it is shown that the cavitation phenomenon in lubrication results from the fact that lubricant can sustain tensile forces as a metastable state. The reason why there is a cavity for high speed and not for low journal speed can be explained as following: for high speed there is no time to get equilibrium state, so low negative pressure is possible; and for medium speed such as 1800 rpm in this experiment the minimum pressure is higher than some value (about -5 bar in this case) and some times up to 0 bar (periodic state). For low speed there is enough time to go to the stable region, there is no cavity. Another fact which support the above explanation was the stability phenomenon of the pressure distributions. The pressure loop of the low speed case (no cavity) was stable, and it was unstable for the high speed case (cavity), with very short time period and moreover it was irregular. The pressure loop of the transition region was changed periodically with a period of about several minutes.

One interesting observation concerns the magnitude of minium oil pressure (p_{min}). This p_{min} was about $-6 \sim -7$ bar for high speed region and never higher than -5 bar. It was usually higher than -5 bar for the transition cavity case. So there should be a certain level for the mininum pressure to get continuous cavity. This is explained in Fig. 7. Another interesting settlement was that when the journal speed is decreased from the cavity region to non-cavity one, the previous cavity was very stable and it took rather long time ($\sim$ 1 hour) to get the non-cavity cases. The required time to get the final state become long in the cases where the previous was

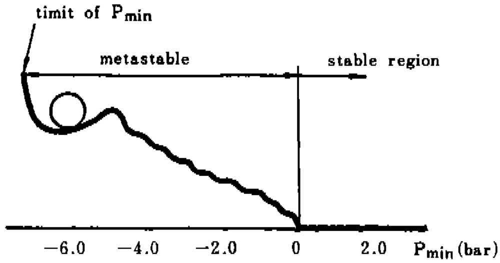

Fig. 7. Schematic Diagram Illustrating a Metastable State for Lubricants.

strong (low minimum pressure) or the reduced speed was close to the transition speed. The above discussion also provides that the cavity phenomenon is a metastable (not stable or unstable) equilibrium process.

The transition speed of the pure hydrodynamic lubrication case might be different from our experimental value of 1800 rpm, because in our journal bearing the whole cavity was enclosed with pressurized oil which is not true for the pure hydrodynamic case. The minimum oil pressure for the hydrodynamic case might also be different from this experiment. Anyway the possible minimum oil pressure in journal bearings would not be lower than about −7 bar for most working conditions.

4. Conclusion

In this experiments following conclusions can be made.

1) The possible minimum oil pressure was about −6, ∼ −7 bar in this testrig.

2) It was possible to classify the cavitation problem into 3 regions depending on the shaft speed,
   a. A stable, non-cavity region for low speeds.
   b. A unstable negative pressure loop with cavity for high speeds.
   c. A transition region between the above speeds.

3) The negative pressure did not occur in low journal speed cases, so there would be a critical time to get a stable equilibrium.

References

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