AN EXPERIMENTAL INVESTIGATION OF OIL FLOW IN HYDRO-SEAL AND MAXIMUM SEALED PRESSURE

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SUMMARY
The oil flow patterns in the hydro-seal are observed experimentally. The steady flow confined between two parallel coaxial rotating disks is used as a model of hydro-seal. Four types of surface texture for inner disks are prepared. They are flat type, groove type, flange type and dimple type. The results are compared with the maximum sealed pressure or the break down pressure of the seal. As a result, the following conclusions are obtained. (1) The flow in the gap of the hydro-seal has 5 types of flow pattern regions. (2) When a rotating speed of the inner disk coincides with the one of the outer disk, the flow is kept steady (region A). (3) When the difference between the rotating speed of inner and outer disks increases, waves or bubbles are generated and the maximum sealed pressure of the hydro-seal becomes low compared with the one in region A.

Keywords: Seal, Hydro-seal, Flow between rotating disks, Oil flow pattern, Maximum sealed pressure

1 INTRODUCTION
The oil flow patterns in the hydro-seal are investigated experimentally. The steady flow confined between two parallel coaxial rotating disks is used as a model of hydro-seal. It has been interesting subjects of investigation for many years. Previous works deal with steady-state laminar flow for infinite or finite disk case [1]...[5] and the stability of the basic flow [6] are investigated. These works deal with the case that the gap between rotating disks is fully filled with liquid. But, in case of the flow in the hydro-seal, the inside of the flow field open to air. In this flow, the primary interest is to observe the basic flows, generation of waves on the inside surface of the fluid and the generation of bubble in the working fluid.

In this paper, the experiments are performed to clarify the relation among instability of the fluid surface, generation of bubble and the maximum sealed pressure (the seal break down pressure).

2 EXPERIMENTAL APPARATUS
The experimental apparatus is shown in Figure 1. Outer (1) and inner (2) disks are attached to the fixed shaft (4) by radial ball bearings and can be rotate in any rotating speeds and directions respectively. Four types of inner disk like as shown in Figure 2 are used.

In the front side of the outer disk, a glass plate (3) is attached. We can observe the working fluid through this glass plate. A standard 35mm camera and CCD video camera are used under appropriate stroboscopic lightning conditions.

Pressurized air Ps can be supplied to the backside gap through the air inlet hole (5). The maximum applied pressure is 0.7 MPa. The maximum sealed pressure or the break down pressure of the hydro-seal can be detected by the abrupt change of the air flow rate and the sound according to break down.

Viscosities of the working fluids are $\mu = 7 \times 10^{-3} \text{ Pa}\times\text{s}$ and $15 \times 10^{-3} \text{ Pa}\times\text{s}$.

The gaps between inner and outer disk are 5 and 10 mm.

Figure 1: The experimental apparatus

Figure 2: Four types of inner disk
3 EXPERIMENTAL RESULTS

3.1 In Case of Flat Disk

In case of the flat disk, Figure 3 and Figure 4 express the observed oil flow and the relation between oil flow pattern and disk speeds respectively. When the inner disk speed (Ni) is the same as the outer disk speed (No), the relation between Ni and No is expressed as the straight line with the gradient of 45°. In the region of near this line, any wave and bubble doesn’t occur (region A).

In the region that the outer disk speed is higher than the inner disk speed, the wave with large pitch and small amplitude occurs on the surface of the working fluid (region B).

When the outer disk speed becomes still larger, the wave amplitude turn to large and bubbles are generated in the fluid (region D).

In the range that the inner disk speed is higher than the outer one, the wave with small pitch and small amplitude occurs slightly on the surface of the fluid (region C).

In still higher inner disk speed region, the wave becomes remarkable and bubbles are also generated in the fluid (region E). Then, the flow patterns are divided into 5 regions by disk rotational speeds like as shown in Figure 4.

The stable region (region A) of the narrow gap is larger than the one for the wide gap. The larger the viscosity of the working fluid is, the wider the stable region becomes as shown in Figure 5. These results are obtained in case of Ps = 0.

Figure 6 shows the Photographs of the working fluid when the seal was break down.

Figure 7 expresses the break down pressure versus disk speeds. When the break down occurs in any flow region (from region A to region E), the bubble can be observed on the inner surface of the fluid and in the fluid. The maximum break down pressure is obtained in case of No=Ni and it is scarcely influenced by the gap.
When the outer or inner disk speed is different from each other, the break down pressure becomes smaller than that of $N_o=N_i$. In case of $N_o\neq N_i$, the outer disk speed influences upon the break down pressure more seriously than the inner disk speed.

### 3.2 In Case of Disk with Flange, Groove and Dimple

Figure 8 shows some observed examples of the fluid flow in these types of hydro-seals and Figure 9 expresses the maximum sealed pressure versus disk speeds. The flow patterns from A to E are almost the same as the one of the flat disk. Compared with the flat disk, maximum sealed pressure of the disk with flange is higher than that of the flat disk for all inner and outer disk speeds.

In case of disk with groove, the maximum sealed pressure is higher than that of the flat disk in the range of low outer disk speed. In the high outer disk speed region, it is almost the same as the one of the flat disk.

Figure 10 shows comparison between disks with dimples and flange. The maximum sealed pressure of the disk with dimples is higher than that of the disk with flange in the low outer disk speed region. Then, in this region, the maximum sealed pressure of the dimple type disk is higher than that of other types of inner disk. It is suggested that the hydro-seal with dimples on the surface of inner and outer disk has high maximum sealed pressure. When the difference between inner and outer disk speed is small, there aren’t serious differences of maximum sealed pressure among four types of disks.
4 CONCLUSION

The following conclusions are obtained.

- The flow in the gap of the hydro-seal divided into 5 patterns
- When a rotating speed of the inner disk coincides with the one of the outer disk, the flow is kept steady (region A).
- When the difference between the rotating speed of inner and outer disks increases, wave has occurred on the inner surface of the flow and bubbles are generated in the fluid. The maximum sealed pressure or the break down pressure of the hydro-seal becomes low compared with the one in region A.
- Disks with flange, groove and dimples make the sealed pressure large
- It is suggested that the hydro-seal with dimples or flange on the inner and outer disk surface makes the maximum sealed pressure large up to the same value as the one for the co-rotating disk (in region A).

5 REFERENCES