Research Committee Report: Tribology of hydraulic equipment and research needs for the future

Research Committee on Tribology, Japan Hydraulics and Pneumatics Society
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ABSTRACT

Hydraulic systems are of great advantages to high-frequency controlling and high-efficient energy-transforming as power transmissions. The prime characteristic is to use hydraulic fluid as lubricant. Hydraulic equipment consists of many bearing/seal parts and its performance depends deeply on them. For improvement of performance of hydraulic systems, it is important to clarify the behavior of their 'tribology'. In our society, the Japan Hydraulics and Pneumatics Society (JHPS), we have been organizing continuously the research committees on tribology and investigating on it. We built test apparatuses and studied experimentally. Also we reviewed the domestic and overseas papers on tribology and discussed them. In this report, we will introduce our activities and researches on tribology of hydraulic equipment, discuss these problems, and mention the trends and the future.

KEYWORDS

Tribology/Lubrication, Hydraulic Equipment, Pumps and Motors, Bearing/Seal Parts, Hydraulic Fluids

INTRODUCTION

Hydraulic drives especially surpass electrical and pneumatic drives in the high-power density per mass or weight. Figure 1 shows the comparison of the operating-limits of several kinds of actuators [1]. From this figure, we understand that it is essential to use the (electro-) hydraulic actuators in the field demanded high-frequency controlling and high-
From the viewpoints of the hydraulic systems as power transmission systems, they consist basically of power sources (hydraulic pumps), control–elements (valves), and actuators (hydraulic motors and cylinders). These components have many bearing/seal parts. Then, the systems depend deeply on the tribological characteristics of these parts.

'Tribology' from the Greek 'tribos' for 'rubbing', is the science of surfaces in moving contact. It is defined that "tribology is the science and technology of interacting surfaces in relative motion and of the practices related thereto (of related subjects and practices) [2]." Recent years, many researchers have been studying 'tribology' [3–5]. Since it is universally recognized that the performance and reliability of virtually many types of machines in use today are critically dependent on the characteristics of their tribological elements. Almost tribologists are interested in several kinds of bearings, lubrication theories, friction, wear, lubricants, and so on. These results are very valid and useful. However, they cannot be applied directly to the bearing/seal parts of hydraulic equipment because the specification is quite different. Therefore, the researchers who have their hand in hydraulics need to clarify the behavior of the bearing/seal parts, that is, tribological parts, of hydraulic equipment.

In order to improve the hydraulic systems more and more, it is indispensable to operate at the high-pressure and reduce the size of the equipment [6]. Also, from the viewpoints of fire prevention and environmental protection, low viscous fluids, such as tap water, seawater, and high water based/content fluid (HWBF/HWCF), are tried to use as hydraulic fluids [7–8]. In order to respond to these demands, it is necessary to clarify lubrication and tribology of the bearing/seal parts.

In this report, we introduce our activities, that is, the history and details of the committees on tribology in the Japan Hydraulics and Pneumatics Society (JHPS). Next, we introduce many researches on tribology of hydraulic equipment in Japan, especially about activities in the universities. The last, we mention the trends and the future on tribology of hydraulic equipment.

ACTIVITIES ON TRIBOLOGY OF HYDRAULIC EQUIPMENT IN JHPS

What is the work of the committee? The research committee’s principal task is to offer the valid information to the members of JHPS. Frequently, a balanced team of experts is assembled to work on the JHPS's project. In such cases, the JHPS's members and experts from other professions work as volunteers. We provide the leadership for interdisciplinary researches and technology–development. The research committees are responsible for carrying out researches or technology–development in specific technical areas.

The research committee on tribology is one of many research committees operating within the JHPS. It is a group of volunteers usually having around twenty members. The
chairman is requested by the JHPS's President and the members are requested by the chairman among the members of the JHPS.

Knowledge developed by research committees can have many effects beyond the publication of a report. There are many benefits from participation in research committee activities.

History of Research Committees on Tribology in JHPS

We have been organizing continuously the research committees on lubrication and tribology of hydraulic equipment in the JHPS [9] because the performance and reliability of hydraulic equipment are dominated by the tribological characteristics of the bearing/seal parts.

The history of the committees is listed in Table 1. The activities of each research committee are published in the special issues of the journal of the JHPS [10–11].

In the first and second terms, we designed test apparatuses simulating the bearing/seal parts of hydraulic equipment. In the next section, we will introduce two of them.

In the third term, the specialists of lubricant and tribology of piston pumps and motors took part in the committees, and discussed generally the problems on tribology of hydraulics. We did not only review and discuss hydraulic pumps and motors but also often invited experts from other disciplines to participate in our committees to broaden the capabilities. We discussed themes of mixed lubrication, fretting, new materials, and so on.

In the fourth term, we mainly reviewed the papers on tribology. We took in the broad sense of the word 'tribology' and discussed many problems. To put it concretely, we mainly discussed four subjects, that is, 'fundamental of tribology', 'hydraulic equipment and tribology', 'materials, surface treatment, and hydraulic fluids', and 'tribological elements of equipment'. In 'fundamental of tribology', lubrication theories as well as bearings are discussed. In 'hydraulic equipment and tribology', the lubrication–performance of piston pumps and motors, and vane pumps are discussed. In 'materials, surface treatment, and hydraulic fluids', the physical properties of materials and surface treatments, and also the application of the usage of seawater are discussed. In 'tribological elements of equipment', we widely discussed tribology such as transmissions, blistering, visualization, space–tribology, and so on. We arranged the results of our research and published the report [12]. They are distributed widely among the members of the society.

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<th>Term</th>
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<td>1:</td>
<td>Research Committee on Lubrication of Hydraulic Equipment (1979)</td>
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<td>2:</td>
<td>Research Committee on Lubrication (1980–1983)</td>
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<td>4:</td>
<td>Research Committee on Tribology (1988–1992)</td>
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Experimental Study by Use of Simulating Test Apparatus

In the first and second terms of the committees, we built the test apparatuses and investigated experimentally. We introduce the outline in this report. Since the JHPS has no laboratories of its own, the experiments were worked in the laboratories of universities.

Experiment of Bearing/Seal Parts Between Valve Plate and Cylinder Block

In order to clarify the behavior between a valve plate and a cylinder block of piston pumps and motors at the virtually operating conditions, we designed and built the apparatus as shown in Fig. 2 [13–15]. Changing in the parameters of four types of fluids (petroleum based hydraulic fluids, solution and emulsion types HWCFs, and kerosene), four types of valve plates, the shaft speed of rotation, and the inlet pressure and temperature, we measured the film thickness, the leakage flow rate, the temperature of a valve plate, and the shaft torque. As a result, we clarified the effects of these parameters on the film thickness, its fluctuation, the power losses, and the degree of wear.

Experiment of Effects of HWCFs on Rolling Contact Fatigue

It is universally recognized that the life of rolling bearings lubricated by HWCFs is much shorter than those lubricated by mineral oils. However, the behavior of the frictional torque and flaking seldom have been reported. Therefore, we built the test apparatus and clarified the effects of HWCFs on rolling contact fatigue [16]. The experimental apparatus is shown in Fig. 3. We used two types of HWCFs (solution and emulsion types) and a mineral oil and measured the frictional torque and the life. As a result, The life by use of HWCFs is clarified.

RECENT RESEARCH ON TRIBOLOGY OF HYDRAULIC EQUIPMENT IN JAPAN

We will introduce some recent researches on tribology of hydraulic equipment at the universities in Japan. We mention only here four research groups studying tribology of hydraulics for want of space. See the details in the references.

FIGURE 2 Test apparatus between valve plate and cylinder block

FIGURE 3 Test apparatus of rolling contact fatigue
At first, we introduce the Prof. Ikeya's group of Technological University of Nagaoka. They are studying experimentally the performance of friction and leakage at the start-up and low speed operating conditions, using the test apparatuses on the supposition of the actual swash plate type hydraulic piston pumps and motors [17-27]. Figure 4 shows their test apparatus of a piston motor. They measure the friction, leakage flow rate, and film thickness. Also they are studying the characteristics of a ball joint connecting a piston and a slipper bearing [28] and the effects of elastic deformation of the slipper bearing [29-30].

Secondly, we introduce the Prof. Nakahara's group of Tokyo Institute of Technology. They study experimentally and theoretically the characteristic of vanes in vane pumps [31-33], considering deeply the elastohydrodynamic lubrication (EHL). Also they measure the friction and the film thickness between a piston and a cylinder bore by use of the test apparatus of swash plate type axial piston pumps and motors as shown in Fig. 5 [34-35].

Thirdly, we introduce the Prof. Hibi's group of Toyohashi University of Technology. They are mainly interested in gear pumps and motors, and the characteristics at the low speed
of rotation of hydraulic motors (in Fig. 6) [36–40].

Finally, we introduce the Prof. Yamaguchi's group of Yokohama National University. They are primarily interested in axial piston pumps and motors. They have been investigating theoretically and experimentally the main bearing/seal parts of hydraulic pumps and motors, that is, between a piston and a cylinder bore [41–43], a slipper and a swash plate [44–47], and a cylinder block and a valve plate [13–15, 48–53]. Figure 7 shows one of their test apparatus of the slipper bearings. Also they have been studying the mixed lubrication [54–55], the thermal and elastic effects [56], and optimum design [57–58] of hydrostatic bearings.

TRENDS AND FUTURE OF RESEARCH ON TRIBOLOGY OF HYDRAULIC EQUIPMENT

We will mention the trends and the future of tribology of hydraulic equipment. As pointed out above, the characteristics of hydraulic systems depend deeply on tribology. Therefore, it is recognized that the trends and the future of tribology almost correspond to those of hydraulic systems.

![Figure 8 Operating limits of hydraulic pumps](image)

Figure 8 shows the limits of operating conditions of hydraulic pumps [59–60]. In this figure, the curved lines are: (1) the limit due to fluid film formation; (2) that due to mechanical strength; (3) that due to heat balance or life of rolling bearings, and (4) that due to cavitation, respectively. One of the future is to breakthrough these limits.

Hydraulic equipment is operated on conditions of high-pressure and wide-speed ranges. From industry–applying hydraulic equipment for automation and energy saving, much lighter and smaller equipment is strongly requested. As to pressure of operating conditions, for example, it has changed to 49–56 MPa for aircraft [61] and 21–35 MPa for construction machineries [62]. In the application to a hydraulic press, the ultra high pressure pumps, more than 70 MPa, are also developed [63].

Recently, it is universally recognized that science and technology should respond environmental/conservation market demands. The high-productivity to meet competition and high reliability and fail-safe design form product liability and environmental requirements are demanded. From the viewpoints of fire prevention and environmental protection, low viscous fluids, such as tap water, seawater, and high water content fluids (HWCFs), are promoted to use as hydraulic fluids. There is already the example of applying hydraulic systems to marine systems [64]. Also, from the viewpoints of human–friendly systems, the noise and vibration should be reduced [65–66].
Otherwise, the contamination control becomes a very important problem [67] since film thickness and restrictors become smaller and smaller.

The bearing/seal parts are designed practically on the basis on experience because of the strict restriction of the size and a large number of the dominating parameters. From the viewpoints of CAD/CAM, new computer modelling techniques are available for the analysis. Summarize these trends and the future in Table 2.

As mentioned above, our society grapples with tribology of hydraulic equipment. Our activities produce many excellent results and we clarify steadily and settle these problems. Also, the committee members published relevant papers under its auspices.

The committee has been a part of these critical breakthroughs by encouraging the research and development to create the present state of the art. We hope that many scientists and researchers as well as tribologists become to be interested in tribology of hydraulics, and study them energetically.

TABLE 2 Trends and future on tribology of hydraulic equipment

| 1) High-pressure, high-efficiency, wide speed ranges |
| 2) Compact, light |
| 3) Usage of low viscous fluids (tap water, seawater, HWCFs) |
| 4) Reduction of leakage |
| 5) Reduction of vibration and noise |
| 6) Contamination control |
| 7) CAD/CAM |

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**APPENDIX**

Members of research committee on tribology
(Fourth term; Chairman**, Secretaries*)

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**Ikeya, M.**, Technological University of Nagaoka
**Ohashi, A.**, Yuken Kogyo Co., Ltd.
**Kazama, T.**, Yokohama National University
**Aiba, K.**, Tokimec Inc.
**Akasaka, Y.**, Hitachi, Ltd.
**Hibi, A.**, Toyohashi University of Technology
**Hirata, K.**, Shinko Engineering Co. Ltd.
**Iboshi, N.**, National Defence Academy
**Kakuta, K.**, Nippon Seiko K. K.
**Kometani, E.**, Hitachi Construction Machinery Co., Ltd.
**Kosodo, H.**, Daikin Industries, Ltd.
**Matsumoto, K.**, Teijin Seiki Co., Ltd.
**Mizuno, K.**, Kayaba Industry Co., Ltd.
**Morita, K.**, Kyodo Oil Technical Research Center Co., Ltd.
**Nakahara, T.**, Tokyo Institute of Technology
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