Importance of Tribology in Positive-Displacement Type of Fluid Machinery and Heat Engine

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1. INTRODUCTION

The industrial revolution in England was based on the manufacturing systems by the power of water mill and rapidly progressed by the innovation of steam engine. It is no exaggeration to say that today's civilization is realized by the development of various types of power machinery, namely fluid machinery and heat engine. The electric energy is converted mainly from thermal energy (mainly steam) of mineral oil, coal and nuclear fuel through generator connected with steam turbine which is a kind of power machinery. There are various types of power machinery as shown in Tables 1a and 1b. They are classified into two types by use. One is absorption type of fluid and/or thermal energy, for examples, windmill and heat engine. The other is provision type of the energies ,for examples, pump, compressor and propulsion. By flow type, they are also classified by two types, turbo type and positive-displacement type. The turbo type began from water mill and windmill and evolve to steam turbine and finally to gas turbine. The positive-displacement type started from reciprocating water pump and developed into steam engine and changed to reciprocating combustion engine. The pumps and motors used in oil hydraulic system for power control are also positive-displacement type.

The aim of this lecture is to show that Tribology is the key

technology in the positive-displacement type of the fluid machinery including refrigerant compressor and the heat engine and as a result to indicate the importance of tribology in today's civilization.

Table 1a Classification of Fluid Machinery and Heat Engine by use

{Energy Absorption}	{Energy Provision}
Water Turbine	Pump
Windmill	Compressor, Blower, Fan
Heat Engine	Propulsion
Combustion	Propeller
Steam Turbine	Jet
Gas Turbine	

Table 1b Classification of Fluid Machinery and Heat Engine by Flow Type

{Turbo type}	{Positive-Displacement type}
Centrifugal	Reciprocal
Mixed-flow	Rotary
Axial	Vane
Cross-flow	Gear
	Screw
	Scroll

2. Characteristics of Positive-Displacement type of Machinery

The conversion between thermal and mechanical energy is performed by the compression work of gas or steam and thus the thermal power which includes the fluid power is the product of pressure by flow rate which is change rate of the volume as well as fluid flow

energy. It is necessary for the positive-displacement type of machinery to make fluid inertia, that is dynamic pressure, as small as possible because this type of machinery utilizes the static fluid pressure. As a result, the condition of low flow rate and high pressure is advantageous for the positive-displacement type and the turbo type of machinery is just the opposite because it makes use of the fluid inertia. Therefore, leakage of the fluid influences significantly on the power loss on the positive-displacement type of machinery.

There must be sliding parts to change the volume of the chamber in this type of machine, for examples, piston/cylinder, rotor/vane, side plate/gear. The friction loss, wear rate and a danger of seizure increase with decrease in leakage flow rate because it is necessary to decrease the clearances between sliding parts. Therefore, the tribology in the sliding parts which relates directly the seal technology is the key technology in the positive-displacement type of machinery.

3. History of Seal Technology in Positive-Displacement Type of Machinery

The reciprocating water pump with multi-cylinder driven by waterwheel through crankshaft was used widely in Europe for supplying water from a river to a city in the latter half of the 16th century. Leathers were used as seals between piston and cylinder. The leather seals had been used also in Newcomen's steam engines and Watt's steam engines until John Ramsbottom innovated piston ring which was made of cast iron in 1854. The life of the seals and the performance of the reciprocating steam engine were improved by leaps and bounds with use of the piston rings of which friction loss is far less than that of the leather seal. It is evident that the wear rate of cast iron is much less than that of leather.

Hydraulic machinery had made rapid progress by the change of

hydraulic fluid from water to lubricant oil made from mineral oil because the lubricating oil is extremely better than water for sealing. Edwin L. Drake in the USA started the oil industry in 1859 as generally accepted. Model T Ford automobile had been started mass production from 1909 and a large quantities of gasoline was supplied and as a result a great deal of lubricating oil could be produced in 1920's. Today's power control machinery is achieved mainly by oil hydraulic equipment and the pumps and motors/actuator are the positive-displacement type.

4. Best Shape and Lubricating Condition for Seal

It is favorable for sealing that the seal area is as small as possible. The cylinder has the smallest surface area as a variable volume chamber and the best machining accuracy. Therefore, the cylinder is the best shape for sealing. This the reason why the positive-displacement type of combustion engine and high pressure oil pump/motor are cylinder type. This is also the cause of failure in the rotary engine.

The friction coefficient under lubricated condition becomes minimum at the beginning of solid contact as we can know it from Stribeck curve. The wear can be ignored in the region of mild mixed lubrication condition. The fluid film thickness between the seal surfaces decrease little even if we make the tribological condition more severe than the mild mixed lubrication in order to decrease the leakage because the leakage flow rate is proportional to the cubic of the film thickness and the solid contact ratio increases as the thickness decreases. Therefore, the mild mixed lubrication is the best lubricating condition for sealing.

5. Today's Triblogical Problems in Positive-Displacement type of Machinery

5.1 Oil Hydraulic Power System

As mentioned above, high pressure is advantageous for the positive-displacement type of machinery. Therefore, the pressure in hydraulic power system is increasing and it reaches to 42 MPa in construction equipment and 56 MPa in combat plane. In the high pressure the elastic deformation and effect of pressure on oil viscosity, namely elastohydrodynamic lubrication EHL must be considered in the design of the tribological elements.

Dr. Jung Jae Youn, the professor of Chonbuk National University, found in his doctor thesis that EHL between vane tip and rotor in vane type of oil hydraulic pump plays an important role and the inlet pressure at the contact has a significant effect on the EHL.

5.2 Refrigerate Compressor

The refrigerant is now being changed from Chloro Fluoro Carbon, which depletes the ozone layer of the earth, to Fluoro Carbon without chloride. The change of refrigerant needs the change of lubricating oil from mineral oil to another oil because the new refrigerant does not dissolve into the mineral oil.

Rotary-vane type of compressor are widely used for air-conditioners as a refrigerant compressor because of compactness and low noise. The lubrication condition between vane and rotor would be more severe than now because new alternative refrigerant has not effect of chloride on the boundary lubrication in metal contacts.

I think that one of the selection for the tribological problem measures is to employ the reciprocating type with cylinders as mentioned above in Section 4, though Daikin Corp. has adopted a swing vane type of rotary compressor which has been use as a vacuum pump to avoid high contact pressure and high velocity.

5.3 Reciprocating Combustion Engine

There are two main problems in the reciprocating engines, one is a decrease in fuel consumption to prevent an increase in petroleum consumption and an increase in exhaust of carbon dioxide, and the other is to clear the strict emission standard.

To answer the first problem, the efficiency of the engine must be improved and thus it is necessary to decrease the friction loss in the tribo-elements and the weight of vehicle including engine parts. However, to decrease the friction and the weight is opposed to the reliability of the engine, namely to keep low wear and to avoid seizure or scuffing.

6. Summary

We can find many tribological problems in the positive-displacement type of machinery and accept the important role of tribology for today's civilization.

It is necessary for answering the today's tribological problems to develop the tribological measuring systems for the tribo-elements in the positive- displacement machinery as well as to develop more accurate and fast computer analysis taking the elastic and thermal deformation and mixed lubrication into consideration.