Improvement of the Low-Speed Friction Characteristics of a Hydraulic Piston Pump by PVD-Coating of TiN

Yeh-Sun Hong*
Faculty of Aeronautical & Mechanical Engineering,
Hankuk Aviation University,
200-1 Hwajeon-dong, Goyang, Gyeonggi-do 412-791, Korea

Sang-Yul Lee
Faculty of Materials Science, Hankuk Aviation University,
200-1 Hwajeon-dong, Goyang, Gyeonggi-do 412-791, Korea

Sung-Hun Kim, Hyun-Sik Lim
School of Aeronautical & Mechanical Engineering,
Hankuk Aviation University,
200-1 Hwajeon-dong, Goyang, Gyeonggi-do 412-791, Korea

The hydraulic pump of an Electro-hydrostatic Actuator should be able to quickly feed large volume of oil into hydraulic cylinder in order to reduce the response time. On the other hand, it should be also able to precisely dispense small amount of oil through low-speed operation so that the steady state position control error of the actuator can be accurately compensated. Within the scope of axial piston type hydraulic pumps, this paper is focused on the investigation how the surface treatment of their cylinder barrel with TiN plasma coating can contribute to the reduction of the friction and wear rate of valve plate in the low-speed range with mixed lubrication. The results showed that the friction torque of the valve plate mated with a TiN-coated cylinder barrel could be reduced to 22% of that with an uncoated original one when load pressure was 300 bar and rotational speed 100 rpm. It means that the torque efficiency of the test pump was expected to increase more than 1.3% under the same working condition. At the same time, the wear rate of the valve plate could be reduced to 40~50%.

Key Words: Low-Speed Friction Characteristics, Hydraulic Piston Pump, Plasma Coating, TiN-Layer, Cylinder Barrel

Nomenclature

$A_b$: Effective area of cylinder barrel (mm$^2$)
$A_p$: Cross-sectional area of piston (mm$^2$)
$\beta$: Balance coefficient
$F_p$: Normal force acting on valve plate (N)
$\mu_o$: Friction coefficient of valve plate

$\dot{p}_i$: Pressure of each cylinder chamber (bar)
$\tau_c$: Moment arm of normal force on valve plate w.r.t. pump shaft (mm)
$\theta_e$: Rotation angle of pump shaft (°)
$T_b$: Friction torque on shaft bearings (Nm)
$T_r$: Friction torque acting on cylinder barrel (Nm)
$T_i$: Ideal input torque of pump (Nm)
$\omega_s$: Rotational speed of pump shaft (rpm)

* Corresponding Author,
E-mail: yshong@hau.ac.kr
TEL: +82-2-300-0287; FAX: +82-2-3158-2988
Faculty of Aeronautical & Mechanical Engineering, Hankuk Aviation University, 200-1 Hwajeon-dong, Goyang, Gyeonggi-do 412-791, Korea. (Manuscript Received September 12, 2005; Revised January 20, 2006)

1. Introduction

In order to save the energy loss of valve-controlled electro-hydraulic actuators, caused by the
flow restriction in control valves and pipe lines, the so-called electro-hydrostatic actuators have been developed and recently activated their application to the aircrafts.

The electro-hydrostatic actuators (abbreviated as EHA in the following) operate in closed circuit, comprising a constant displacement pump and a hydraulic cylinder, as shown in Figure 1. The pump is driven by an electrical servomotor whose angular velocity is controlled to position the hydraulic cylinder.

As for the pump of the EHAs, its operation is almost unsteady because it has to continuously compensate the position control error. For example, if a sinusoidal command signal is input to the position controller, the pump speed changes in the form of a cosine function. Therefore, the lubrication condition of the pump is much worse than that of conventional pumps running at a constant speed in open circuit.

In particular, the low speed friction characteristics of internal pump parts come into serious question as they are influenced by the mixed lubrication condition which augments friction loss and wear rate to a great extent.

Apart from the lubrication performance in the low speed range, the bent-axis type piston pumps with timing gears shown in Fig. 2, seem to most advantageously meet the functional requirements of the EHAs. They allow rapid change of the rotational speed and high operation pressure with low leakage loss, while their pistons are kept almost free from lateral forces.

Hong (2004) analyzed the friction loss of a bent-axis type hydraulic piston pump based on the experimentally identified friction models for shaft bearings, piston heads, spherical joints and valve plate. This study was mainly focused on the high speed friction characteristics of the object pump to show that, in the high speed range over 5,000 rpm, the friction torque is produced significantly by the viscous friction acting on the shaft bearings and the valves plate.

On the contrary, this paper is dealing with the low speed friction characteristic of the valve plate under the mixed lubrication condition. The valve plate usually made of bronze is the softest part of the pump. Therefore, its wear rate is significantly dependent on the lubrication condition. In order to improve the tribological interaction between the valve plate and its mating cylinder barrel, the PVD-coating process was employed in this study. To be more specific, the surface of the cylinder barrel contacting with the valve plate was coated with TiN in the form of a thin layer which was expected to enhance the tribological property even under the mixed friction condition.

The researches carried out by Nevoigt (2000) or Bebber (2002) aimed at the improvement of the tribological property of hydraulic pumps handling environment-friendly fluids by the PVD-coating technology. There were tried and tested various kinds of materials including ZrC which is characterized by good lubricity and affordability.