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Analysis of the cylinder block tilting inertia moment and its effect on the performance of high-speed electro-hydrostatic actuator pumps of aircraft

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Abstract Electro-hydrostatic actuator (EHA) pumps are usually characterized as high speed and small displacement. The tilting inertia moment on the cylinder block produced by the inertia forces of piston/slipper assemblies cannot be ignored when analyzing the cylinder block balance. A large tilting inertia moment will make the cylinder block tilt away from the valve plate, resulting in severe wear and significantly increased leakage. This paper presents an analytical expression for the tilting inertia moment on the cylinder block by means of vector analysis. In addition, a high-speed test rig was built up, and experiments on an EHA pump prototype were carried out at high speeds of up to 10,000 r/min. The predicted nature of the cylinder block tilt at high speeds corresponds closely to the witness marks on the dismantled EHA pump prototype. It is suggested that more attention should be given to the tilting inertia moment acting on the cylinder block of an EHA pump since both wear and leakage flow between the cylinder block and the valve plate are very much dependent on this tilting moment.

1. Introduction

The future development of general aircraft systems is directed towards more electric aircraft (MEA), in which traditional central hydraulic systems are replaced with local electrically powered actuation systems.[1] Successful application of the power-by-wire (PBW) technology to MEA makes EHAs easily realizable. Local electrically powered actuation systems have some potential advantages, such as weight reduction, power saving, and improved maintainability, over conventional central hydraulic systems.[2–5] As shown in Fig. 1, a typical EHA system mainly consists of a variable-speed servo motor, a fixed displacement and bi-directional axial piston pump, a symmet-

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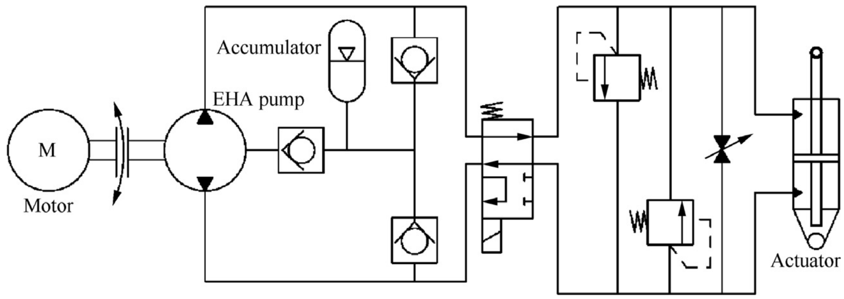

Fig. 1 Schematic of an electro-hydraulic actuation system.

rical linear actuator, an accumulator, and some related valves, etc. In an EHA system, the symmetrical linear actuator of the primary flight control surface is motivated using hydraulic fluid, the velocity and direction of which are controlled by the fluid flow from a servo motor driven hydraulic pump called EHA pump. The accumulator is mainly to maintain the pressure in the system, to cool the hydraulic fluid, and to compensate any fluid loss over the lifetime of the actuator.

Fig. 2 shows the general configuration of an axial piston pump, a type of EHA pump. The cylinder block is held tightly against the valve plate by means of a compressed cylinder block spring, while the valve plate is held in a fixed position. There are several piston/slipper assemblies nested within the cylinder block at equal intervals about the centerline of the cylinder block. The slippers remain in a reasonable proximity with the swash plate utilizing a spherical cup and a hold-down device called retainer. The shaft is coupled with the cylinder block using a spline mechanism and is supported by two bearings at both shaft ends. When the shaft is driven by a servo motor, the cylinder block rotates about the axis of the shaft and thus all the piston/slipper assemblies reciprocate within the cylinder bores because of the hold-down mechanism and the inclined swash plate. During rotation, thin oil films form between the cylinder block and the valve plate, between the pistons and the cylinder block, and between the slippers and the swash plate. These thin oil films serve as combined hydrostatic and hydrodynamic bearings respectively. However, a leakage flow occurs across the sliding interfaces due to the existence of these thin oil films. Unreasonable gaps between the sliding parts tend to increase the leakage flow as well as the potential for undesirable wear.

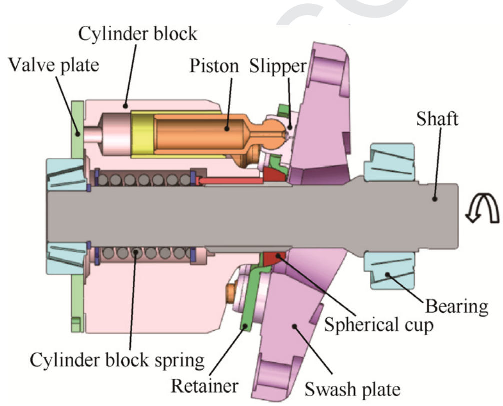

Fig. 2 General configuration of an axial piston pump.

An EHA pump usually operates at a high speed of more than 10,000 r/min since a higher speed means a smaller displacement for a given volumetric flow of the actuator. Therefore, more compact EHA pumps can be realized by increasing the pump speed, which is of importance for improving the power density of the EHA system. Messier-Bugatti and Parker claimed that they have produced very high-speed EHA pumps whose rotational speeds can even reach more than 15,000 r/min. For the aim of higher power density, the continuing development of EHA systems makes a further demand upon EHA pumps for greater rotational speeds. However, high-speed operating conditions will bring several practical problems imposed on EHA pumps.

The first problem regards pressure pulsation.[6,7] The pressure within the cylinder block of an axial piston pump easily exhibits undershooting or overshooting when the pump is operating at a high speed. It is found that the undershooting or overshooting pressure increases almost linearly with increased rotational speed.

The second problem associated with a high speed is the cavitation.[8–11] An axial piston pump with a high speed is likely to be in accompany with obvious cavitation. On one hand, the pump speed should be limited below the critical speed that exactly causes cavitation. On the other hand, a higher suction tank pressure is needed for which a booster pump may be used.

The third problem of a high speed may be concerned with power losses.[12–17] Power losses arising from high speeds mainly involve friction losses due to metal-to-metal contact, and viscous friction and churning losses due to rotating elements interacting with the fluid filled in the pump case. Some special surface treatments of metals such as duplex TiN coatings[14] and novel structures such as Power Boost™[18] have proven to be effective in reducing power losses through experimental studies.

The last problem caused by a high speed is the tilt of rotating parts in an axial piston pump. In the past decades, some theoretical and experimental research has been devoted to the slipper tilt.[19–25] It was found that the slipper tends to tilt away from the swash plate when a pump reaches a high speed. Although some academic attentions have been given to the cylinder block tilt, most studies were occupied with the traditional cylinder block tilt resulting from the pressure difference between the discharge and intake sides.[26–30] In reality, another type of cylinder block tilt due to the cylinder block tilting inertia moment produced by the inertia forces of piston/slipper assemblies cannot be ignored when a pump operates at a high speed. Ivantysynova et al.[29,31,32] included the inertia forces of piston/slipper assemblies in elastohydrodynamic (EHD) and

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