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Variable load failure mechanism for high-speed load sensing electro-hydrostatic actuator pump of aircraft

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High-speed pump;
Partial abrasion;
Slipper pair;
Variable load

Abstract This paper presents a novel transient lubrication model for the analysis of the variable load failure mechanism of high-speed pump used in Load Sensing Electro-Hydrostatic Actuator (LS-EHA). Focusing on the slipper/swashplate pair partial abrasion, which is considered as the dominant failure mode in the high-speed condition, slipper dynamic models are established. A forth sliding motion of the slipper on the swashplate surface is presented under the fact that the slipper center of mass will rotate around the center of piston ball when the swashplate angle is dynamically adjusted. Besides, extra inertial tilting moments will be produced for the slipper based on the theorem on translation of force, which will increase rapidly when LS-EHA pump operates under high-speed condition. Then, a dynamic lubricating model coupling with fluid film thickness field, temperature field and pressure field is proposed. The deformation effects caused by thermal deflection and hydrostatic pressure are considered. A numerical simulation model is established to validate the effectiveness and accuracy of the proposed model. Finally, based on the load spectrum of aircraft flight profile, the variable load conditions and the oil film characteristics are analyzed, and series of variable load rules of oil film thickness with variable speed/variable pressure/variable displacement are concluded.

1. Introduction

More Electric Aircraft (MEA) is the future development trend for general aircraft, which partially replace the conventional central hydraulic system by local electrically Power-By-Wire (PBW) system. The successful application of PBW technology brings less energy loss and higher efficiency. Among them, Electro-Hydrostatic Actuator (EHA) is the key component of the PBW system, which has already been applied in the large civil aircraft, such as A380 and A350.[1–3] However, because of

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Nomenclature

v_p, a_p	linear reciprocating motion velocity and axial acceleration
r, θ	polar radius and polar angle
F_g	slipper gravity
F_{sa}	slipper inertial force of linear reciprocating motion
$F_{a_{\Delta\delta}}$	slipper inertial force of sliding motion
M_{gx}, M_{gy}	extra tilt moments produced by slipper Gravity
M_{sax}, M_{say}	extra tilt moments produced by slipper Inertial force of linear reciprocating motion
$M_{a_{\Delta\delta}x}$, $M_{a_{\Delta\delta}x}$	extra tilt moments produced by slipper Inertial force of sliding motion
$F_{Ts}(p,h)$	friction force between the slipper and swash plate
T_s, T_{tx}, T_{ty}	friction moments between the piston and the slipper socket along the x-, y- and z-
f_s	friction coefficient of piston ball
F_1	bearing force between the slipper and the swash plate along z-axis
M_2, M_3, M_4	anti-overturning torques of the slipper on x-, y- and z-
ρ	oil density
μ_0	oil viscosity at the initial condition
α_p, α_T	pressure coefficient, temperature coefficient
T_0	reference temperature
d_1, l_1	length and diameter of the damping orifices of piston
d_2, l_2	length and diameter of the damping orifices of slipper
$\dot{\mathbf{h}}^{(k)}$	oil film thickness shifting rates vector in kth iteration
$\mathbf{F}'(\dot{\mathbf{h}})$	jacobi matrix of $\mathbf{F}(\dot{\mathbf{h}})$
$\mathbf{E}_k$	diagonal matrix to revise Newton iterative method

the heating problem, they are just used as standby systems.[4] To solve the motor heating problem in EHA, a Load Sensing Electro-Hydrostatic Actuator (LS-EHA) scheme has been proposed, which can solve the heating problem and the dynamic problem simultaneously. The schematic diagram of the LS-EHA is shown in Fig. 1. When the LS-EHA works in high load and slow rate conditions, the pump displacement is reduced through decreasing the angle of the swashplate, and the motor speed is improved at the same time to maintain a stable output of the actuator. Hence, the armature current will also be decreased due to the reduction of the motor torque. Consequently, the energy loss can be effectively reduced and the system heating can be limited greatly.[5,6] Based on the insightful advantages, LS-EHA should be the future development trend for the next generation of actuation system of aircraft.

The LS-EHA system consists of a brushless DC motor, a LS-EHA pump, a Load Sensing Mechanism (LSM), etc. Among them, the LS-EHA pump plays a core role for converting mechanical power into hydraulic power, which directly determines the service life and reliability of the LS-EHA. Fig. 2 shows the cross section of the high-speed pump used in the LS-EHA system, which comprises nine pistons mounted within the cylinder at an equal angular interval around the centerline of the cylinder, the cylinder is pushed towards the fixed valve plate by a compressed cylinder spring, and the com-

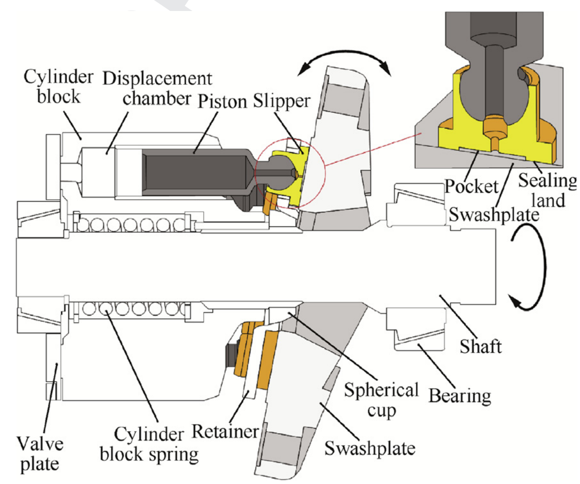

Fig. 2 Cross section of high-speed pump used in LS-EHA.

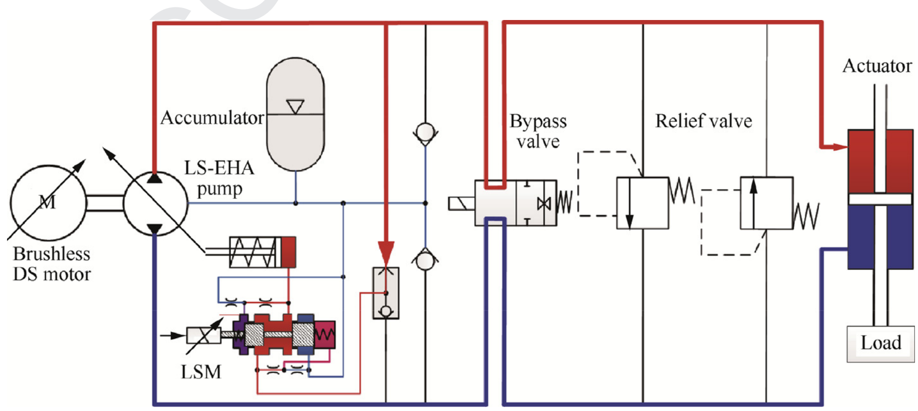

Fig. 1 Schematic of LS-EHA system.

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