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Review on Hydraulic Design & Analysis

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Abstract: The hydraulics are used in various heavy-duty applications involving elevating weight or rotating any mechanical component. The current research studies the work conducted on hydraulic systems using experimental or numerical methods. The application of electro mechanical systems, latest sensor technologies, novel material combinations in hydraulic systems is thoroughly studied. The research findings have shown that significant improvement in performance of hydraulic system can be achieved using various techniques.

Key Words: Hydraulic system, performance, pressure

1. INTRODUCTION:

Rapidly growing rate of industry of earth moving machines is assured through the high-performance construction machineries with complex mechanism and automation of construction activity. Backhoe excavators are widely used for most arduous earth moving work in engineering construction to excavate below the natural surface of the ground on which the machine rests. Hydraulic system is used for operation of the machine while digging or moving the material [1]. An excavator is comprised of three planar implements connected through revolute joints known as the boom, arm, and bucket, and one vertical revolute joint known as the swing joint [2]. Kinematics is the science of motion which treats motion without regard to the forces that cause it. Within the science of kinematics one studies the position, velocity, acceleration, and all higher order derivatives of the position variables (with respect to time or any other variables) [3]. The excavator linkage, however, is a complex link mechanism whose motion is controlled by hydraulic cylinders and actuators. To program the bucket motion and joint-link motion, a mathematical model of the link mechanism is required to refer to all geometrical and/or time-based properties of the motion. Kinematic model describes the spatial position of joints and links, and position and orientation of the bucket. The derivatives of kinematics deal with the mechanics of motion without considering the forces that cause it [4]. In the hydraulic system of civil aircraft, the piston pump is one of the most critical power components. The pumps convert mechanical energy into hydraulic energy, supplying power to the actuators to fulfill the flight posture adjustment, and retraction and extension of the landing gear and braking. Due to their compact and simple design, swash plate type axial piston pumps are widely used in the aviation field, and they are capable of working at extremely high pressures and speed while maintaining high overall efficiency.

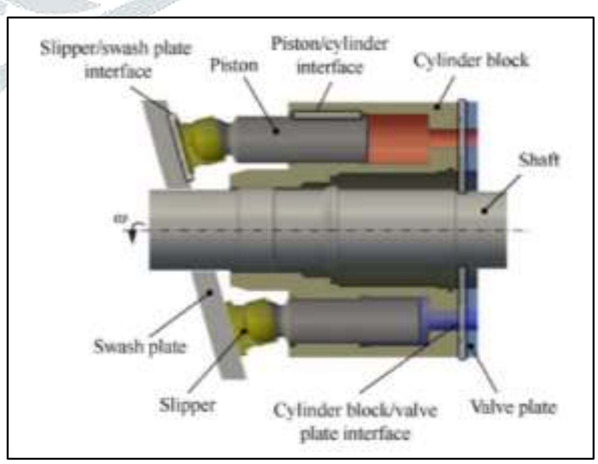

Fig. 1 Lubricating interfaces in swash plate type axial piston machines [30]

The lubricating gaps of the friction couples in piston machines represent the main source of power loss. The three main lubricating gaps (Fig. 1) [30] in these machines must fulfil the functions of sealing and bearing. Unlike other tribological contacts, the gaps of axial piston machines fulfill simultaneously bearing and sealing functions under extreme oscillating loads, making the optimization of gap geometry an extremely challenging task. Besides the main movement (for example, axial movement and piston spin motion for the piston), a micro movement is performed in the piston, slipper and cylinder block, changing the film thickness and generating an additional squeeze film effect. Recently, the problem of friction couples has become a hot topic due to its importance and complexity.

2. LITERATURE REVIEW

Zhang and Chao et al. [5-8] investigated the cylinder block tilt in a high-speed electro-hydrostatic actuator pump of aircraft, considering the effect of piston-slipper assembly mass difference and the geometric errors of the cylinder block. The schematic of electro hydraulic actuation system is shown in figure 2 below.

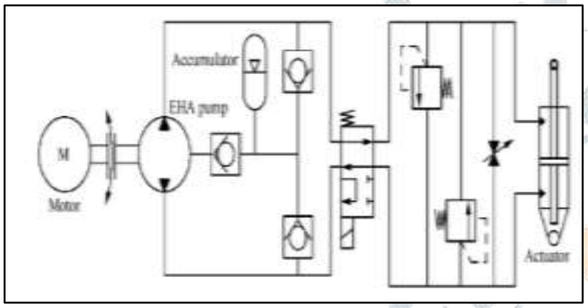

Figure 2: Schematic of an electro-hydraulic actuation system [7]

Ouyang et al. [9,10,11] conducted dynamic analyses of the swash plate vibration and pressure pulsation of an aircraft piston pump based on fluid-structure interactions (FSIs), and presented the attenuating characteristics of the integrated buffer bottles. In addition, the researchers from Beihang University have carried out effective studies and achieved significantly in fault diagnosis, and prognostics and health management (PHM) of aviation mechatronic systems and components.

Wang et al. [12,13] analysed the failure mechanism of high-speed aircraft pumps, and presented the fault diagnosis methods based on the layered clustering algorithm, Dempster–Shafer evidence theory and a nonlinear unknown input observer.

Ma et al. [14-18] studied the typical failure modes of the aircraft hydraulic pump such as wear, fatigue, and thermal aging, and proposed the accelerated lifetime test methods including strengthening the load and worsening the operation conditions.

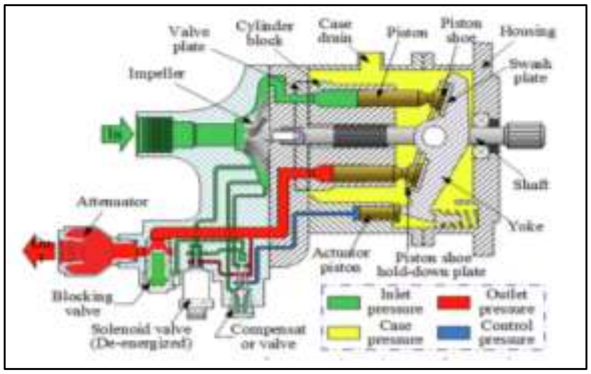

Fig. 2 Cross-section view of a typical civil aircraft hydraulic pump [14]

Pelosi,[19] Zecchi [20] and Schenk [21] investigated the fluid structure interaction modeling of the three primary sliding interfaces in swash plate type axial piston machines. In their dissertations, each lubricating interface model can capture the complex fluid-structure interaction and thermal phenomena affecting the non-isothermal fluid film conditions. In particular, the models consider the change in fluid film thickness and squeeze film effect due to the component micro-motion as well as the elastic deformations of solid boundaries. The elastic deformation of the surfaces is related to the fluid film pressure and thermal stresses. The models couple iteratively different numerical domains and solution schemes, as depicted in the case of piston/cylinder The numerical model can be used to investigate better lubricating interface designs, including novel material combinations [22,23] and micro-shaped surfaces.[24]

The researchers in MAHA [25,26] discovered that a micro metric sine waved piston shape could reduce power loss generated in the piston/cylinder assembly. Simulations have demonstrated the potential decrease of overall power loss up to 50% at full displacement and 65% at partial displacement at higher pressures, and even up to 20% and 60% at full and partial displacements, respectively, at lower pressures. These results represent a major breakthrough in this research direction, suggesting that an even deeper study of the possible new technologies will lead to a new generation of pumps and motors.

Seeniraj et al. [27] found that among the passive design methods, precompression grooves and precompression filter volume (PCFV) were most effective in reducing noise sources. The authors also explained the limitations of precompression grooves and PCFV, and further proposed a new design method which combines the precompression grooves, PCFV and decompression filter volume (DCFV).

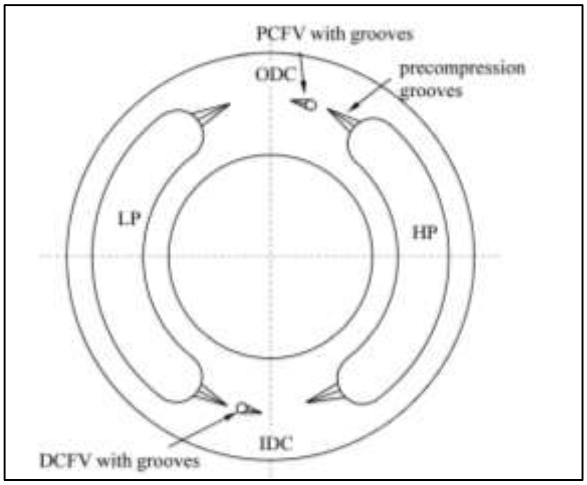

Fig. 3 Valve plate 3 (VP3) with precompression grooves, PCFV with groove and DCFV with groove [27]

Xu et al. [28] proposed a new design method for the transition region of valve plate based on the matching of the flow area and the reduction of transient reverse flow. The authors discussed the impact of the flow ripple in the discharge line of an axial piston pump and the impact of the pressure overshoot and undershoot in the piston chamber on the fluid borne noise. The results showed that the new method could reduce the flow ripple and eliminate the pressure overshoot and undershoot. In 2016, this research group continued the investigation of the potential of flow ripple reduction using a combination of cross-angle and pressure relief grooves. [29]

Manring and Dong [31] pioneered the analysis of the control and containment forces acting on the swash plate. In their research, the dynamic characteristics of the control and containment forces were calculated by deriving instantaneous and average equations of the motion for the swash plate. The results showed that using a secondary swash plate angle could limit the magnitude of the required control effort for the pump, and further reduced the flow ripple in a large range of operating conditions.

Kim and Ivantysynova35,36 proposed the concept of swash plate active vibration control with Two-Weight Notch Least Mean Square/Filtered-x Least Mean Square (LMS/FxLMS) Filters. The concept of AVC is the reduction of the swash plate vibration by means of creating a destructive interference force using the swash plate control. As a pump rotates, the oscillating swash plate moment (MX) is converted to the oscillating force (FSL) which is acting on the swash plate control actuator. The active vibration control adjusts the high response servo valve and generates a destructive interference force to the oscillating force (FSL) as shown in Fig. 4 (in this figure, FSL represents the self-adjusting force; FControl represents the control force; SPAcc represents the acceleration of the swash plate; usv represents the control voltage of servo valve)

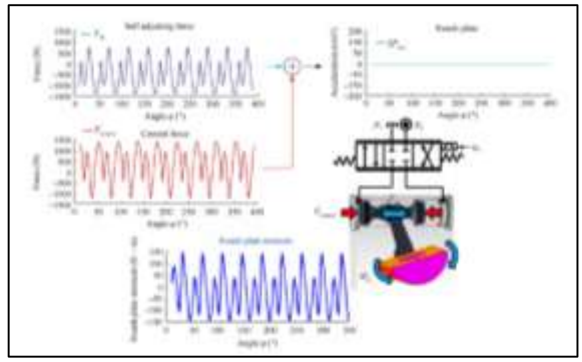

Fig. 4 Concept of swash plate AVC [32,33]

5. CONCLUSION

The development of hydraulic pumps is accelerated with the recent advancements in CFD simulation techniques, sensor technologies along with material development. The paper presented an overview of the description, future directions and critical technologies of the piston pump used in hydraulic systems. The insight of critical technologies used in hydraulic systems is also presented.

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