Design and Performance Analysis of a Local Electro-hydraulic Generation System

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Abstract. This paper is aimed at a design of a local electro-hydraulic generation system following the trend of more electric aircraft. This design integrating a motor and a pump is called electric hydraulic pump and it is applied as the power unit of the whole system. Modeling and sub-models based on AMESim are built as well as the primary experiment validation. To enhance the precision of the model in AMESim and verify the pressure fluctuation as well as the pulsation when the system is working, the model of pump designed as a super component with nine pistons is present. Furthermore the leakage from the swash plate and the slipper, pistons and the valve plate are taken into consideration. The preliminary experiments show that the performance of the local electro-hydraulic generation system is also acceptable. Electric hydraulic pump that brings the weight and noise benefits can be the substitute of traditional pumps and motors.

Keywords: Electro-hydraulic pump · Local electro-hydraulic generation system · Simulation

1 Introduction

Both militaries and civilian fields have attached great importance to the development of aircraft weight loss and efficiency. On the other hand, the application of electrical technology to aircraft has become more and more widespread under the trend of MEA (More-Electric-Aircraft) and AEA (All-Electric-Aircraft). MEA and AEA are general names for aircrafts that combines electromechanical systems with airplanes. In those aircraft, the secondary energy such as hydraulic and pneumatic is replaced by electric energy mostly even totally. Compare with the traditional hydraulically actuated aircraft, MEA and AEA have great advantages in terms of power, weight, reliability, installation and maintenance. The efficiency of aircraft energy transmission is boosted while reducing weight and maintenance costs.

Local Electro-Hydraulic Generation System (LEHGS) is a hydraulically actuated aircraft used to replace the traditional central hydraulic system gradually under this trend. In the design of the most advanced passenger aircraft, like A380 and B787, an EDP (Engine Drive Pump) is used as the main power source and an EMP (Electric Motor Pump) for the backup. A LEHGS expected to be used in the emergency

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hydraulic system of aircraft, landing gear retractions, front wheel turning system even braking system is designed in this paper as well as the emulation and experimental verification. The second part of this paper describes the schematic design of the LEHGS while third part shows the verification of modeling and simulation. The fourth part demonstrate the experiments which validate part of the performance of LEHGS.

2 System Description

The LEHGS is composed of a fuel tank, an electro-hydraulic pump, the motor controller, three oil filters, two contamination indicators, a serial of valves, temperature sensors as well as pressure sensors. The schematic diagram of the LEHGS with the loading platform is shown in Fig. 1.

The tank is used for oil supply and heat dissipation. The electro-hydraulic pump unit integrating a motor and a pump is the primary power source of the whole system. This design removes the coupler linking the shaft and two dynamic friction pairs, therefore the efficiency and the impedance of leakage are both improved. The LEHGS controlled by an independent control unit whose kernel is a digital signal processor (DSP). Rotate speed of the motor is adjusted according to the system pressure fluctuation to provide a steady flow output. On the other hand, the states of system such as temperature, pressure, flow are transformed into digital signal sent to the flight control computer (FCC). Meanwhile, Filters are used to ensure the oil cleanliness of both inlet and outlet of the pump. Pressure sensors located at the outlet of pump and the oil tank are used to cope with speed calculation, pressure pulsation as well as the surveillance of the pressure in the tank. Temperature sensors embedded inside the motor and the oil tank can collect the temperature for alarm when the system is working in a limit circumstance.

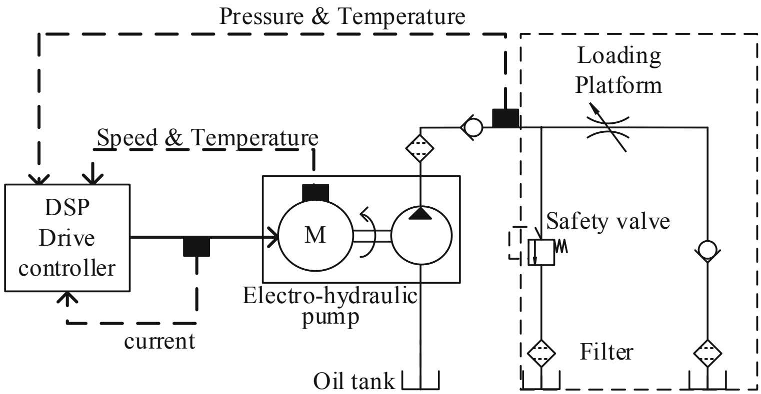

Fig. 1. Principle diagram of the local electro-hydraulic generation system.

3 Modeling and Simulation

In order to verify the performance of LEHGS, simulation based on AMESim (AMESim is a software which can assist the analysis and optimization of a design, so as to help with reducing the cost of development and shorting the development cycle) is processed. The model of system consists of a motor and a pump. Result of efficiency, pressure fluctuation and pulsation are obtained by emulation.

3.1 Modeling Based on AMESim

The AMESim modeling is made up by two sub-models: motor sub-models and pump sub-models.

To narrow the gap between the results of the simulation and the actual apply for both pressure pulsation and flow, the modeling of the pump made by super components is considered while the motor uses the brushless DC motor model from the AMESim platform.

3.1.1 Modeling of DC Motor

A schematic of the motor submodel in LEHGS is illustrated in Fig. 2. According to Eq. (3.1), the theoretical output flow is proportional to the rotation speed.

$$q_t * w = q \tag{3.1}$$

q_t means the displacement of pump; w is the rotation speed, q is the theoretical flow.

Therefore, double-loop is adopt in motor drive. The external loop is speed loop while the inner one is current and PI control law is used in both of them.

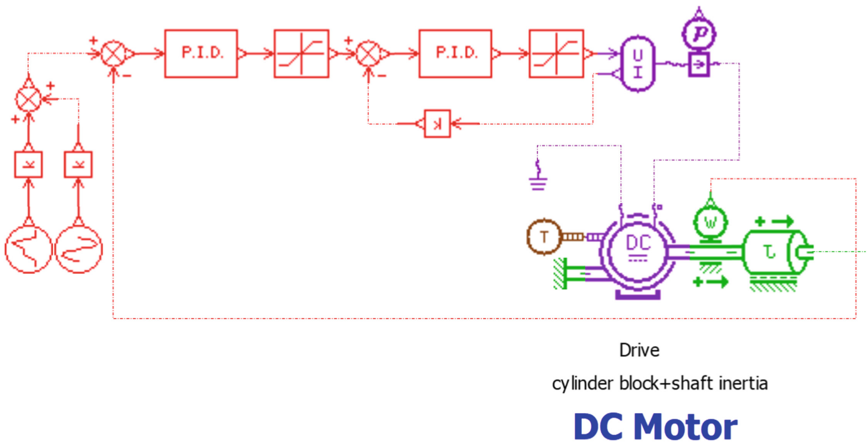

Fig. 2. Chart of the DC motor in system.

3.1.2 Modeling of Pump

To make sure the accuracy of this model which can show the pulsation and pressure fluctuation, the model of pump from AMESim library is abandoned while a super component built with nine pistons is adopted in simulation. As the Fig. 3 shows, the friction and leakage of plungers and plunger chamber, slippers and the swash plate are taken into consideration. Figure 4 shows the relationship between relative position of a single plunger and flow.

In order to verify the efficiency of LEHGS, the viscous force during the motor and the pump rotating in oil, Coulomb's friction force and static friction factors are considered in this model.

According to Eq. (3.2), the output power of the LEHGS P_0 can be expressed as:

$$P_0 = \Delta p \times q \tag{3.2}$$

Where Δp means the pressure of the LEHGS, while q is the flow.

The efficiency of the whole system η is given by expression (3.3):

$$\eta = P_0 / P \tag{3.3}$$

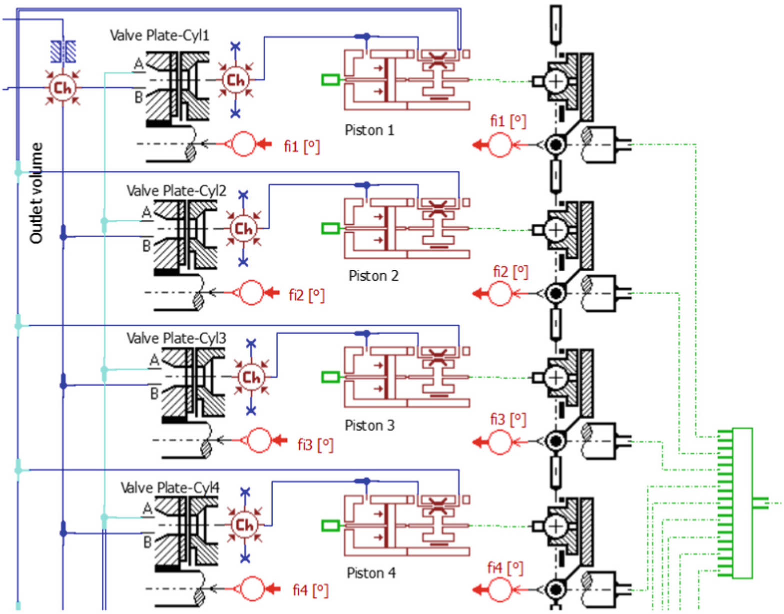

Fig. 3. Hydraulic chart of sub-model of pump in AMESim.

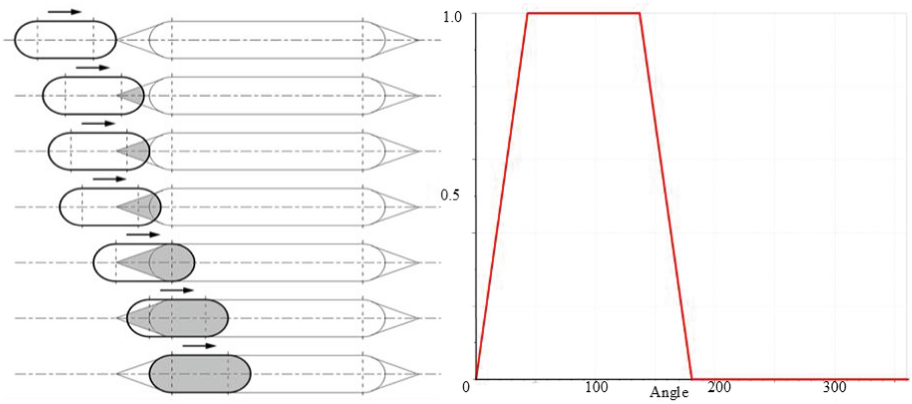

Fig. 4. Relationship between the relative position and flow.

3.2 Simulation Analysis

Parameters of the motor and the super component should be set after the model finished. The system parameters are shown in Table 1. Flow of outlet, pulsation of the system, pressure fluctuation can be obtained from the simulation. The results are shown in Figs. 5 and 6.

Table 1. Basic parameters of an LEHGS

Parameter	Value
Bus voltage (V)	270
Max speed (r/min)	13000
System pressure (Mpa)	28
Pump delivery (mL)	1.2
Rated power (kW)	10
Continuous current (A)	40

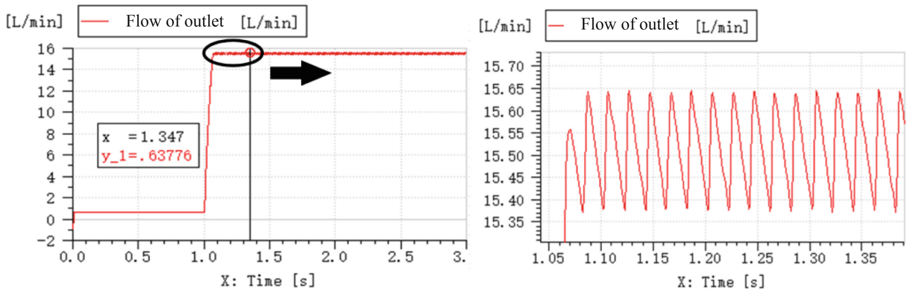

Fig. 5. Result of flow and pulsation simulation.

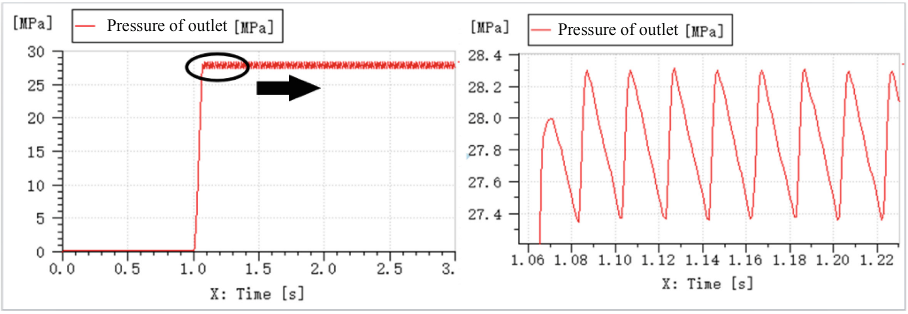

Fig. 6. Result of pressure and fluctuation simulation.

As is shown in Fig. 5, according to the simulation, the average flow of LEHGS is 15.5 L/min while the amplitude of flow pulsation is 0.15 L/min. Minimum flows of the system, 15.4 L/min, meets the requirements of design which is shown in Sect. 4. As is shown in Fig. 6, LEHGS starts without load until simulation time is 1 s and the pressure of the system ascend from 0 Mpa to 27.8 Mpa within 0.2 s. The peak-to-peak value of pressure fluctuation is below 0.9 Mpa and the maximum pressure is 28.3 Mpa while 27.3 Mpa is the bottom value. It's an ideal result based on simulation.

According to the simulation and Eq. (3.3), the global efficiency of the LEHGS is 71.8% that can meet the design criteria of the system as the flow and the pressure pulsation are also acceptable.

4 Experimental Analysis

The motor, pump, tank and manifold are fabricated and assembled, to optimize the model built in AMESim and test the real performance sufficient for requirements of LEHGS. Requirements are listed as below:

1. Output flows surpass 15 L/min.
2. The limit power of system is 10 kW while global efficiency should be higher than 70%.
3. Pressure fluctuation should be prohibited beneath 1.5 Mpa, while pulsation no more than 0.5 L/min.

As can be seen from Fig. 7, the motor, pump and manifold are integrated as one part of LEHGS, which immerges into oil totally.

The diagram of speed-flow experiments is made with the pressure in LEHGS is 0 Mpa, 7 Mpa, 28 Mpa while rotate speed ranges of 0 rpm to 13000 rotate per minute. The result of those experiments is shown in Fig. 8. When the system is working without any load, the flow (line blue) is beneath the theoretical value (line pink) obviously because the force supported by a spring is too weak to keep the port plate fitting tightly. Meanwhile, when the load rises to 7 Mpa, the leakage coming from the plate gets smaller than previous due to the pressure. Therefore, red line is the closest to the pink one. When the load gets to 28 Mpa, there is a tiny downward offset between the red line and the black line. Through analysis, when the system works at without any workload, the preload existing between the pump and the valve plate is maintained by a spring whose stiffness is not big enough. Therefore, the leakage keeps the flow down. When the pressure ascends to 7 Mpa, the force maintained by workload is much higher than the spring and thus the leakage disappears almost. Moreover, when the pressure is 28 Mpa, leakage from slippers and swash plate leads the downward offset.

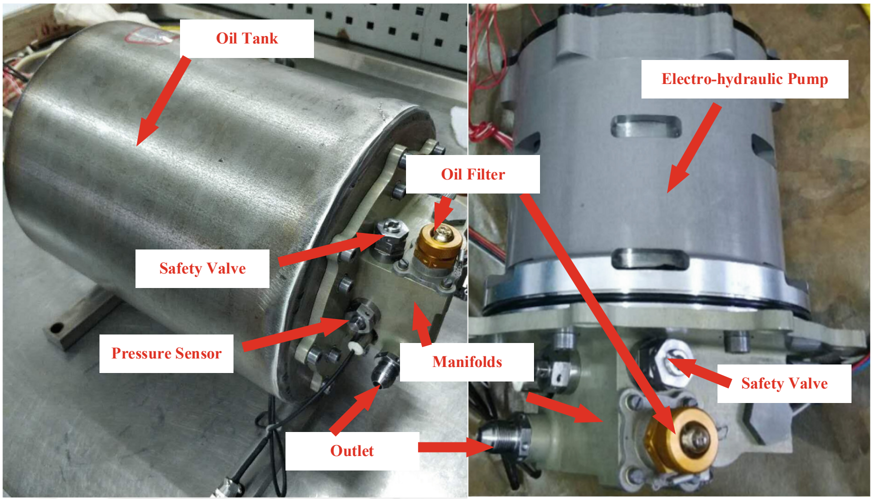

Fig. 7. Photo of the test rig of LEHGS

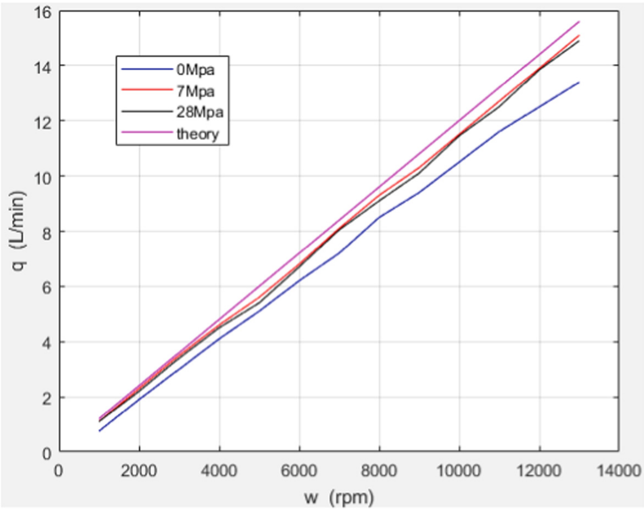

Fig. 8. Chart of the relation of flow and rotate speed in different pressure.

5 Conclusion

With the trend of MEA, this paper designs a LEHGS which expected to be used in the emergency hydraulic system on aircraft, landing gear retractions, front wheel turning system even braking system. The electric hydraulic pump applied in the LEHGS replaces the power unit made of traditional motors and pumps. Flow pulsation and pressure fluctuation are analyzed based on AMESim simulation.

The simulation results illustrate that the model can simulate the function of the LEHGS accurately. The experimental results demonstrate that the LEHGS can meet the requirements. However, the dynamic performance analysis of the LEHGS including pressure and flow pulsation as well as the pressure built-up times span requires more theoretical analysis and experimental verification.

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