Application of Constant-Power Control Electronically Technology in Local Electrical Hydraulic Generation System

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Abstract. The application of constant-power control electronically technology in LEHGS (Local Electrical Hydraulic Generation System) is introduced briefly in this paper. The combination of variable speed motor and fixed displacement pump serves as the power source for the LEHGS. The shaft torque and the system output pressure are characterized by phase current load analysis method. The constant-power control electronically strategy is realized through the way that a controller controls the motor speed. The simulation analysis of the electronically controlled constant-power EMP (electric motor pump) is performed by using commercial AMESIM software, and the principle prototype was produced according to the simulation results. Results show that the application of constant-power control electronically technology in LEHGS is capable of meeting the needs of low-pressure large flow and high-pressure low-flow conditions, which ensures that the special flow needs of aircraft hydraulic users under extremely harsh conditions.

Keywords: LEHGS · Constant-power Control Electronically Technology · Variable speed motor · Fixed displacement pump · Phase current load analysis

1 Introduction

In addition to meeting the basic functions and performance, the aircraft hydraulic system should also have the characteristics of high power-to-weight ratio, high reliability, and long life to meet with the increasing requirements of modern warfare for a new generation of combat aircraft, which which brings major challenges to the design of aircraft hydraulic system [1, 2]. Fortunately, in recent years, the development technology of power generation/distribution and high-power electronic equipment has developed rapidly. A new design concept, Local Electrical Hydraulic Generation System (LEHGS) [3, 4], which is regarded as an effective way to solve this challenge, has become a research hotspot in aircraft hydraulic system design.

EMP is one of the core components of the electro-hydraulic system, which is capable of converting mechanical energy into hydraulic energy. The variable control methods of EMP include constant-pressure control, constant-current control, constant-power control

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and load-sensitivity control [5]. The application of constant-power control technology enables the pump to adjust its output flow according to the change of load pressure, so that the output power of the pump is close to the power required by the load. The power adaptation and matching between the power source and the load are realized to make the system works under the best working conditions, thereby reducing the energy consumption and improving the power to weight ratio of the system.

The ways of controlling the constant-power EMP are usually regarded as hydraulic-control or digital- control respectively [6, 7]. The hydraulic-control technology has been very mature and widely used in many kinds of variable displacement pumps. However, it does not work when operating at complex conditions, especially at load changes frequently and requirement of sensitive responses, and frequent swing angles will increase leakage and reduce the service life of the pump [8]. With the development of computer applications, digital- control technology, that is, control electronically, has been more and more widely used.

This paper introduces the application of constant-power control electronically technology in LEHGS. The combination of variable speed motor and fixed displacement pump serves as the power source for the LEHGS. The shaft torque and the system output pressure are characterized by phase current load analysis method. The constant-power control electronically strategy is realized through the way that a controller controls the motor speed. The performance of constant-power EMP is simulated and analyzed by AMESIM, and a principle prototype was produced for test verification. The results show that under the condition of constant extraction power, the pump output flow rate continues to increase when the pressure continues to decrease, and the maximum output flow rate can be increased from 15 L/min to 25 L/min, which proves that the constant-power EMP can ensure the special flow needs of aircraft hydraulic users under extremely harsh conditions.

2 Constant-Power Control Electronically LEHGS

2.1 LEHGS

The traditional hydraulic system converts the engine shaft power and grid electrical power into hydraulic energy and supplies pressure to the user centrally by a lot of hydraulic pipes. In the design of traditional hydraulic systems, it is necessary to consider the redundancy design to ensure the reliability of hydraulic users, resulting that multiple sets of hydraulic pipelines need to be laid to supply energy to users. This results in difficultly in layout of the hydraulic system and in meeting with isolation requirements.

LEHGS is sub-hydraulic system that highly integrates controllers, motors, pumps, oil tanks, filters and other components, as shown in Fig. 1. LEHGSes can replace traditional hydraulic energy sources and are installed as stand-alone components close to the hydraulic users, providing high-pressure hydraulic oil to one or more hydraulic users nearby. This concept of design can reduce pipeline laying, system weight, and increase system redundancy configuration, safety and reliability simultaneously.

Features of LEGHS are listed below:

1) LEGHS provides high hydraulic pressure for specific users separately, the pressure and flow requirements of users are clear. So that there are conditions to adjust the flow rate in real time according to load changes.
2) Various sensors are integrated in LEGHS for monitoring system status, controller collects and processes various signals, which can be used for system control with abundant signals.
3) The highly integrated system results in weak heat dissipation capacity. It is necessary to reduce the system heating by reducing the throttling loss and improving the system working time.

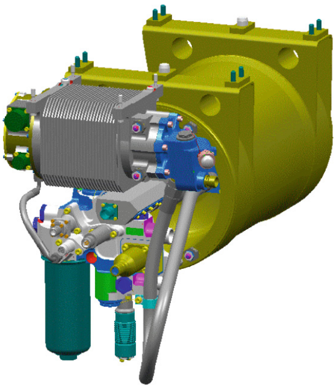

Fig. 1. Local Electrical Hydraulic Generation System

2.2 Constant-Power Control Electronically Technology

The flow rate of the hydraulic pump is determined by two factors, speed and displacement. For the fixed displacement pumps, the adjustment of the flow rate is regulated by the motor. As shown in Fig. 2, the motor controller monitors the output pressure of the pump outlet in time according to the phase current fed back on the motor. Then it performs closed-loop control of the motor speed in time according to the control law to ensure that the output flow of the motor pump changes meeting with the load. When the output pressure is lower than the minimum working pressure of the system, the motor pump speed is the largest and the output flow is the largest; When the output pressure is the maximum working pressure of the system, the motor pump speed is maintained at a small speed, just to maintain the pump internal leakage, and the output flow is almost 0; When the output pressure is between the minimum working pressure and the maximum working pressure, the motor pump outputs according to the constant-power control mode, the output flow and pressure product are guaranteed to be constant approximately.

The flow-pressure curve of one typical LEHGS as shown in Fig. 3. When using an constant-power EMP, the operating conditions of the system are as follows:

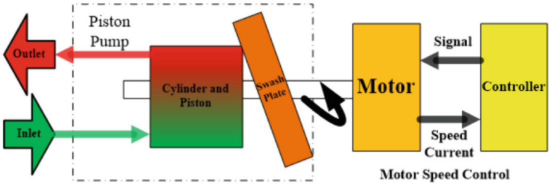

Fig. 2. Functional diagram of electronically controlled constant-power EMP

1) The EMP is capable of outputting a flow rate of 15 L/min at a pressure of 26.6 MPa when starting;
2) The output flow of the EMP can be stopped by reducing the motor speed through controller when the system pressure is higher than 28MPa, which makes the constant-pressure variable function realized;
3) When the system pressure is less than 26.6 MPa, the motor speed is increased to keep the total output power constant. As the pressure continues to decrease, the pump output flow continues to increase, and the maximum flow rate can be output 25 L/min, which quickly replenishes the system to further meet the flow requirements of the system.

There are two limit states according to the working scenario of output flow of the LEHGS: full-flow state and zero-flow state. The full-flow state refers to the state with the largest output flow of the system. The zero-flow state refers to the state where the output flow of the LEHGS is almost 0 at the design operating pressure (DOP). The region between the two limit states is called the constant-power region as shown in Fig. 3.

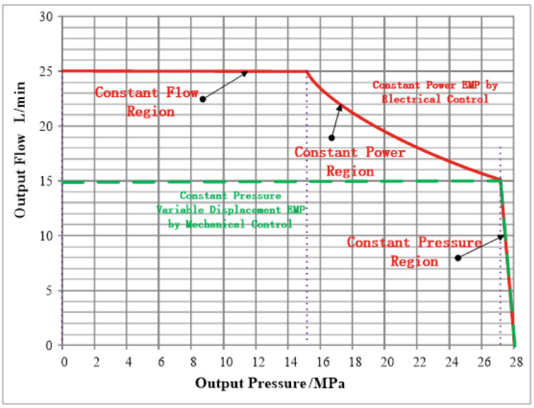

Fig. 3. Flow pressure curve of electronically controlled constant-power EMP

The constant-power control electronically strategy adopts motor speed regulation, the stirring loss and oil temperature can be decreased by reducing the motor speed under the condition of small flow demand. This method is flexible in control and the flow rate can be adjusted in time according to load changes, which is capable of meeting with the requirements of high-pressure small-flow conditions and low-pressure large-flow conditions respectively.

The use of constant-power control electronically technology makes the LEHGS select EMP with small flow, which reduces the power of the EMP and energy consumption so as to make the utilization of energy more reasonable.

2.3 The Analysis Method of Phase Current Load

The analysis method of phase current load is that uses current signals as information reflections to study the state of mechanical systems. For mechanical systems where the plunger pump is dragged by a motor, the motor is connected to the plunger pump through a coupling as a power source. Both the stator and rotor windings in the motor can be equivalent to electromagnetic coupling circuits [9].

When the hydraulic load change of LEHGS causes the torque change on the shaft of the piston pump, the relationship between them is proportional as shown in Eq. (1):

$$M_P = \frac{V_p \cdot \Delta P_s \cdot \eta_p}{2\pi} = k_p \cdot \Delta P_s \tag{1}$$

where M_p is the torque of the shaft of the hydraulic pump; V_p is the displacement for hydraulic pump; ΔP_s is the output pressure for the system; η_p is the mechanical efficiency for plunger pumps; k_p is a constant.

The state change of the torque of the hydraulic pump shaft affects the output torque of the motor through the transmission shaft between the motor and the hydraulic pump, and the relationship between them is proportional as shown in Eq. (2) below:

$$M_m = M_p \cdot \eta_m = k_m \cdot M_p = k_m \cdot k_p \cdot \Delta P_s \tag{2}$$

where M_m is the output torque for the motor; η_m is the for motor mechanical efficiency; k_m is a constant.

The change of motor output torque leads to a change in the electromagnetic coupling flux between the stator and rotor, which causes the stator current to change. The relationship between the two is shown in Eq. (3) below:

$$I_m = \frac{M_m}{C_m} = k_i \cdot M_m = k_i \cdot k_m \cdot k_p \cdot \Delta P_s \tag{3}$$

where I_m is the equivalent phase current of the motor,; C_m is the motor torque constant,; k_i is a constant.

3 Control Strategy of Constant-Power of LEHGS

In this paper, the control strategy combining the speed regulating motor and the quantitative pump is used to realize the constant-power control function. The phase current of motor is used to characterize the torque of the shaft of the EMP [10]. The control law of LEHGS can be divided into motor driven control law and outer loop control law. The motor driven control law includes the motor driven algorithm and the current loop control algorithm. The current loop control strategy and driving algorithms of motor are usually considered together since different types of motor have different driving algorithms and the current loop control strategy is closely related to the motor driven method. The inner ring servo control frame of a motor of a LEHGS is shown in Fig. 4.

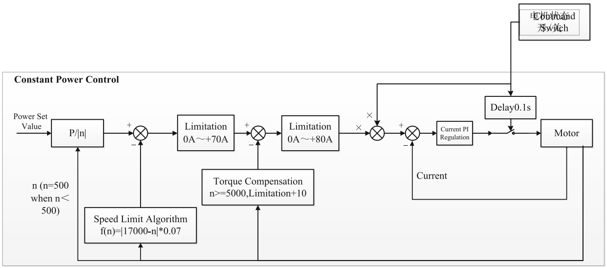

Fig. 4. Block diagram of servo control of LEHGS

4 Simulation Analysis and Test Verification of Constant-Power LEHGS

4.1 Amesim Simulation

The control law model of constant- power LEHGS is shown in Fig. 5. The torque control mode of motor is realized through the closed-loop control of the motor current, and the motor speed is introduced into the current loop for correction to achieve accurate control of torque and speed simultaneously. Each loop mainly contains a signal filter, a PI controller, and a saturation link.

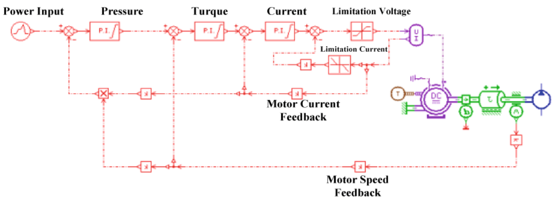

Fig. 5. Control law model

The construction of the simulation model and the selection of parameters would directly affect the accuracy of the simulation results, so it is particularly important to build a correct simulation model. The LEHGS verification model is shown in Fig. 6 below.

The flow-pressure curve of the EMP is shown in Fig. 7. As can be seen that:

1) When the LEHGS is started, the EMP is capable of outputting a flow rate of 15 L/min at 26.6 MPa;

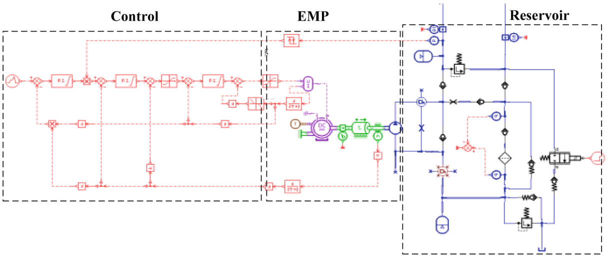

Fig. 6. LEHGS verification model

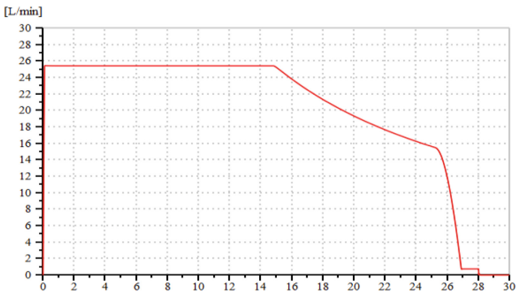

Fig. 7. Flow-pressure curve of the EMP simulation verification curve

2) When the pressure of the accumulator is higher than 28 MPa, the output flow of the pump can be stopped by reducing the motor speed through controller, and then the constant pressure variable function can be realized;
3) When the pressure of the accumulator is less than 26.6 MPa, the speed of the motor is increased to maintain a constant total output power. When the pressure continues to decrease, the pump output flow continues to increase, and the maximum output flow rate is 25 L/min.

Through the above simulation analysis and verification of EMP of the LEHGS, it can be concluded that:

In addition to all the pressure and flow indicators of the traditional constant-pressure variable pump, the electronically controlled constant-power EMP is capable of increasing the maximum output flow from 15 L/min to 25 L/min, which ensures the special flow needs of aircraft users in extremely harsh situations. At the same time, since the power extraction does not change, there is no additional demand for the power supply.

4.2 The Analysis of Phase Current Load

Different types of eigenquantities have different sensitivity to the system working conditions, hence finding the eigenquantities that reflect the optimal load action is the key to the phase current load analysis of electronically controlled constant-power electric pumps.

In order to find the eigenquantities that reflect the load optimally, it is necessary to screen and refine the commonly used eigenquants. The current signal is extracted to convert the three-phase alternating current of the stator into equivalent direct current in this paper. The relationship between equivalent characteristic current and shaft torque and output pressure is shown in Fig. 8 below. The output pressure "sensed" according to the sensed current value is carried out for a closed-loop design.

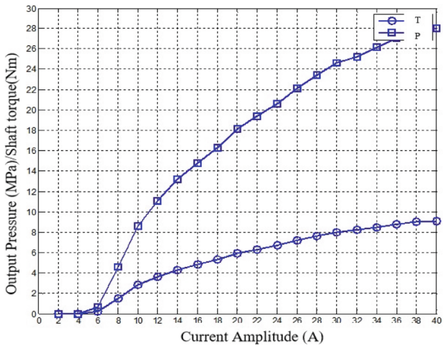

Fig. 8. The relationship between equivalent characteristic current and shaft torque and output pressure

4.3 Experimental Validation

In order to verify the application of constant-power control electronically technology, a EMP prototype was developed and a test-bench for LEHGS was built. The principle of the test-bench was shown in Fig. 9. The test results are shown in Fig. 10.

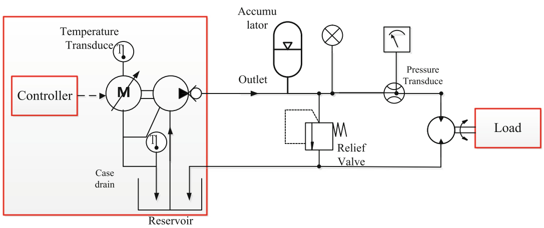

Fig. 9. Constant-power EMP prototype test schematic

The test results show that the pressure and flow characteristics of the developed EMP principle prototype are consistent with the AMESIM simulation results and the performance can meet the technical requirements. At the same time, the constant-pressure variable pump control electronically scheme can realize the constant-power control requirements of specified flow and pressure output under dynamic load pressure.

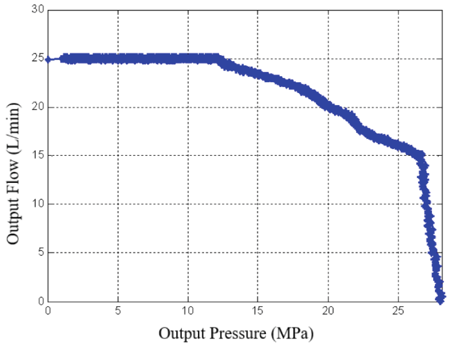

Fig. 10. The test pressure-flow curve of EMP principle prototype

5 Conclusion

This paper presents the application of constant-power control electronically technology in LEHGS:

1) The control mode combining speed regulating motor and quantitative pump is adopted to realize the constant-power control function;
2) The analysis method of phase current load is used to characterize the output pressure, which ensure the control accuracy of the LEHGS without adding additional sensors and ensure the large starting torque, high efficiency and sensitive action when LEHGS starts;
3) The test results show that the maximum output flow rate of the electronically controlled constant-power EMP developed in this paper can be increased from 15 L/min to 25 L/min, an increase of 70%;
4) The test results show that when the working conditions of the system require the load to be constant power, the constant power speed regulation system can achieve the power matching between the prime mover and the load, and reduce the waste of energy: the transmission efficiency of the spectrum variable variable pump system under this working condition is only 82% ~ 86%, while the constant power speed regulation system can reach about 94%, and the transmission efficiency is at least 7% higher than the former.

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