Hydraulic motor constant low speed characteristics measurement study

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Abstract. Due to the special characteristics of hydraulic motors, the minimum stability characteristics are often one of the important characteristics to be considered in hydraulic system applications. In this paper, based on the analysis of the hydraulic mathematical model of the axial piston hydraulic motor, the model of the axial piston motor is established by using AMESim simulation software, and its low-speed characteristic curve is output through simulation to verify the validity and reasonableness of the low-speed characteristic testing scheme of the hydraulic motor. Finally, a hydraulic motor constant low speed characteristic test system is built based on LabVIEW software, and a field verification test of the hydraulic motor constant low speed characteristic is carried out, which provides some engineering reference value for the hydraulic motor constant low speed characteristic test.

1. Introduction

Hydraulic motors have been widely used in the field of construction machinery at home and abroad because of a series of advantages such as high output torque, good starting characteristics, simple overload protection, and the ability to drive loads directly. At present, the main problem in the use performance of hydraulic motor is that it is not easy to be stable at low speed operation, and often appears crawling and inter-stopping[1]. For this reason, this paper proposes a constant low-speed load device based on a combination of a turbo reducer and a variable frequency motor, and uses AMESim software to establish a simulation model of the constant low-speed test system of an axial piston motor to verify the effectiveness and applicability of the test system scheme. Based on the simulation results and theoretical analysis, the actual measurement of the constant low speed characteristics of the hydraulic motor is carried out in the test system built based on LabVIEW, which verifies the correctness of the simulation model and the effectiveness of the test scheme proposed in this paper.

2. Hydraulic Motor Constant Low Speed Characteristics Test Program

The main purpose of testing the characteristics of hydraulic motor under constant low speed load is to investigate the torque output characteristics of hydraulic motor under constant speed load when the inlet pressure of hydraulic motor is constant:

a) Keep the measured inlet and outlet pressure constant within ±2% of the read value or 0.1 MPa variation, whichever is greater. Maintaining the output shaft speed within ±2% variation of the average value.

b) Record each variable in each set of test values for motor inlet and outlet differential pressure, displacement, and direction of rotation.

c) Note any tendency for the motor to run in a crawling or uneven manner.
d) Any tendency for the motor to show non-repetitive torque or leakage should be noted\(^\text{[2]}\).

From the above, it can be seen that the technical difficulty of motor constant low speed characteristic test is the design of adjustable constant speed load device. For this reason, this paper designs a combination of inverter motor and turbo reducer adjustable constant speed load device, the inverter can make smooth stepless adjustment of motor speed, considering that the motor will be at low speed (2-10 r/min) when the inverter is at the lowest output frequency, the output torque and speed of the inverter motor are unstable at this time, for this reason, the turbo reducer is added to the output shaft of the inverter motor, so that the inverter motor can still provide low and stable torque output when the motor is working at higher speed. The output shaft of constant speed load device can still provide low speed and stable torque output when working at higher speed. The schematic diagram of the motor constant low-speed characteristic test system designed in this paper is shown in Figure 1.

![Schematic diagram of motor constant low speed characteristic test system](image)

1.1~1.2 Hydraulic Pumps; 2.1~2.2 Proportional relief valve; 3.1~3.2 Flowmeter; 4.1~4.2 Thermometer; 5.1~5.2 Pressure Gauge; 6 Hydraulic motor under test

**Fig 1 Schematic diagram of motor constant low speed characteristic test system**

3. Simulation analysis of AMESim based hydraulic motor constant low speed characteristics determination

The relevant test standards for the determination of the constant low speed characteristics of hydraulic motors only put forward the test steps and requirements, but no specific loading method is given, and there are few relevant research materials. Therefore, the loading method of the hydraulic motor constant low speed characteristics test system in this paper is simulated to verify the feasibility of the test scheme designed in this paper.

AMESim is a new graphical simulation software for engineering applications\(^\text{[4]}\), which is specially used for mechanical hydraulic system modelling and simulation analysis. Users can establish system models in multidisciplinary fields on a single platform and complete simulation calculation and analysis of complex target tasks, especially in establishing mathematical models of hydraulic systems, the software fully considers the physical characteristics of hydraulic oil and the nonlinearities of hydraulic components characteristics of hydraulic components. In this paper, an axial piston motor test system model based on AMESim software is established and simulated to provide a reliable basis for the experimental verification of the hydraulic motor constant low speed characteristics test system.

3.1 Axial piston motor hydraulic mathematical model analysis

This paper takes the swashplate axial piston hydraulic motor shown in Figure 2 as an example to illustrate the working principle of the hydraulic motor and provide reference for the hydraulic motor simulation model building in Section 3.2.
The plunger of the swashplate axial piston hydraulic motor is axially arranged, the cylinder axis and drive shaft axis coincide, when the motor inlet input pressure fluid, with the flow plate 4 of the inlet window corresponding to the work plunger is pushed out by the hydraulic pressure and pressed on the swashplate 1. The swash plate produces a force $F$ on the plunger, and its horizontal component force $F_x$ is:

$$F_x = \Delta p \frac{\pi}{4} d^2$$

The vertical component force $F_y$ is:

$$F_y = F_x \tan \gamma = \Delta p \frac{\pi}{4} d^2 \tan \gamma$$

The horizontal component force $F_x$ is balanced with the hydraulic pressure acting at the bottom of the plunger; while the vertical component force $F_y$ is transmitted through the plunger to the cylinder 2, generating torque on the drive shaft 5, and the torque generated by any one working plunger is:

$$T_i = F_y R \sin \theta = \Delta p \frac{\pi}{4} d^2 \tan \gamma \cdot R \sin \theta$$

$\gamma$—Inclined angle of swash plate (°)
$R$—Radius of distribution circle of working plunger in cylinder block (mm)
$d$—Working plunger diameter (mm)
$\theta$—Instantaneous angle between axis of working plunger and vertical bisector of transmission shaft (°)
$\Delta p$—Pressure difference between inlet and outlet of motor (MPa)

As can be seen from the above equation, the size of the torque generated by each working plunger varies depending on the location, and the output torque of the hydraulic motor is the sum of the torque generated by the plunger instantaneously on the drive shaft while it is in the inlet window, that is:

$$T = \sum T_i = \sum \left( \Delta p \frac{\pi}{4} d^2 \tan \gamma \cdot R \sin \theta \right)$$

### 3.2 Simulation modelling of axial piston motor

As can be seen from section 3.1, the main components of the hydraulic motor under test are swashplate, plunger and flow distribution disk. In this paper, we choose AMESim software's mechanical library, hydraulic library and the relevant models of hydraulic original design library to model the hydraulic motor, and get the hydraulic motor simulation model as shown in Figure 3. The main simulation parameters are shown in Table 1.

| Parameter Name               | Parameter Value | Unit    |
|------------------------------|-----------------|---------|
| Inclined angle of swashplate | 45              | degree  |
| Swashplate pitch circle diameter | 55              | mm      |
3.3 Simulation analysis of axial piston motor test system

A constant low-speed load device consisting of a motor and a reducer is connected to the output shaft of the motor model to form a simulation model for constant low-speed motor testing. The motor speed is set to 6r/min, the reduction ratio is 0.5, and the motor inlet pressure is set to 100 bar, 200 bar and 300 bar respectively. As a result, we obtain the constant low speed characteristic test curves of the motor at different test pressures, as shown in Figure 4.

Fig 3 Hydraulic motor simulation model

| Number of plungers | 7 null |
|-------------------|--------|
| Plunger diameter  | 28.6 mm|
| Plunger length    | 56 mm  |
| Plunger-cylinder clearance | 0.1 mm |
| Output shaft rotational inertia | 0.095 Kgm² |
As can be seen in Figure 4, the pulsation of the output torque can be clearly observed when the motor input pressure and shaft end speed are kept constant. As the motor pressure increases, the torque pulsation rises and the peak torque pulsation becomes larger.

The motor constant low speed characteristic curve is shown in Figure 5 when the pressure is constant and the test speed is different. As can be seen from the Figure 5, as the test speed increases, the motor output torque pulsation changes at a higher frequency, which requires a higher signal acquisition frequency if sufficient measurement data is to be obtained.

![Fig 5 Simulation curve of constant low speed characteristics of hydraulic motor at different speed](image)

From the above simulation test results, it can be seen that the test scheme designed in this paper can effectively test the constant low speed characteristics of the hydraulic motor. In order to observe, record and analyse the output fluctuation of motor torque, a higher test pressure and the lowest possible test speed should be used in the hydraulic motor constant low speed test site.

4. Hydraulic motor constant low speed characteristics measurement field test analysis

4.1 Hydraulic motor constant low speed characteristic test system

The hydraulic motor constant low speed characteristic test system consists of an electrical control system, a data acquisition system, and a computer measurement and control system. The main hardware includes industrial control computer, PLC, pressure sensor, flow sensor, data acquisition card, proportional amplifier, and digital display meter. Its composition is shown in Figure 6.

![Fig 6 Hydraulic motor constant low speed characteristics test system structure diagram](image)

In addition, LabVIEW 2018 also integrates RS-232 and RS-485 protocols and functional modules for data acquisition card communication, and its built-in library functions of TCP/IP, ActiveX and other software standards are convenient for the axial piston motor constant low speed test system. The built-in TCP/IP, ActiveX and other software standard library functions provide convenience for the axial piston motor constant low speed test system. The system uses TCP/IP protocol to communicate with the lower computer and collects real-time speed and torque of the inverter motor through Modbus
communication protocol. A Siemens PLC was selected as the lower computer for electrical logic control. In addition, analog signal output and input modules were added to provide channels for analog signal acquisition and to provide suitable control signals for fully automatic testing.

In the data acquisition system, the PCI-1710u data acquisition card is used to collect the real-time analog signals such as pressure and flow rate. Due to the limitation of the number of input points of Siemens PLC, a digital acquisition channel is also used to identify the opening and closing status of the pneumatic ball valve at the suction port of the pump under test, and these signals enter the measurement and control software of the IPC through the PCI-E bus for data processing.

4.2 Analysis of test results
According to the simulation results in section 3, in order to better complete the hydraulic motor constant low speed characteristics test, should use a higher test pressure and as low as possible test speed. Therefore, in this section, the 07B-MG-0811 series hydraulic motor with a displacement of 40mL/r is selected for the hydraulic starting characteristics test, and the inlet pressure of the motor under test is set to 300 bar, and the load speed is 3 r/min. The relationship curve between the motor output torque and its rotation angle is shown in Figure 7.

Using the test software developed in this paper to automatically analyze the characteristic curve data, according to the relevant torque inhomogeneity formula $I_{RT} = \Delta T_{e,ma} / T_{e,ma}$, the torque inhomogeneity coefficient of the tested motor can be calculated as 0.026.

The test shows that the constant low speed load device combining turbo reducer and inverter motor proposed in this paper can calculate and analyse the test data using the developed measurement and control system, and can accurately achieve the determination of the constant low speed characteristics of the hydraulic motor.

5. Conclusion
This paper uses AMESim software to model the swashplate axial piston hydraulic motor, and simulates and analyses the constant low speed testing process of the swashplate axial piston motor to verify the effectiveness and applicability of the test system. On the basis of the simulation, a hydraulic motor constant low speed characteristic measurement and control system is developed based on LabVIEW measurement and control software. The constant low speed load device combined with reducer and inverter motor accurately realizes the constant low speed characteristic test of hydraulic motor, which has certain engineering reference significance for the optimization of hydraulic motor manufacturing and maintenance parameters.

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