Analyses of Influential Factors of Dynamic Characteristics of Hydraulic Pump Test System

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Abstract. A set of hydraulic pump test system was designed according to national test standard. The simulation model of the test system was built in hydraulic simulation software AMESim. Through setting and adjusting simulation parameters, groups of simulation results were obtained and graphed with different pipeline diameter, pipeline length, elastic modulus of pipeline material, oil temperature and oil bulk modulus. The description about the influences of the above factors on system dynamic characteristics and the analyses about the reasons were given. The advices on optimizing design of hydraulic test system were presented contraposing different parameters and design requirement.

Introduction

Hydraulic pump is the power component of hydraulic system and its performance directly affects the property of whole system, which makes the accurate test for hydraulic pump performance particularly important. At present, the research on hydraulic pump test system at home and abroad has become mature, but few scholars carried on special discussion upon the dynamic characteristics of the test system. In fact, besides the performance test items and static characteristics, dynamic characteristics are also important indexes to evaluate a set of hydraulic test system which include response speed, concussion in response process, response stability etc. A set of hydraulic system generally contains various components. The interaction among the dynamic characteristics of the components in system and nonlinearity of the system itself causes the complicacy of the dynamic characteristics of the hydraulic system. With the improvement of complexity and the requirements of hydraulic system dynamic characteristics, the significance of dynamic characteristics analyses on hydraulic system becomes more and more important. Lei Yulong et al. established the dynamic simulation model of hydraulic system of dual-clutch automatic transmission with AMESim after calculating the structure size of each body through theory and practical algorithm and analyzing the dynamic characteristics of the system from simulation results [1]. Wang Zhenchuan proposed an electrical power recovery hydraulic pump test bench, carried out the simulation of the test system and analyzed its dynamic characteristics [2]. Liu Shaohui et al. simulated a hydraulic test system of construction machinery by the dynamic simulation module of Simulink in Matlab, discussed the influence to the system performance and optimized its dynamic characteristics [3]. Zhao Qiang et al. used AMESim to model the hydraulic system of 2JTP-1.2 mine hoist and analyzed the influences of spring accumulator, hydraulic line, hydraulic oil air content and the flow section area of the solenoid valve on the dynamic performance of the system [4]. Wang Jing et al. carried out the dynamic simulation of the hydraulic system of hydraulic support test-bed based on AMESim and MATLAB, obtained related pressure and flow curves and analyzed the movements of components [5].

In this paper, a set of hydraulic pump test system was designed and modeled in AMESim. The targeted simulation was carried out to analyze the influential factors on the dynamic characteristics of the system and the simulation results were analyzed.
Principle of Hydraulic Test System

Figure 1. The principle of hydraulic pump test system.

1 hydraulic cylinder   2 import oil filter   3 butterfly valve   4 supply pump   5, 19 motor   6 export oil filter
7, 13 pressure gauge    8, 22 electromagnetic relief valve   9-12 check valve   14, 20 temperature sensor
15,21,25 pressure sensor   16 tested pump  17 torque sensor  18 speed sensor  23 directional valve
24 flowmeter   26 cooler

The principle of the test system is shown in Figure 1. Motor 5 and supply pump 4 constitute the power unit. The supplied oil from supply pump 4 for tested pump is more than needed quantity and redundant oil overflows through electromagnetic relief valve 8. Electromagnetic relief valve 8 is used to adjust the oil pressure at the outlet of supply pump 4, electromagnetic relief valve 22 is used to adjust the oil pressure at the outlet of tested pump and load on tested pump. Electromagnetic relief valve 22 is connected in parallel with directional valve 23 to form an impact test unit which forms an impact test unit by adjusting the directional valve 23 to switch over the pressure at the outlet of tested pump. Four check valves 9-12 compose the rectifying circuit unit to switch over the oil circuit of tested pump, which can improve the reversing stability, decrease the hydraulic impact and complete bidirectional test of tested pump. The torque and speed of tested pump is measured and exported by torque-speed transducer. Traditional pressure gauge and oval gear flowmeter are also used to make observation on the spot convenient.

Simulation Model of Hydraulic System

Hydraulic simulation software AMESim contains many general hydraulic components and can meet the requirements of modeling and simulating in most situations. While in the cases that model contains special components and simulation requires more accurate results, the HCD library of AMESim can be used to build required components according to actual dimensions and parameters. In precondition of satisfying requirement, the easier simulation model is better. Therefore the factors which have little effect on the dynamic characteristics of the system were ignored when the hydraulic test system was modeled.

Based on the above discussion, the simulation model of the hydraulic pump test system was built and shown in Figure 2. The research focused on the hydraulic system rather than some certain components, so the most components in the system used common components in the hydraulic library except the relief valve at the outlet of tested pump which was built using HCD library to improve the precision of simulation results.

Figure 2. Simulation model of test system.
Considering the accuracy of data and the ideality of used components, the print interval in simulation was set as 0.002s. The parameters of components in the test system are listed in Table 1.

<table>
<thead>
<tr>
<th>Items</th>
<th>Parameter setting</th>
<th>Items</th>
<th>Parameter setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement of tested pump</td>
<td>15</td>
<td>Displacement of supply pump</td>
<td>20</td>
</tr>
<tr>
<td>Rated pressure of tested pump</td>
<td>31.5</td>
<td>Rated pressure of supply pump</td>
<td>3</td>
</tr>
<tr>
<td>Rated speed of tested pump</td>
<td>1500</td>
<td>Rated speed of tested supply</td>
<td>1500</td>
</tr>
<tr>
<td>Critical pressure of check valves</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Simulation Results and Analyses**

Many factors can affect the dynamic characteristics of hydraulic system and pipeline and hydraulic oil have quite significant influence. Therefore the simulation was conducted for the two aspects. Default simulation conditions are pipeline diameter 20mm, pipeline length 1m, elastic modulus of pipeline $2.06 \times 10^5 \text{MPa}$, oil temperature 40, and elastic modulus of oil $1.7 \times 10^3 \text{MPa}$. The influence of a certain parameter on the dynamic characteristics can be obtained by changing that parameter in simulation and measuring the pressure fluctuation at tested pump outlet.

**The Influence of Pipeline on Dynamic Characteristics of the Hydraulic Test System**

Hydraulic pipeline is necessary auxiliary element in hydraulic system, which not only connects hydraulic components but also transfer energy and signals. Therefore the parameter setting of pipeline can has a strong influence on system performance, in which the main parameters are pipeline diameter, length and material [6].

**The Influence of Pipeline Diameter on Dynamic Characteristics.** Set the pipeline diameter as 50mm, 40mm, 30mm, 20mm, and 10mm respectively and keep the rest simulation parameters invariant, the simulation results can be obtained and shown in Figure 3. The results show that pipeline diameter can has a great influence on the system dynamic characteristics: with the increasing of pipeline diameter, the time required to reach steady state increases from about 0.03s to about 0.12s which means the response rate of the system decreases, and the system fluctuation before reaching steady state decreases. The reasons are the oil velocity in pipeline decreases with the increase of pipeline diameter, which reduces the impact from oil and system fluctuation; and the increasing of pipeline increases liquid capacity, which lowers response rate. Therefore, in the design of test system, the pipeline diameter in system should be reduced appropriately to raise system response rate; while the diameter should not be too small to avoid great vibrate of system pressure which can shorten system using life.

![Figure 3. The influence of pipeline diameter.](image1)

![Figure 4. The influence of pipeline length.](image2)

**The Influence of Pipeline Length on Dynamic Characteristics.** The simulation was carried out with the pipeline length 4m, 3m, 2m, 1m, and 0.5m respectively and obtained simulation results shown in Figure 4. It shows that, the rise of pipeline length diminishes the slope of characteristic curve, increases the resistance loss along its tracks and reduces the fluctuation before steady state,
and the required time to reach steady state increase from about 0.03s to about 0.08s. That’s because the rise of pipeline diameter augments resistance loss long the track and liquid capacity, which reduce the impact from oil, system fluctuation and response rate. Thus shortening pipeline length appropriately can effectively improve the response rate of test system, but too short length can cause inaccuracy of test results.

The Influence of Pipeline Material on Dynamic Characteristics. The simulation was carried out aiming at two kinds of hydraulic pipes: steel tube and hose. The simulation parameters were setting as elastic moduli of steel tube and hose were $2.06 \times 10^5$MPa and $1.0 \times 10^3$MPa, respectively. The simulation result in Figure 5 shows that the difference between influences of the two kinds of materials on system dynamic characteristics is small. The hydraulic test system using steel tube has high pressure peak, fast response rate and high steady-state value.

The Influence of Oil on Dynamic Characteristics of the Hydraulic Test System

The quality of hydraulic oil is generally believed to have little influence on system, therefore the oil is seemed as ideal and incompressible in general researches on hydraulic system. While in actual application, the oil quantity is a significant influence factor on dynamic characteristics of hydraulic system, in which the oil temperature and bulk modulus are main parameters [7].

The Influence of Oil Temperature on Dynamic Characteristics. The simulation was carried out with the oil temperature set as 20, 40, 60, and 80 respectively. It can be known from result curves shown in Figure 6 that the rise of temperature improves the response rate, pressure peak and steady-state value; the interval between contiguous result curves broadens with the temperature increasing. The reason is that the increase of oil temperature reduces the viscosity of oil, which causes increase of oil leakage and extends the required time to reach steady state. The viscosity reduction can also decrease pressure loss, which increases pressure peak and steady-state value. Therefore in the design of hydraulic test system, cooling and heat dissipation elements should be added in the system; the system temperature should be real-time monitored by temperature element in the operation process to avoid the adverse effect of high temperature on dynamic characteristic of hydraulic test system.

Figure 5. The influence of pipeline material.

Figure 6. The influence of oil temperature.
The Influence of Oil Bulk Modulus on Dynamic Characteristics. The simulation was carried out with the bulk modulus 1200MPa, 1600MPa, 2050MPa and 2600MPa respectively and obtained simulation results shown in Figure 7. It shows that the increasing of oil bulk modulus enlarges the fluctuation before steady state, improves the velocity of reaching steady state and slightly heightens steady-state value. In the operation process of hydraulic system, the gas content in oil is a key factor of influencing oil bulk modulus and the great compressibility of gas can reduce the oil bulk modulus. So reducing gas content should be considered in design of hydraulic test system, such as applying pressured oil tank, enlarging oil tank volume, to improve the bulk modulus of oil.

![Figure 7. The influence of oil bulk modulus.](image.png)

Conclusions
A set of hydraulic pump test system was designed to research influence factors on dynamic characteristics of the hydraulic system. The designed system was modeled and simulated in AMESim. The main factors influencing the system dynamic characteristics were analyzed by changing simulation parameters and the conclusions were drawn as follows:

The ways of reducing pipeline diameter, shortening pipeline length, avoiding high oil temperature, and decreasing the gas content in oil to improve oil bulk modulus can effectively increase response velocity. In order to reduce fluctuation and improve stability of the hydraulic system, measures can be taken like appropriately enlarging pipeline length, prolonging pipeline length and decreasing oil bulk modulus.

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