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Research on the Acceleration Performance of a Wheel Drive Hydraulic Hybrid Vehicle Driven by Accumulators

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Abstract. In order to meet the driving and mobility requirements of a wheel drive hydraulic hybrid vehicle, the mathematical model of the airbag type accumulator was established, and its basic working parameters were determined initially. The accumulator's individual drive variable motor/pump test was carried out by using the test bench. The experiment was conducted by using the orthogonal experimental design method. The rationality of the accumulator operating parameters was verified. The rational voltage value adjustment range was determined. It was shown that the effect of the load on the acceleration performance of the variable motor/pump was greater than that of the accumulator working pressure. Furthermore, the measures and methods for improving the acceleration performance of the variable motor/pump were obtained.

1. Introduction

The wheel drive hydraulic hybrid vehicle uses hydraulic transmission as the driving method of the vehicle. The transmission system makes the operation mode of the wheel drive hydraulic hybrid vehicle and the traditional vehicle different due to the addition of the accumulator. The main performance is that the working mode of the power source is basically not related to the load. The flow difference between the two kinds of vehicles will flow directly into or out of the accumulator, so that the power source can work in a relatively stable working area, which will improve the fuel economy and reduce the emissions [1-3].

As an auxiliary power component of the hydraulic system, the accumulator is always in an important position throughout its whole operation. Its working process and working characteristics directly affect the driving characteristics of the vehicle (including vehicle starting and acceleration performance), and the starting and acceleration performance of the vehicle is critical to the maneuverability of the wheel drive hydraulic hybrid vehicle [4, 5]. Wang Cheng et al. [6] studied the accelerated driving performance and control method of the wheel drive hydraulic hybrid vehicle and proposed two kinds of acceleration control strategies: initial pressure regulation scheme and command speed regulation scheme. Between them, the command speed regulation scheme has better fuel economy performance, and the initial pressure regulation scheme has better acceleration driving performance. This paper focuses on the effects of accumulators on the accelerated driving performance of the wheel drive hydraulic hybrid vehicle.

2. Preliminary determination of accumulator basic operating parameters

2.1. Mathematical model

According to the requirements of the test bench, comprehensive performance analysis, the airbag type



accumulator is selected as the accumulator of the test bench. The capacity of the accumulator to store and release the pressurized oil is equal to the volume of the gas in the bladder, and the change of gas state should conform to Boyle's law [7, 8], as shown in Eq. 1.

$$p_0 V_0^n = p_1 V_1^n = p_2 V_2^n = p V^n = \text{constant} \quad (1)$$

In the formula, p_0 is the initial inflation pressure of the accumulator; V_0 is the volume of the accumulator inflation; p_1 and p_2 is the initial working pressure and the final working pressure of the accumulator respectively; V_1 and V_2 is the gas volumes of the above two states respectively. p and V is the working pressure and gas volume of the accumulator at any moment respectively; n is the gas multi-variable index.

When the accumulator is used for holding pressure, the gas expansion process is slow, and the heat exchange with the outside is relatively sufficient, which can be considered as an isothermal process, $n = 1$. When the accumulator is used as an auxiliary power source, the time for releasing the liquid is short, the gas expands rapidly, and the heat exchange is insufficient, which can be regarded as an adiabatic process, $n = 1.4$. In actual work, the state changes are between the isothermal process and the adiabatic process, so, $1 < n < 1.4$.

Considering the actual working conditions, the working process of the accumulator is regarded as a variable process ($n \neq 1$). Theoretically, the energy stored and released by the accumulator is shown in Eq. 2.

$$E = - \int_{V_1}^{V_2} p dV \quad (2)$$

It can be concluded that $p = p_0 \left(\frac{V_0}{V}\right)^n$ from Eq. 1. Substituting p into Eq. 2, it can obtain Eq. 3.

$$E = - \int_{V_1}^{V_2} p dV = \frac{p_0 V_0}{n-1} \left[\left(\frac{p_0}{p_2}\right)^{\frac{1-n}{n}} - \left(\frac{p_0}{p_1}\right)^{\frac{1-n}{n}} \right] \quad (3)$$

For the isothermal process ($n=1$), the energy can be calculated by Eq. 2.

$$E = - \int_{V_1}^{V_2} p dV = p_0 V_0 \ln\left(\frac{p_2}{p_1}\right) \quad (4)$$

By differentiating the variable p_0 in Eq. 3 and that in Eq. 4, the corresponding state quantities can be obtained by using extreme conditions. If $p_1 = p_0$, $p_2 = p_{\max}$ ($p_{\max}$ is the set maximum working pressure), and V_0 and $p_{\max}$ are regarded as constants. According to the Eq. 3, the condition that the accumulator absorbs energy E to a maximum value is obtained by Eq. 5.

$$\frac{dE}{dp_0} = \frac{V_0}{n-1} \left[\frac{1}{n} \left(\frac{p_0}{p_{\max}}\right)^{\frac{1-n}{n}} - 1 \right] = 0 \quad (5)$$

From Eq. 5, when the accumulator absorption energy E takes the maximum value, the relationship between the pre-charge pressure, the maximum working pressure and the multivariate index can be obtained. Figure 2 shows the variation of the pressure ratio r_0 ($r_0 = p_0/p_{\max}$) of the pre-charge pressure and the maximum working pressure with the multi-variable index n when the accumulator absorption energy takes the maximum value. When $r_0 = 0.368$ in the isothermal process ($n=1$), E takes the maximum value. It can be found from the Figure 1 that with the multivariate index increases, the pressure ratio r_0 gradually decreases. That is, when the initial inflation pressure p_0 is constant, the maximum working pressure $p_{\max}$ of the accumulator is gradually increased. Therefore, the set maximum working pressure of the accumulator should be determined during the isothermal process.

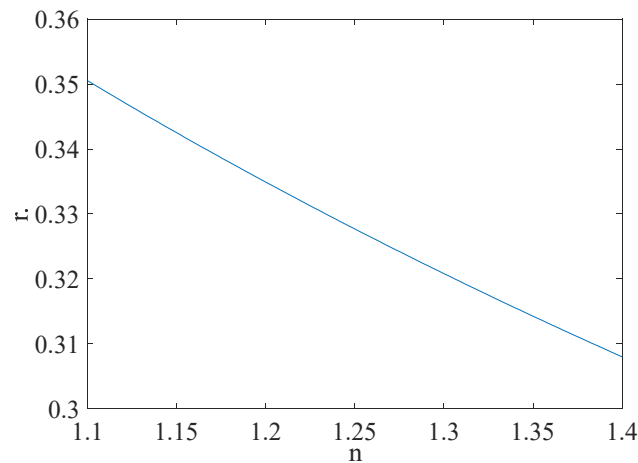


Figure 1. Curve of pressure ratio with multivariate index.

2.2. Preliminary determination of basic working parameters

The pre-charge pressure of the accumulator selected in this test bench is 12 MPa. In order to ensure the long service life of the airbag, the pre-charge pressure shall not exceed 90% of the minimum working pressure, and the initial selection of the minimum working pressure is 13.5MPa. According to $r_0 = p_0/p_{\max} = 0.368$, the theoretically calculated maximum working pressure is 36.6MPa. However, when the accumulator absorption energy takes the maximum value, it has a greater impact on the damage of the accumulator and subsequent tests. On the other hand, for safety reason, the final determined maximum working pressure should be less than the theoretically calculated maximum working pressure.

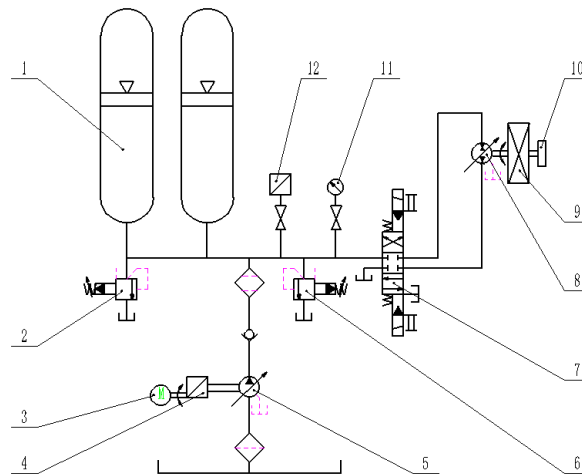
3. Bench test and result analysis

3.1. Test bench

The test bench is a semi-physical simulation platform based on the working principle of the wheel drive hydraulic hybrid vehicle transmission system. From the system configuration of the bench to the processing of the bench, the electromotor is used to replace the original vehicle engine as the main power source of the whole test bench, and the rotational inertia of the inertia flywheel is used to replace the rotational inertia of the whole vehicle 1/4, and the magnetic powder brake is used to simulate the load and the brakes of the original vehicle. The test bench is mainly composed of main electromotor, constant pressure variable pump, variable motor/pump, hydraulic accumulator, inertia flywheel, magnetic powder brake, accelerator, fuel tank, pressure sensor, torque sensor, proportional reversing speed control valve, relief valve, check valve, pressure gauge, and integrated electronic control mechanism. The hydraulic schematic of the test bench is shown in Figure 2.

3.2. Test program

The test factors include magnetic powder brake torque, accumulator working pressure and motor displacement. For the magnetic powder brake torque, 0, 16.67, 33.33, 50Nm are selected as the test set values. For the accumulator, 18, 19, 20, 23MPa are selected as the test set values. Motor displacement corresponds to voltage value, so, 0.5, 1.5, 2.5, 3.5V are selected as the test set values. Because of the number of test factors is 3, the number of test levels is 4. If all test conditions are to be completed, the total number of tests will be 64. Therefore, in order to improve the test efficiency, the experiment is conducted by using the orthogonal experimental design method, and some representative level combinations are selected for testing. Finally, 16 test conditions as shown in Table 1 are selected.



1-accumulator; 2-accumulator relief valve; 3-electromotor; 4-torque sensor; 5- constant pressure variable pump; 6-relief valve; 7- proportional reversing speed control valve; 8- variable motor/pump; 9-inertia flywheel; 10- magnetic powder brake; 11- pressure gauge; 12- pressure sensor

Figure 2. The hydraulic schematic of the test bench.

Table 1. Orthogonal test record table.

Test conditions	Magnetic powder brake torque (Nm)	Accumulator working pressure (MPa)	Voltage value (V)
Working condition 1	0	18	0.5
Working condition 2	16.67	18	1.5
Working condition 3	33.33	18	2.5
Working condition 4	50	18	3.5
Working condition 5	0	19	1.5
Working condition 6	16.67	19	0.5
Working condition 7	33.33	19	3.5
Working condition 8	50	19	2.5
Working condition 9	0	21	2.5
Working condition 10	16.67	21	3.5
Working condition 11	33.33	21	0.5
Working condition 12	50	21	1.5
Working condition 13	0	23	3.5
Working condition 14	16.67	23	2.5
Working condition 15	33.33	23	1.5
Working condition 16	50	23	0.5

3.3. Test results and analysis

Figure 3 shows the motor speed change curves of the working conditions 1-16. The accumulator working pressures of the four test conditions in each figure are the same. A comprehensive analysis of the four figures shows that when the accumulator working pressure is 21MPa or less and the set voltage value is 2.5V and 3.5V, no matter how much the magnetic powder brake torque is adjusted, the motor cannot be driven. However, when the accumulator working pressure is 23MPa, the working condition of the voltage of 3.5V can't drive the motor, the working condition of the voltage of 2.5V can drive the motor. Therefore, to ensure the normal operation of the motor and better acceleration performance, the

relatively reasonable voltage value adjustment range is 0.5-2.5V. Furthermore, increasing the working pressure of the accumulator can meet the requirements of faster motor speed.

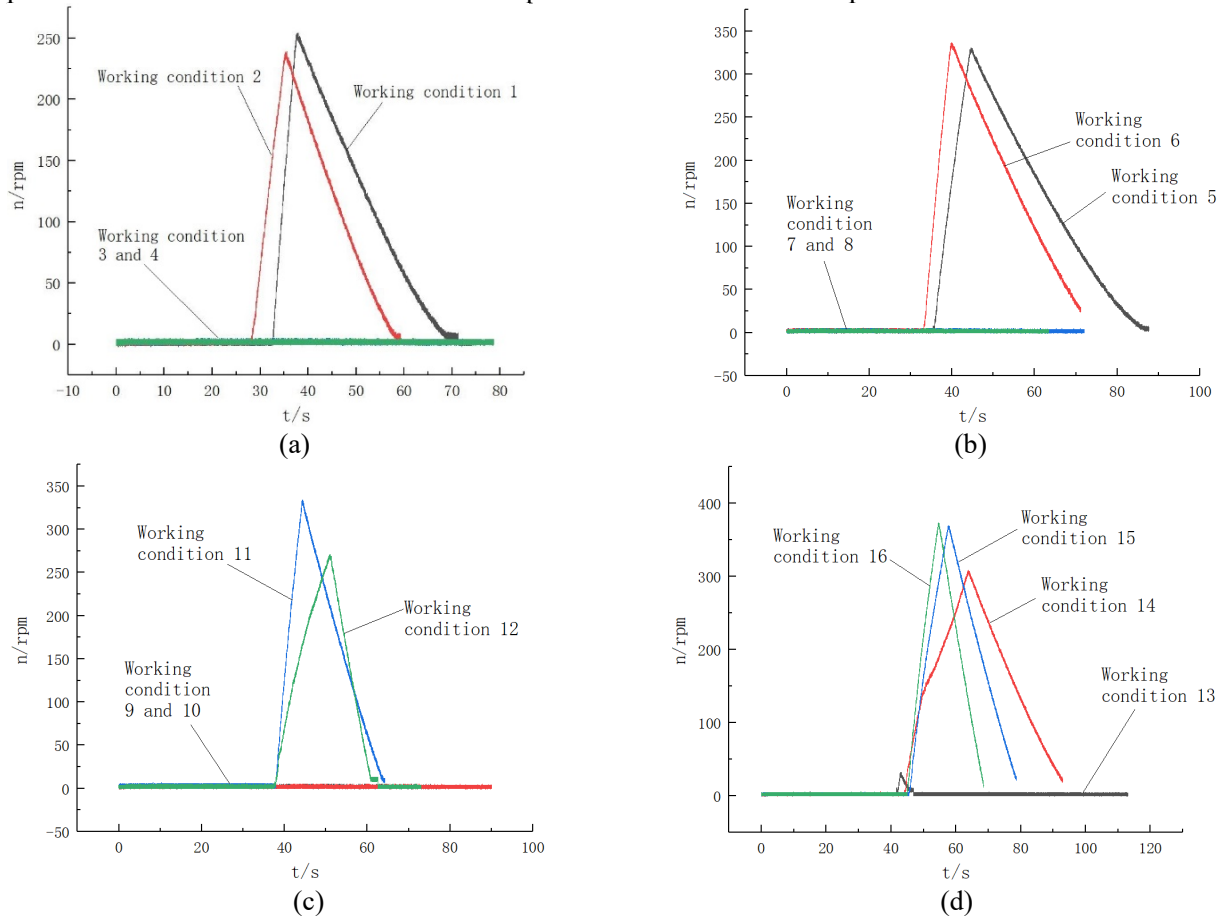


Figure 3. Motor speed change curves of working conditions 1-16.

Figure 4 shows the motor speed change curves of the working conditions 1, 6, 11, and 16. The motor displacements of the four operating conditions are the same. By analyzing the curves of the four working conditions in the Figure 4, it can be found that as the magnetic powder brake torque increases gradually, the acceleration performance of the motor decreases even when the accumulator working pressure is high. It is indicated that the influence of the magnetic powder brake torque on the acceleration performance of the motor is greater than that of the accumulator working pressure.

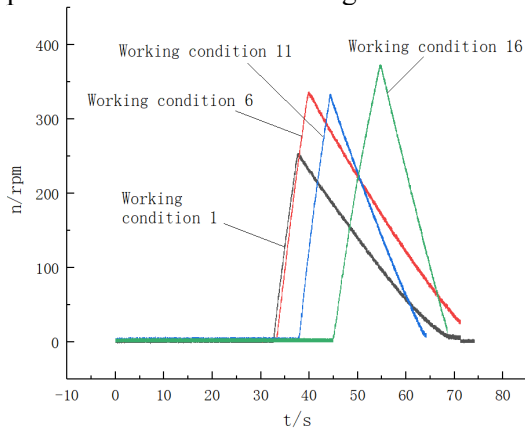


Figure 4. Motor speed change curves of working conditions 1, 6, 11 and 16.

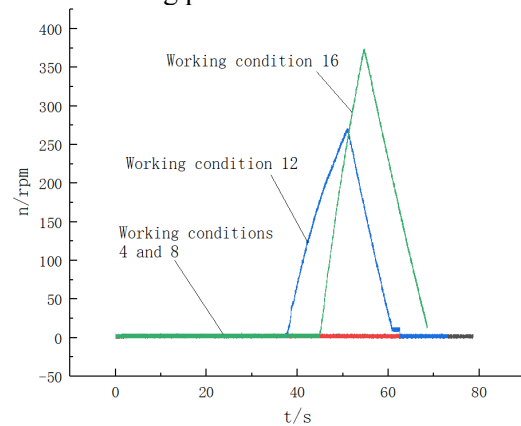


Figure 5. Motor speed change curves of working conditions 4, 8, 12 and 16.

Figure 5 shows the motor speed change curves of the working conditions 4, 8, 12, and 16. The magnetic powder brake torques of the four operating conditions are the same. In the Figure 5, the accumulator working pressures of the working conditions 4 and 8 are small, and the torque of the magnetic powder brake is large, so that the accumulator cannot separately drive the motor. By analyzing the working conditions 12 and 16, it can be found that the higher the accumulator working pressure and the larger the displacement of the motor, the better the acceleration performance of the motor.

4. Conclusions

(1) The accumulator working pressure has less influence on the acceleration performance of the motor, but increasing the accumulator working pressure can meet the higher motor speed requirement, which proves that the working pressure range of the accumulator is set to be reasonable.

(2) The effect of the load (the magnetic powder brake torque) on the acceleration performance of the motor is greater than the accumulator working pressure. At the same time, it is determined that the reasonable voltage value adjustment range is 0.5-2.5V (the reasonable motor displacement range) to improve the driving efficiency of the accumulator and motor efficiency.

(3) By analyzing the test conditions, it is concluded that increasing the accumulator working pressure and the motor displacement can improve the acceleration performance of the motor (the acceleration performance of the corresponding vehicle).

Acknowledgments

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