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Simulation Study of the Vehicle Hydraulic Retarder

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Abstract

Hydrodynamic retarder is one of the important auxiliary braking systems among oversize vehicle. Internal flow field in this paper, the retarder has carried on the innovation design and modeling and simulation, and in the design of test bed frame for retarder was tested, through the comparison of simulation data and experimental data, in order to get more reliable data of retarder braking torque. Using simulation software AMESim braking whole model, set up a retarder and under different conditions are simulated with retarder, compared with the result of simulation analysis, do the further research of the hydraulic retarder braking performance of the system. Braking and driving through the retarder braking joint simulation of braking curve, it can be seen that the use of hydraulic retarder of automobile braking performance, driving safety and economy superiority.

Keywords: *Retarder, Hydraulic, Simulation, Service brake*

1. Introduction

The transport vehicles working in the mining area and buses in the city, because of the frequently use brake or use for a long time, causing friction disc overheating, braking efficiency decline, even lead to brake failure which is a threat to safety [1]. At the same time, because of the frequent replacement of brake shoe and tire, vehicles transportation cost increase. Auxiliary brake system is developing rapidly, therefore, all kinds of vehicles, hydraulic retarder is one of the important auxiliary braking form.

Hydraulic retarder has many advantages, such as braking torque, smooth braking, small size and low noise, long service life and so on, which has been used in the military vehicles, heavy trucks and engineering machinery and other fields. In addition, the hydraulic retarder appliance for long time continuous braking ability. Especially when the vehicle ramp down in a long way, it can keep stable brake, which is the traditional friction brake cannot be achieved. So it is of great significance on the traffic safety on the vehicle equipped with hydraulic retarder unit.

The author uses ZYBX4451 type hydraulic mechanical automatic transmission hydraulic retarder system that is developed by Beijing university of science and technology independently as the research object. Through the design and simulation analysis of retarder, in order to further improve the retarder design provides more accurate results.

2. Introduction of ZYBX4451 Hydraulic Retarder

2.1. Introduction of the Structure

Structure of hydraulic retarder is shown in Figure 1. The internal hydraulic retarder is double circular structure. It is composed of two rotors and the two stators. The two rotors

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arranged opposite and the two stators relative layout. Thus, this forms a circle of two symmetry [2, 3].

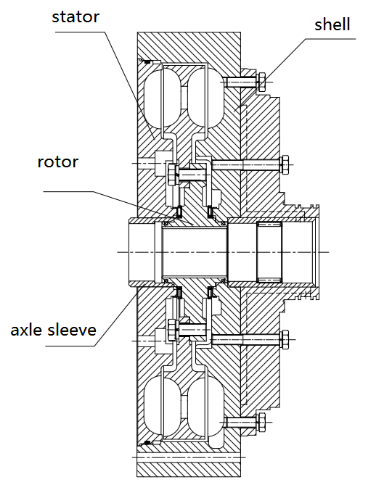

Figure 1. The Internal Structure of the Retarder

Rotor and stator blades are radial straight blade, the rotor number is 36, the number of the stator is 32, and the hydraulic retarder inlet and the oil outlet are open on the shell. The side face of the shell has five oil grooves which are respectively corresponding with five oil cavity in the hydraulic retarder control valve.

It can be seen from Figure 2 that hydraulic amble control valve is mainly composed of valve body, valve core and upper and lower two end cover parts and other components.

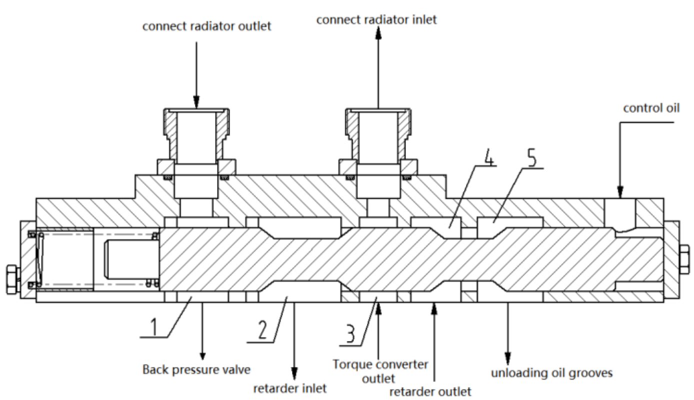

Figure 2. The Appearance of the Control Valve

2.2 Introduction of the Retarder Working Oil-way

The retarder working oil-way is shown in Figure 3 and 4. Red arrows mark the direction of flow of oil.

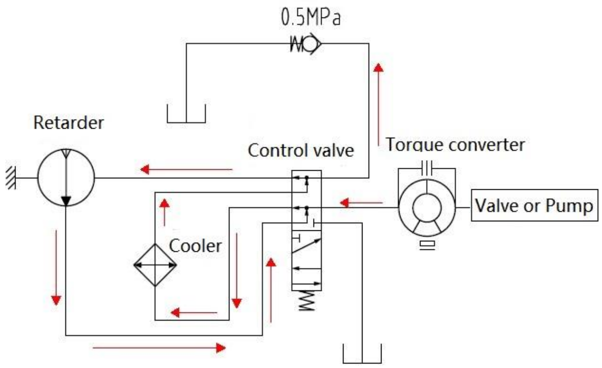

Figure 3. Working Principle Diagram of Retarder

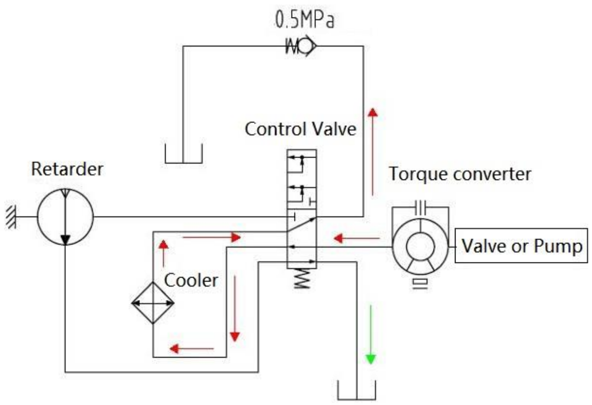

Figure 4. Not Working Principle Diagram of Retarder

In normal operation, it can be thought that retarder oil itself through the cooler has a small circulation. Torque converter oil can be seen as filling oil source. The excess oil flows back to the oil tank through the check valve. When the retarder need to stop working, the retarder working oil-way changes into Figure 4. Retarder entrance is cutoff, the oil inlet no longer, outlet oil flows back to the tank through the valve.

3. Calculation and Verification of Retarder Braking Torque Data

To get braking torque data for the simulation of the vehicle brake, Full retarder flow field model is established and simulated. Meanwhile, bench test is designed to verify the simulation results.

3.1 The Whole Flow Field Simulation

According to the working condition of the slow oil connection, full flow field simulation model is set up as shown in Figure 5 [4].

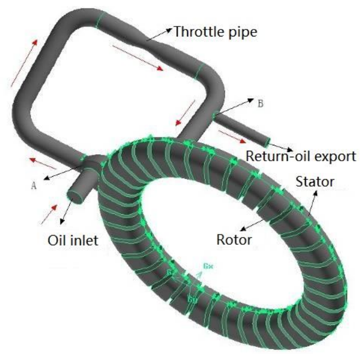

Figure 5. The Simulation Model Diagram of the Retarder Considering the Flow Field

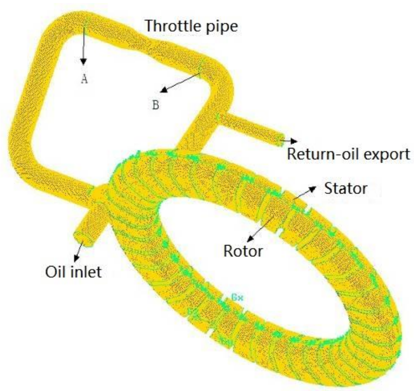

Figure 6. The Grid of the Simulation Model

Retarder flow model parameter data such as Table 1

Table 1. Parameter Data of the Retarder Flow Field Model

	blade number	blade Thickness	Runner inner diameter	Runner outer diameter	Axial size
Stator	32	7mm	243mm	359mm	17mm
Rotor	36	7mm	243mm	359mm	17mm

The software Gambit is used for carrying on the grid division of the whole flow passage model, and the boundary conditions are made [5]. The model after mesh generation is shown in Figure 6. The grid size is 2.

Import the grid and the boundary conditions into the software Fluent for simulation calculation [6]. In the material definition, Air information directly calls Fluent material database, Transmission oil density is defined as 860kg/m3 and viscosity is defined as 0.0061kg/ms. Sliding grid settings: in the cell zone conditions, define 2000r/min for the speed of the rotor part model region, and use the sliding mesh algorithm, The stator area is stationary [7].

After the torque curve and the mass flow rate curve are basically stable, we finish the simulation. The static pressure and the dynamic pressure distribution are shown in Figure 7 and Figure 8.

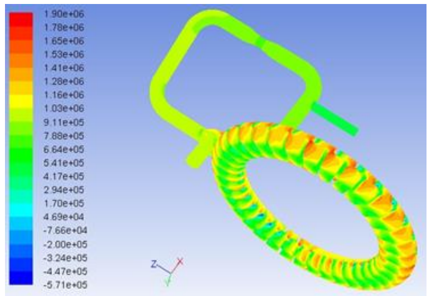

Figure 7. The Static Pressure Distribution

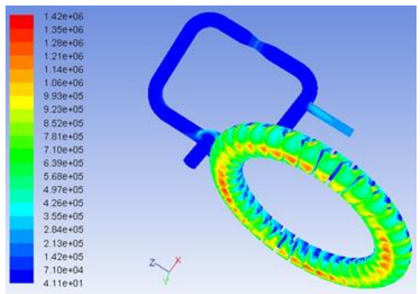

Figure 8. The Dynamic Pressure Distribution

From Figure 7, the static pressure span is about 2.5 MPa in the simulation model considering import and export of retarder, which is basically the same the model that does not consider the import.

From the Figure 8, we can know that the dynamic pressures of high pressure areas are mainly concentrated in the rotor area, the fluid flow in the rotor rotation driven with high speed. Thus dynamic pressure value is higher.

Flow diagram as the change of time is shown in Figure 9. We can get cooling circulation flow.

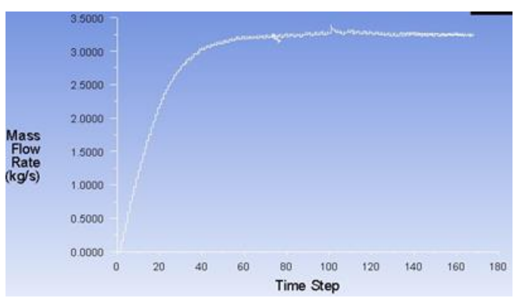

Figure 9. Mass Flow Diagram

The calculation results of throttle pipe inlet mass flow:
Mass Flow Rate (kg/s)
Throttle pipe inlet 3.2879653
Net 3.2879653
The calculation results of pressure inlet mass flow:
Mass Flow Rate (kg/s)
Inlet 3.0640123

Net 3.0640123

The difference between the two can be thought of retarder itself ability to pump oil, it is about 0.224kg/s.

This value indicates that after the heat exchanger heat oil accounted for the entrance to the retarder oil quantity is 7.3%, a small proportion. It is necessary to improve the inside and outside ring size difference appropriately, in order to improve the inner and outer pressure difference, increase the cooling flow, improve the cooling capability, and improve the retarder continuous working ability

Under different conditions, simulation and calculation of braking torque in the closed model is shown in Table 2.

Table 2. The Simulation Result of the Torque

speed / liquid filled ratio	800 r/min	1000 r/min	1200 r/min	1400 r/min	1600 r/min	1800 r/min	2000 r/min	2200 r/min
10%	14.2	22.3	35.3	56.3	82.0	123.7	158.0	173.0
20%	27.4	45.3	75.6	107.8	163.3	259.5	273.4	346.6
30%	42.3	71.3	109.5	163.5	247.8	361.5	405.0	543.1
40%	56.9	88.0	132.5	217.5	330.5	489.6	550.3	694.2
50%	67.1	110.8	170.8	271.1	402.5	592.6	721.8	879.1
60%	80.5	131.8	196.5	321.5	485.9	721.3	867.9	1058
70%	94.0	156.4	228.8	380.4	574.9	836.6	971.0	1195
80%	109.9	178.6	263.5	479.5	649.7	945.8	1087	1412
90%	123.8	197.8	299.7	506.1	739.0	1068	1204	1531
95%	126.8	211.1	313.1	570.4	776.8	1127	1318	1678

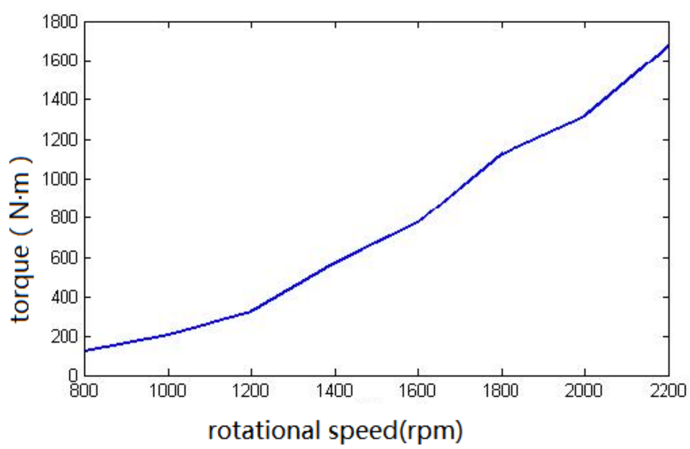

Figure 10. The Torque Curve under Different Rotational Speed

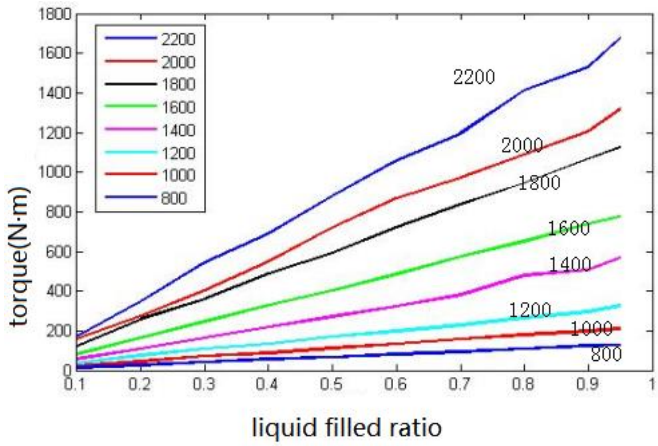

Figure 11. The Braking Torque Simulation Curve under Different Charging Rate

According to the data in Table 2, it can be concluded that different speed torque curves in the maximum filling rate 95% are shown in Figure 10. As can be seen, the torque is basically the two functions of speed. The speed under different filling rate braking torque simulation curve as shown in Figure 11.

2.2 Retarder Test Bench

The design of retarder test-bed is reference to the retarder in automatic gearboxes arranged. In the original foundation, we use the external valve control instead of the retarder starting valve, and change the original oil-way into the pipeline connecting [8]. Test rig arrangement is shown in Figure 12.

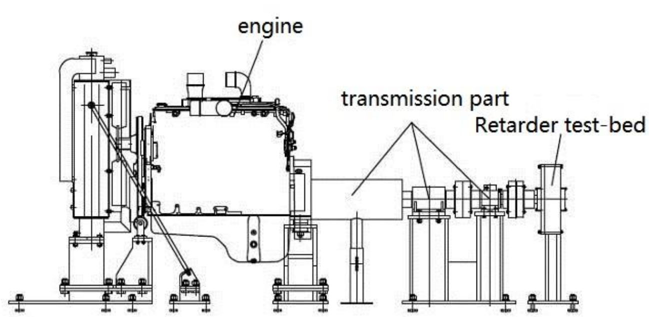

Figure 12. The Whole Layout of the Bench Test

The following is retarder specific layout. Front end is connected with the turbine shaft, and back end is connected with the clutch. Through the gearbox, clutch and the axle are connected through a transmission shaft [9].

Figure 12 represents only the connection of the mechanical parts, cooler, oil pump, pipeline connecting parts as shown in Figure 13.

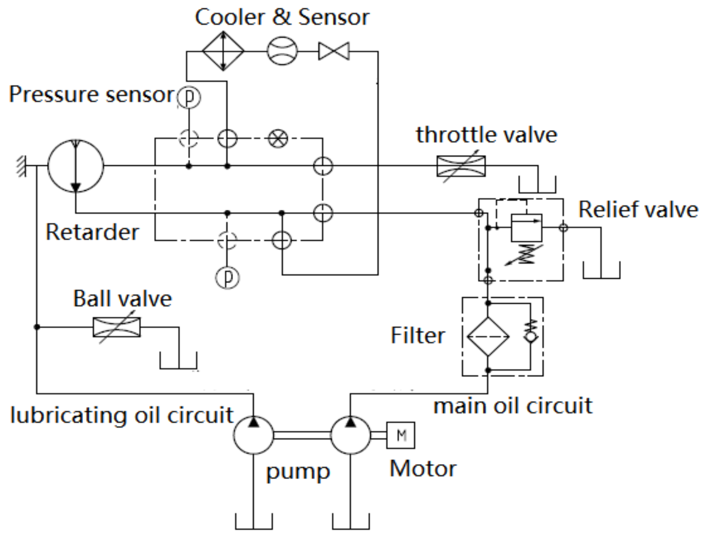

Figure 13. The Oil Circuit Principle Diagram of the Retarder Test

Figure 13 specifically include the following several parts: fuel tank, oil pump and motor, filter, relief valve, retarder system, cooling system, throttle valve. The oil pump is a double gear pump, two oil outlet respectively into the two circuit, a main circuit enters retarder entrance, all the way to the cooling oil, cooling oil entrance into the retarder.

After checked test bench we started the engine under no-load (retarder no liquid filled) operation, which ensured that that the mechanical parts without fault. Changed the engine speed, and recorded the no-load loss in the stable speed. Started the engine at idle speed 750r/min stable. Meanwhile, maintained the motor frequency converter at low frequency, the throttle valve is fully open state [4]. Started motor after the engine run idle for two minutes, adjusted the frequency converter to improve the motor speed. The rotation speed of the motor is divided into several stages under the inlet pressure is less than 3MPa, adjusted the throttle valve in each stage. Gradually decreasing throttle valve opening, the opening was divided into several stages, each stage was recorded in the stable, results as shown in Table 3 and Table 4.

Table 3. Idling Loss Data Records

Rotational speed (rpm)	Torque (Nm)
750	8.5
1000	9.7
1200	11.2
1400	15.6
1600	23.8

Table 4. The Retarding Torque Test Data

Opening \ Speed	750	1000	1200	1400	1600
5	79.0	85.6	104.4	162.2	191.4

4	142.6	198.6	269.2	379.6	549.4
3	203.4	270.8	398.6	598.6	864.2
2	231.2	358.4	523.4	825.4	1224.6
1	291.6	540.6	799.2	1293.8	——

We work out unilateral retarder braking torque from the test data, in order to compare with the simulation data. The two groups of data were shown in Figure 14 in the same coordinate system.

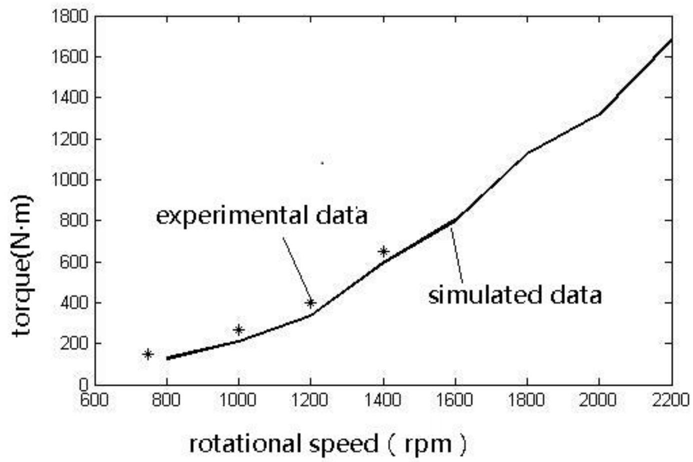

Figure 14. The Simulation Data and Experiment Data Comparison

From the Figure 14, it can be seen that the test data compared with the simulation data is slightly big. There may be two reasons, one is the mechanical loss caused by processing installation, another is the retarder cavity pressure rise for the throttle control. As a closed area simulation, the simulation has no part of this pressure rise. Overall, the test data and simulation data are basically identical.

4. The Retarder Simulation in Vehicle Braking

Author names and affiliations are to be centered beneath the title and printed in Times New Roman 12-point, non-boldface type. Multiple authors may be shown in a two or three-column format, with their affiliations below their respective names. Affiliations are centered below each author name, italicized, not bold. Include e-mail addresses if possible. Follow the author information by two blank lines before main text.

4.1. The Brake Torque Data Processing

We use the Matlab [10] to fit the experimental data and obtain fitting function under maximum filling rate as following:

$$M = 0.0005n^2 - 0.2407n + 2.45$$

where M is torque, and n is rotate speed.

The control of the test data curve and the fitting curve are shown in Figure 15.

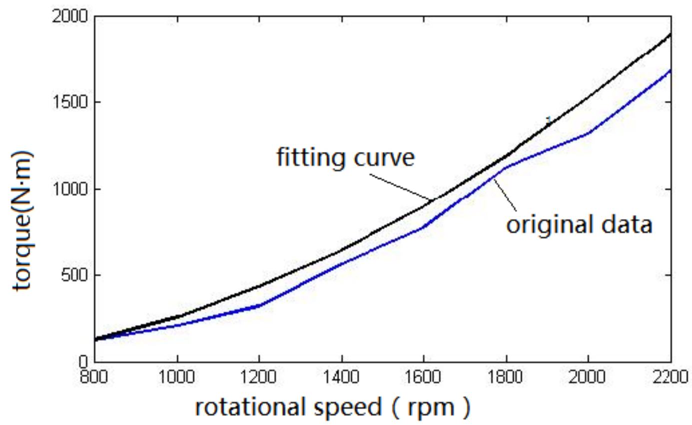

Figure 15. The Original Data Curve and the Fitting Curve Comparison

Because the test date is relatively big, the fitting curve can reduce the difference between with the test. It is more appropriate.

4.2. Modeling of Vehicle Braking Simulation

The retarder is designed for 30 tons mining dump truck, and vehicle related parameters as shown in Table 5

Table 5. Vehicle Parameters

GVW (kg)	53000
GVW-a(m)	2.445
GVW-b(m)	1.205
GVW-h_g(m)	1.370
EVW(kg)	23000
EVW-a(m)	1.825
EVW-b(m)	1.825
EVW-h_g(m)	1.150
Axle Base-L(m)	3.650
Axle Ratio	2.8
Ratio	4.47

We use the simulation software AMESim to build the model of retarder, The model is composed of the following several parts of integration, including the vehicle model [11, 12], transmission model of mechanical part, speed feedback and calculation model, retarder and control part of the model, it is shown in Figure 16.

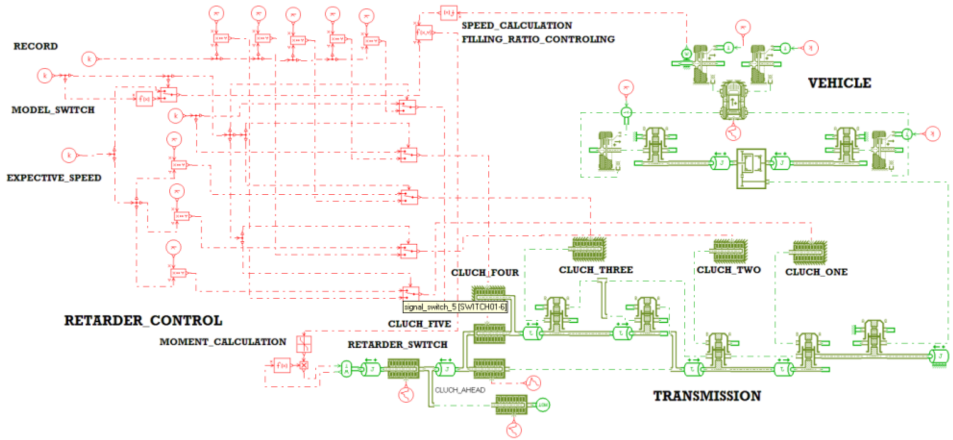

Figure 16. The Whole Model of Retarder Braking

Through rotating speed sensor, the control part gets real-time value of speed is composed from the front wheel, and calculates speed for vehicles as retarder control reference. Control part mainly include: (1) shifting clutch gearbox control, to select the appropriate gear to provide braking strength suitable; (2) the retarder filling rate adjustment control, fine-tuning of the retarder braking torque, so as to achieve the constant speed downhill and precise control.

Gear box planetary gear input end is connected with the retarder torque calculation part, and it's output end is connected with the vehicle rear axle differential. Thus, according to the real-time speed from the rear wheel by the vehicle transmission system to the retarder rotor, the retarder calculation can calculate the braking torque that retarder can provide. At the same time, considering taking control of the liquid filling rate fine-tuning. Finally, we obtain actual braking torque to the transmission input end, through the transmission to the wheel to slow speed brake

4.3. Brake Simulation Process and Result

Brake simulation mainly considers the vehicle loaded with the following condition process

(1).On the flat road braking process under every speed and each gear

We drive the vehicle to a steady state in the 1000 r/min, 1500 r/min and 1800 r/min and 2000 r/min speed in turn, and then slowly brake. Simulation curves as shown in Figure 17~21.

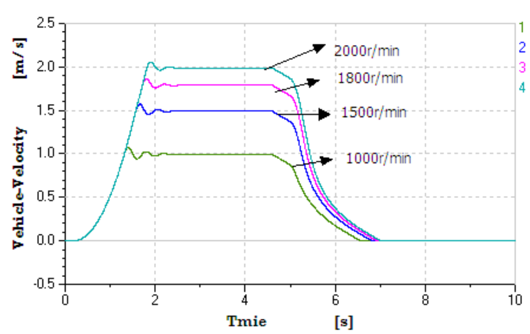

Figure 17. Braking Curves under Different Speed in One Gear

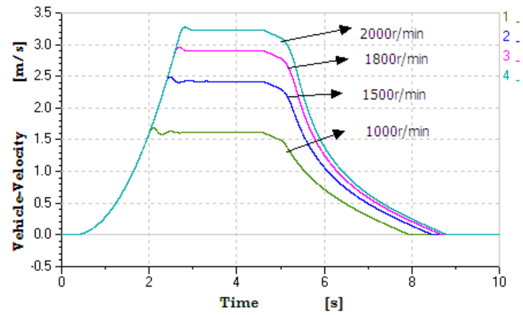

Figure 18. Braking Curves under Different Speed in Two Gear

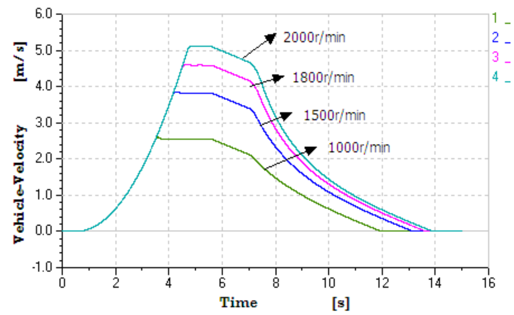

Figure 19. Braking Curves under Different Speed in Three Gear

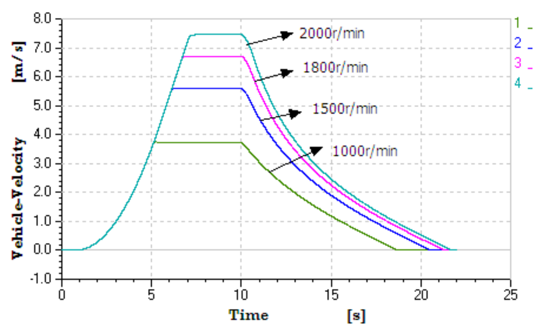

Figure 20. Braking Curves under Different Speed in Four Gear

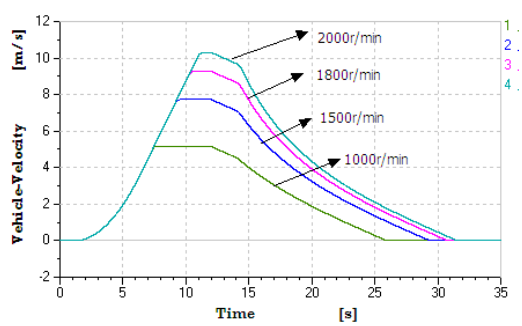

Figure 21. Braking Curves under Different Speed in Five Gear

As you can see from Figure 17 ~ 21, from one to five gears, braking phase curve slope is more and more small, the reason is that the higher the gear, the transmission ratio is smaller, the same rotor speed to retarder speed is smaller, resulting in a moment also is smaller, braking effect will be poor.

(2) Brake simulation process in the different angles ramp

Considering the limit conditions, we only consider the loaded vehicle downhill amble. Maximum capacity is equivalent to the assessment of retarder. Thus, vehicle can more easily meet safety slow speed under light loaded [13].

On the different slope road, we go slow brake for each gear in turn, and record the maximum braking ability under various operating conditions. Each gear braking curve as shown in Figure 22~26:

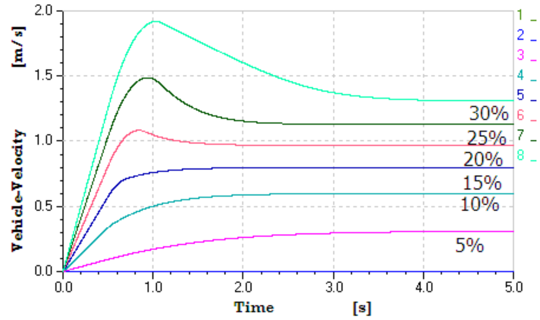

Figure 22. Braking Curves at Different Slope on the Road in One Gear

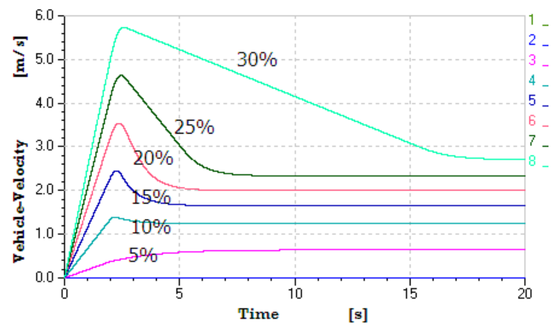

Figure 23. Braking Curves at Different Slope on the Road in Two Gear

It can be seen from Figure 22, when the transmission gears is first and the slope between the smallest and 30%, vehicles can be stable in a certain speed due to the retarder system (below 1.3 m/s), which can achieve the vehicle constant speed downhill. Of course, along with the slope increasing, the lowest constant speed can be realized will increase

It can be seen from Figure 23, when the transmission gears is second, and the slope between the smallest and 30%, vehicles can be stable in a certain speed due to the retarder system (below 2.8 m/s), which can achieve the vehicle constant speed downhill. Of course, along with the slope increasing, the lowest constant speed can be realized will increase

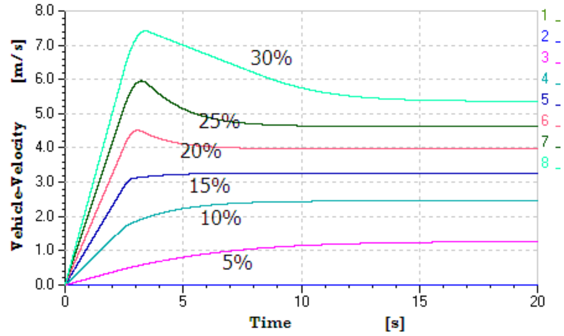

Figure 24. Braking Curves at Different Slope on the Road in Three Gear

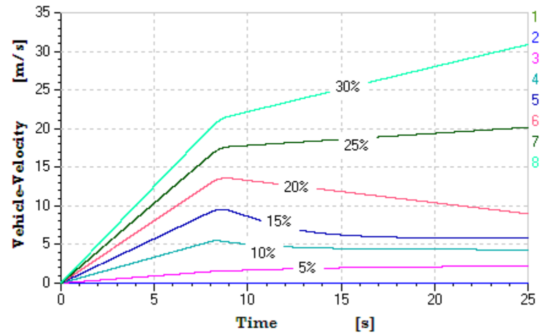

Figure 25. Braking Curves at Different Slope on the Road in Four Gear

Figure 24 shows that, when the transmission gears is third and the slope between the smallest and 30%, vehicles can be stable in a certain speed due to the retarder system (below 5.5 m/s), which can achieve the vehicle constant speed downhill. Of course, along with the slope increasing, the lowest constant speed can be realized will increase. Compared to the first, second, steady speed on each slope also increased.

Figure 25 shows that, when the transmission gears is fourth and the slope is unless than 23%, vehicles can be stable in a certain speed due to the retarder system (below 8 m/s), which can achieve the vehicle constant speed downhill. Of course, along with the slope increasing, the lowest constant speed can be realized will increase. Compared to the first, second and third ,steady speed on each slope also increased. When the slope is more than 23%, The system will not be able to make the vehicle stable at a certain speed, on the large slope road vehicle speed will gradually increase.

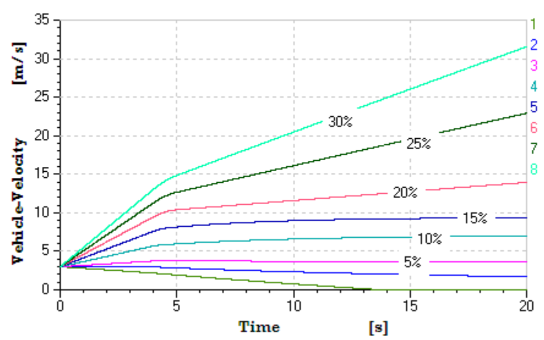

Figure 26. Braking Curves at Different Slope on the Road in Five Gear

Figure 26 shows that, when the transmission gears is fifth and the slope is unless than 19%, vehicles can be stable in a certain speed due to the retarder system (below 8 m/s), which can achieve the vehicle constant speed downhill. Of course, along with the slope increasing, the lowest constant speed can be realized will increase. Compared to the first, second, third and fourth, steady speed on each slope also increased. When the slope is more than 19%, the system will not be able to make the vehicle stable at a certain speed, on the large slope road vehicle speed will gradually increase.

Table 6. The Brake Capacity Simulation Data Table

slope	First (m/s)	Second (m/s)	Third (m/s)	Forth (m/s)	Fifth (m/s)
1%	0	0	0	0	0
3%	0	0	0	0	0
5%	0.21	0.43	0.87	1.53	2.48
7%	0.38	0.79	1.57	2.77	4.50
9%	0.50	1.04	2.05	3.63	5.89
11%	0.60	1.24	2.45	4.33	7.03
13%	0.68	1.41	2.80	4.95	8.04
15%	0.76	1.57	3.12	5.51	8.95
17%	0.83	1.72	3.42	6.04	9.80
19%	0.90	1.87	3.70	6.53	---
21%	0.97	2.00	3.97	7.01	---
23%	1.03	2.14	4.24	7.48	---
25%	1.10	2.27	4.50	---	---
27%	1.16	2.41	4.77	---	---
30%	1.27	2.63	5.21	---	---

According to the data in Table 6, we use MATLAB rendering minimum speed curve when the vehicle is fully loaded on different slope road with different shift downhill amble. It is shown in Figure 27.

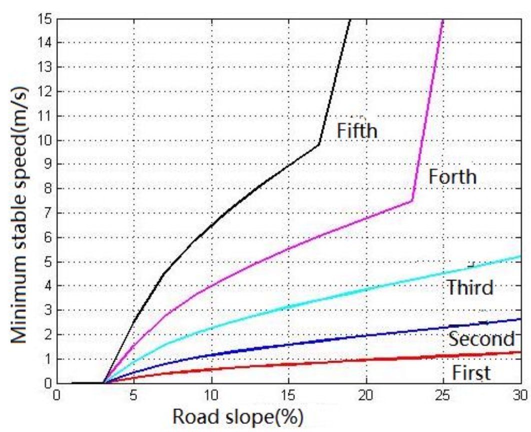

Figure 27. Minimum Speed Curve

From Figure 27, if the transmission gears is fourth, we can see that vehicles cannot reach the steady speed when the road slope is more than 17%, speed will be increased gradually with time in the downhill. so we only use first, second and third to take control of constant speed. Considering the adequacy of retarder and heat stability, we try to reduce gears on the premise that the vehicle can achieve the predetermined speed, in order to ensure that the filling rate is higher value.

It can be concluded that the relationship between expected constant speed and optimal gear, and then complete the downhill retarder control strategy. We give six constant speed for choice. 1.5m/s and 2m/s corresponds to first, 3m/s and 5m/s corresponds to second, 7m/s and 10m/s corresponds to third.

(3) Constant and slow speed simulation process in the different angles ramp

Firstly, we identify several predetermined speed, then determine which gear should be selected from Figure 28 The selection principle is, in the premise that vehicle can achieve the predetermined speed, trying to choose higher gear [14]. So that liquid filling rate of the retarder is largest, to improve the heat dissipation and stability.

According to the comparison of feedback speed with predetermined speed, we get the retarder conditions. Depending on the adjustment of the liquid filling rate, we make vehicle speed closed to the predetermined speed, for the purpose of constant speed downhill [15].

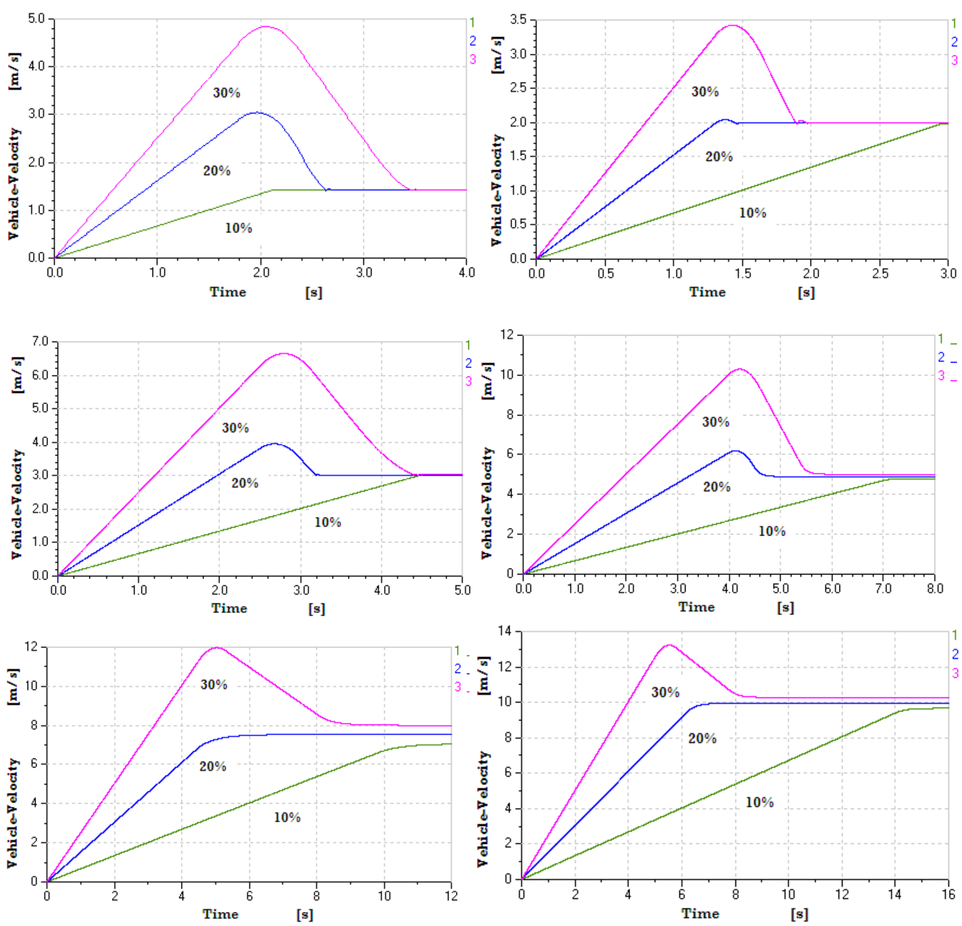

Figure 28. The Simulation Curve

We use the software AMESim to simulation on the different slope road, such as 10%, 20%, 30% and so on, and choose the vehicle speed as following, 1.5m/s, 2 m/s, 3 m/s, 5m/s, 7m/s, 10m/s. The simulation curves are shown in Figure 28. As you can see, no matter that the speed is above or below the set speed, vehicle can be steady at the set speed in a few seconds, and then drives downhill at the constant speed.

5. Conclusion

In this paper, retarder full port flow simulation model is established, we calculate the braking torque values at different speed and liquid filling rate, get the complete torque data, and draw the curve of the basic. It provides a basic theoretical basis for the design and simulation of the vehicle retarder.

Through bench test, we can know that test data and simulation data are in substantial agreement, and the simulation results are reliable.

By using the AMESim to the vehicle braking simulation, we get the simulation curves at different working conditions when vehicle is loaded. On a flat road, the higher gear is, the smaller the braking torque generated by retarder is; in the different angles ramp, the greater the ramp is, the greater the constant speed downhill is. According to the curves, we can get the relationship between the expected constant downhill speed and optimal gear, and then complete the downhill control strategy, which provides the basis for the pilot operation gear selection.

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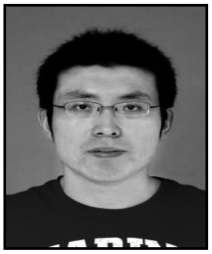

Li Ronghao was born in a small village of Shan Dong Province on Dec 13th, 1986. In 2011 he was admitted by University of Science and Technology Beijing as a PhD student. His major is mechanical engineering. mainly engaged in the research and design of automobile. Since 2011, he has participated in the "863" national major science and technology research projects, and completed the research, design, manufacture and experiment of the mining truck.