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Research on Energy Saving Technology of Load Sensitive Variable Steering System for Vehicles

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Abstract: In view of the large energy loss problem in the traditional full hydraulic steering system, a scheme of replacing the ordinary pump with the priority valve with the load sensitive variable pump is proposed to make the variable pump provide the corresponding flow rate according to the needs of the steering system to achieve the purpose of energy saving. Through the establishment of the system AMESim simulation model, the data comparison shows that the energy loss of the load sensitive variable steering system is significantly reduced relative to the traditional full hydraulic steering system.

Keywords: variable load pump; steering system; energy saving; hydraulic; AMESim; simulation

1 Introduction

The commonly used steering system of vehicles is mainly classified into mechanical steering system, hydraulic power steering system, electric power steering system and full hydraulic steering system. Full hydraulic steering has the advantages of large power density ratio and flexible

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arrangement, and is widely used in engineering vehicles[1]. The full hydraulic steering system is realized by hydraulic energy conversion to mechanical energy, and the control part and the actuator are connected completely via fluid. The steering pump is driven directly by the engine, the pump is always in the working state, the flow rate of the quantitative pump is proportional to the engine speed, and the excess flow is returned to the tank[2-3]. According to statistics, because the steering state only accounts for about 20% of the running time of the vehicle and 80% of the running time of the vehicle is in the non-steering state, the energy consumption of the steering system is very large, and the low energy utilization ratio of the system will not only lead to higher oil consumption and pollution, but also the heat generated will affect the reliability of the parts and components, so it is necessary to reduce the energy consumption of the steering system. The load-sensitive variable pump has the characteristics of energy saving and high efficiency and has be widely used in the field of construction machinery[4]. The load-sensitive variable pump can adjust the pressure and flow of the pump according to the pressure required by the load, so that the load-sensitive variable pump can effectively reduce the energy loss of the system[5-6].

2 Principle and energy consumption analysis of traditional full hydraulic steering system

The full hydraulic steering system structure is shown in Figure 1, which is mainly composed of steering pump, full hydraulic steering gear, priority valve, booster cylinder, oil storage tank, tubing, etc. When the steering gear is in the median, the engine is not started, the steering pump does not supply oil, and the spring pushes the spool of the priority valve to the right end, so that the *EF* port is closed and the *CF* oil circuit is connected. When the engine starts, the steering pump outputs the oil through the *CF* valve port of the priority valve into the diverter *P* interface, and the oil produces a pressure drop through the middle section of the diverter and passed through the *LS* oil mouth to the two ends of the spool of the priority valve, the resulting hydraulic force is balanced with the spring force, hydraulic power, so that the spool stays in a equilibrium position. When the static pressure difference exceeds the spring force, it will push the spool to the left. Increase the *EF* valve port, reduce the *CF* valve port, the flow of the supply steerer is very small, most of the oil through the valve mouth *EF* return tank or supply other working devices. When turning the steering wheel, the relative angular displacement between the spool of the steerer and the valve sleeve is generated. When the angular displacement exceeds a certain value, the middle segment of the steering gear is completely closed. The oil enters the metering device through the oil inlet *P* of the diverter and then flows through the oil outlet *L* or *R* into the steering booster cylinder to provide steering power.

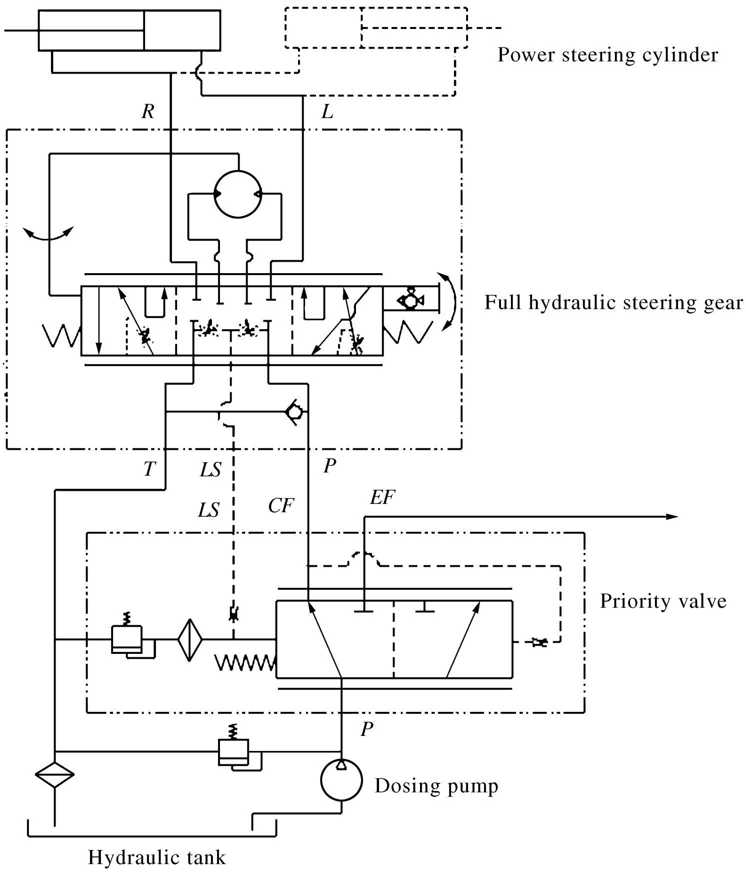

Figure 1 Schematic diagram of full hydraulic steering system

According to the above principle, the traditional full hydraulic steering system is always in the working state of the steering quantitative oil pump when the vehicle is idling or running in a straight line, and the flow rate of the pump is proportional to the engine speed. Because the hydraulic oil is sticky, the excess flow rate will inevitably lose a certain amount of energy when the pipeline flows, and the loss energy will change to heat, resulting in the increase of the system temperature and the deterioration of the performance.

Energy loss power generated by hydraulic oil through a pipeline is

$$P = \Delta p \times q \tag{1}$$

Where: Δp is pipeline pressure loss, MPa; q is flow rate of pipeline, L/min.

The calculation formula of pipeline pressure loss is as follows

$$\Delta p = \sum \lambda \frac{L}{d} \frac{\rho v^2}{2} + \sum \zeta \frac{\rho v^2}{2} \tag{2}$$

Where: d is pipe flow diameter, m; v is oil flow velocity in the tube, m/s; L is pipe length, m; ρ is the density of hydraulic oil, kg/m^3; λ is drag coefficient along the way; ζ is local resistance coefficient.

Through equation (1) and equation (2), it can be seen that the main energy loss of the full hydraulic steering system is closely related to the flow rate, and the greater the loss of the flow rate, in addition to increasing the pipe diameter of the system and the joint valve opening diameter in the design process, reducing the flow rate of the non-working state of the system is the main improvement method for energy saving. Therefore, the improved scheme in this study is to replace the traditional combination of hydraulic steering system with the characteristic of load-sensitive variable pump. The advantage is that the pressure and flow rate of the steering pump will be adjusted dynamically according to the demand, and the variable pump output low pressure and very small flow can keep the system low energy loss under idle or straight running conditions, so it can reduce the unnecessary flow loss.

3 Principle analysis of load sensitive variable pump

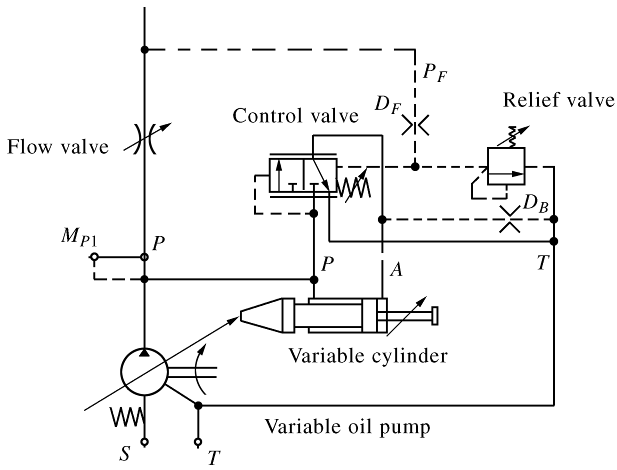

Figure 2 Schematic of load-sensitive variable pump

The load sensitive variable pump structure principle is shown in Figure 2. The load pressure P_F and the preset spring force are introduced at the right end of the control spool. At the left end of the spool, the balance force is from the pump outlet oil pressure P. The formula of the force balance relationship of the control spool is as follows:

$$P \times A = P_F \times S + F_t \tag{3}$$

Where: P_F is load pressure, MPa; P is pump outlet pressure, MPa; S is valve cross-sectional area, mm^2.

When the pump is not started, the load pressure P_F is zero, when the pressure at the pump is gradually rising to the right when the control valve core can overcome the right spring force F_t, the pressure oil P is connected to the oil port A, the oil enters the non-bar cavity end of the right side of the variable oil cylinder, because the force area of the non-bar cavity is larger than the rod cavity on the left, the piston moves to the left, the angle of the oblique disk is pushed to the near zero state, the pump flow is maintained at the minimum, the pump pressure is only greater than the spring force to overcome the pre-set control valve, and the pump power consumption is very small, so the purpose of non-working energy saving is achieved.

When the steering is working and the system has a load, the P_F and the spring force push the control spool to the left. When the oil outlet A communicates with the oil outlet T through the control valve, the pressure at the end of the rodless cavity of the variable piston decreases, and the variable piston pushes the inclined disc towards the large angle position under the combined action of the bias spring and the ring area of the rod cavity. When the steering speed of the system increases, the system needs a larger flow rate, the throttle valve port increases, and the pressure difference Δp_1 on both sides of the throttle valve decreases. Shifting so that port A and port T communicate, the pressure at the rodless cavity end of the variable piston decreases, and the swashplate angle increases, so the pump outlet flow increases to meet the system flow demand. The pressure difference Δp_1 on both sides increases accordingly, until the forces on both sides of the control spool are balanced and the pump flow rate stabilizes again.

On the other hand, the flow rate required by the system is reduced, the throttle outlet decreases, the pressure difference Δp_1 at both ends of the throttle valve increases, and under the action of pressure P, the control spool moves to the right, the pressure oil enters the right side of the variable oil cylinder without rod cavity to push the oblique disk angle to decrease, the pump flow decreases, and the pressure difference Δp_1 on both sides of the throttle valve decreases to the force balance on both sides of the control spool, and the pump flow remains stable again. Therefore, the characteristics of load sensitive variables can supply oil according to the needs of the system to achieve the purpose of energy saving.

4 AMESim model

According to the hydraulic schematic diagram of steering system, the models of steering system before and after improvement are built and simulated by AMESIM software, and the simulation data are finally analyzed and compared, shown in Figure3 and Figure 4.

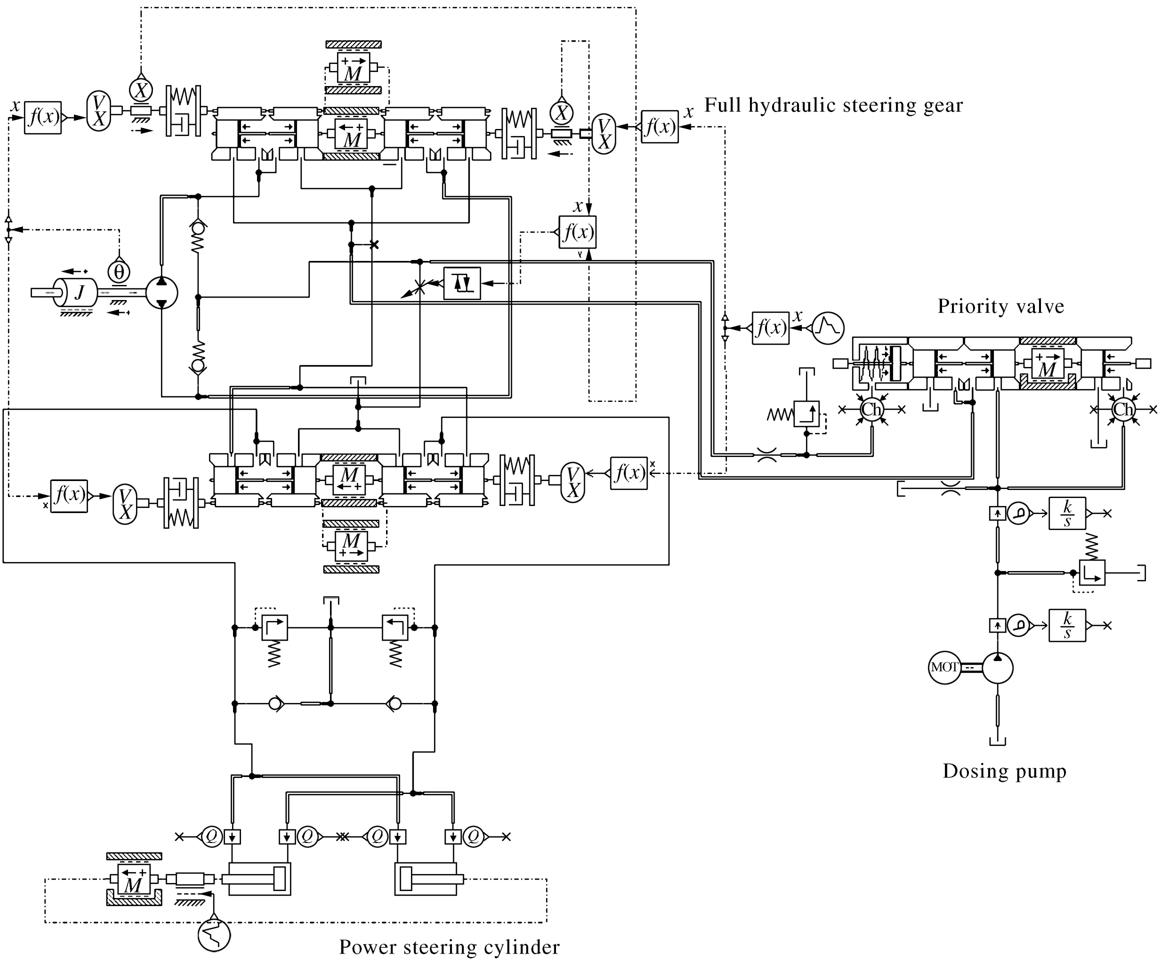

Figure 3 Simulation model of full hydraulic steering system

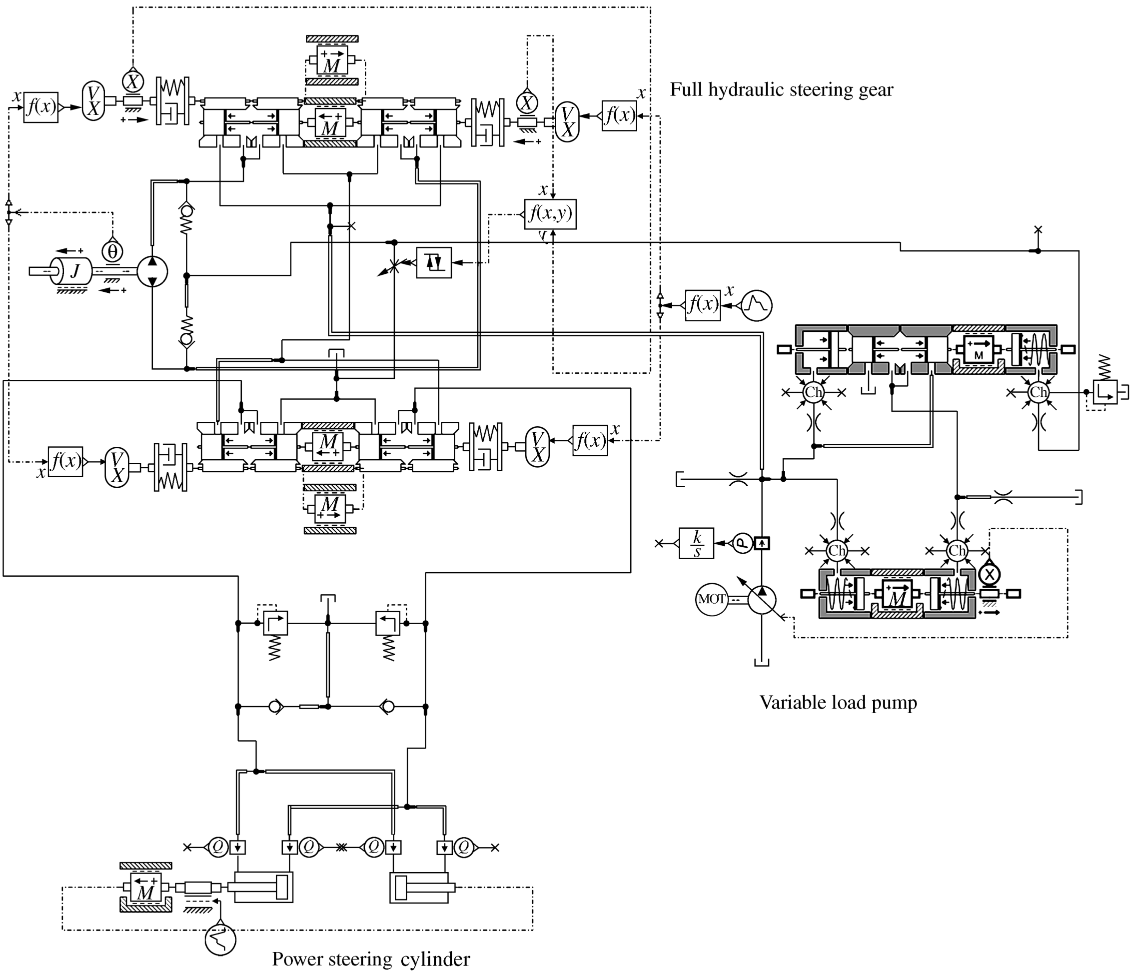

Figure 4 Simulation model of load-sensitive variable steering system

5 Simulation analysis

The simulation parameters of a steering system are set in Table 1, for a certain type of dump truck with a front axle weight of 19T as the research object. The input signal is that the simulated driver pauses for two seconds when turning the steering wheel at a uniform speed to the left and right limit position, and then turns back. The final angle is kept in the positive state, the simulation time is 15 s, the step is 0.01 s. The simulation model setting parameter values are shown in Table 1.

Table 1 Main parameters of the steering system

Parameter	Value
Maximum system pressure	16 MPa
Pumpage	40 mL/r
Pump speed	1 050 r/min
Control valve piston diameter	5 mm
Control valve preset pressure difference	1 MPa
Cylinder load pressure	15 MPa
Steering wheel corner	±720°
Steering wheel angular velocity	1 r/s
Pump variable cylinder diameter	20 mm
Control valve spring stiffness	5 N/mm

The pump pressure curve, flow curve and power curve are shown in Figure 5 − Figure 7.

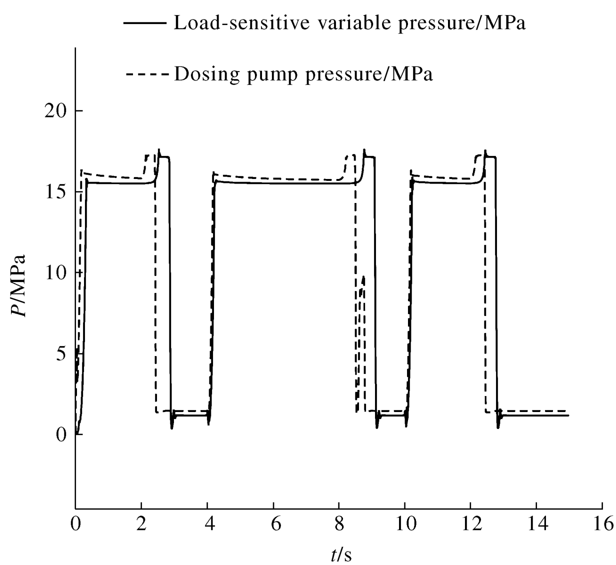

Figure 5 Pump pressure curve

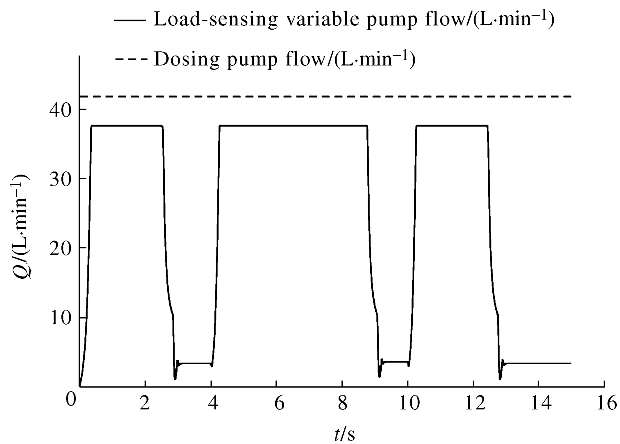

Figure 6 Flow curve of the pump

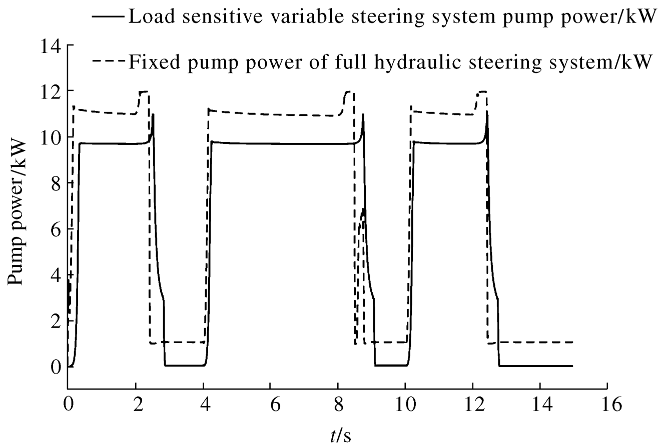

Figure 7 Pump power curve

Figure 5 to Figure 7 shows that:

1) The full hydraulic steering system is always in the full flow state in either the steering state or the non-steering working state, and there is a large power loss phenomenon;

2) The load sensitive variable steering system can provide the required flow rate in either the steering state or the steering wheel stop state according to the system condition, and the pump is in the low-voltage small flow unloading state in the steering disk stop state (the vehicle is in the idle or

straight running state), which effectively reduces the energy loss of the system. The simulation data pairs are shown in Table 2.

Table 2 Comparison of simulation data

Parameter	Full hydraulic steering system	Load sensitive variable steering system
Pump pressure when steering/MPa	16	15. 8
Pump flow during steering/($L \cdot min^{-1}$)	41	38
Pump power when turning/kW	11	9. 7
Pump pressure during non-steering/MPa	1. 3	1. 1
Pump flow in non-steering/($L \cdot min^{-1}$)	41	2. 2
Pump power in non-steering/kW	0. 9	0. 04

6 Conclusions

This paper introduces the structure principle of full hydraulic steering system and load sensitive variable pump respectively, and makes model construction and simulation analysis of two kinds of hydraulic steering system.

1) The load sensitive variable steering system can provide the corresponding flow and pressure according to the system needs.

2) Using the load-sensitive variable steering system can maintain the low-voltage small flow state in the non-steering state (vehicle straight-line driving or idle-speed working conditions), and reduce the energy consumption of the traditional full hydraulic steering system by more than 85%.

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Brief Biographies

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