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Simulation and experimental research for the dynamics characteristics of steering PUM based on speed compensation

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ABSTRACT

In view of steering pump of automobile hydraulic power steering system has the problem of larger energy loss, put forward a kind of speed compensation type hydraulic steering pump which contains variable mechanism; the pump can effectively reduce the energy loss in the normal condition of steering pump. Using the method of complex plane to analyze the variable mechanism dynamic characteristics of new steering pump with speed compensation, build dynamic equations of variable mechanism and through simulation and prototype test studies the motion law of variable mechanism, verify and improve the dynamic equations of variable mechanism, establish the foundation of organization optimization and flow output equation of new pump.

KEYWORDS

Steering pump; Simulation; Variable mechanism; Speed compensation; Dynamics; Energy saving.

INTRODUCTION

In the spring of 2013, the haze weather was appeared frequently in China. How to control PM 2.5 pollution effectively, this problem became the focus of public attention. The source of PM2.5 in Beijing had carried on the overall analysis, the first of the list is the motor vehicle exhaust, accounted for 22.2%, came in second is the industrial production particles[1]. So how to reduce the fuel consumption and vehicle emissions, it is the important measures to improve the urban air quality and reduce the pollution of the haze. The vehicle steering system usually consumes about 3% of the energy consumption of prime mover, but the real energy consumption accounts for only less than 40% of them[2]. Therefore we need study the problem of automobile steering system, especially the steering pump energy saving has important practical significance. This paper puts forward a kind of energy-saving steering pump with speed compensation characteristics; it can effectively reduce the energy loss of hydraulic steering system, automobile fuel consumption and emissions.

SPEED COMENSATAION TYPE STEERING PUMP KINEMATICS ANALYSIS

The working principle of energy saving pump

The new steering pump is improved on the basis of the existing constant double action vane pump of certain structure. It is based on the structure of traditional vane pump, by changing the mechanical structure inside of the pump to achieve the goal of saving energy and reducing consumption.

Compared with the traditional steering vane pump, the new type steering vane pump keeps the advantage of rotor radial force equilibrium in the existing constant vane pump. Moreover, it can be very convenient to automatically change the displacement that based on the different rotational speed, for steering system output pressure oil according to the change of rotating speed, to improve the traditional hydraulic power steering system of large energy loss. The working principle of the new pump is that installs up and down adjustable floating block in the rotor slot. As the change of the rotor rotational speed, floating block can slides up and down inside the slot. Therefore, the amount of space that floating block occupies in the oil chamber is related with the rotation speed of the pump, and the pump is variable. When the rotor speed increases, due to the centrifugal force, floating block stretches out of the rotor slot, takes up more effective volume space between two vanes, turns the amount of suction and displacement of oil pump decreases every time. Based on the same theory, when the rotor speed decreases, floating block was retracted in the rotor slot, the effective volume of pump was increased, and the pump suction and displacement of oil increases every time when it turns[3].

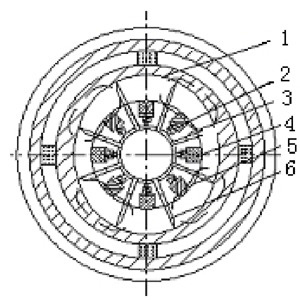

Figure 1 : Schematic diagram of new pump; 1. Stator 2.spring 3.rotor 4.floating blocks 5. Floating tank 6.vane

Dynamic analysis

The variable displacement mechanisms of new steering pump with speed compensation slide up and down inside the sliding groove along with the rotation of the steering pump. Because of the different rotating speed, variable displacement mechanism dynamics analysis have two different situations including variables mechanism did not contact with the stator curve and contact with the stator curve.

The variable mechanisms do not contact with the stator curve

Throughout the steering pump working speed range, only at a high speed range variable displacement mechanism arc top profile will contact with the stator curve, at low speed range variable displacement mechanism will not contact with the stator curve. When the pump rotates, the variable displacement mechanisms movement including relative sliding along the sliding groove and transport motion with rotor rotation under variable displacement mechanism did not contact with the stator curve. So in this condition the dynamic equations of variable mechanisms in sliding groove sliding:

$$\eta\dot{x} + K(L+x) + ma_c\mu = ma_r + m\omega^2(R + x - \frac{H}{2}) \qquad (1)$$

Where, m is the quality of variable displacement mechanism; R is the radius of vane type steering pump; a_c is the Coriolis inertia force acceleration $a_c = 2\omega \cdot v_r$; a_r is the sliding inertial force acceleration; L is the pretensioning length of join the spring; K is the spring elasticity coefficient; H is the height of variable displacement mechanism; η is the damping coefficient of the oil; μ is the friction coefficient of the variable mechanisms and sliding groove.

The variable mechanisms contact with the stator curve

When the steering pump is at a high speed region, the variable displacement mechanism will contact with the stator curve arc top profile under the effect of large centrifugal force. Because of the variable displacement mechanism rotated with pump rotor, so the contact point of variable institutions top profile with the stator curve changes within a certain range. The contact point has not only relative motion with the rotor but the relative sliding with the stator curve; the arc top profile must be got the counterforce of the stator curve. The variable displacement mechanisms movement is limited by sliding groove with contacting with the stator curve, the variable displacement mechanisms itself received the counterforce from the sliding groove, all of those will make the variable mechanism movement analysis become very complicated. Let N_1 is the counterforce of the sliding groove and bottom contact point of variable mechanisms; N_2 is the counterforce of the sliding groove and top contact point of variable mechanisms, N_3 is the counterforce of the stator surface are subject to the arc top profile of variable mechanism of contact counterforce. By the moment balance,

$$\begin{cases} N_3\cos a+\mu N_3\sin a+\mu(N_1+N_2)-F_p-F_e+F_r=0 \\ N_2-N_1-F_c+N_3(\sin a-\mu\cos a)=0 \\ N_2D-N_1\left[L-r(1-\cos a)\right]-F_c\left[l-r(1-\cos a)\right]+F_e r\sin a- \\ \mu N_1(r\sin a+\dfrac{M}{2})+\mu N_2(\dfrac{M}{2}-r\sin a)+F_p r\sin a-F_r r\sin a=0 \end{cases} \quad (2)$$

Where, M is the width of variable displacement mechanisms; D is the height of the variable displacement mechanisms out of sliding groove; F_p is the hydraulic oil pressure of the top variable displacement mechanisms; r is the radius of circular arc top profile; d is the length from the center of mass to the arc top profile of variable displacement mechanisms .

After solving the corresponding contact counterforce, the contact dynamics equation of variable mechanism and the stator curve is

$$\eta\dot{x}+K(L+x)+\mu(ma_c+N_1+N_2+N_3\sin a)+N_3\cos a=ma_r+m\omega^2(R+x-\frac{H}{2}) \quad (3)$$

DYNAMICS OF SIMULATION SPEED COMPENSATION

Using the simulation software ADAMS to build rotor, variable displacement mechanism and joining spring 3D models of steering pump with speed compensating. It can be convenient to study the dynamic simulation characteristics of the variable mechanism by the 3D models when the steering pump rotates. The structure parameters of variable displacement mechanism are follow: Floating block width of variable mechanism is designed into 4.5 mm, height is 6.2 mm, and thickness is 22.0 mm, radius of floating block at the top part is arc top profile structure with 2.5 mm height, bottom on both sides are 0.8 mm chamfer and there is a threaded hole, the diameter is 3.0 mm at the bottom of the plane. The joining spring are cylindrical spiral tensile springs, the diameter of steel wire is 0.5 mm. The radius of steering pump rotor is 28.25 mm, the thickness is 22.0 mm; Speed range: 500 ~ 3000 r/min.

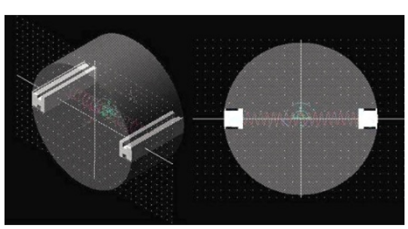

Figure 2 : Simulation model

It can be calculated the sliding displacement and speed change of variable displacement mechanism through the simulation calculation under different rotational speed. By comparing to the calculation results of dynamics equation, not only can be revised kinetics equation, but also according to the motion law of variable mechanism, improve and optimize the internal structure design of steering pump. Assuming the speed compensation steering pump clockwise rotation in the simulation, when the speed is 2000 r/min, the centroid trajectory changes simulation results of the right side of variable displacement mechanism in Figure 2 are shown in Figure 3. The top of the graph is the synthesis simulation displacement curve of mass center for variable displacement mechanism in all directions in the process of work. The bottom left of the graph is the X axis displacement simulation curve, the bottom right for displacement simulation curve in the Y axis. Figure 4 is centroid speed change simulation curves of variable displacement mechanism.

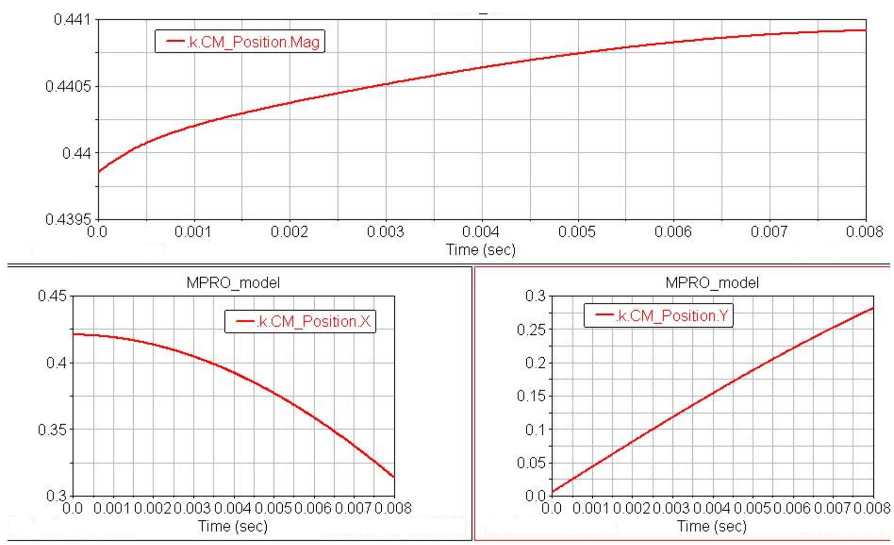

Figure 3 : Graph of centroid trajectory changes simulation results in 2000 r/min

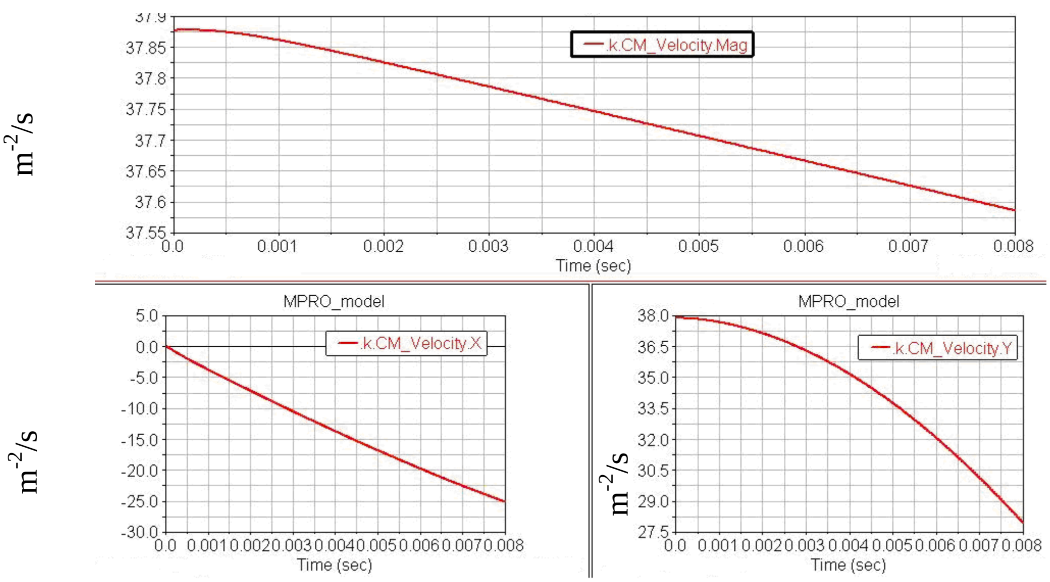

Figure 4 : Graph of centroid speed changes simulation results in 2000 r/min

The synthesis displacement curve of centroid trajectory of variable displacement mechanism is similar to parabola shape, the X axis displacement and Y axis displacement in the opposite direction. The centroid trajectory displacement of variable displacement mechanism is relatively bigger in the high speed, while numerical simulation is relatively smaller under the condition of low speed. Those show that the centroid trajectory changes of variable displacement mechanism mainly depends on the square of the speed relations and indicated that the variable displacement mechanism mainly are greatly influenced by centrifugal force, less influence of other factors. Comparing centroid trajectory simulation curves of variable displacement mechanism under different rotational speed, all of them have basically the same change trend, which conforms to the working principle of steering pump with speed compensation. The speed changes and trajectory changes of the mass center on the contrary for variable displacement mechanism. Because of the result of connecting spring action, making the speed of variable displacement mechanism decreasing in every direction, the change trend of velocity of mass center is related to the rotation speed.

Comparison velocity curves of mass center for two symmetrical variable displacement mechanisms which along the axis of spindle, due to the variable displacement mechanisms by gravity to do work in different directions, having different results and influence. From the simulation results show that the kinematic parameters of variable displacement mechanisms are affected by the gravity is smaller than other factors.

TEST VERIFICATION

To test the steering pump prototype with speed compensation and measure kinetic parameters of variable displacement mechanisms in a test-bed. Due to the limitation of test conditions, it cannot be directly measured numerical value of displacement changes for variable displacement mechanism in test. A plan is proposed by measured prototype displacement under different rotational speed, using the theory of vane pump output flow equation and parameter values of variable displacement mechanisms, obtained the displacement trajectory changes of mass center for variable displacement mechanisms by calculation under different rotational speed. Compared with the simulation results, it can revise dynamic equation which was established. To measure prototype flow values under different rotational speed in the test-bed in TABLE 1.

TABLE 1 : Measuring displacement of pump

Rotation speed (r/min)	Output flow of a prototype (L/min)
1300	28.73
1400	30.94
1500	32.40
1600	33.80
1700	35.10
1800	36.10
1900	37.00
2000	37.70
2100	38.20
2200	38.40
2300	38.40
2400	38.10
2500	38.25

Calculated the theory displacement of centroid trajectory of mass center and reckoned the numerical displacement of centroid trajectory for the variable displacement mechanisms in the tests according to the dynamics equation under different rotational speed variable are shown in TABLE 2.

TABLE 2 : Displacement of centroid trajectory

Rotation speed(r/min)	The theory of mass center displacement(mm)	Derivation displacement in test (mm)
1300	0.0127	0.0132
1400	0.0969	0.0974
1500	0.2765	0.2772
1600	0.4713	0.4721
1700	0.6819	0.6826
1800	0.9091	0.9099
1900	1.1536	1.2546
2000	1.4163	1.4272
2100	1.6983	1.8993
2200	2.0004	2.0015
2300	2.3240	2.0018
2400	2.6703	2.0010
2500	3.0407	2.0417

Due to the limitation of test conditions, the test can only be deduced to the centroid motion parameters of variable displacement mechanism indirectly. The conditions of test and measuring and the accuracy of dynamics equations which was established will affect the comparison results. But from the theory data and derivation data comparison, the change tendency of the two kinds of data are nearly consistent under different rotational speed, the difference is small. When the rotating speed is at 2000 r/min, the simulation data, the theoretical calculation results and numerical value deduced from the test are very close to show that the dynamic equation was established is reliability. The simulation results and preliminary established dynamic equations have a certain guidance and reference significance for further researching the change rule of movement and optimization design of structure for variable displacement mechanisms in the future.

CONCLUSIONS

For studying the dynamic characteristics and optimize the structure parameters of variable displacement mechanism of steering pump with speed compensation, and the three-dimensional model of variable displacement mechanism for dynamic simulation researching was established by using ADAMS software. To analyze movement rules of variable displacement when pump rotation speed change, the simulation results intuitively reflect that the dynamic characteristics of variable displacement mechanism under different working conditions. The displacement of centroid trajectory and derivation results of dynamic equation has a good match; using bench test indirectly verified the accuracy of the preliminary established dynamic equation.

Based on the research of the dynamic characteristics of variable displacement mechanism, for optimum design of steering pump in the next step and laying a good foundation for the industrialization application.

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