Power steering control valve structural design optimization

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Abstract: This paper analyses the two different structure of the rotary valve structure, and lists the working principle and oil circuit of power steering gear in different tectonic. Through analysis the two kinds of structure proves the more conducive to improve the structure of the rotary valve sensitivity and stability. It can be used for reference in the actual processing.

1. Introduction
In the vehicle steering systems, steering plays a vital role. Power steering according to different motion of control valve is divided into two types: rotating valve and slide valve\cite{1}. This article mainly introduces the structure and principle of the control valve of the rotary valve power steering gear. The key to the structural design of the rotary valve control valve lies in the direction of the oil circuit of the control valve. When the driver turns the steering wheel, the sensitivity and stability of the control valve largely determine the pros and cons of the car's steering function\cite{2}\cite{3}.

2. Three-piece type power steering control valve structure

2.1. Show structure
As shown in Figure 1, This power steering control valve structure is determined by the screw shaft, the valve sleeve and the input shaft consisting of three core parts. In the circumferential direction of the screw shaft are evenly distributed around three inlet ports, three ports and six out of the oil return port (which include three oil port leading to the upper chamber of the housing, the other three oil ports through the housing of the inferior vena). It is opened six longitudinal sump same width on the inner surface thereof which cooperates with the valve set.

![Figure 1. Three-piece type control valve structure diagram](image-url)
There are six longitudinal oil grooves not penetrating on the surface of the valve sleeve, and a broad distribution of equivalent keys between every two sump, which is to form the flow of the oil clearance the inner surface of the longitudinal oil groove of the screw axis. There is a rectangular notch at the bottom of the cylindrical surface of valve sleeve. It is used to install the positioning pins bottom input shaft, which is to ensure that the valve can be set to synchronize with the input shaft.

The input shaft is a hollow tubular shaft, have blind hole at the bottom. One end of the torsion bar is fitted in the blind bore, and then fixed together with the input shaft by a pin coupling. The other end of the torsion bar match the inner hole in the bottom of the screw shaft, which also locked together by a pin coupling (see figure 1).

2.2. **Steering gear working principle analysis**

The structure shown in the following figure, when the car in the process of steering, On the one hand, The driver will turn the steering wheel to transmit the steering torque to the input shaft, which will Drive the valve sleeve rotation by a pin; On the other hand, drag torque from the ground through the rocker arm shaft and the piston effect on the screw shaft that make the screw shaft fixed for the time being. Due to the input shaft and the screw shaft are connected with elastic torsion bar, it will produces a relative Angle between them (which is equal to the torsion Angle of torsion bar), it is that the key on the surface of the valve sleeve and inner surface of screw shaft tank to produce relative angular displacement. At this time the control valve is opened, the pressure oil flowing into the corresponding hydraulic chamber (The upper chamber or the lower). The oil pressure pushes the piston so as to drive the linear motion rocker shaft rotation, to achieve power steering.

![Figure 2. Steering gear assembly and the oil strike schematic](image)

1. Input shaft 2. Valve sleeve 3. Screw shaft 4. Rocker arm shaft 5. Piston

A. The valve inlet  B. The screw shaft inlet  C. The screw shaft oil outlet (Lead to inferior cavity)  D. The valve oil oblique mouth  E. Shell oil deep hole  F. The screw shaft oil outlet (Pass on the upper cavity)

2.2.1. **The car driving straight**

When the car is traveling in a straight line state, the control valve structure is in the middle of normally open position which is formed by the outer surface of the sleeve Cooperate with the inner surface of the screw shaft (As shown in figure 3 middle view), each key of Valve relative to the both side gaps of the screw shaft tank. High pressure oil from the oil pump from the inlet into the steering gear body and through the external surface of the screw shaft inlet flow into the internal cavity, then through the normally open gap between the sleeve valve and the screw shaft and the return oil port back into port storage tanks. In this case, the upper and lower chambers of the housing have the same hydraulic, Rack piston equilibrium position in the middle, there is no power.
2.2.2. **Automotive steering**

When the left turn, the input shaft is rotated counterclockwise, which will drive valve sleeve relative to the screw shaft left. It makes each gaps are closed which is between the key on the left side of the valve sleeve and the screw shaft sump (left side view shown in Figure 3). Steering pump oil flow from the oil inlet valve, in turn by the screw shaft inlet, oil outlet, the ramp into a deep hole on the body of the housing hole, eventually leading to the lower chamber of the housing, and pushes the piston chamber axially upward movement (Oil to see in figure 2, A→B→C→D→E), the the oil in upper cavity through the return oil port back into port storage tanks.

When the right turn, the input shaft is rotated clockwise, which will drive valve sleeve relative to the screw shaft right. It makes each gaps are closed between the key on the right side of the valve sleeve and the screw shaft sump (right side view shown in Figure 3). High pressure oil from the oil pump from the inlet into the steering gear body and through the screw shaft inlet and outlet, the upper cavity and pull it into the inferior cavity by a power. On the left side of the piston (Oil to see in figure 2, A→B→F), inferior cavity oil return oil storage tanks in reverse.

3. **Two-piece type control valve structure of power steering gear**

3.1. **Show structure**

As shown in figure 4, compared with three-piece control valve structure, two-piece type less of a valve sleeve. In the three-piece type structure, it is the use of the outer surface of the valve every two key between the tank and the inner surface of the screw shaft tank for relative angle to implement open control valve.

But in the two-piece type structure, the outer surface of the input shaft is cut with three long, three short of six longitudinal tank, and use the key between the two oil tank and the relative position between the screw shaft tank inside the control oil, so this structure is no longer needed valve sleeve.

Long and short oil groove in the process of different steering input shaft, plays the role of guiding the oil into the different pressure chamber. Therefore, the structure of the screw shaft is adjusted appropriately with respect to the three-piece sleeve type: Nine oil holes are retained on the outer circle surface - three oil inlet, three oil return port and three oil port lead to the upper chamber of the housing.

![Figure 3. Auto Steering schematic](image1)

![Figure 4. Two-piece type control valve structure diagram](image2)
3.2. Analysis of the steering principle
When the vehicle is traveling straight, the state of the various components of the steering device of the structure is identical with the three piece sleeve type. Now we only discuss the working principle of the vehicle steering.

When the vehicle turns left, the input shaft rotates counterclockwise, the key on its outer circular surface relative to the oil groove of the inner surface of the screw shaft generates left rotation displacement. Oil fluid from the steering pump enters the oil inlet of the valve body, through the oil passage into the oil inlet on the outer circular surface of the screw shaft, then the long oil groove on the outer circle of the input shaft, flowing into the lower end of the screw shaft inner cavity, and through the hole in the lower end of the screw shaft flow out, thus lead to the shell inferior vena (Oil path as shown in Figure), the shell cavity of the oil flow back to the storage tank through the oil return port.

![Figure 5. Two-piece type control valve structure left oil to the sketch](image)

1. The screw shaft oil outlet   2. Input shaft long sump   3. The lower end of the screw shaft through hole

When the vehicle turns right, the input shaft rotates clockwise, the key on its outer circular surface relative to the oil groove of the inner surface of the screw shaft generates right rotation displacement. Oil fluid from the steering pump enters the oil inlet of the valve body, through the oil passage into the screw shaft inlet, then flows out from the outer surface of the input shaft short sump, and flow to the upper chamber of the housing access to the oil hole on the screw shaft (Oil path as shown in Figure 6), the oil of shell cavity flow back to the storage tank through the oil return port.

![Figure 6. Two-piece type control valve structure right oil to the sketch](image)

1. The screw shaft oil outlet   2. Input shaft Short sump   3. The screw shaft oil outlet

4. Comparative analysis
Through the above analysis, it can be seen that, compared with three-piece, two-piece type control valve structure type has the following advantages:

The first: Reducing a valve sleeve part, saving a certain amount of production costs, the economic effect is remarkable.

The second: When the input shaft rotates, two-piece type control valve using its own key directly with wide screw shaft groove Angle relative to the way open it, there is no middle power transmission parts, Thus avoiding the transmission process gaps and improving the sensitivity of the valve.

The third: The valve sets belong to the thin wall parts, and the thickness of the parts is about 4 ~ 5 mm, But the use of the steering gear temperature is commonly - 40 °C ~ 120 °C, extreme pressure of 15 MPa is even higher. Two-piece of control valve without using the sleeve, thus avoiding the valve issuer risks, improve the stability of steering.
The fourth: The two same bore ($\phi 120$ bore) of the control valve structure were load test, test data force characteristic test and functional test, the resulting test data shown in the following table:

| Name of test                              | Two-piece control valve structure | Three-piece control valve structure |
|-------------------------------------------|-----------------------------------|-------------------------------------|
| The total number of laps and no-load rotational torque test | ![Graph](image1.png) | ![Graph](image2.png) |
| $\phi = 6.3\text{turns}$ Consequent average $=2.6\text{Nm}$ MR $=2.6\text{Nm}$ | Mean difference $=0\text{Nm}$ Inverse average $=2.5\text{Nm}$ ML $=2.5\text{Nm}$ | $\phi = 4.2\text{turns}$ Consequent average $=2.5\text{Nm}$ MR $=2.9\text{Nm}$ |
| Mean difference $=0\text{Nm}$ Inverse average $=1.8\text{Nm}$ Consequent average $=2.0\text{Nm}$ | | Mean difference $=0\text{Nm}$ Inverse average $=1.4\text{Nm}$ Consequent average $=2.3\text{Nm}$ |
| Function tests                            | ![Graph](image3.png) | ![Graph](image4.png) |
| Max $=6.5\text{Nm}$ | $\triangle MR_{max}=0.8\text{Nm}$ | $\triangle MR_{max}=0.6\text{Nm}$ | Mean difference $=0.2\text{Nm}$ Inverse average $=7.4\text{Nm}$ Consequent average $=6.2\text{Nm}$ |
| Mean difference $=0.2\text{Nm}$ Inverse average $=7.4\text{Nm}$ Consequent average $=6.2\text{Nm}$ | | | |
| Force characteristic test                 | ![Graph](image5.png) | ![Graph](image6.png) |
| $\phi_{self}=8.8\degree$ | $\phi_{self}=11.7\degree$ | $\phi_{self}=11.7\degree$ | Verification of correction ability $ML_{max}=108\text{Nm}$ $MR_{max}=-118\text{Nm}$ $t_R=3.4\text{S}$ Internal leakage test and external leakage test | $QL=0.07\text{L/min}$ | $QR=0.19\text{L/min}$ $K_{me}=97.1\%$ | $ML_{max}=105\text{Nm}$ $MR_{max}=-115\text{Nm}$ $t_I=3.5\text{S}$ Internal leakage test and external leakage test | $QL=0.15\text{L/min}$ | $QR=0.06\text{L/min}$ $K_{me}=98.8\%$ |
| $K_{me}=98.2\%$ | $PM=105\text{Nm}$ | $PM=111\text{Nm}$ $t_I=3.5\text{S}$ | Verification of correction ability $ML_{max}=93\text{Nm}$ $MR_{max}=-87\text{Nm}$ $t_R=1.6\text{S}$ Internal leakage test and external leakage test | $QL=0.15\text{L/min}$ | $QR=0.06\text{L/min}$ | $K_{me}=98.2\%$ | $PM=111\text{Nm}$ $t_I=1.6\text{S}$ |

5. Conclusion

From the analysis of the test data, as can be seen, two-piece control valve structure of the steering gear is better than Three-piece structure in various performance parameters. At present, the two-piece type control valve structure has on the company's comprehensive application in the production process, and get good economic benefits.

References
[1] Zhang Jing, Fang Zhidong. Loop ball redirector screw reliability calculation[J]. Coal Mine Machinery, 2006, 27(2): 187-188.
[2] Jiang Huaping. Structure and principle of power steering control valve analysis[J]. Jinan Special Journals, 1993, (2).
[3] Miao Lidong, Xia Zhanggao, Gao Xiang. Circulating ball type hydraulic power steering system analysis[J]. Journal of Jiangsu University, 2002, 23(3): 50-53.
[4] Li Songhe. The structure and principles of control valve type power steering gear and the use of maintenance[J]. Automotive Technology, 1998, (6): 36-38.
[5] Li Qibo, Xie Zhuowei, Gao Youfang. Constant flow control valve type power steering gear dynamic and static characteristics of the study [J]. South China University of Technology, 1997, 25(11): 74-79.

[6] Bi Daning. Design and application of the auto rotary valve type power steering gear [M]. Beijing: China Communications Press, 1998.