Advances in Machinery, Materials Science and Engineering Application X
M. Giorgetti et al. (Eds.)

doi:10.3233/ATDE240601

Research and Design of Hydraulic System for CNC Radial Drilling Special Machine Tool

Yanhong ZHANG [a,1]
[a] *Shandong Huayu Institute of Technology, Dezhou, Shandong,253034 China*

Abstract. The petroleum perforation gun is a very important tool in the petroleum extraction industry. The processing of shallow blind holes in the manufacturing of petroleum perforation guns is a key and difficult point in the processing technology. Traditional processing requires experienced and experienced turning masters to process, which is time-consuming and laborious. CNC radial drilling specialized machine tools can achieve automated high-precision processing, high efficiency, good quality finished workpieces, and consistent shallow blind hole depths. CNC radial drilling specialized machine tools are increasingly widely used in oil well exploitation. This paper aims to design a hydraulic system suitable for CNC radial drilling special machine tools. Firstly, this article introduces the application background and main performance parameters of CNC radial drilling special machine tools. Then, a hydraulic system design scheme was proposed, including system framework, hydraulic component selection, pipeline design, etc. Next, performance verification and evaluation will be conducted on the designed hydraulic system, including verification of performance indicators, stability and reliability of the system.

Keywords. Radial drilling, hydraulic system, hydraulic components, pipeline

1. Introduction

The CNC radial drilling special machine tool is a product launched for the petroleum drilling industry. With the rapid development of the oil drilling industry, CNC radial drilling specialized machine tools have been widely used, greatly improving production efficiency in the production process. In order to achieve complete automation, machine tools not only require the use of CNC systems, but also require a set of hydraulic drive devices to help the machine complete automated operations. The hydraulic drive system used should have the characteristics of compact structure, reliable operation, and convenient control and adjustment.

The hydraulic transmission device uses liquid with high working pressure as the transmission medium. Its mechanism has strong output power, compact structure, flexible action, simple operation, high operating efficiency, and can be adjusted according to actual conditions, while also having low noise. The hydraulic system has a crucial impact on the installation and operation of CNC machine tools. In order to adapt to the development trend of CNC machine tools and achieve efficiency during

[1] Yanhong ZHANG, Corresponding author, Shandong Huayu Institute of Technology, Dezhou, Shandong, 253034 China; E-mail: 2681359066@qq.com.

installation and operation, designers need to optimize the current hydraulic system based on the nature and characteristics of CNC machine tools, integrate existing design resources, and make up for the shortcomings of previous designs.

2. Current Research Status of the Project

As a major manufacturing country, China is very active in research and development in the field of machine tools. As a very important machine tool in the field of machine tools, drilling CNC machine tools have been widely researched and applied.

The development history of CNC drilling machine tools in China is relatively short. Since the 1980s, China's machine tool manufacturing industry has begun the research and production of drilling CNC machine tools. In 1992, China Xinqiao Machine Tool developed the first domestic drilling CNC machine tool and began production in 1994. Since then, China's CNC drilling machine tool technology has continued to develop, and product performance and processing capabilities have been greatly improved.

As an important part of the machine tool, the hydraulic system of CNC drilling machine tools has received extensive attention and research. The hydraulic system is one of the key components of CNC machine tools, and its reliability is directly related to the stability and processing accuracy of the machine tool. Scientific researchers from the Guangdong Academy of Mechanical Science conducted research on the reliability of CNC machine tool hydraulic systems and established a corresponding evaluation index system to evaluate and monitor the reliability of machine tool hydraulic systems [1].

In summary, the research status of hydraulic systems for CNC drilling machines in China is relatively rich, with research directions focusing on structural design, energy-saving, reliability, and automatic control. There is still great potential and space for future development.

3. Overall Scheme Design

3.1. Basic Design Requirements and Working Principle

3.1.1. Basic Structure and Action Sequence

The equipment consists of a workbench, a bed, a positioning clamping device, etc. It takes the plane blind hole on the pipe wall as the processing target and can complete automatic positioning, clamping and processing. The work cycle is as follows:

The workpiece is transported to the workbench, the power slide fast-forwards, clamps the workpiece, and releases the workpiece. As shown in figure 1.

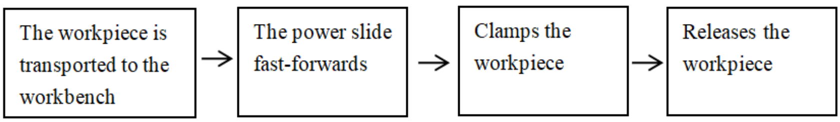

Figure 1. Work cycle diagram.

3.1.2. Main Performance Parameters

In the process of oil field exploration and development, perforation technology is a very critical technology. The oil field itself is in a special location and the underground geological environment is also relatively complex. According to the environment and required working conditions of the machine tool, the following parameters are set as the main performance parameters of the machine tool:

1. Axial cutting force Ft=12000N;
2. Acceleration and deceleration time Δt=0.2s;
3. Workbench weight is 2000N, power head weight is 1t;
4. Use plane guide rail, static friction coefficient fs=0.2, dynamic friction coefficient fd=0.1;
5. The working process l2=100mm, the working speed is 30~50mm/min, and the fast forward and rewind speeds are both 3.5m/min;
6. The working platform needs to move smoothly, but it can stop at any time. The individual slides complete their respective cycles without interfering with each other and ensure the clamping is adjustable [2].

3.2. Load Analysis

The load pattern during the working process of the machine tool was analyzed. In the load calculation, the back pressure generated by the oil return chamber was temporarily ignored, and only the friction resistance generated by the hydraulic cylinder seal was considered. Since the machine tool workpiece is installed horizontally, the cutting force, as well as the friction and inertia caused by the guide rail, must be taken into account during the machining process. Because the force on the track is equal to the gravity of the power source, the static friction resistance of the guide rail is, and the kinetic friction resistance is, then

$$F_{fs}=f_s F_N \tag{1}$$

By formula 1 $F_{fs}=0.2*(2000+9800)=2360N$

$$F_{fd}=f_d F_N \tag{2}$$

By formula 2 $F_{fd}=0.1*(2000+9800)=1180N$

Inertial force
$$Fm=m\frac{\Delta v}{\Delta t}=\frac{G}{g}\times\frac{\Delta v}{\Delta t} \tag{3}$$

By formula 3
$$Fm=\frac{(2000+9800)\times\frac{3.5}{60}}{9.8\times 0.2}=351.2N$$

If the influence of flipping torque caused by axial cutting force on guide rail friction is ignored, the mechanical efficiency of the hydraulic cylinder is set to 0.95. Therefore, the total mechanical load of the hydraulic cylinder at each working stage can be calculated, as shown in table 1 [3].

Table 1. Load table for each movement stage of hydraulic cylinder.

Exercise Stages	Formula	Total mechanical load F/N
start up	$F= F_{fs}$	2360
fast forward	$F= F_{fd} /\eta m$	1242.1
Fast rewind	$F=F_{fd}/\eta m$	1242.1

4. Hydraulic System Scheme Design

4.1. Types and Speed Regulation Methods of Hydraulic Pumps

Taking similar equipment as a reference, as shown in table 2, the system pressure p<21MPa, Therefore, an open circuit with a double-acting variable vane pump (figure 2) for oil supply, a one-way throttle valve for throttling and speed regulation, and a relief valve as a safety valve are selected. In order to avoid the fixture being suddenly clamped due to loss of load after the drilling fluid is drilled, a pressure reducing valve is shared on the oil return line and used as a back pressure valve. The initial back pressure value is 0.8MPa.

Table 2. Common pressure of various equipment.

Equipment type	Machine tool					Agricultural machinery, small construction machinery	Hydraulic press, heavy machinery
	Grinde	Modular machine tool	Lathe and milling machine	Gear cutting machine	Broaching machine, gantry plane		
Working pressure p/MPa	≤2	3~5	2-4	<6.3	<10	10~16	20~32

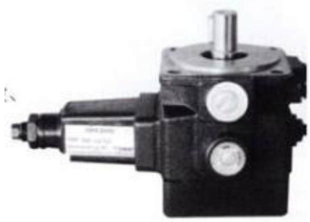

Figure 2. Double acting variable vane pump.

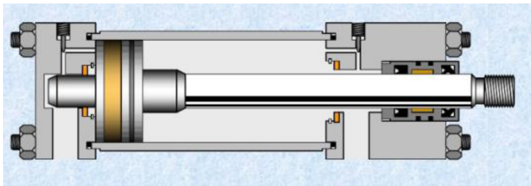

Figure 3. Schematic diagram of single acting hydraulic cylinder.

4.2. Selection of Execution Elements

The action cycle of the system requires the machine tool to operate in a forward fast forward direction, reverse fast backward direction, with the same fast forward and fast backward speeds, and achieve linear motion. Therefore, the executing element adopts a single acting hydraulic cylinder (figure 3).

4.3. Selection of Hydraulic Oil

The hydraulic system of the drilling machine tool must be able to transmit and operate power well. The hydraulic oil used must have appropriate viscosity, good viscosity temperature characteristics, good lubrication, thermal stability, hydrolysis stability, oxidation stability, good anti emulsification and rust resistance, corrosion resistance, and good safety. It is harmless to human health and has low cost. Based on the above, mineral oil hydraulic oil can be selected as the working medium.

4.4. Selection of Hydraulic Valves and Filters

Select the type and technical parameters of the valve based on the maximum working pressure of the hydraulic valve in the system and the maximum flow rate through the valve. The rated pressure of all valves in this hydraulic system is based on the flow rate of each hydraulic valve. The rated flow rates are determined as 10L/min, 25L/min, and 63L/min, and the filters are selected based on twice the rated flow rate of the hydraulic pump.

4.5. Selection of Oil Pipes

Determine the length of the pipeline based on the size of the oil hole on the selected hydraulic valve. Calculate the inlet and outlet oil pipes of the oil cylinder based on the maximum input and maximum output flow rates. When the hydraulic cylinder in this system performs a fast forward and fast reverse action, the oil flow inside the oil pipe is relatively large, and its actual flow rate is twice the rated flow rate of the pump, which can reach 32 L/min. Therefore, the diameter d of the hydraulic cylinder's inlet and outlet oil pipes is based on the relationship between the pump's flow rate and pipe diameter (table 3), and a No.10 cold drawn steel pipe with an inner diameter of 15 mm and an outer diameter of 19 mm is selected.

Table 3. Relationship between pump flow rate and pipe diameter.

flow/(L/min)	Oil suction pipe diameter/mm	Return oil pipe diameter/mm	Pressure oil pipe diameter/mm
2	5~8	4~5	3~4
3	7~11	6~7	4~6
5	8~14	7~8	4~7
6	10~16	8~10	5~8
9	12~20	10~12	6~10
11	13~22	11~13	6~11
13	14~24	12~14	7~12
16	15~26	13~15	8~13
18	16~28	14~16	8~14
20	17~30	15~17	8~15
23	18~32	16~18	10~16
25	20~33	16~20	10~16
28	20~34	17~20	10~17
30	20~36	18~20	10~18
32	21~37	18~21	10~18
36	22~40	20~22	11~20
40	24~40	20~24	12~20
46	26~44	22~26	13~22
50	27~46	23~27	14~23

4.6. Hydraulic System Schematic Diagram

Based on the selected oil pressure circuit, make appropriate adjustments and additions as needed to form a schematic diagram of the oil pressure system, as shown in figure 4. For the convenience of observation and adjustment, a pressure measuring point and a pressure gauge are arranged at the entrance of the rodless chamber of the oil cylinder. This makes it easy to observe the pressure in the system [4].

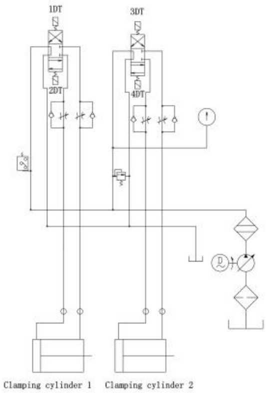

Figure 4. Hydraulic schematic diagram.

The action sequence of each directional valve solenoid in the hydraulic system is shown in table 4.

Table 4. Electromagnet Action Sequence Table.

	1DT	2DT	3DT	4DT
Clamp	+	-	+	-
Release	-	+	-	+

5. Performance Verification of Hydraulic System

5.1. Verification of Pressure Loss

During the rapid retraction process, the return oil capacity of the rodless cavity of the oil cylinder is twice that of the inlet oil capacity. Therefore, during the rapid retraction process, it is necessary to calculate the pressure loss of the inlet and return oil circuits during the rapid retraction process in order to determine the unloading pressure of the variable vane pump. The length of the oil inlet and return pipes during fast reverse is l=1.8m, and based on the diameter of the oil pipe, d=15m can be obtained. The flow rate passing through the return oil circuit is 16L/min=0.267, and the inlet oil circuit is 3st=1.5. The hydraulic system components adopt an integrated block configuration [5].

5.2. Heat Generation and Temperature Rise Verification of Hydraulic System

Due to the fact that fast forward and fast reverse are the main motion modes throughout the entire work cycle, most of the system's heat comes from the fast forward and fast reverse stages. However, the power required for fast reverse is very high. Therefore, the temperature rise of the system is calculated according to the fast reverse working condition. The input power of the hydraulic pump during fast reverse is calculated as before P2=736W

Assuming good ventilation, take the heat dissipation coefficient of the fuel tank CT=15×10-3kW/(m^2.℃),Using the formula, the oil temperature rise can be obtained as $\Delta T = \frac{547.2\times10^{-3}}{15\times10^{-3}\times1.21}$ ≈30.2℃. Normally, the working temperature of a hydraulic system should be controlled within the set ambient temperature, and the thermal equilibrium temperature is T1=25℃+30.2℃=55.2℃≤ [T1]=55℃. So it can be calculated that the heat dissipation of the fuel tank is within the allowable range, thus meeting the requirements of stable and reliable operation [6].

6. Conclusion

This article studies and analyzes the design of the hydraulic system for logarithmic control radial drilling special machine tools, and proposes a hydraulic system design scheme. Through performance verification and evaluation, the feasibility of the design scheme in actual operation is verified.

The hydraulic components used in this hydraulic system are of high quality, strong reliability, and long service life, such as the YBX-C10 (V3) hydraulic pump and the Y90S-4B5 electric motor. This ensures the reliability of machine automation operation while meeting the working requirements of the machine.

In terms of performance verification and evaluation, this article has calculated the performance indicators of the hydraulic system and conducted verification calculations for the stability and reliability of the system, including pressure loss and temperature changes of the hydraulic system. The results indicate that the designed hydraulic system is stable and reliable, meeting the operational requirements under the working conditions of the machine tool.

Acknowledgement

This research is supported by School Grants platform for Scientific Research of Shandong Huayu University of Technology in 2019: CNC Tool Manufacturing Process Research and Development Center.

References

[1] Liu YL. Design of special machine tool for processing connecting rod bolt holes and small head holes. Manufacturing Technology and Machine Tool. 2020; (08): 178-181

[2] Li H, Xiao TZ, Huang J. Design of special machine tool for machining diagonal oil holes in engine block. Combination Machine Tool and Automation Processing Technology. 2019; (08): 130-132

[3] Dong SJ. Design of special machine tool scheme and process equipment for processing oil holes on the top surface of PPD cylinder body Machine Tool and Hydraulic. 2020; (09): 120-124

[4] Li SZ, Yang ZJ, Tian HL, et al. Failure analysis for hydraulic system of heavy-duty machine tool with incomplete failure data. Applied Sciences. 2021; 11(3): 1249-1249.

[5] Mohaspa AM, Yusoff MN, Othman WAFW, et al. Design of drilling mechanism for aquilaria tree climbing modular robot. Proceedings of Symposium on Intelligent Manufacturing and Mechatronics. 2022; p. 397-403.

[6] Geffroy S, Brautlacht A, Wegner S, Gels S and Schmitz K. Experimental validation of a new design concept for the increase of efficiency of the hydraulic drive system in mobile working machines. IOP Conference Series: Materials Science and Engineering. 2021; 1097(1): 012017.