Scientific and Social Research, 2024, Volume 6, Issue 8
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Research on Digitalization of Hydraulic Valves

Shuangjun Hu*

Guangxi Vocational & Technical College of Manufacturing and Engineering, Nanning 530105, China

***Corresponding author:** Shuangjun Hu, hushuangjun9@163.com

Abstract: The hydraulic pilot valve is an important component in hydraulic systems. Hydraulic systems and hydraulic control technology are the core of the development in the field of construction machinery. This article mainly introduces the concept and research significance of hydraulic valves, analyzes the current research status, level, and development trends at home and abroad, and is committed to researching, designing, and applying a hydraulic pilot valve with an electromagnetic positioning handle to improve the control performance of construction machinery.

Keywords: Digitalization; Hydraulic valve; Application research

Online publication: August 23, 2024

1. Introduction

As a common component of hydraulic systems, hydraulic valves are mainly used to control the pressure and fluid flow within the system. With the rapid development of computers and intelligent devices, factories have put forward higher requirements for the accuracy and digitalization of hydraulic systems. At present, the main research directions of digitalization are focused on improving performance parameters such as response speed and output flow rate. The research areas mainly involve signal control, valve body structure, stepper motors, and so on. New materials such as piezoelectric crystals and magnetostrictive materials, as well as digital hydraulic valves, have become the research hotspots and directions of digital valves.

2. Research status and development trends of hydraulic valve control technology

2.1. Research status of hydraulic control technology at home and abroad

Research on hydraulic pilot valves abroad mainly focuses on how to improve their performance, response speed, and control accuracy. At present, hydraulic systems are applied in fields such as agriculture and construction, and hydraulic control systems have always been the forefront direction of research in the field of construction machinery [1]. Among them, the application of electromagnetic positioning technology to improve the intelligence level of the control system is a research hotspot in the field of hydraulic control abroad. In addition, exploring new materials and structures for hydraulic system components to improve energy efficiency and stability is also a hot research topic for foreign research institutions [2–3].

The research on hydraulic control technology in China mainly focuses on improving system efficiency, reducing flow loss, and improving sealing performance [4]. Significant achievements have been made in the design and performance optimization of hydraulic components in China, but the integration application of electromagnetic positioning handles and hydraulic pilot valves is still weak. The research on domestic hydraulic systems tends to focus more on system stability, and the widespread application of hydraulic control technology has led researchers to pay more attention to the ability of construction machinery to operate stably under various complex working conditions, meeting the actual needs of enterprises.

2.2. Development level of hydraulic pilot valve technology

Hydraulic pilot valve technology has achieved fruitful research results worldwide, especially in terms of structure, materials, control algorithms, and electromagnetic positioning handle technology, which have made significant progress. The research and development of this technology abroad mainly focuses on structural optimization and material innovation, which enhances the performance, durability, reliability, adaptability to changing working conditions, and service life of hydraulic pilot valves [5]. In terms of electromagnetic positioning handle technology, the human-machine interaction experience has been optimized, allowing operators to operate construction machinery more intuitively and flexibly.

In China, research on hydraulic pilot valve technology focuses more on performance improvement and cost control. Many enterprises, universities, and research institutions are committed to optimizing the structure and improving materials of pilot valves to enhance their response speed, stability, and accuracy [6]. Although significant progress has been made in hydraulic pilot valve technology domestically, there is still a certain gap compared to foreign countries. However, both domestically and internationally, the continuous innovation and improvement of hydraulic pilot valve technology have injected new vitality into the development of engineering machinery, providing more advanced and reliable hydraulic control technology for the field.

2.3. Development trend of hydraulic pilot valve technology

With the development of society and the advancement of technology, the awareness of environmental protection among all sectors of society is constantly strengthening, and the development of hydraulic pilot valves is also moving towards the direction of environmental protection and easy operation. The development of hydraulic pilot valve technology in the future will pay more attention to intelligence, automation, and human-computer interaction [7]. The selection of materials and processes will also be more economical and environmentally friendly. The accuracy of user operation of hydraulic pilot valves will be improved, and the user experience will be enhanced. The firmness of hydraulic pilot valves will be stronger, and their service life will be longer. The introduction of electromagnetic positioning handle technology provides a new way to improve the performance and intelligent control of hydraulic pilot valves. There is a need to conduct in-depth research on the collaborative working mechanism between electromagnetic positioning handle technology and hydraulic pilot valves, improve the stability and reliability of the system, and inject new power into the future development of construction machinery.

3. Design scheme for hydraulic pilot valve

3.1. Structural design

Digitization of hydraulic control components has gradually become an inevitable development trend, and digital valves, as a type of digital fluid component, play an important role in hydraulic servo systems. Firstly, the design of the structure of the electromagnetic positioning handle includes sensors, control levers, and electromagnetic components [8–10].

The hydraulic digital valve combines the axial movement of the main valve core and the circumferential rotation of the valve sleeve to independently adjust the valve opening and achieve precise control of large flow. Its structure covers three major modules: valve body, electro-mechanical conversion, and transmission. The valve body includes a main control and a diversion valve body to ensure precise flow distribution. The electromechanical conversion is achieved by linking the controller with the brushless DC motor to convert electrical signals into mechanical actions. The transmission mechanism integrates the coupling, screw nut, and main valve core finely regulates the valve opening, and together form an efficient hydraulic control system [11].

In the design process of valves, when the opening of the valve and the structural dimensions of the valve core and body are fixed, the flow rate is proportional to the pressure loss, that is, as the flow rate increases, the pressure loss also increases. Reasonably controlling the maximum flow rate of the fluid inside the valve is the key to the design. The conventional design sets the flow rate within the range of 3–6 m/s in low-pressure environments and relaxes it to 10–15 m/s in high-pressure environments. The flow rate limitation is not absolute and needs to be flexibly adjusted based on specific structural design. This project uses pure water as the medium, and based on its low viscosity characteristics, we set the flow rate limit value to 10 m/s. Based on this, we optimize the basic size design of the valve body to ensure system efficiency and stability.

Firstly, calculate the diameter of the inlet and outlet of the valve body. The inlet and outlet diameters of the valve body are the same, and the calculation formula is shown in **Formula 1**.

$$d_0 \geq \sqrt{\frac{4Q_{\max}}{\pi v_0}} \qquad (1)$$

In the formula:

Q_{max}: maximum flow rate, L/min; V_0: Limit value of flow velocity inside the valve body, m/s; The rated flow rate of the valve designed in this article is 28 L/min, which means Q_{max} = 30 L/min.

$$d_0 \geq \sqrt{\frac{4Q_{\max}}{\pi v_0}} = \sqrt{\frac{4 \times 28}{60 \times 1000 \times 3.14 \times 10}} = 7.7\text{mm}$$

Take d_0 = 8mm, connect it to the second branch pipe joint, and externally connect the second branch hydraulic pipe. Verify the fluid flow rate inside the valve body,

Calculated as:

$$v_0 = \frac{4Q_{\max}}{\pi d_0^2} = \frac{4 \times 28}{60 \times 1000 \times 3.14 \times 0.008^2} = 9.29\, m/s$$

The calculation shows v_0 = 9.29 m/s, which is less than the set flow velocity limit of 10 m/s inside the valve body and meets the design requirements.

Next, calculate the structure of the valve core, including the large diameter D and small diameter d1 of the main valve core shoulder.

To ensure the overall structural strength of the valve core, d1 ≥ D/2 is generally taken. The small diameter part of the valve core forms an annular channel with the valve sleeve, and the flow formula for pure water passing through this annular channel is shown in **Formula 2**.

$$Q_{\max} = \frac{\pi}{4}(D^2 - d_1^2)v \qquad (2)$$

In the formula:

D: Large diameter of the main valve core shoulder, cm; D1: Small diameter of main valve core, cm; V:

Flow velocity of the water in the valve chamber, m/s. If d1 = 0.5 D and v ≤ 6 ms, then:

$$16.67Q_{\max} \leq \frac{\pi}{4}\left[D^2 - \left(\frac{D}{2}\right)^2\right] \times 100 \times 6$$

$$D \geq 0.22\sqrt{Q_{\max}} = 0.22 \times \sqrt{30} = 1.12\text{cm}$$

This design takes D = 2 cm and d1 = 1.0cm, and the reverse calculation meets the requirements.

3.2. Control system design

The application range of digital valves is limited by their control accuracy, and the performance of stepper motors, especially output accuracy and step accuracy, is one of the limiting factors. By improving the control accuracy of digital valves and simplifying their structure, a new idea of using DC motors to drive hydraulic valves can be proposed to construct corresponding control systems. **Figure 1** visually illustrates the workflow of this system. In traditional designs, stepper motors have limited resolution, which limits the control accuracy of digital valves and results in slow response speed [12]. Therefore, using brushless DC motors as an alternative solution, as the energy conversion core from electricity to machinery, it can efficiently convert digital signals into mechanical actions. With the help of a rotary to linear motion mechanism, the rotation of the brushless DC motor is accurately converted into linear motion, thereby achieving precise control of the main valve core and enhancing the digital control capability of the entire valve. In the scheme shown in **Figure 1**, both the control logic and user interface are developed on a PC using C language. The user sends instructions to the controller through the interface, and the controller then drives the brushless DC motor to rotate at a predetermined angle. This rotation action is directly applied to the main valve core through a precision transmission device, achieving precise adjustment of its position. This design not only overcomes the shortcomings of stepper motors but also improves the overall performance of the system and the convenience of user operation through structural optimization.

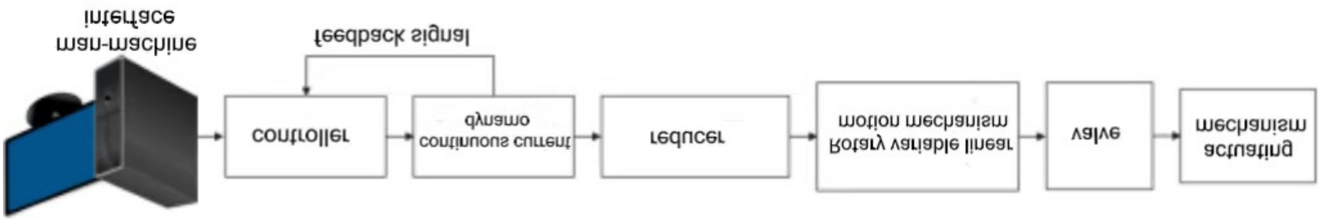

Figure 1. Control system workflow diagram

To ensure the smooth operation of hydraulic digital valves and efficient data collection, it is necessary to design and create integrated software as a solution. The core of this software is program development for the digital valve platform, relying on the powerful computing power of external X86 architecture computers to achieve precise command sending to the controller, and then drive the brushless DC motor to ensure accurate adjustment of the valve core position [13]. The core functions of this software are reflected in two aspects. Firstly, through an efficient command transmission mechanism, it accurately controls the motion trajectory of the brushless DC motor, enabling the main valve core to reach the preset position accurately and without error, ensuring the stability and accuracy of the system operation. Secondly, real-time feedback on key parameters of motor motion, including motion angle and direction, provides a reliable basis for verifying the accuracy of valve core position and enhances the system's self-monitoring and adjustment capabilities [14]. The design of this software enhances the overall performance of the digital valve system and provides a method for subsequent data collection and analysis.

3.3. Experimental system design

To ensure that the experiment can proceed normally, the team needs to analyze the feasibility of the experiment. Firstly, under the current technological conditions, both electromagnetic positioning handle technology and hydraulic pilot valve technology have matured. Secondly, the combination of numerical simulation and experimental verification can comprehensively evaluate system performance. Furthermore, team members have relevant technical and experimental experience, and schools and enterprises have strong guarantees in terms of policies, financial and material resources, as well as technical experts and advanced equipment. The experiment can be conducted safely and efficiently.

The first step of the experiment is to establish a joint experimental platform for the electromagnetic positioning handle and hydraulic pilot valve, ensuring the tight integration of the electromagnetic positioning handle and hydraulic pilot valve, simulating the real engineering machinery control environment, and establishing a reliable communication mechanism to ensure real-time signal transmission and response. Next, design experiments under different working conditions, including different workloads, speeds, and directions, covering the diverse control requirements of actual construction machinery, and determine key performance parameters in the experiment, such as control accuracy, response speed, and system stability, as indicators to evaluate system performance [15]. Then collect data and analyze it for user experience evaluation, real-time record electromagnetic positioning handle output signals, hydraulic pilot valve response, and other data, collect subjective feedback from operators, evaluate system performance under different working conditions, and further optimize system design. After completing the basic experiments, it is necessary to conduct system stability testing and performance optimization experiments, run the system for a long time or under extreme conditions, adjust parameters, and conduct repeated experiments to verify the stability and adaptability of the system in harsh environments, identify potential problems, continuously optimize system performance, and ensure that it can perform well under different working conditions.

4. Conclusion

To meet the rapid development of science and technology and keep up with the trend of social market development, all industries need to carry out reforms and innovations. China's research on hydraulic systems started relatively late, and domestic research on the integrated application of electromagnetic positioning handles and hydraulic pilot valves is still weak. Therefore, strengthening research on hydraulic valves can elevate China's scientific and technological level to a higher level.

Funding

2024 Guangxi University Young and Middle-aged Teachers Research Basic Ability Enhancement Project "Development and Research of a Hydraulic Pilot Valve with Electromagnetic Positioning Handle" No. 2024KY2097.

Disclosure statement

The author declares no conflict of interest.

References

[1] Xie S, 2020, Research and Practice on Digital Manufacturing Technology of High Pressure and High Flow Hydraulic Valves. Modern Manufacturing Technology and Equipment, 2020(04): 107–109.

[2] Wang YT, Chang XS, Wei TX, et al., 2023, Latest Research Progress on Digitalization of Hydraulic Valves. Machine Tool and Hydraulic, 51(09): 197–206.

[3] Zhang CG, Tai GR, Yang X, et al., 2024, Simulation Analysis of Hydraulic Valve Plate Sealing in Automatic Transmission. Automotive Technology, 2024(03): 45–49.

[4] Chen YP, Liu XY, 2024, Virtual Disassembly and Assembly System for Marine Electromechanical Equipment Based on Hydraulic Electromagnetic Directional Valve. Electromechanical Equipment, 41(03): 53–58.

[5] Wang CY, 2024, Diagnosis and Maintenance of Hydraulic System Faults in Offshore Cranes. Chemical Management, 2024(12): 134–136.

[6] Yu Q, Xie XY, Xu Y, et al., 2024, Intelligent Detection of Abnormal Flow of Hydraulic Balance Valve in Electric Rotary Drilling Rig. Hydraulic Pneumatic and Sealing, 44(04): 105–110.

[7] Ding PZ, 2024, Analysis of Design Points for Hydraulic Valve Group Automation Assembly Control System. Modern Industrial Economy and Informatization, 14(03): 83–85.

[8] Du B, 2024, Common Faults and Maintenance of Mechanical Hydraulic Systems. Forging Equipment and Manufacturing Technology, 59(01): 72–74.

[9] Li J, 2024, Exploration of Heat Treatment Process for Hydraulic Valve Core. Construction Machinery Technology and Management, 37(01): 68–70.

[10] Wang HW, Zhang D, Han K, et al., 2024, Development Overview and Application Prospects of Digital Hydraulic Technology. Engineering Machinery and Maintenance, 2024(02): 25–29.

[11] Li J, 2023, Research on Processing Technology of Hydraulic Valve Core in Construction Machinery. Construction Machinery Technology and Management, 36(06): 81–84.

[12] Tong GQ, Hui GZ, Xiang YC, et al., 2023, Research on Remote Control Technology of Hydraulic System in Front of Blast Furnace. Heavy Machinery, 2023(05): 8–11

[13] Chen EY, Zhang QY, Ouyang ZX, et al., 2023, Numerical Study on Vortex Flow inside Hydraulic Valves. Energy Research and Information, 39(03): 189–197.

[14] Ding XK, 2023, Steady State Flow Field Analysis and Hydrodynamic Compensation Research of Hydraulic Valves, 2023, Qilu University of Technology.

[15] Wang CL, 2023, Optimization Design of Hydraulic Valve Integrated Block Pipeline Structure for Additive Manufacturing, thesis, Shandong Jianzhu University.