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Structural Characteristics Analysis and Optimization of Large Hydraulic Press Water Control System for Marine Engineering

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ABSTRACT

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With the development of science and technology and the construction of offshore oil platforms, the optimization of water control systems for large hydraulic press has become an inevitable trend in marine engineering research. Combining with related theories of mechanical engineering and marine engineering, and numerical analysis method, this paper adopted the finite element analysis software ABAQUS to establish numerical models for the water inlet and outlet valves of the hydraulic press, it simulated and analyzed the flow field state of the valve port under different fluid pressures and spool displacements, thereby studying the structural characteristics and optimization of the hydraulic press water control system. The results showed that when the fluid past through the inlet valve, local low-pressure zones appeared at the inlet valve port, and the low-pressure zones inside the inlet valve port increased with the increase of the spool displacement; the fluid pressure had a certain degree influence on the flow performance of the inlet valve, under the same spool displacement, the fluid flow increased with the displacement of the inlet valve spool; the speed increase of fluid flow past through the outlet valve gradually increased with the increase of the displacement of the outlet valve spool, the fluid pressure of the outlet valve increased first and then decreased as the displacement of the spool increased. This study provided technical support for the application of hydraulic press in marine engineering and laid a theoretical foundation for the structural optimization of hydraulic press.

ADDITIONAL INDEX WORDS: *Marine engineering, hydraulic press, water control system, structural characteristics, flow field simulation.*

INTRODUCTION

With the rapid development of aerospace, marine, military and shipbuilding industries, hydraulic presses are playing an increasingly important role in social development and national defense security (Sun, Grácio, and Ferreira, 2006; Lu and Huang, 2012; Du *et al.,* 2014). Especially in marine engineering, the requirements for the processing technology, components and control systems of hydraulic presses are quite stringent, so it is necessary to develop new hydraulic presses with higher reliability (Lin *et al.,* 2016; Montanari *et al.,* 2004). The hydraulic press is a device for hydrostatic testing of steel pipes and the like based on oil-water balance control. It is mainly composed of oil circuit system, water circuit system, control system and stepping mechanism (Kilic *et al.,* 2012; Lovrec, Kastrevc, and Ulaga, 2009; Truong and Ahn, 2011). Hydraulic presses are widely used in marine engineering, oil exploration, light industry, metallurgy, energy power stations and other fields (Bronuzzi *et al.,* 1998; Smeed, 2000).

The study found that the main control performance of the hydraulic press control system directly affects the normal operation of the hydraulic press, and the hydraulic press control system is one of the key factors affecting the performance of the hydraulic press (Han, Wang, and Huang, 2012; Jun *et al.,* 2013; Owolarafe, Faborode, and Ajibola, 2002). The structural design and deformation of the control system directly affects the performance of the hydraulic press control system and the operation of the overall structure (Fulland *et al.,* 2008; Olajide *et al.,* 2007). In order to explore the structural characteristics of the hydraulic press control system, based on the theory of fluid mechanics, this paper analyzed and optimized the structural characteristics of key components in the hydraulic press control system by establishing a numerical model of the hydraulic press control system. This study laid a theoretical foundation for the research and engineering application of the overall control characteristics of hydraulic presses (Lv *et al*., 2018).

FLOW FIELD ANALYSIS OF HYDRAULIC PRESS

The block diagram of the hydraulic press studied in this paper is shown in Figure 1. The main distributor of the hydraulic press is the core component of the control system (the principle of the control system is shown in Figure 2), and the force and flow characteristics of the spools of the inlet and outlet valves are directly related to the performance of the hydraulic press. Therefore, this paper used the finite element analysis software to establish numerical models of the inlet and outlet valves to simulate the flow field, so as to obtain the flow field distribution and the stress state of the spools of the inlet and outlet valves.

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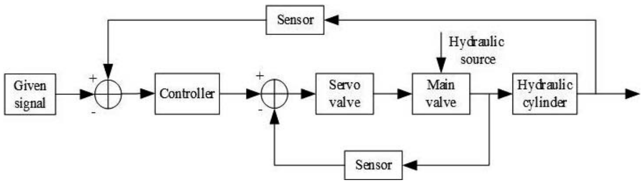

Figure 1. Control flow of hydraulic press.

Flow Field Simulation of the Inlet Valve

The flow of the fluid past through the inlet valve of the hydraulic press is usually determined by the flow area of the spool, and the arrangement of the valve port determines the flow area of the inlet valve, so we can optimize the flow of the inlet valve by adjusting the arrangement of valve ports. In this paper, based on a hydraulic press applied in marine engineering, a flow field simulation model of the inlet valve was established by simplifying the flow field model. During the modeling, some conditions were set as follows: (a) no heat conduction occurs in the fluid passes through the inlet valve; (b) the fluid is not compressible; (c) the Pressure Input and Pressure Outlet are selected as the boundary conditions of the water inlet and outlet, respectively; assume that the movement speed of the water body is 0.03 m/s and the movement time is 0.1s.

Under the premise that the outlet pressure was set to 10 MPa, before and after the optimization, the local stress nephogram of the inlet valve of the hydraulic press when the spool displacement was 28 mm is shown in Figure 3. By comparing and analyzing the local stress nephogram under different spool displacements (8 mm, 16 mm, 22 mm, 28 mm), it is found that when the spool displacement was relatively small, the pressure dropped faster when the fluid past through the valve port, and local low-pressure zones appeared at the valve port; as the displacement of the spool increased, the low-pressure zones inside the valve port expanded continuously; the internal heating pressure of the spool before and after optimization had basically the same trend.

When the water pressure difference between the two ends of the water inlet valve of the hydraulic press was 3 MPa, the flow-displacement curves of the inlet valve of the hydraulic press before and after optimization were obtained, as shown in Figure 3. It can be seen from the figure that the flow-displacement curves of the inlet and outlet valves before and after the optimization were basically the same at a displacement of 8 mm (at the first row of holes), this is mainly due to the same flow area of the inlet and outlet valves before and after the optimization; with the increase of the spool displacement, the flow-displacement curve gradually showed small fluctuations. Before the optimization, the linear characteristic of the curve was not obvious, while the linear characteristic of the flow-displacement curve of the inlet valve was better after the optimization. Studies showed that after the optimization, the flow performance of the inlet valve had been significantly improved.

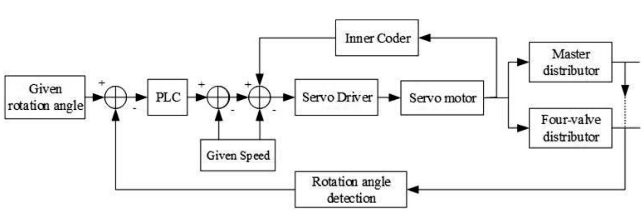

Figure 2. Working principle of control system.

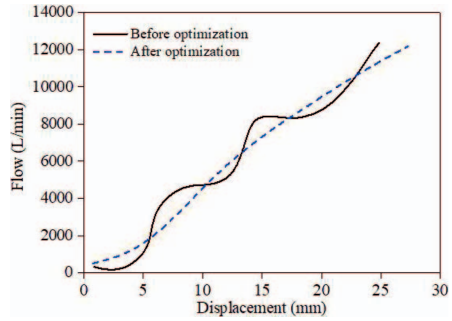

Figure 3. Flow-displacement curves of inlet valve before and after the optimization.

To study the flow performance of the inlet valve under different water pressures in detail, under the condition of a water pressure of 2 MPa, 4 MPa and 6 MPa, the change of inlet valve flow with the increase of displacement was investigated. Figure 4 shows the flow-displacement curves of the inlet valve under different pressure drops. It can be seen that the water pressure had a certain degree of influence on the flow performance of the inlet valve. As the water pressure increased, the slope of the flow-displacement curve gradually increased, and the fluid flow under the same spool displacement showed a trend of gradual increase.

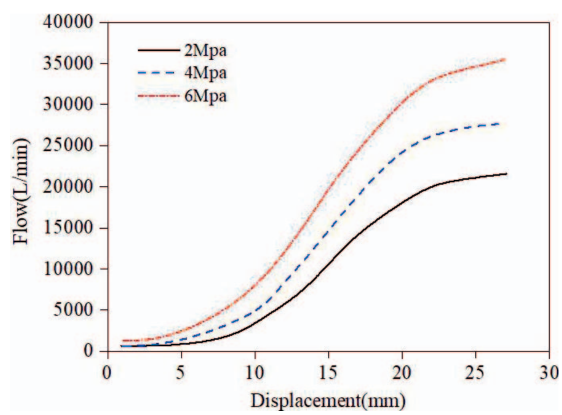

Figure 4. Flow-displacement curves of inlet valve under different pressure drop.

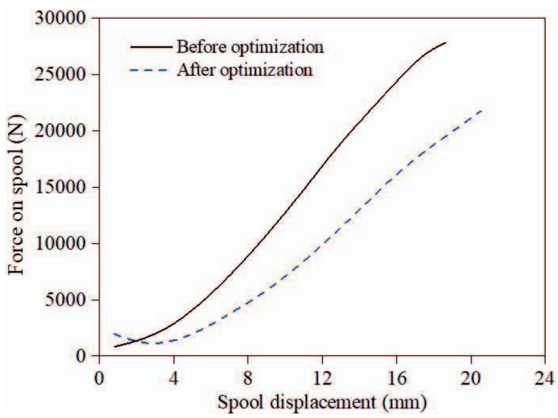

Figure 5. Hydraulic pressure curves of the spool.

Force Analysis of the Inlet Valve

During the operation of the hydraulic press, the inlet valve is subject to the frictional force, self-weight, spring force and fluid pressure of the valve stem. Except for the spring force, other forces will act on the spool of the inlet valve. In addition, the magnitude and direction of the fluid pressure determine the opening load and opening mode of the inlet valve. When the fluid pressure difference was 16 MPa and the fluid pressure was acted along the closing direction of the inlet valve port, the spool fluid pressure curves before and after the inlet valve optimization are shown in Figure 5. It can be seen that the trend of the curves before and after the optimization of the inlet valve was basically the same, but the force on the valve stem was significantly reduced after optimization, which helped to improve the structural characteristics of the control system.

Figure 6 is the fluid pressure curve of the inlet valve spool under different fluid pressure drops. It can be seen that as the displacement of the spool increased, the fluid pressure decreased first, increased later and then decreased again. With the increase of the fluid pressure drop, the fluid pressure on the spool gradually increased, and the force of the fluid pressure acted on the inlet valve spool along the spool closing direction decreased. When the spool displacement exceeded 28 mm, the high-pressure zone at the outlet of the inlet valve expanded, while the range of the local low-pressure zone decreased, and the fluid pressure acting on the spool showed a trend of decrease.

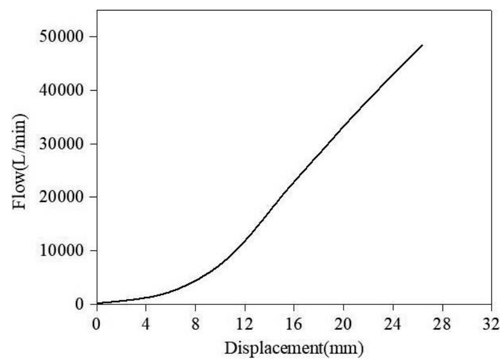

Figure 7. Flow-displacement curve of outlet valve.

Flow Field Simulation of the Outlet Valve

The relationship between the fluid flow and the spool displacement of the outlet valve is shown in Figure 7. It can be seen from the figure that in the beginning the flow increased slowly with the displacement of the spool, after reaching a certain value, it showed a trend of rapid increase, when the spool displacement was 10 mm, the flow was very small; when the displacement was between 10 mm and 15 mm, the flow increased gradually; when the displacement was above 15 mm, the flow increased rapidly. This characteristic can meet the requirements of the outlet valve in early stage pressure relief and later stage unloading.

The relationship between the force applied on the outlet valve and the displacement of the spool is shown as Figure 8. It can be seen from the figure that the force applied on the outlet valve first increased and then showed a trend of decrease, when the spool displacement was less than 35 mm, the relationship

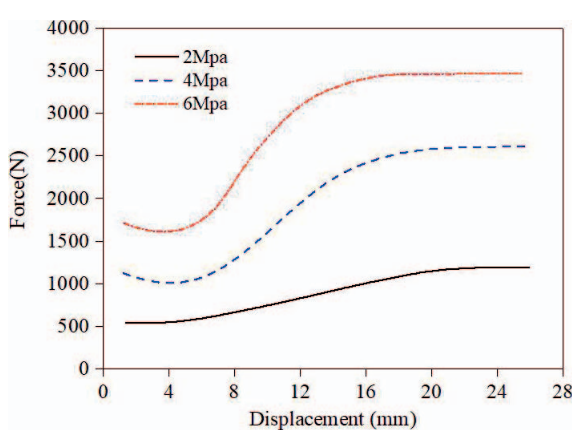

Figure 6. Hydraulic pressure curves of spool under different pressures.

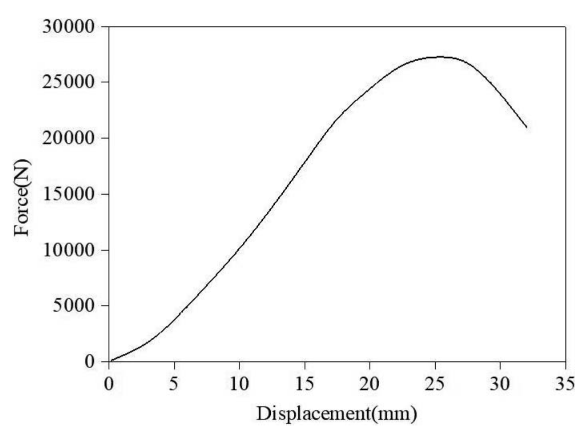

Figure 8. Fluid pressure-displacement curve of outlet valve.

Table 1. *Speed and flow statistics of return cylinder.*

Valve opening (*mm*)	Return Cylinder Speed (*mm/s*)	System traffic (*L/min*)
0.5	31.67	570.01
1.1	204.43	3679.71
2.5	357.86	6441.43
5	732.86	13191.43
8	840.86	15135.43
10	949.29	17087.14
13	1107.00	19926.00
20	1188.21	21387.86
21	1297.29	23351.14
23	1275.77	22963.89
26	1348.07	24265.29

between the force on the outlet valve and the spool displacement was basically linear; when the displacement was larger than 35 mm, the force on the outlet valve tended to decrease, at this time, the pressure at the bottom of the spool increased.

HYDRAULIC PRESS STRUCTURAL CHARACTERISTICS TEST

The hydraulic throttle valve was used for testing. By adjusting the position of the spool and detecting the main cylinder speed, the flow was calculated, and then the measured data was adopted to draw the flow-displacement curve of the optimized throttle valve. During the test, the return cylinder flow was calculated to obtain the flow of the throttle valve. The formula for the return cylinder flow is:

$$Q = 60 \times Sq \quad (1)$$

where: Q — return cylinder flow (L/min)

S — return cylinder area (mm^2)

q — return cylinder speed (mm/s)

The test data is shown in Table 1, in which, the return cylinder area is 320,000 mm^2.

The flow-displacement curve of the throttle valve of the hydraulic press is shown in Figure 9. When the displacement of the throttle valve was relatively small, the flow ran through the throttle valve changed fast, so the slope of the curve was relatively large, and the slope of the curve gradually decreased as the displacement of the main spool increased; when the displacement of the throttle valve was greater than 5 mm, the flow change tended to be stable, and the relationship between flow and displacement was basically linear; when the displacement of the throttle valve exceeded 21 mm, the flow change gradually decreased; when the displacement of the throttle valve was less than 5mm or more than 21 mm, the spool of the inlet valve was located in the first or last row of inlet holes and the linearity of the curve was poor, the water flow was not stable; while at other positions, the curve had better linear characteristics, indicating that the improved inlet valve is conducive to the control of the hydraulic press and position (Guo *et al.,* 2013; Li *et al*., 2015; Liu *et al*., 2016).

CONCLUSION

Based on the finite element numerical analysis method and the related theory of fluid mechanics, this paper analyzed the structural characteristics and optimized the water control system of a large hydraulic press for marine engineering. The

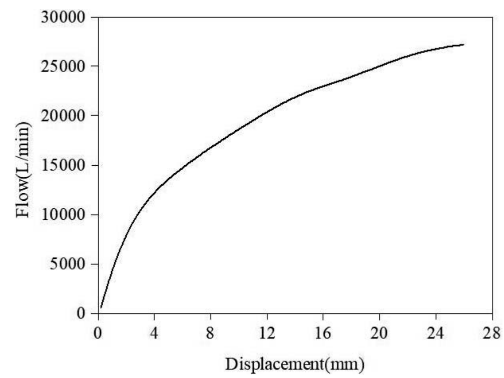

Figure 9. Flow-displacement of inlet valve.

finite element analysis software ABAQUS was used to establish the numerical models of the water inlet and outlet valves of the hydraulic press, and the flow field states of the valve port under different fluid pressures and different spool displacements were simulated and analyzed. The main conclusions are as follows:

(1) The outlet pressure was set to 10 MPa, the force of the fluid past through the inlet valve port decreased faster when the spool displacement was smaller, and local low-pressure zones appeared near the valve port; as the spool displacement increased, the low-pressure zones inside the valve port expanded continuously; the internal heating pressure of the spool before and after the optimization had basically the same change trend.

(2) With the increase of water pressure, the slope of the flow-displacement curve at the inlet valve spool gradually increased; under the same spool displacement, the fluid flow increased with the increase of the spool displacement, and the fluid pressure had a certain degree of influence on the flow performance of the inlet valve.

(3) The flow of the fluid passing through the outlet valve increased slowly with the increase of the displacement of the outlet valve spool, and the fluid pressure on the outlet valve increased first and then decreased with the increase of the displacement of the spool.

LITERATURE CITED

Bronuzzi, F.; Cigna, C.; Patrucco, M., and Sassone, M., 1998. Sound power emission measurement and control on a 300-t hydraulic press. *Journal of the Acoustical Society of America,* 103, 2964.

Du, H.; Huang, B.; Wang, L., and Chen, S.M., 2014. The design of monitoring system in large hydraulic press aiming at the precise closed-loop control. *Advanced Materials Research,* 989-994, 3062-3069.

Fulland, M.; Sander, M.; Kullmer, G., and Richard, H.A., 2008. Analysis of fatigue crack propagation in the frame of hydraulic press. *Engineering Fracture Mechanics,* 75, 892-900.

Guo, X.; Yang, N.; Liu, X.; Chang, X., and Hwang, C., 2013. Decadal Variation in Surface Characteristics over Xinjiang, Western China, from TAP Altimetry Backscatter Coefficients: Evidence of Climate Change. *Terrestrial Atmospheric and Oceanic Sciences*, 24, 565-579.

Han, H.Y.; Wang, J., and Huang, Q.X., 2012. Analysis of unsymmetrical valve controlling unsymmetrical cylinder stability in hydraulic leveler. *Nonlinear Dynamics,* 70, 1199-1203.

Jun, Y.; Jianping, T.; Zhaoqiang, S., and Ling, C., 2013. Approximate variable structure control for transient load in large hydraulic press. *IEEE,* 3*,* 310-312.

Kilic, E.; Dolen, M.; Koku, A.B.; Caliskan, H., and Balkan, T., 2012. Accurate pressure prediction of a servo-valve controlled hydraulic system. *Mechatronics*, 22, 997-1014.

Li, J.; Su, B.; Sha, J.; Fan, Z., and Sun, Z., 2015. Architecture and facies model in a non-marine to shallow-marine setting with continuous base-level rise: An example from the Cretaceous Denglouku Formation in the Chang ling Depression, Songliao Basin, China. *Marine and Petroleum Geology*, 68, 381-393.

Lin, Y.C.; Chen, D.D.; Chen, M.S.; Chen, X.M., and Li, J., 2016. A precise bp neural network-based online model predictive control strategy for die forging hydraulic press machine. *Neural Computing and Applications,* 29, 585-596.

Liu, N.; Lin, L.; Wang, Y.; Kong, B., and Zhang, Z., 2016. Arctic autumn sea ice decline and Asian winter temperature anomaly. *Acta Oceanologica Sinica*, 35, 36-41.

Lovrec, D.; Kastrevc, M., and Ulaga, S., 2009. Electro-hydraulic load sensing with a speed-controlled hydraulic supply system on forming-machines. *International Journal of Advanced Manufacturing Technology,* 41, 1066-1075.

Lu, X.J. and Huang, M.H., 2012. System-decomposition-based multilevel control for hydraulic press machine. *IEEE Transactions on Industrial Electronics,* 59, 1980-1987.

Lv, M.; Liu, H.; Xia, M.; Wang, J.; Nie, X.; Zhu, H., and Zhu, Z., (2018). Simulation of flow field in theoretical water lifting system with temperature difference in vertical tubes on large scales. *Applied Ecology and Environmental Research,* 16, 7435-7446.

Montanari, M.; Ronchi, F.; Rossi, C.; Tilli, A., and Tonielli, A., 2004. Control and performance evaluation of a clutch servo system with hydraulic actuation. *Control Engineering Practice,* 12, 1369-1379.

Olajide, J.O.; Igbeka, J.C.; Afolabi, T.J., and Emiola, O.A., 2007. Prediction of oil yield from groundnut kernels in an hydraulic press using artificial neural network (ANN). *Journal of Food Engineering,* 81, 643-646.

Owolarafe, O.K.; Faborode, M.O., and Ajibola, O.O., 2002. Comparative evaluation of the digester–screw press and a hand-operated hydraulic press for palm fruit processing. *Journal of Food Engineering,* 52, 249-255.

Smeed, D.A., 2000. Hydraulic control of three-layer exchange flows: application to the bab al mandab. *Journal of Physical Oceanography,* 30, 2574-2588.

Sun, P.; Grácio, J.J., and Ferreira, J.A., 2006. Control system of a mini hydraulic press for evaluating springback in sheet metal forming. *Journal of Materials Processing Technology,* 176, 55-61.

Truong, D.Q. and Ahn, K.K., 2011. Force control for press machines using an online smart tuning fuzzy pid based on a robust extended kalman filter. *Expert Systems with Applications,* 38, 5879-5894.