An AMESIM-based simulation of hydraulic system design for ultra-high pressure tablet presses

Kailin Feng¹, Bihai Deng²,³ and Chuanzhen Zha¹

¹ College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao 266590, China
² College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao 266590, China
³ E-mail: 1547719270@qq.com

Abstract. Aiming at the problems of large bore of hydraulic cylinders of high tonnage quantity tablet press, large size of tablet press and wide area, a method of using ultra-high pressure hydraulic system to streamline the structure of tablet press is proposed, and a laboratory ultra-high pressure tablet press for XRF spectral analysis specimen manufacturing is designed. The AMESIM software was used to simulate the established hydraulic system model, and the theoretical analysis and relevant experience were combined to reasonably set the relevant parameters of the simulation model, and the AMESIM simulation results were obtained to analyze the motion and flow characteristics of each hydraulic circuit system, which verified the rationality of the hydraulic system.

1. Introduction

XRF spectroscopy is widely used in geology, metallurgy, environment, chemical industry, materials and other fields [1], the method mainly uses powder samples pressed and formed specimens for the relevant analysis, powder sample preparation technology is an important research topic in XRF spectroscopy. There are two main methods for making powder samples for XRF spectroscopy: the powder compacting method and the fusion method. The process of making a powder tablet is simple, fast and economical, which is commonly used [2, 3]. Therefore, the method of powder tablet preparation using a tablet press is widely used in the field of XRF spectroscopy.

It can be seen from Figure 1 that within a certain range, the greater the holding pressure, the better the analyzability of the formed sample, and the pressure rating of the tablet press used to make the sample should reach 320 tons. At present, the hydraulic system of tablet press is rated at 20MPa, 25MPa, and 32MPa, and in the case of 320 tons, it can be seen from Equation (1) that if the hydraulic system is rated at 20MPa, the hydraulic cylinder has a larger bore. This will make the tablet press bulky, not easy to move, and occupy a large area. Therefore, to address this problem, this paper designs an ultra-high pressure hydraulic system with a rated pressure of 65 MPa, which greatly reduces the bore of the hydraulic cylinder and the overall volume of the tablet press, reduces the footprint of the equipment, and facilitates the use of the laboratory and the handling of the equipment. [4, 5]

\[ F = \frac{\pi}{4} p d^2 \]  

(1)
Figure 1. Comparison chart of samples under different pressures.

Figure 2. Mechanical structure of XRF sample preparation tablet press.

1, 4, 8. hydraulic cylinder; 2. the upper die piece; 3. the lower die piece; 5. the loading port; 6. the cylinder; 7. robot; 9. console

2. Mechanical structure of ultra-high pressure tablet press
The mechanical structure diagram of the ultra-high pressure tablet press designed in this paper is shown in Figure 2. The tablet press is controlled by the console 9. When the machine starts to work, it is loaded from the feed port 5 and cylinder 6. After the loading is completed, the lower die 3 is pushed to the tablet press station by the hydraulic cylinder 8, and the hydraulic cylinder 1 drives it up. The mold is pressed down, and after the pressing is completed, the hydraulic cylinder 8 pulls the lower mold back, and the hydraulic cylinder 4 ejects the formed sheet, which is picked up by the manipulator 7 to complete a feeding-feeding-pressing-pickup process.

3. Hydraulic system working principle analysis and design
The main workflow of the ultra-high pressure tablet press is the same as most hydraulic presses, which includes fast downward travel, pressurization to a specified value, holding pressure, pressure relief, fast return and other actions, and the hydraulic cylinder is installed vertically, which needs to ensure that the
hydraulic cylinder can be suspended and stopped. The principle of the hydraulic system of the ultra-high pressure tablet press is shown in Figure 3: the hydraulic system uses a double pump system, hydraulic pump 1 for the high flow rate piston pump, 2 for the ultra-high pressure radial piston pump. The relief valve 3 and 13 mainly plays the role of constant pressure relief, pressure stabilization, unloading and safety protection [6].

3.1. Hydraulic system working process
Auxiliary cylinder working process: After the sheet press is loaded, the auxiliary cylinder 17 pushes the lower die piece to the sheet press station, and returns it after the pressure-holding is completed, and three-position four-way solenoid valve 15 executes the reversing action. After the pressing action is completed and returned, the auxiliary cylinder 16 will push out the finished pressing piece and retract it after the robot picks it up, which is controlled by three-position four-way solenoid valve 14. The movement speed of the piston rods of the two auxiliary cylinders is regulated by throttle speed control valves 18, 19.

Main hydraulic cylinder work flow: the main hydraulic cylinder fast downward by two pumps at the same time, one-way valve 5 to ensure that the ultra-high pressure oil pump only to the main hydraulic cylinder circuit supply oil; the upper die downward contact with the lower die, the pressure rises, high flow pump sequence valve 6 unload, by the high pressure pump 2 continue to supply oil to make the pressure rise to the specified value; pressure-holding stage three four-way electromagnetic reversing valve 4 switch to the middle position, by the hydraulic control check valve 10 to achieve pressure-holding [7], pressure-holding completed After the pressure-holding stage, the two-position two-way solenoid valve 11 is turned on, and the pressure is quickly relieved through the sequence valve 9, at the same time, three four-way electromagnetic reversing valve 4 is switched to the right position, and the cylinder piston rod is quickly returned. The throttle valve 8 serves to generate back pressure to open hydraulic control check valve 10.

![Figure 3. Hydraulic schematic diagram of ultra-high pressure tablet press.](image)

3.2. Parameter design
It can be seen from the foregoing that the tablet press for making XRF samples must reach a pressure of 320 tons, the main hydraulic cylinder is rated at 65 MPa, and the main hydraulic system should select professional ultra-high pressure hydraulic system components.
The ultra-high pressure pump is Rexroth PR4-3X radial piston pump: the maximum working pressure is 70MPa, the maximum displacement is 11.4L/min, the speed is 1000r/min, and the volumetric efficiency is 0.95.

The main hydraulic cylinder is a super high pressure double acting cylinder: the maximum working pressure is 70MPa, the cylinder stroke is 150mm, the cylinder inner diameter is 260mm, the piston rod diameter is 200mm. the force required for the feeding and taking cylinder is not large, so the cylinder bore is 50mm, the rod diameter is 36mm double acting hydraulic cylinder, the stroke is 450mm selected by the 3D model [8].

The force required for the sample ejecting cylinder action is also not large, so the cylinder bore is 50mm, the rod diameter is 36mm double-acting cylinder, the cylinder stroke is 200mm selected by the three-dimensional model.

As the three hydraulic cylinders of the tablet press are not simultaneous action, through the above determined hydraulic cylinder size structure, by the Formula (2), it is known that the double pump supply flow to meet the main hydraulic cylinder fast forward and fast reverse action, it can meet the needs of the entire hydraulic system, according to the hydraulic design manual set the main hydraulic cylinder fast forward speed of 0.045m/s.

\[ q = \frac{\pi}{4} d^2 v \]  

(2)

Required flow rate for fast forwarding of the main hydraulic cylinder: \( q = 145.35 \text{L/min} \).

The flow rate of the ultra-high pressure radial piston pump is 11.4L/min, and the flow rate required for the work of the other two hydraulic cylinders is much smaller than that required for the fast-in and fast-out action of the main cylinder, considering that the hydraulic system has a certain leakage, so the quantitative piston pump is selected, with a flow rate of 150L/min and a rated pressure of 16MPa.

4. AMESim simulation analysis
As shown in Figure 4, a simulation model was established with AMESim software based on the hydraulic schematic, and AMESim system simulation was used to characterize the hydraulic system of the tablet press and verify the rationality of the hydraulic system design [9, 10].

![Figure 4. AMESIM simulation model diagram.](image)

By setting the input signal of the corresponding valve of the three cylinder circuits to control the opening and closing of the corresponding valve, the hydraulic cylinder can complete the set action at
the set time [11, 12]. The simulation time is set to 32s, the high pressure pump motor is set to 1500r/min, the displacement of high pressure pump is 11.4ml/r, and the low pressure pump motor is set to 1500r/min, the displacement is 93.3ml/min.

Figure 5 shows the pressure characteristic curve of the main hydraulic cylinder inlet. The three-way solenoid valve of the main hydraulic cylinder opens at 2s, and the main hydraulic cylinder inlet starts to feed oil. At the beginning, the pressure at the inlet end is small, and the piston rod of the cylinder is going down quickly to approach the workpiece, which is in accordance with the theoretical design. After the piston rod touches the workpiece, the pressure at the inlet end rises rapidly to the required pressure for the press. 7-17s the pressure remains constant, and is in the pressure-holding stage, which lasts for 10s. 17-21s the two-position two-way valve is turned on, and the system relieves pressure through the sequence valve, and the pressure drops rapidly.

**Figure 5.** Pressure diagram at the inlet of the main hydraulic cylinder.

**Figure 6.** Flow chart of main hydraulic cylinder inlet port.

Figure 6 is the main hydraulic cylinder inlet flow characteristics curve, from the figure can be seen, 2-5.24s inlet flow is larger, in 5.24s-7s flow becomes very small, this is due to the rapid downward movement at the beginning, the system pressure is low, double pumps together to the system supply, in 5.24 system pressure rises, by the high pressure small flow pump alone to the system supply, until 7s when the pressure rises to the rated pressure 63MPa,7-17s system pressure, the flow rate is zero, 17-18.92 piston rod returned. The flow characteristic curve is in accordance with the theoretical design.

Three hydraulic cylinder piston rod action speed characteristics curve as shown in Figure 7, from the figure can be seen in each cylinder piston rod speed size, the main hydraulic cylinder action speed and design is basically the same. In addition, the speed of the other two cylinders can be adjusted by throttling speed control valve.

**Figure 7.** Piston rod displacement diagram of hydraulic cylinder.

**Figure 8.** Piston rod speed diagram of hydraulic cylinder.
As shown in Figure 8, the feeding cylinder starts to move at 0-2s, sending the lower mold part to the bottom of the main hydraulic cylinder, after that the main hydraulic cylinder starts to move, at first the main hydraulic cylinder is supplied by the double pump to move down quickly to contact the workpiece, when the pressure at the inlet end rises, the main hydraulic cylinder continues to supply oil to make the pressure at the inlet end rise to the pressure required for holding pressure, after the holding pressure is completed the main hydraulic cylinder returns quickly, the feeding cylinder pulls the lower mold part back, and the ejector cylinder After the pressure-holding is completed, the main hydraulic cylinder returns quickly, the feeding cylinder pulls back the lower mold part, and the ejector cylinder takes out the sample after the pressure-holding is completed.

5. Conclusions and prospects
This paper designs a tablet press for sample production by XRF spectroscopy. The difference from traditional tablet presses is that the tablet press designed in this paper uses an ultra-high pressure hydraulic system. The analysis concludes:

(1) When the ultra-high pressure tablet press can reach the working pressure, the ultra-high pressure hydraulic system is adopted to greatly reduce the size of the working hydraulic cylinder, and the whole mechanism has the advantages of small volume, compact structure, and easy handling;

(2) This paper analyzes the work requirements of the ultra-high pressure hydraulic system of the tablet press through theoretical calculations, designs the corresponding hydraulic circuit, and selects appropriate hydraulic parts;

(3) This paper uses the AMESim simulation platform to establish a hydraulic circuit simulation model, adopts the empirical method and system parameter design theory, sets the simulation parameters, and completes the hydraulic circuit characteristic analysis. The simulation results are roughly in line with the theoretical design analysis.

The ultra-high pressure tablet press designed in this paper still has problems and shortcomings, and further research is needed.

(1) The design simulation of the hydraulic system in this paper is limited to my current academic level, and there is still a lot of room for optimization. In addition, the mechanical structure needs further analysis and improvement;

(2) This paper only conducts design analysis in theory, the ultra-high pressure hydraulic system is sealed in practical application, and the selection and arrangement of pipelines need further study.

References
[1] Liu Shanghua, Tao Guangyi and Ji Ang 1998 Powder compacting method for sample preparation in X-ray fluorescence spectroscopy[J]. Spectroscopy Laboratory (06) pp 10-16
[2] Bertin E P 1975 Principles and Practice of X-Ray Spectrometric Analysis. second Edition, Plenum, N. Y. pp 397-429
[3] R Teshion, F Klett, Gao Xinhua, et al. 1982 Beijing: General Research Institute of Iron and Steel, Ministry of Metallurgy, pp 280-302
[4] Li Wanzhou, Cui Chenxing, Beng Shaoshi, Li Wenjie and Huang Luming 2018 Hydraulic system control method of ultra-high pressure hydraulic press[J]. Forging Technology 43(12) 79-85
[5] Li Yang, Yu Ancai, Li Tian Tao, Liang Haoqian, Wang Jianren and Wang Chaoguang 2019 Design of ultra-high pressure hydraulic system[J]. Hydropneumatics and Sealing 39(07) 12-14
[6] Deng Xishu and Li Ziguang 2003 Current development status and trend of hydraulic system simulation technology[J]. Machine Tool and Hydraulics (01) pp 20-22
[7] Xu Ming and Kang Fenglin 2005 Pressure-holding circuit of hydraulic system and its control[J]. Journal of Anyang Institute of Technology (01) 25-27
[8] Lu Yongxiang 2002 Manual of Hydraulic and Pneumatic Technology Beijing: Mechanical Industry Press, pp 542-585
[9] Qiang Li, Xiaofeng Chen and Rong Shang 2015 Application of piping resistance in hydraulic circuits[J]. Hydraulic Pneumatics and Seals (3) pp 40-42
[10] Zhang Xianyu, Chen Xiaohu, He Qingfei and Wan Junsheng 2012 Modeling and simulation study of hydraulic system based on AMESim hydraulic component design library[J]. *Machine Tools and Hydraulics* **40**(13) pp 172-174

[11] Li G and Hu H C H 2012 Study on real-time simulation of AMESim hydraulic system model[J]. *Computer CD-ROM Software and Applications* **(23)** pp 70-71

[12] Sun Chengtong, Chen Guohua and Jiang Xuehua 2008 Hydraulic system simulation technology and simulation software research[J]. *Machine Tools and Hydraulics* pp 140-1