The Design and Key Technology Research of the Hydraulic System of Large-Scale Accumulator Blow Molding Machine

Wei-min LI[1, a], Meng-de ZHOU[1,b] Yang XU[1,c] Bao-rong BAI[2,c]

[1]Faculty of Mechanical Engineering and Automation, Liaoning University of Technology, Jinzhou 121001, China

[2]Overhaul Center, Lingyuan Iron & Steel Co., LTD., Chaoyang, 122500, China

[a]Liwmqh@163.com, [b]Mengde.521@163.com, [c]Xuyangon@163.com

Keywords: Large-scale blow molding machine, Hydraulic system, Energy saving, Double proportion, Accumulator

Abstract. Through the analysis of molding process of large-scale plastic hollow containers, this paper carries on the simulation and optimization of hydraulic system, which focuses on the high energy consumption problem of large-scale blow molding machine. According to the characteristics of long work period and great fluctuation of flow demand, the paper designs the oil supplying system that can match the actuators' hydraulic energy demand, introduces the working process of each component in the system, and analyzes the key technology of hydraulic system as well. The design and research avoids the shortcomings such as more components, complex debugging, discontinuous control and unstable operation, substantially reduces the installed capacity of variable pump and driving motor, and in the meantime, solves the impact problem of actuators effectively, which can make hydraulic system high efficiency, energy saving and run steadily.

Introduction

Compared with small plastic packaging containers, large-scale plastic packaging containers have the characteristics of convenient conveyance, low storage and transportation costs, convenient filling and discharging, low residual liquid and so on. Thus, some developed countries start using large-scale plastic hollow containers in such industries as chemical, transportation and auto. There have been a lot of large-scale plastic hollow containers which are heat-resistant, corrosion resistant and high-strength applying to store various hazardous and non-hazardous chemicals, oils and other liquids, and they are replacing the metal containers day by day. Therefore, large-scale plastic packaging containers will become an important direction of the development of plastic packaging containers in the future, which will drive the development of large-scale molding machine [1]. However, because of the late appearing, the domestic large-scale blow molding machine industry is of less kinds, poor adaptability, poor reliability and high energy consumption. Due to the constantly appearing of world energy crisis, the high energy consumption of blow molding machine has become an urgent problem. Compared with small- and medium-sized blow molding machine, the Large-scale one has a certain difference in structure, dynamic system and control system, as well as in energy-saving technology. Large amount of extrusion and long cooling time are the main characteristics, and developing energy-saving technology in such aspects as plasticizing mechanism, molds clamping device and power drive system is the key to energy saving of large-scale blow molding machine. This paper will research on the key technology such as high efficiency, energy saving and running steadily of the hydraulic driving system of large-scale blow molding machine.

Molding Process Analysis of Large-Scale Plastic Hollow Containers

Traditional plastic blow molding methods are mainly refer to extrusion blow molding, injection blow molding and stretch blow molding [2]. Extrusion blow molding is the most common method that has the advantage of low cost, high flexibility, low residual stress and high impact toughness, and

Published by Atlantis Press, Paris, France.

it is applicable to mold industrial large-scale plastic hollow containers. The fundamental process is shown in Fig.1.

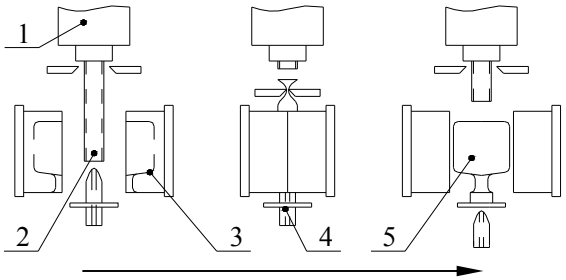

Fig.1 The fundamental process of extrusion blow molding
1-Parison head, 2-Parison, 3-Mold, 4-Intake rod, 5-Product

The extruding method includes accumulator type and continuous extrusion. In order to extrude enough plastic melt in just a short time, generally, accumulator head is used to mold parison in extrusion blow molding of large-scale plastic hollow containers. Therefore, large-scale blow molding machine generally include plasticizing mechanism, accumulator head, mold clamping device, blowing system, product removing device, power drive system and parison wall thickness control system, etc. The main process is shown in Fig.2.

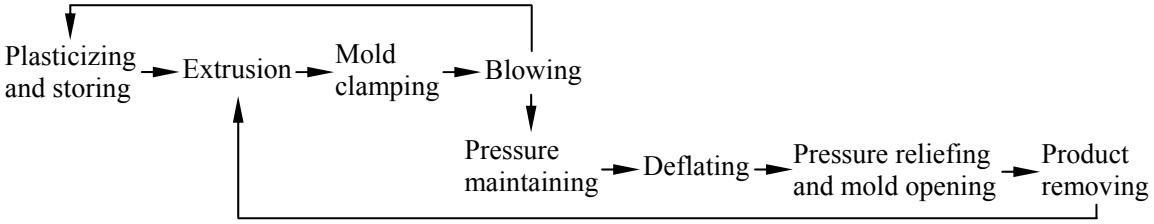

Fig.2 The main molding process

The granular or powder plastic which is plasticized into molten state by extruder enters into accumulator head. When the storage of accumulator head reaches the setting value and extrusion instruction is sent, plastic melt in accumulator head is extruded by extrusion hydraulic cylinder at a constantly rate and the parison is created. The parison wall thickness is determined by the opening degree of die outlet which is controlled by parison wall thickness control system according to the parison wall thickness curve. Blowing after mold is clamped, the parison is shaped in hollow container by mold. Deflating after cooling and pressure maintaining, reliefing pressure, opening mold, and the product is removed by robot.

Design and Key Technology Research of Hydraulic System

The extrusion blow molding process of large-scale blow molding machine is a multi-actuator periodic system which works in a given order according to different performance requirements. The movements are specially complicated and strict, and this system requires a level of dynamic response characteristics [3]. Therefore, hydraulic system is used as power drive system of large-scale blow molding machine. Traditional hydraulic system uses constant delivery pump and multilevel relief valves to supply oil, and it will produce energy loss concerning with flow during working process. Especially, with the long period of work, the energy loss of large-scale blow molding machine is even more serious. Thus, it is essential to seek for an oil supplying system perfectly matching with the hydraulic energy in order to reduce energy consumption.

At present, the practical energy-saving oil supplying systems that are under study and gradually applied in plastics industry are as follows:

- Duplex pump+ accumulator auxiliary power drive system
- Variable pump+ double proportional hydraulic system
- AC servo motor power drive system [4]

● Variable frequency hydraulic power drive system

The flow demand of each step of large-scale accumulator blow molding machine is of great difference, and the component that is driven by each actuator is heavy. Thus, the oil supplying system of this heavy duty system whose velocity changes frequently must be characterized by flow flexibility. Finally this paper decides to use Variable pump＋double proportion＋accumulator auxiliary power drive system as the design plan of oil supplying system.

Combined with blow molding process to analyze working condition, and to give an adequate consideration in loads and action requirement of each actuator, the main parameters are determined. According to standard requirements, the hydraulic circuits are designed, and the schematic of hydraulic system is mapped out shown in Fig.3.

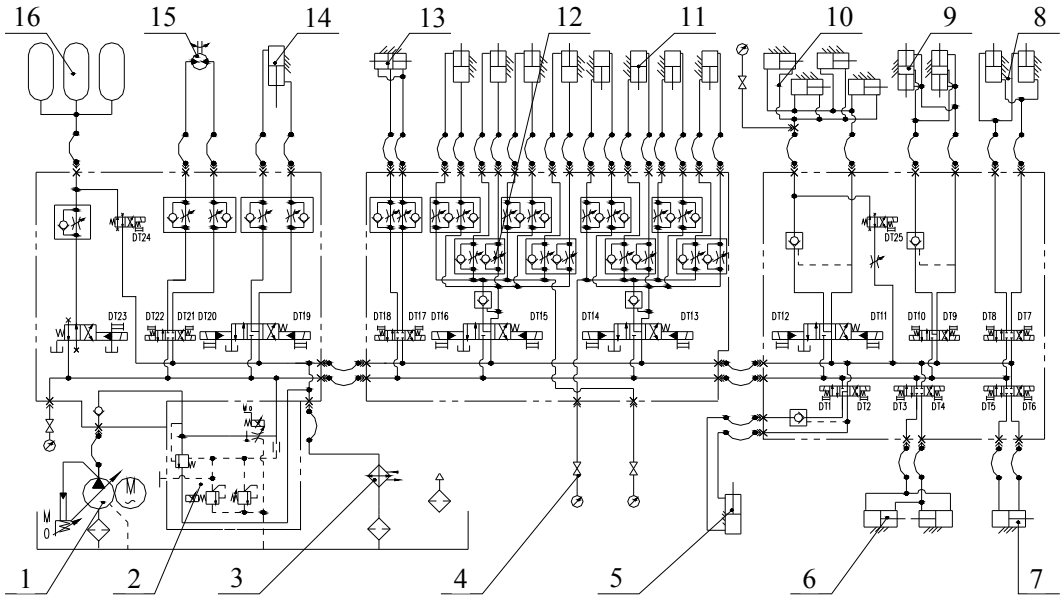

Fig.3 The schematic of hydraulic system

1-Variable pump, 2-proportional electro-hydraulic relief and flow control valves, 3-Heat exchanger 4-Pressure switch, 5-11, 13-15-Hydro-motor, hydraulic cylinder, etc, 12-Directional or flow control valves 16-Accumulators

The hydraulic system consists of extrusion system, mold clamping and pressure maintaining system, assisted molding system and adjustment system. Variable pump supplies oil to each actuator through the double proportional control consisted of flow and pressure proportional control, and multiple accumulators are used as auxiliary power source. The maximum value of system pressure is set by variable pump 1 according to mold clamping force, the maximum value is 16Mpa. The velocity of each actuator can be set by proportional electro-hydraulic relief and flow control valves 2 according to specific working condition, the flow of proportional electro-hydraulic relief and flow control valves can range from 1 to 125 L/min.

The actuator of extrusion system is extrusion hydraulic cylinder. When all actuators are in initial state and the storage in accumulator head reaches the setting value, solenoid DT20 and DT23 are on, hydraulic oil provided by variable pump and accumulators begins to enter into the rodless cavity of extrusion hydraulic cylinder 14 and parison is extruded. The length of parison is measured by electronic feet, when the length reaches the setting value, DT20 and DT23 is off and extrusion process is completed.

The actuator of mold clamping and pressure maintaining system includes mold clamping hydraulic

cylinder10, flashboard hydraulic cylinder 9 and mold moving hydraulic cylinder 13. Mold clamping mechanism is shown in Fig.4.

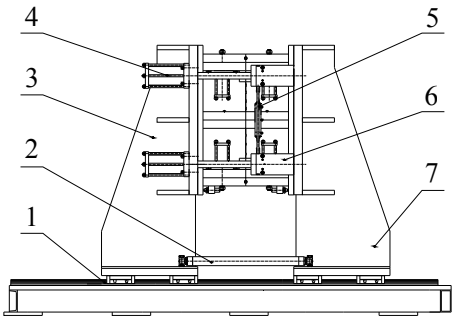

Fig. 4 Bolt type tension rodless mold clamping mechanism
1-Ball straight-line guiding rail, 2-Mold moving hydraulic cylinder, 3-Left mold frame, 4-Mold clamping hydraulic cylinder, 5-Flashboard hydraulic cylinder, 6-Hydraulic lock, 7-Right mold frame

The system turns into mold clamping and pressure maintaining process after expanding action driven by the inserted pin opening/closing hydraulic cylinder 6, solenoid DT17 is on, the smooth and continuous output flow of variable pump controlled by proportional electro-hydraulic relief and flow control valves 2 enters into the rod cavity of mold moving hydraulic cylinder to drive the mold frames as the pre-set velocity curve. After mold smoothly closed, the piston rods of mold clamping hydraulic cylinders 10 on left mold frame have inserted into the hydraulic locks on right frame. Solenoid DT9 is on, and hydraulic oil enters into the rod cavity of flashboard hydraulic cylinder 9. After the piston rods are locked, solenoid DT12 is on, hydraulic oil enters into the rod cavity of the two pairs of mold clamping hydraulic cylinders on left mold frame to strain right mold frame. The pressure in rod cavity of mold clamping hydraulic cylinder 10 rises rapidly, eventually reaching the setting value of pressure switch's high-pressure connection, after a few seconds' delay, solenoid DT12 is turned off, pilot controlled check valve closes, the system enters mold clamping and pressure maintaining state. In unexpected situations, when the pressure in rod cavity of mold clamping hydraulic cylinder bellows the setting value of pressure switch's low-pressure connection, the connection sends a signal to control system and solenoid DT12 is on, hydraulic oil enters into the rod cavity of mold clamping hydraulic cylinder 10 again to ensure the mold clamping force in safe ranges. During pressure maintaining process, solenoid DT12 is on and accumulators are filled. The system turns into unlock and mold opening process after deflating, in order to reduce line shock and mechanical shock, pressure relief process is set before unlocked. At the moment of deflating is finished, the system sends pressure relief signal and solenoid DT25 is on, hydraulic oil in the rod cavity of mold clamping hydraulic cylinder 10 flows out through pilot controlled check valve and restrictor, and the rate of pressure relief can be controlled by restrictor. When pressure is below the setting value, solenoid DT10 is on, hydraulic oil enters into the rodless cavity of flashboard hydraulic cylinder and the hydraulic lock is opened. Then solenoid DT18 is on, the flow controlled by proportional electro-hydraulic relief and flow control valves 2 enters into the rodless cavity of mold moving hydraulic cylinder to achieve a series of actions such as slight mold-opening, slow mold-opening, quick mold-opening, etc. In the process, solenoid DT12 is on and the rods of mold clamping hydraulic cylinders return.

The actuator of assisted molding system includes under blowing device lifting hydraulic cylinder 5, inserted pin opening/closing hydraulic cylinder and mouth pushing hydraulic cylinder 8. This system is mainly used to complete the molding process of container's whorl and seal ring groove, etc. The rotary action of inserted pin is achieved by servo motor, it is easy to determine and adjust the length of whorl. After slight mold-opening, the servo motor starts and inserted pin is unscrew, at the same time solenoid DT8 and DT2 are on and the mouth pushing hydraulic cylinder and under blowing device lifting hydraulic cylinder return back to the origins respectively. When product is removed, a series of actions such as inserted pin screwing, inserted pin closing and under blowing device lifting start to put the system in initial state, and the system is waiting to enter next cycle.

The actuator of assisted molding system includes lifting hydro-motor15 and mold frame moving hydraulic cylinder 7. This system is mainly used during installation and commissioning. Operations staff manually adjusts the height of up-platform through the upper computer according to different

molds, and it is the distance between accumulator head and mold. Before mold handling, solenoid DT5 is on and hydraulic oil enters into the rodless cavity of mold frame moving hydraulic cylinder 7 to drive the left & right mold frames which is connected to under blowing device by synchronous mechanism to the handling position. When mold handling is finished, solenoid DT6 is on and hydraulic oil enters into the rod cavity of mold frame moving hydraulic cylinder 7, mold frames return back to work position.

The key technologies applied in this hydraulic system are mainly as follows:

Energy-saving measures. Variable pump is used in this hydraulic system, variable pump system does not do lost work in theory and the hydraulic energy loss is minimal. It is a kind of energy-saving technology based on dynamic stability and dynamic adjustment of modern control theory, this technology can reduce the energy loss concerning with overflow to the minimum.

In this hydraulic system, multiple accumulators are used to recycle and store energy, serving as auxiliary power source to supply oil together with variable pump. Under the condition of meeting function requirements, to match the parameters of accumulators and variable pump reasonably, the installed capacity of variable pump and driving motor is sharply reduced, thus, system energy is rationally used, heating and temperature rise is decreased, and system efficiency is improved.

Velocity control of actuators. This system is a heavy duty system whose velocity changes frequently. The double proportional control in this hydraulic system makes actuator's velocity change flexibility and continuously, avoids the rigid contact of actuators in motion effectively, and improves the system's stability. It also avoids such shortcomings of traditional hydraulic system as more components, complex system, discontinuous control, unstable operation, high failure rate and difficult diagnosis, in the meanwhile, it shows the performance of energy saving.

Bolt Type Tension Rodless Mold Clamping System. At present, domestic mold clamping system of small- and medium-sized blow molding machine is still adopted in large-scale blow molding machine, mold clamping mechanism still is two-rod or four-rod three-board linkage mechanism. In this system, the phenomena of insufficient mold clamping force, uneven stress on mold board and mold expanding often appear, and the rods limit mold space and robot operational space to some extent. To avoid the insufficiencies, a bolt type tension rodless mold clamping system is designed for this large-scale blow molding machine, the mold clamping mechanism is shown in Fig.4. The motion of frames is guided by ball straight-line guiding rail which works stably and accurately, and frames are driven by mold moving hydraulic cylinder 13. Two pairs of mold clamping hydraulic cylinder finish four-point hydraulic mold clamping. The mold clamping force is adequate and even, and it also has the advantages of large mold holding capacity, mold handling easily, etc.

Control Technology of Parison Wall Thickness. This hydraulic system is a multi-actuator periodic system that has a strict process requirement and complex actions, thus technology of PLC is adopted. There are three operating modes: manually, auto and adjustment. Relevant parameters can be adjusted easily through the upper computer according to different products and the change of process requirement. Parison wall thickness controller needs two displacement pick-ups: one is used to measure the storage in accumulator, called accumulator electronic feet, and the other one is used to measure the opening degree of die outlet, called die outlet electronic feet.

Design of Hydraulic Integrated Block Based on CAD Technology. Hydraulic valves in this system are installed on hydraulic integrated blocks. The hydraulic integrated blocks are designed with the help of developed 3D hydraulic system CAD software, which avoid the tubing connection in the external of sub-plate mount. It is easy to assemble, adjust, replace and maintain. Application of CAD technology reduces probability of hydraulic system leakage to a great extent.

Optimization of hydraulic System Based on Simulation Technology. During the design process of hydraulic system, AMESim simulation technology is used to analyze all the hydraulic circuits and the hydraulic system is optimized according to analysis results. Among them, the relevant displacement and velocity curves of mold clamping hydraulic cylinder's piston rod are obtained through the analysis of mold clamping system. The curves are shown by dotted line in Fig.5 and Fig.6.

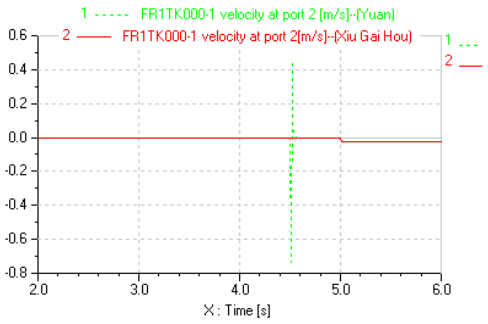

Fig.5 Velocity curve of piston rod

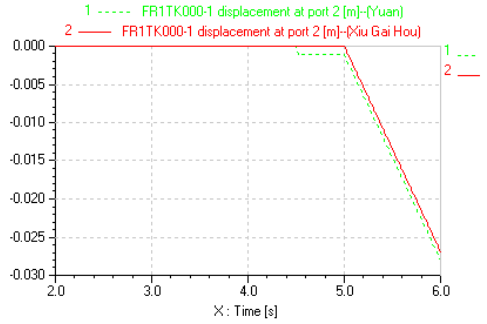

Fig.6 Displacement curve of piston rod

Analyzing causes of piston rod's instability, and a pressure-relief circuit consisted of pilot controlled check valve, two-position Directional control valves and restrictor is set in mold clamping system, shown in Fig.3. After optimization, the analysis results are shown by full line in Fig.5 and Fig.6. The problem of impact generating while opening the mold is solved, and the shock and noise are reduced, which improves the stability and reliability of the entire system.

Conclusions

This paper carries on the simulation and optimization of hydraulic system, through the analysis of molding process of large-scale plastic hollow containers. In the system, a combination of variable pump and proportional electro-hydraulic relief and flow control valves supplies oil to actuators, and multiple accumulators are used as auxiliary power source, which configures the power resource reasonably, substantially reduces the installed capacity of variable pump and driving motor, solves the impact problem of actuators effectively, and achieves the high efficiency, energy saving and steadily running of large-scale blow molding machine.

Acknowledgements

The Authors are grateful for support of science and technology found of Liaoning Province, No. 2011216012.

References

[1] Yibing Wang and Yonghong Shi: Plastics Packaging. Vol. 6 (2007), p. 36
[2] Hanxiong Huang: *Plastic Blow Molding Technology* (Chemical Industry Press (CIP), Beijing 1995)
[3] Jingyi Xing: Machine Tool & Hydraulics. Vol. 9 (2009), p. 121
[4] Yougen Zhang: Packaging Engineering. Vol. 4 (2008), p. 172
[5] Jyh-Cheng Yu, Xiang-Xian Chen, Tsung-Ren Hung, Francis Thibault: Journal of Intelligent Manufacturing. Vol. 5 (2004), p. 625
[6] Y. Béreaux, J.-Y. Charmeau and J. Balcaen: International Journal of Material Forming. Vol. 3 (2010), p. 595