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Optimization for the Hydraulic Clamping System of an Internal Circulation Two-Platen Injection Molding Machine

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***Abstract*—**Internal circulation two-platen clamping system for injection molding machine (IMM) has many potential advantages on energy-saving. In order to estimate its properties, experiments were carried out in this paper. Displacement and pressure of the components were measured. In comparison, the model of hydraulic clamping system was established by using AMESim. The related parameters as well as the energy consumption could be calculated. According to the analysis, the hydraulic system was optimized in order to reduce the energy consumption.

***Keywords*—**AMESim, energy-saving, injection molding machine, internal circulation.

I. Introduction

INJECTION MOLDING MACHINE (IMM) is a main equipment in plastics industry. More than one third of all thermal plastic products are injection molded, and more than half of all polymer-processing equipment is for injection molding [1]. Injection molding is a cyclical process including four significant stages: filling, packing, cooling and ejecting. First, the resin and additives are fed from a hopper to a heating/plastication system of the IMM, then the hot polymer melt at injection temperature is injected into the mold cavity with an injection velocity which refers to the “filling stage”. In next “packing” stage, additional polymer melt is packed under a packing/holding pressure to compensate the expected shrinkage that occurs as the polymer solidifies. In the “cooling” stage, the mold is cold until the part is solidified, followed by the “ejecting” stage in which the mold is opened and the plastic part is ejected. The injection molding process is complicated; engineers must take into account material properties, formulation, molding processes, equipment, and other considerations [2]. Precision, cleanliness, saving and benefit are the main themes of the IMM. Although the weight and repeatability of the plastics are widely accepted, the main factors of influence on IMM’s performance are machine’s design, parts processing and control precision. IMM consists of clamping system, mold system, injection system, hydraulic system and control system [3]. Clamping system is one of the important structures among the components of IMM. It is used to open and close the mold as well as clamp the mold tightly to avoid flash during filling and packing, and furthermore, to eject the product from the mold. The mold-clamping process is directly related to the molding process and is essential to product quality [4].

There are two main types of clamping system in common use: toggle clamping and direct hydraulic clamping [5]. With energy conservation, efficiency, and high speed, the toggle clamping has obvious advantages in the field of standard machines. Compared with the toggle clamping, the direct hydraulic clamping has more excellent performances: 1) uniform force for the template, 2) steady speeds for opening and closing mold, 3) excellent repetition of clamping force. In the early 90s, a new direct hydraulic injection molding machine was invented in Europe, the direct hydraulic two-platen IMM was a representative [6]. The direct hydraulic two-platen clamping system is mainly divided into three types: non-circulation, external circulation, and internal circulation. The internal circulation clamping system has all the advantages of toggle clamping system and direct hydraulic clamping system. The internal circulation clamping system is also excellent in stability and energy saving due to the hydraulic oil is internally circulated.

AMESim is the integrated simulation platform for mechatronic systems modeling and enables multi-domain systems analysis. It was released by French IMAGINE Company in 1995. Users can build complex multi-disciplinary systems on a single platform. Then, simulation and analysis could be performed. The graphical interface let users release from a tedious mathematical model and focus on the physical system itself. This can improve the design efficiency greatly.

In this paper, a patented two-platen clamping system [7] was used as an example model. The internal circulation hydraulic system model was established by using AMESim. The experimental and simulation results were analyzed to determine the performance of the hydraulic clamping system, and then optimization was carried out.

II. Experimental and Modelling

A. Equipment

A two-platen IMM (Type BM200) manufactured by Guangzhou Bloomachine Company (China) was used. The clamping system of the BM200 has a patented technique [7]. Fig. 1 shows the sketch of the clamping system. There is a valve in the piston, during platen moving the piston moves and the hydraulic oil transfers internally from one side of the piston to the other side through the valve in the clamping cylinder.

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During clamping stage, the valve should be closed. Because the piston rod hold a volume in one side of the piston, in order to compensate the volume of the piston rod, the clamping system uses three internal circulation cylinder and one special cylinder. In the special cylinder, the piston has no valve, one side of it contains oil but the other side connected to the air. Therefore, the volume of the internally circulated oil could be kept equal during mold opening and mold closing.

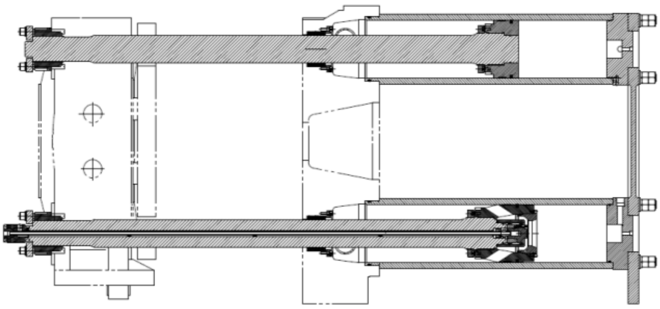

Fig. 1 Sketch of the clamping system

B. Experimental Devices

An oscilloscope (Tektronix TD220S) was used to measure some parameters such as displacement and pressure of the components during the clamping system worked.

C. AMESim Modelling

The model of internal circulation two-platen hydraulic system can be established by using hydraulic library, mechanical library and signal library. The AMESim has standard hydraulic model libraries, but there are lots of different forms of hydraulic components. Therefore, AMESim provides a library of hydraulic components design (HCD) for non-standard components. The internal circulation hydraulic cylinders had to be established by HCD. This model consisted of two cylinder blocks and a 2 position 2 port hydraulic control valve. The two cylinder blocks can realize circulation by using the 2 position 2 port hydraulic control valve, as shown in Fig. 2. The hydraulic system model of the internal circulation two-platen IMM was established, as shown in Fig. 2. The mold-moving system was composed of two hydraulic cylinders which were connected differentially. This connection can improve the speed of the mold-moving cylinders and reduce cycle time. The mold-clamping system was composed of three internal circulation cylinders and a cylinder connected to the air. The pipeline characteristic was set to direct connection. The diameter of the cylinder was set to 190 mm. The diameter of the piston rod was set to 90 mm. The flow rate at maximum opening of the valve was set to 708.82 L/min. The equivalent cross-sectional area at maximum opening of the valve was set to 5153 mm^2.

D. Parameters Setting

Table I shows the parameters of the main elements. The values were all set according to the experimental process. The hydraulic system of IMM was a nonlinear complex system. For the convenience of controller design, the system was simplified as a combination of proportional link, first-order inertia link and delaying link. The mold-moving system adopted position closed-loop control. The mold-clamping system adopted pressure closed-loop control. When the pressure of mold-clamping cylinders reached 100 bar, the booster cylinder began to work. When the pressure reached the set value, the servo motor stopped turning and the system continue to the next procedure.

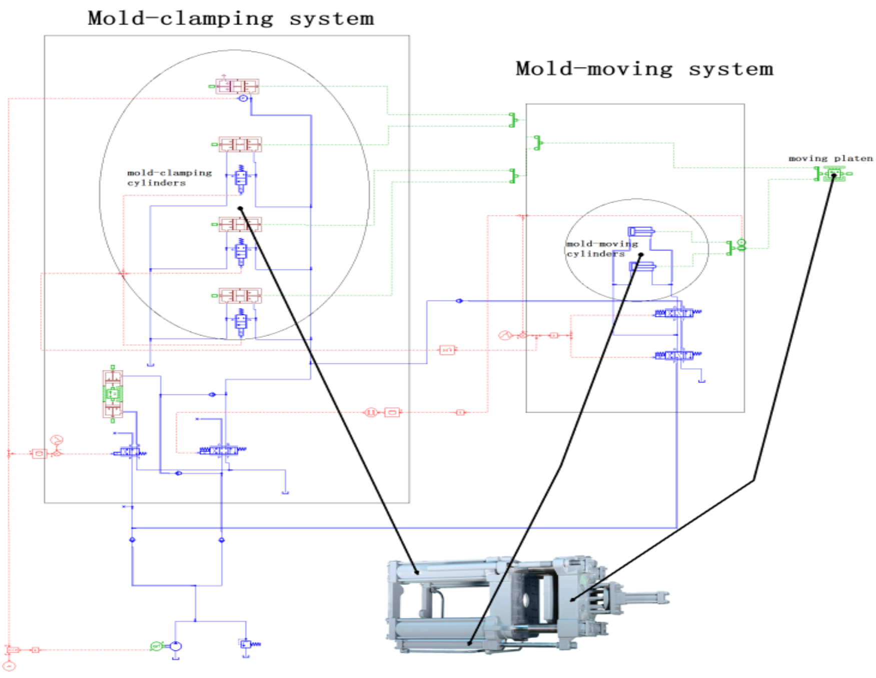

Fig. 2 The AMESim model of the internal circulation two-platen clamping system

TABLE I
PARAMETERS OF THE MAIN ELEMENTS

Parameter			Value
Mold-moving	Cylinders	piston diameter	60 mm
		rod diameter	40 mm
		length of stroke	0.65 m
	Valve	Import and export flow	128 L/min
Mold-clamping	Cylinders	piston diameter	190 mm
		rod diameter	90 mm
		length of stroke	0.65 m
	Valve	Import and export flow	128 L/min
	Booster cylinder	piston diameter	110 mm
		rod diameter	75 mm
		length of stroke	0.182 m
	Internal circulation valve	characteristic flow rate at maximum opening	708.82 L/min
		equivalent cross-sectional area at maximum opening	5153 mm^2
Power system	Pump	pump displacement	64 ml/r
		maximum flow	128 L/min
	Servo motor	rated speed	2000 r/min
		rated power	25 kW
	Decompression valve	pressure relief	160 bar
Control system	Piecewise linear signal source	output at start of stage 1	0 null
		output at end of stage 1	0.334 null
		duration of stage 1	4.26 s
		output at start of stage 2	0.334 null
		output at end of stage 2	0.334 null
		duration of stage 2	11.36 s
		output at start of stage 3	0.334 null
		output at end of stage 3	0 null
		duration of stage 3	1.8 s
Moving platen	Mass with ideal end stops	mass	1000 kg
		higher displacement limit	0.334 m

III. Results and Discussion

A. Comparison Analysis of Simulation and Experimental Results

According to the process of the clamping system, 18 seconds were used as one cycle period including mold opening, mold clamping, and mold closing. The simulation time step is 0.05 s. Fig. 3 shows the displacement variation of the moving platen in one cycle time. The speed of mold opening is faster than that of mold closing. According to the simulation displacement curve of the moving platen, the machine can run steadily. It can be seen that the simulative displacement is in accordance with the actual movement.

Fig. 4 shows the pressure variation of the mold clamping cylinders. The extreme and slope of the curve show the pressure of the mold-clamping cylinders can reach the set value (150 bar). The mold-clamping pressure curve has a step. That is because the clamping pressure is too high, the clamping cylinders have to reduce pressure step by step. This way is helpful to reduce the impact on the hydraulic system and improve the stability of the hydraulic system. It is in accordance with the process setting. The accordance between the simulation curve and the experimental curve also proves the reliability of the software AMESim. Therefore, AMESim could be used in the optimization without experiments which may cost more money and testing time.

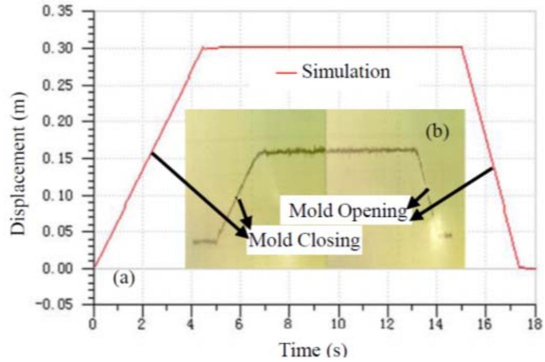

Fig. 3 Displacement variation of the moving platen in one cycle time: (a) Simulation, and (b) Experimental

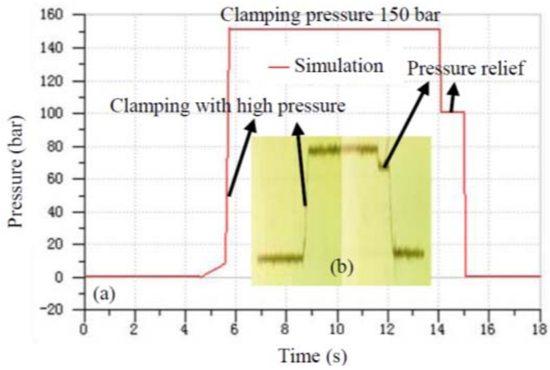

Fig. 4 Pressure variation of the mold clamping cylinders: (a) Simulation and (b) Experimental

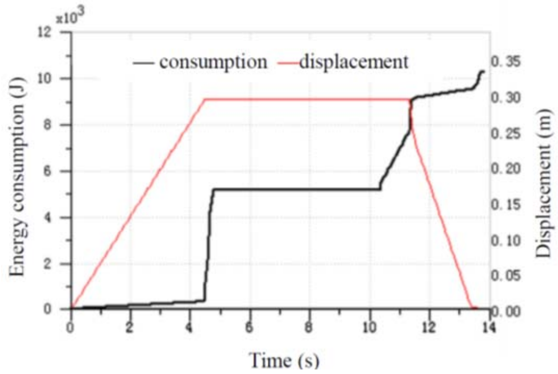

Fig. 5 Variation of the energy consumption and the displacement variation with time

B. Energy Consumption

The energy consumption could be calculated by adding a numerical temperature sensor and a numerical pressure into the model of the clamping system. Fig. 5 shows the variation of the energy consumption and the displacement variation with time. It can be seen that the total energy consumption of this cycle was up to 10264.1 J. From the curve of the energy consumption, we can also see that the energy consumption during mold opening and mold closing is very low, but the energy consumption during clamping and pressure relief is very high. There is a platform line from 4.75 s to 10.3 s. It was the working time of injection system.

C. Optimization

In order to improve the efficiency of the hydraulic circuit, the hydraulic system could be modified. Considering the one-way valve connected with the pressurize cylinder has no enough function, we removed it in the hydraulic system then calculated the energy consumption as well as the displacement of the moving platen. Fig. 6 shows the sketch of the modified hydraulic system. Fig. 7 shows the energy consumption and the displacement via time. As we can see, the energy consumption of the modified system is lower than that of the origin system, especially in the "pressure relief" stage. The total energy consumption reduced to 7522.65 J, 26.7% lower than that of the origin one. The displacement of the moving platen was not changed indicating that the modification is feasible.

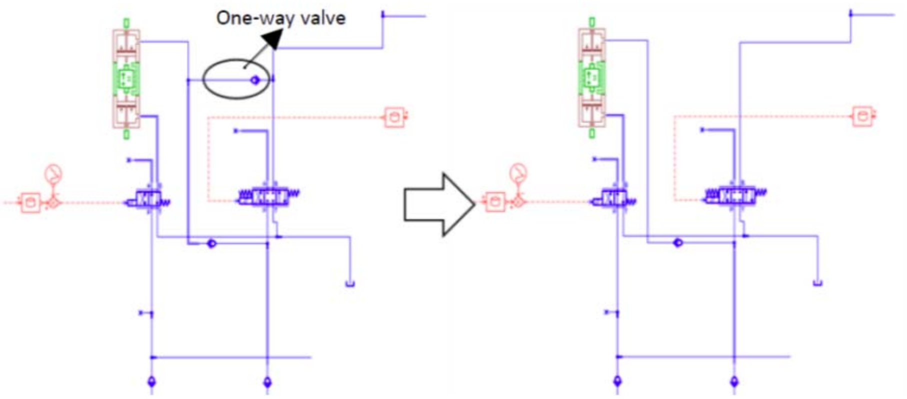

Fig. 6 Modification I of the hydraulic system

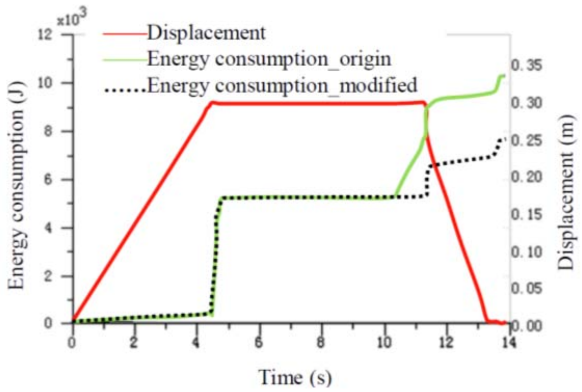

Fig. 7 Energy consumption and the displacement variation with time for Modification I

Hydraulic accumulator can absorb hydraulic impact and pulsating, storage and recycle excess energy; therefore, we used the accumulator into the hydraulic system to improve the energy conservation. Fig. 8 shows the modified sketch of the hydraulic system. Fig. 9 shows the energy consumption and the displacement. It can be seen that the energy conservation is significant. The energy consumption especially in the "clamping" stage is very low. The total energy consumption is 3617.12 J, 26.3% lower than that of the origin one. The excess energy in pressurization process was recycled by the accumulator. Additionally, the accumulator can also reduce the system noise. The displacement of the moving platen was also not changed indicating that the feasibility of the modification using accumulator.

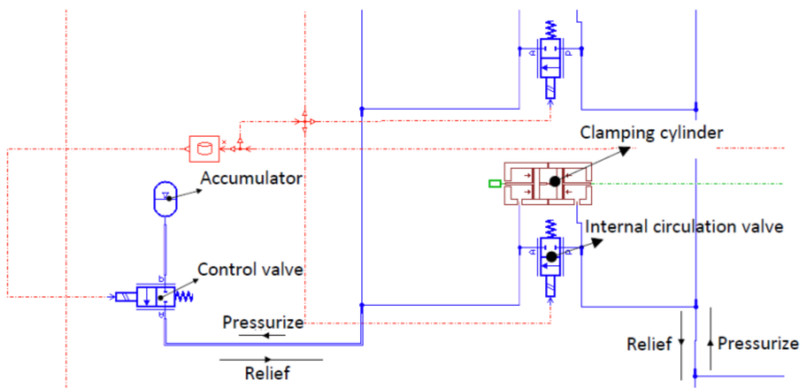

Fig. 8 Modification II of the hydraulic system

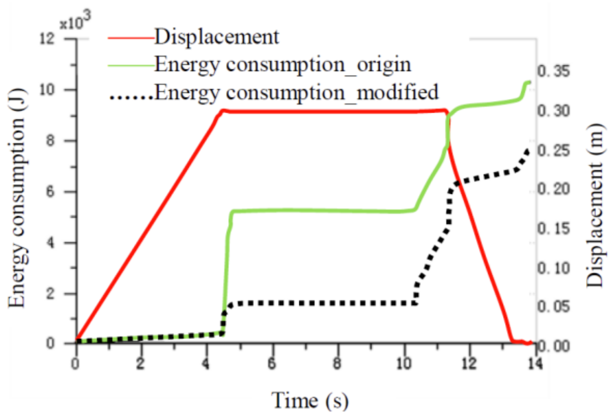

Fig. 9 Energy consumption and the displacement variation with time for Modification II

IV. Conclusion

In order to estimate the properties of the hydraulic clamping system of an internal circulation two-platen IMM, experiments and simulation were carried out. The model of hydraulic clamping system of the internal circulation two-platen IMM was established by using AMESim. The displacement of the moving platen and the pressure variation of the mold clamping cylinders were measured by using an oscilloscope and calculated by AMESim. The simulated results were in accordance with the experimental results, which demonstrated the reliability of AMESim. Then the AMESim was used in the optimization of the hydraulic system. The simulated results indicated the improvement of the two modifications. In Modification I, a useless one-way valve was removed, the total energy consumption reduced to 7522.65 J, 26.7% lower than that of the origin one. In Modification II, a hydraulic accumulator was used into the system, the total energy consumption is 3617.12 J, 26.3% lower than that of the origin one.

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