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Synchronized Injection Molding Machine with Servomotors

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Abstract

Injection Molding Machine (IMM) is one of the most important equipment in plastic industry. As a cyclic process, injection molding can be divided into three steps includes filling process, packing-holding process and cooling process, among which filling process and packing process are both most important phases for the quality of part, and the corresponding crucial process variables are injection velocity and packing pressure in filling and packing phases. Moreover the determining a suitable injection time, screw position and cavity pressure for transfer from injection velocity control to packing pressure control which is commonly called filling to packing switchover point is also critical for high quality part. This study is concerned with two research aspects: double servomotors synchronization control for injection unit, and filling to packing switchover methods. The simulation result of switching method based on injection time and ball screw position those are similar, and the result of switching method based on the cavity pressure that is better.

Keywords: servo motors, synchronization, velocity to pressure switchover, pressure control, injection molding machine.

1. Introduction

Injection molding machine used servo motor to save energy and suit for precise products. Plastic Injection molding an extensive range of modern injection molding machines means that most custom molding requirements can be met. Plastic injection moldings will be manufactured using the most cost effective production methods. The injection process included heating process and injecting the material into the mold [1]. The process produces are very quickly with great accuracy. It is widely accepted that all-electric injection molding machines are the most energy efficient of the three technologies [2]. In [3], there analysis and give some solution about clamping system. Hydraulically driven injection translates the movement offering high force combined with high speed or electric servomotors has created the groundwork for realizing linear electromechanical screw movement with stronger force and more accurate.

In this research, we focus only 2 phases, filling phase and packing phase, each of them has distinct control requirement and how to switchover from one to other. In the filling phase, the position and velocity of the injection screw are controlled ensure the correct melt front velocity. At the beginning of the packing phase, the cavity pressure is controlled at a higher boost pressure to ensure correct part weight. After that, the cavity pressure is controlled at a lower pressure to maintain the part quality and avoid over packing. It ends after the gate freezes off.

2. Methodologies and System Modelling Design

2.1. Methodologies

Control of an injection molding machine consists of many aspects. However, in this research we focus on designing controller for injection unit and techniques in filling phase and packing phase. The required injection force is so large but servo motor is employed that means designing control system for injection unit is extremely important. Even an injection molding machine with perfect injection unit control system but that does not mean the product quality is assured. As discussed previously, to achieve high quality product, the process variable, cavity pressure is controlled. And the most difficult but most important in controlling cavity pressure is how to switchover from filling phase to packing phase.

When the required injection force or pressure is so large but because of energy saving, cost effective, environment pollution and flexi-

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ble, the servo drive is a good choice for the injection unit drive system. However, the servo drive has power limitation, if the capacity of the injection molding machine is huge so one servo motor cannot supply enough power and it costs a lot. That is why double servo motor is employed in the injection unit drive system. How to make them go smoothly with the same motion is one of the research objectives and the other is investigating some methods to switchover between filling phase and packing for our application. The specific objectives of the present work are:

- Design a control system to control two servo motors move with the same motion. Double servo motors drive the injection unit and they are controlled in order to achieve a high stable large injection force or pressure.
- Investigate some methods of switchover filling controlling and packing controller.

2.2. System Modelling Design

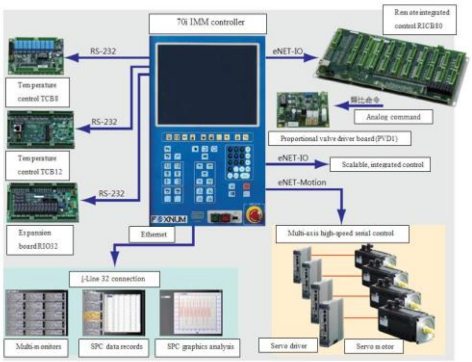

Fig. 1 The schematic of the injection molding control system[4]

The present work uses PC-based control system. The servo drives communicate with the controller via Ethernet. The controller sends command to the servo drives and receives the encoder feedback signals from the servo drives. The cavity pressure is measured by a load cell and it communicates with the controller via RS232. The data are monitored on the screen and can be collected by input output programming. The control algorithms and the human machine interface are written in visual C # 2005, as shown the overall injection molding control system in Fig. 1.

Servo motor system identification and characterization: the first step in the system identification stage is collecting data that are input and output in operating system. Then system identification is done by using the system identification toolbox in Matlab. The transfer functions in z domain are obtained. The systems here consist of servo drive and servo motor, and the velocity controller is integrated in the driver. So, the transfer functions are the velocity closed loops.

System identification verification: verify the system identification result by com- paring simulation and experiment. That means with the same commands one passes by the physical system the others passes by the transfer function, and then compare the outputs.

Control system design: the transfer functions of two servo motors are obtained; control theory is applied to design the control system. More specific, first, design individual motor controller and then design controller for double servomotors control system. All steps are simulated in Matlab and Simulink. After that, the controller algorithms are written in computer programs, the performance of the controllers are tested, and the controller parameters can be tuned and adjusted. With acceptable synchronous error, two servomotors are connected to a timing belt and this system will drive a ball screw.

3. Double Servomotors Control System

3.1. Control System Design

According to the different parameters of system are input, are calculated and converted from control signals to drive motors, then applied to machine. Four servo motors control moving platen slip on main tie bar. Servo motor as drive injection machine, servo motor speed stability and high precision position control, in addition to control effect of allowing high reproducibility can also fine-tune the speed control and position control.

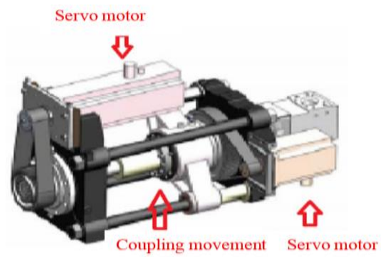

Fig. 2 Structure of motors block control in injection machine

The purpose of motion control system is used to calculate the random variable consists of slide motion, velocity. Developing state-space form, the governing equations can be written by using the rotational speed and electric current are the state variables.

$$\frac{d}{dt}\begin{bmatrix}\omega_m \\ i\end{bmatrix} = \begin{bmatrix}-\frac{B}{J_m} & \frac{K}{I_m} \\ -\frac{K}{L} & -\frac{R}{L}\end{bmatrix}\begin{bmatrix}\omega_m \\ i\end{bmatrix} + \begin{bmatrix}0 \\ \frac{1}{L}\end{bmatrix}u \quad (1)$$

$$y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\omega_m \\ i\end{bmatrix} \quad (2)$$

Where L is the winding inductance, R is the winding resistance, B is damping coefficient, i is the current, u is the armature voltage, K is the torque gain, ω_m is the rotational velocity, J is the armature (rotating part of motor) moment of inertia.

Some experiences have done, we find the transfer function of two servo motors with 2000rpm, and position outputs are measured. The transfer functions from velocity command to velocity output of two AC servo motors can be expressed in Laplace variable s.

$$G_1 = \frac{14.62s + 0.06412}{s^2 + 0.02812s + 0.243} \quad (3)$$

$$G_2 = \frac{14.23s + 1.708}{s^2 + 0.6198s + 0.4279} \quad (4)$$

The cross coupled control system minimizes synchronous errors in multi-axis motion control system [5]. It is common used in CNC motion control system. Technology of cross couple control is developed for multi axis [6]. The parallel technique control in multi parallel system was proposed [7]. The technique used feedback signal as positional signal and velocity signal to modify the command signal. This control has simple structure, and easy to implement. However, some possible effects can decrease the performance of this control method, for example, unmatched sinusoidal disturbances; reduction degrades the stability, unmatched model. Utilize the advantages of the control methods above, combination between them was made. The new synchronous controller is mentioned in [8]. This controller can overcome the difficulty of the master slave control method and utilize the advantages of the synchronous controller and the relative dynamic stiffness motion control.

We have realized that cross-coupled control is used to increase the coupling relationship between axes. It also makes the capacity of disturbance better, decrease the error model. However, the measuring performance cannot improve in each axis.

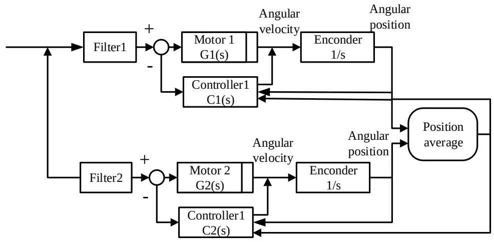

Fig. 3 Block diagram of cross-coupling controller of two motor

The errors of coupling axis are determined by the difference between the angular position and the average angular position. To tracking the same trajectory input, where appropriate filter s. In this case the control laws adopted for all system

4. Pressure Control and Velocity to Pressure Switch Control

4.1. Velocity to Pressure

After two servomotors are synchronized, we connect them to a ball screw by a timing belt in Fig. 4 [9].

Assume that, the gear ratio is unity, the pitch radius of the ball screw is equal to the shaft radius of the motor, and the thread lead of the ball screw is 5mm. So now, the motion command of the ball screw can be computed from the motion command of the motor. The ball screw position x and the ball screw linear velocity v are expressed by the following equations.

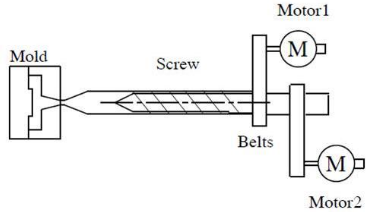

Fig. 4 Schematic of the injection unit drive system[9]

$$x = \theta\frac{h}{360} \quad (mm) \quad (5)$$

$$v = \frac{dx}{dt} \quad (mm/s) \tag{6}$$

In which, θ is the motor position in degree, and h is the thread lead of the ball screw in mm. When ball screw move, the cavity pressure will be changed when the mold is closed. Assume we can measure the cavity press by a load cell. But the difficulty is how to call calculate the pressure command. In this study we don't jump into the theoretical way, for example, with a given material, mold, and parameters of the mechanisms we have to calculate the pressure command via mathematics way. But we will use a practical approach. Because the servomotors are stet-upped in the velocity control mode that means the final command to the driver is velocity command, so the pressure command has to be transferred into the velocity command. The relationship between them is found by finding the relationship between the pressure feedback and the velocity feedback.

The velocity of the ball screw is computed from its position by taking a discrete derivative. The procedure to connect pressure to velocity is shown in Fig. 5.

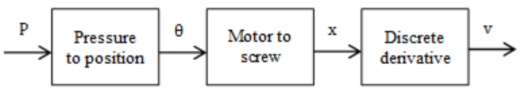

Fig. 5 Conversion of pressure into velocity procedure

4.2. Pressure Control

Cavity pressure measurement is crucial for process parameter. The flow of the plastics is increase in high pressure injection. In low pressure case, the flow of the plastic also reduces. And the cavity pressure during the packing phase is the key variable to ensure the complete filling and the weight of the final product. But we can see the performance of the pressure controller in a whole cycle. A pressure controller is designed to make sure the output cavity pressure follow the command cavity pressure command. The closed loop pressure is show in Fig. 6. The pressure controller is a simple proportional controller and the proportional gain is tuned by try-and-error method.

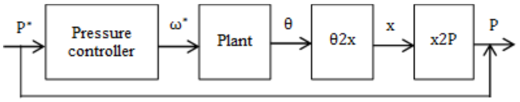

Fig. 6 The closed loop pressure

4.3. Switchover from Velocity to Pressure

Filling to packing switchover is known as velocity to pressure switchover, where velocity refers to injection velocity and pressure to packing pressure. In the filling phase, the velocity of the injection screw is controlled ensure the correct melt front velocity. At the beginning of the packing phase, the cavity pressure is controlled at a higher boost pressure to ensure correct part weight. After that, the cavity pressure is controlled at a lower pressure to maintain the part quality and avoid over packing. It ends after the gate freezes off. The velocity to pressure switchover structure is shown in Fig. 7.

The most important in velocity to pressure switchover is how to locate the switching point. If switchover occurs too late, cause an over-packed cavity, characterized by a pressure peak in the packing phase. The pressure peak will not reduce to the lower holding pressure until the switchover because the high injection pressure is still applied after volumetric filling. Switching over early may generate an under-packed cavity, characterized by a pressure drop in the packing phase.

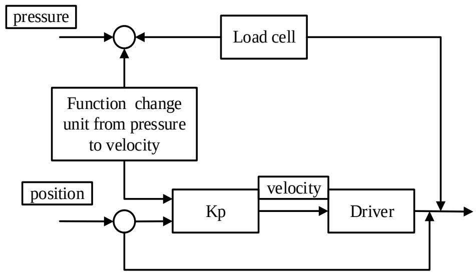

Fig. 7 Flow chart of inject processing machine

As we know that the reference input command is velocity, but output is pressure. Therefor we must find the relation between velocity and pressure.

Following [6], relation between displacement, axial motor input differential pressure and flow rate is founded as

$$Q(t) = \frac{1}{\sqrt{2}}[g_1(y(t))\sqrt{Ps - P(t)} - g_2(y(t))\sqrt{Ps + P(t)}] \tag{7}$$

where Q(t), P(t) are flow rate and differential pressure of motor input, Ps is source pressure, $g_1(y(t))$, $g_2(y(t))$ are conductance of all edges of value calculates by

$$g_1(y(t)) = \begin{cases} \sqrt{2}K_g(y(t)) + B \ if \ y(t) \geq -B \\ 0 \ if \ y(t) < -B \end{cases} \quad (8)$$

$$g_2(y(t)) = \begin{cases} \sqrt{2}K_g(-y(t)) + B \ if \ y(t) \leq B \\ 0 \ if \ y(t) > B \end{cases} \quad (9)$$

5. Simulation and Experiment Results

The present work uses PC-based control system. The servo drives communicate with the controller via Ethernet. The controller sends command to the servo drives and receives the encoder feedback signals from the servo drives. Hardware is use in this study is provided by Foxnum Company. It includes controller, servomotors and servo drivers. Servo driver can connect to controller via a communication card COMM3.

The simulation stage follows the control system design stage. We show the simulation results step-by-step, the error of master and slave motors in Fig. 8. Without synchronous controller, the error will increase. In fact, even we select the same motors, but it will happen. With synchronous controller, the error is compensated. That makes the error reduce so much.

The performance of the closed loop pressure with the proportional gain Kp = 2.0 is show in Fig. 8. At the beginning of the cycle, the output pressure cannot track the pressure command but when time goes on nearly 2seconds, the output can track the command. It is easy to recognize that in the injection phase the system is a non-linear system that is why only a simple proportional controller cannot deal with. However, our purpose is to control the cavity pressure during the packing phase, and at this interval, time is larger than 2 second, the out pressure can follow the pressure command. If the system is non-linear in any phase, especially in packing phase, we must take its properties into account.

Until now, we can just only make sure two motors can tracking the command. How is about the synchronous position error between them? We cannot predict it in the physical system, because when some controllers are employed, they will take action every time to compensate the errors. Even the feedback controller can eliminate the steady sate error, the feed forward controller can reduce the tracking error, but at the transient state, two motor response very differently. Using synchronous controller to decrease the synchronous error of motors

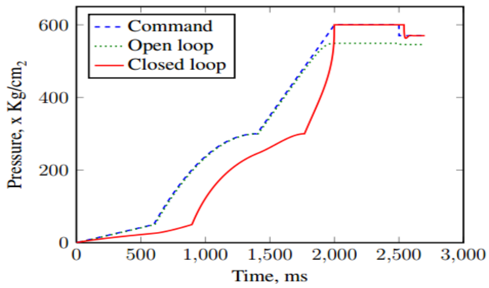

Fig. 8 Performance of the closed loop pressure

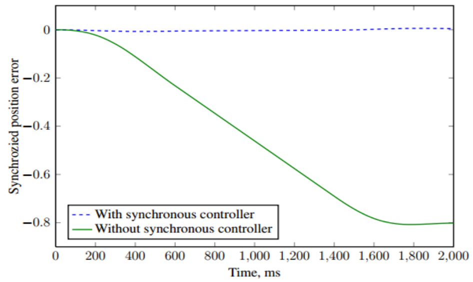

Fig. 9 Synchronous error with synchronous controller and without synchronous controller

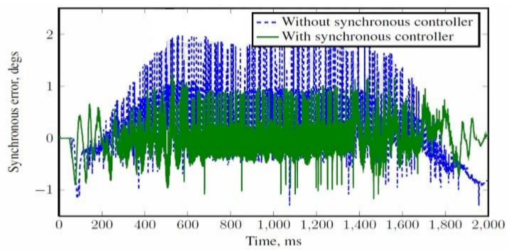

Fig. 10 Synchronous position error, without synchronous controller and with synchronous controller

From Fig. 10 we get the comparison the Maximum absolute of synchronous error between using with synchronous controller and using without synchronous controller.

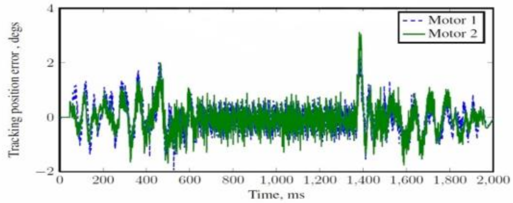

Fig. 11 Tracking position error of motor 1 and motor 2

We may consider now, when the synchronous controller is added into the system, it has effect on the performance of the overall control system or not? So, we have to study about some properties of the overall system. Two important properties of a control system are time response and tracking error. So, we can see time response of motor 1 and motor 2 in Fig. 10 and Fig. 11. The position errors of two motors have a little suddenly values. The overall control is better than using open loop controller.

Table 1 The value of synchronous position error

System	Without synchronous controller	With synchronous controller
Maximum absolute of synchronous error	2.0304^0	1.2300^0

6. Conclusions

This research focuses on two subjects: (1) design and implement control algorithm for double servo motors and their application to the injection unit control system. In particular, the present work utilizes these advanced algorithms on the injection unit that is driven by double servo motors; and (2) investigate some methods to switchover from filling phase to packing phase for our application. The accomplishments in this research involve modelling, control algorithm implementation, simulating, and experimental implementation. Control system can be made more intelligently with artificial intelligence techniques. The advent of low cost very large scale integrated microprocessor and the proficiency of hardware, control algorithms can be implemented in the hardware to get high response and performance.

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