Development of the Six-Axis “S-MAC” for the Small-Size Electric Injection Molding Machine

Yoshinori Kimura Hideki Fukasawa

1. Introduction

With TECHMAN INDUSTRIES Co., Ltd., we have jointly developed the “S-MAC” controller for a small-size injection molding machine. To achieve energy saving and noise reduction, all the control axes of which injection molding machine were changed from hydraulic cylinders to servo motors.

This device has functions such as digital setting of the molding condition and molding conditions storage to achieve ease of operability and high reproducibility. Moreover, equipping these functions has made this device more flexible system that can handle molding for a wide varieties and small lot quantities of product. Our open architecture PC base controller, “S-MAC” was adopted as the control device, and the control software was created with “AML”, which reduced the development time. This document introduces the outline of this controller as currently defined. It is continuously being upgraded as well.

2. Outline of The Solution of This System

So far, electric injection molding machine makers have been making decade-long various efforts and acquiring patents about electrifying of control method of large-size injection molding machine. There have been three control methods as shown in Fig.1, and they were all invented before pc base controllers became common.

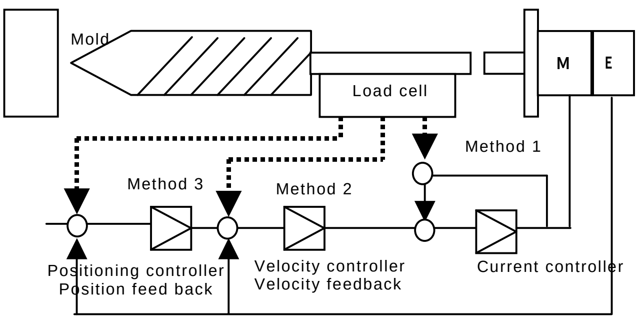

Fig.1 Control Method of Large-Size Injection Molding

2.1 ［Method 1］:Feedback to Current Loop

The feedback value from the load cell directly returns to the drivers. This method originally used as a control method of the hydraulic servo valve, ensuring a process of certain safety.

2.2 ［Method 2］:Feedback to Speed Loop

This is a typical control method of electric injection molding machine, which conducts the velocity control up to a set pressure and switches to the pressure control when set pressure is exceeded. This method has two kinds; returning the feedback signal from the load cell to the driver and also returning it to the controller directly.

2.3 ［Method 3］:Feedback to Position Loop

This is a method that conducts the position control up to set pressure and switches to the pressure control when the set pressure reaches the target position or the set pressure. It is regarded as the control method that will become a mainstream in the future, and this system is also roughly included into this method.

2.4 Method Adopted in This System

The AML program used in this system has resulted in the mixture of method 2 and method 3 after repeated trial and error. The reasoning and the solution method are as follows. For industrial machinery, usually the load torque and the load inertia onto servo motors hardly change. However, for an injection molding machine, the load state changes a lot depending on the temperature of resin, the shape of mold and the injection interval etc. Temperature changes of the resin or difference of the injection intervals cause the change of viscosity of the resin and it changes the flow of the resin. In addition, as for the shape of the mold, there are differences of the flow of the resin between where the mold is thin and where it's fat, and also changes in pressure depending on the part cooled during injection. These changes in load condition, after all, pose problems that the responses of the servo motors become worse because of the lack of sufficient gain, or that the motors oscillate because the gain is too high, during various injection stages. The gain cannot be raised because of such phenomena though it is necessary to raise the servo gain in an actual injection machine to hold pressure to be constant. We created the program paying attention to the following points in order to solve this.

1) Improve the loop speed (the sampling rate) faster.
2) Reduce the time from sampling to the output of the operation result.
3) Change the setting to a proper gain during the injection process.
4) The tasks that affect the operation speed of the control loop, such as an analog input from the load cell and an analog output to a driver, are given the top priorities.

3. Injection Machine

Fig.2 shows the appearance of small-size injection molding machine developed.

Fig.2 Vertical Injection Molding Machine (10 ton)

3.1 Servo Motors Configuration

The machine developed this time is the vertical injection molding machine for 10ton(100kN) with five axes: an injection axis, a screw axis, a mold clamping axis, a nozzle touch axis, and an eject axis. This system equips two servo motors to perform synchronized control, and this improves the clamping force of mold clamping axis. Thus, the system consists of a total of 6 axes.

Operation and driving motor output of each axis are as follows.

1) Mold Clamping Axis

The mold is opened and closed by moving the upper mold up and down, and the mold is closed with constant clamping force at clamping. The pressure is maintained while molding the resin. (4.5kW, 2 axes)

2) Nozzle Touch Axis

Takes charge of connection and disconnection with the mold by moving the injection nozzle up and down. (1kW, 1axis)

3) Eject Axis

Takes charge of moving the eject pin up and down to remove the work from the mold when the mold is open. (0.75kW, 1axis)

4) Screw Axis

Takes charge of rotating the screw to supply resin to the nozzle point when measuring the amount of the resin. (2kW, 1 axis)

5) Injection Axis

Takes charge of moving the injection screw up and down, pouring the constant amount of resin when injecting and pulling up the screw until the amount of the resin reaches a certain measured amount. (5.5kW, 1 axis)

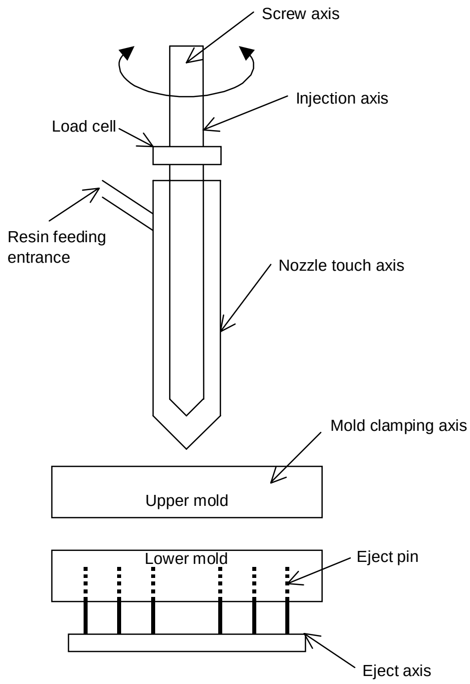

Fig.3 Operation of Axes

3.2 Servo-Controlled Injection Process

The process of the injection is done in the following order. It is a simple sequential operation including the servo-controlled injection nozzle. Fig.4 shows the structure of the injection nozzle.

1) Measure the Amount of Resin

First, send resin to the nozzle point by rotating the screw axis, and then raise the injection axis to hold the resin pressure in the nozzle that rose by feeding resin to be constant. This process ends when the raised injection axis reaches a configured amount of height.

2) Removing the Finished Piece

Raise the nozzle touch axis and detach from the nozzle point from the mold. Next, raise the mold clamping axis and open the mold, then remove and take out the finished piece from the mold by moving the eject axis up and down. Afterwards, conduct the mold clamping and the nozzle connection.

3) Inject Resin in the Mold

Inject a constant amount of resin in the mold with a constant pressure.

4) Holding Pressure for a Constant Time.

Keep the pressure of the injection axis constant to prevent the deformation of the work including shrinkage by cooling.

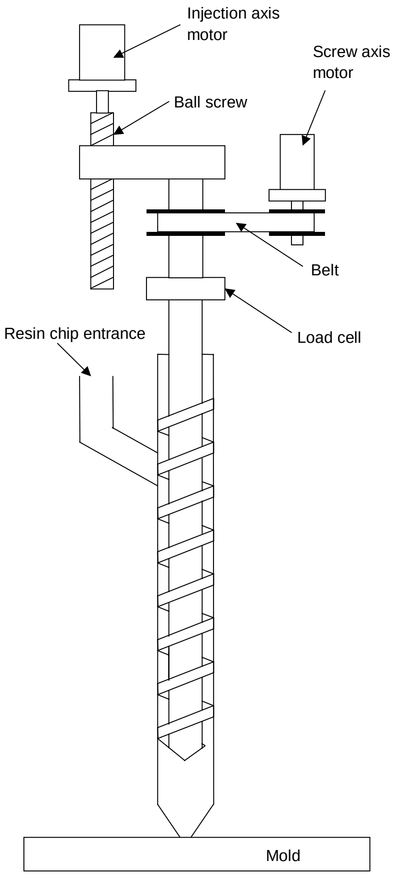

Fig.4 Structure of the Injection Nozzle

3.3 Servo-Controlled Measurement Process

The development of this process was conducted to achieve creating the same motion waveform by using software control as that by the conventional hydraulic control. Fig.5 shows a motion waveform of the measurement process. The measurement process is done by using two axes of the screw axis and the injection axis. First, the screw shaft is rotated with a constant rotation, and resin is fed into the nozzle tip. The resin from the last injection is still in the mold, and the resin pressure in the nozzle rises because the nozzle tip is blocked. Then, the screw axis is pushed up by the pressure, which is detected by a load cell. The injection axis is raised when this pressure exceeds the measurement target pressure and the pressure in the nozzle is lowered. Measurement is done under the constant pressure by repeating this to keep the amount of the resin constant. In an actual control, the injection axis is raised with the speed corresponding to the difference between the load cell pressure and the target pressure. Afterwards, stop both injection axis and the screw axis when the injection axis rose to a certain position and this completes the measurement process.

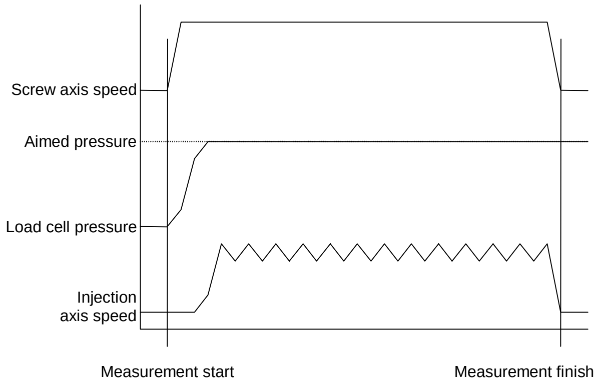

Fig.5 Motion Waveform During Measuring Process

3.4 Servo-Controlled Injection Process/Pressure Keep Process

Fig.6 shows the motion waveform during the injection/pressure processes. The injection process is done by using only the injection axis without using the screw axis. Resin is poured in the mold when the injection axis is lowered but resistance pressure to obstruct the inflow is generated depending on the viscosity of the resin and shape of the mold. However, since the resin has to be injected with a constant pressure to manufacture products with a constant density, the injection target pressure is compared with the pressure from the load cell to lower the injection axis and adjust the speed as necessary. After that, if the injection axis reaches the injection target position, it shifts straight to the holding pressure process. In the holding pressure process, the holding pressure target pressure that is different from injection target pressure is controlled by changing position of the injection axis.

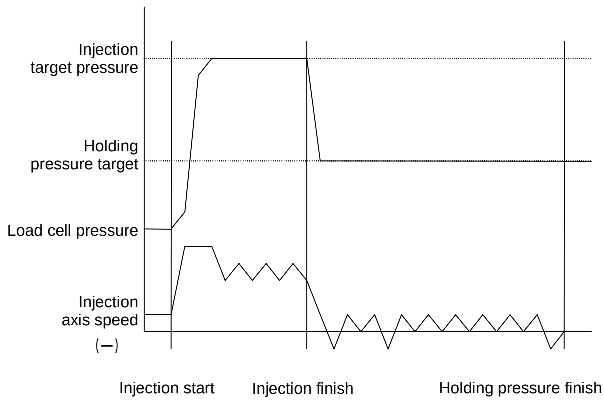

Fig.6 Motion Waveform of During Injection/ Holding Pressure Processes

4. Component of the System

The “S-MAC” system was adopted to control six axes, and the system configuration shown in Fig.7 was created considering the characteristics of the control. The details of “S-MAC” system and “SMS-10” have been published in No.4 and No.6 of our Technical Report' respectively.(1)(2) Generally, the handling of the feedback signal from the load cell becomes a problem in the control of the injection molding machine, especially when trying to replace the hydraulic system with the servo system. In this system, only the injection axis was made as an independent controller since the feedback signal from the load cell is processed by software operation. This is the measure taken to check the control software performance of the injection axis separately from other axes as well as to shorten the evaluation test. At this stage of commercialization, the controller for the exclusive use of the injection axis is planned to be built into the “SMS-10” as one of the main controller axes. The biggest feature of an open architecture controller is to be able to adopt the development method like the above example, which is to advance the development of each software with the distributed system at the same time and integrate them at the stage when the whole software becomes more stable. The control language, “AML” also has the structure that can easily accommodate this method of developing with the distributed control system and integrating later. Details have already been published in the ‘Technical Report' No.7. (2)

This system is the combination of two sub systems shown in Fig.7; the main controller (AML program 1) and the injection axis controller (AML program 2). The functions distributed to each controller to take charge are as follows.

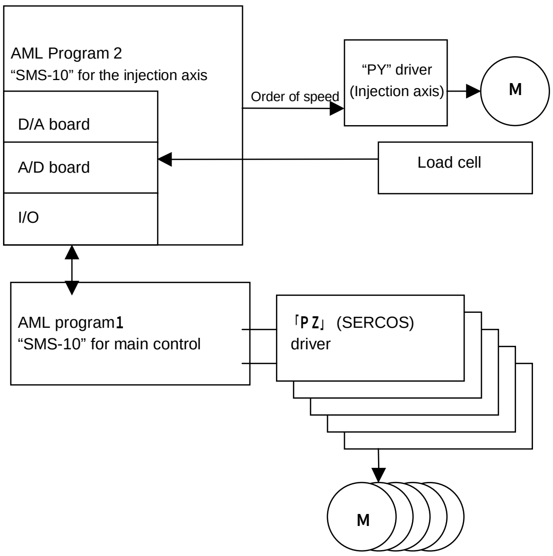

Fig.7 Outline of Control System Configuration

4.1 Main Controller (with AML program 1) Hardware Configuration

The main controller is managing the sequence control of the each process of injection, control of the screw axis, the nozzle touch axis, the mold clamping axis, and the eject axis and also managing HMI panel. Additionally, start and stop operation of the injection axis controllers is operated by using the I/O signal. The controller for the injection axis does the control operation of the injection process, holding pressure process, measurement process and other movements of the injection shaft using start signal sent by the controller.

4.2 Controller for Injection Axis Control (with AML program 2)

This is a controller that conducts the control operation of the injection axis independently and is structured by adding A/D and D/A boards to “SMS-10”.

5. AML Software Configuration

The outline of the software created by “AML” is shown in the block chart by each process. The configuration of the control program at normal stop is shown in Fig.8, and the configuration of the control program at the injection process is shown in Fig.9 and the configuration of the control program at the holding pressure process is shown in Fig.10. In addition, the configuration of the control program of the measurement process is shown in Fig.11. Each process has a separate operation program and the optimal loop gain for the process is calculated.

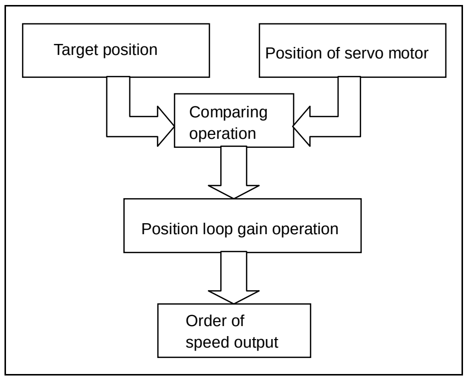

Fig.8 Software Configuration of Normal Stop State

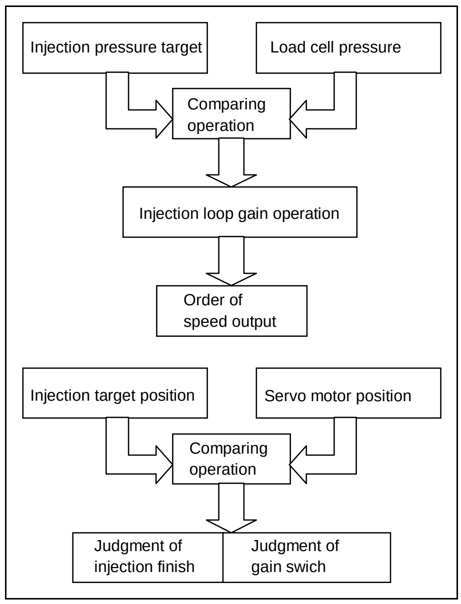

Fig.9 Software Configuration During Injection Process

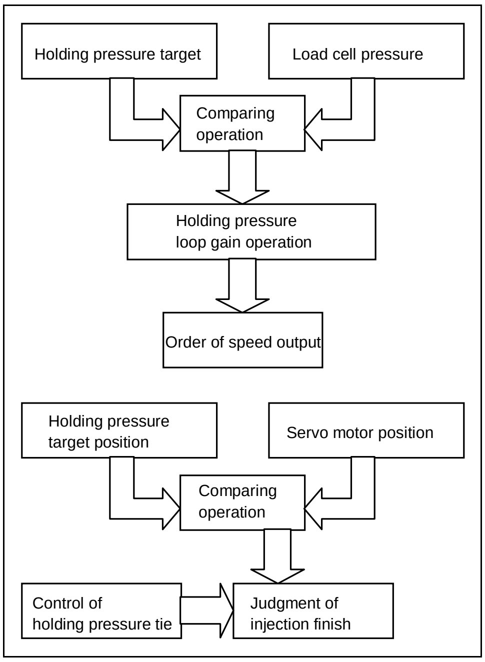

Fig.10 Software Configuration During Holding Pressure Process

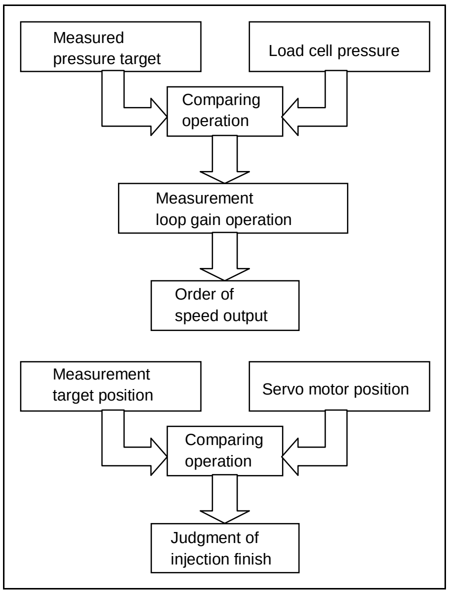

Fig.11 Software Configuration During Measurement Process

6. Conclusion

We had a chance of developing all axes of the small size injection molding machine to electrical, and the real-time control part which had been processed with hardware was replaced with software by using “AML”. The control level of the injection axis does not have any disadvantage when compared to the hardware method. The results are telling us that is a very practicable solution in the small size injection molding machine. In the future, we will use different type of metal mold and molding material, and repeat practical use test for further evaluation. The software control method developed with this system is currently being patented

Lastly, we would like to express special gratitude to Mr. Eiichi Hanzawa and Mr. Hisataka Uji from TECHMAN INDUSTRIES Co., Ltd., who provided great cooperation to this development and evaluation.

Reference

(1) Yoshikawa：Development Concept of Networking Controller “S-MAC”
SANYO DENKI Technical Report No.4 Nov.-1997
(2) Satou and others：Development of Industrial PC “SMAC-PC” and “S-MAC” Components
SANYO DENKI Technical Report No.6 Nov.-1998
(3) Yoshikawa：Development and Characteristics of Advanced Motion Language (AML)
SANYO DENKI Technical Report No.7 May-1999

Yoshinori Kimura

Joined company in 1985
Control Systems Division, 1st Solution Dept.
Worked on development of S-MAC system after experiencing the development of digital controller

Hideki Fukasawa

Joined company in 1991
Control Systems Division, 2nd Solution Dept.
Worked on development of S-MAC system after experiencing the development of power supply monitoring device