The Mold Close and Open Control of Injection Molding Machine Using Fuzzy Algorithm

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Abstract: In this paper, the development of an IMM(Injection Molding Machine) controller is discussed. Presently, the Mold Close and Open Control Method of a toggle-type IMM is open-loop control. Through the development, a PC based control system was built instead of an existing controller and a closed-loop control replaced the previous control method by using PC based PLC. To control the nonlinear system of toggle type clamping unit, a fuzzy PI control algorithm was selected and it was programmed by an IL(Instruction List) and a LD(Ladder Diagram) on a PC based PLC. The application of fuzzy algorithm as the control method was also considered to change a control object like a mold replacement or an additional apparatus. For the development of an IMM controller, PC based PLC of PCI card type, distributed I/O modules with CANopen and Industrial PC and HMI (Human Machine Interface) software were used.

Keywords: PC based PLC, Injection Molding Machine, Mold Close and Open Control, fuzzy

1. INTRODUCTION

As a kind of a controller, a PLC, which integrates various functions like relay, timer and counter, etc with micro controller, has already confirmed its crucial stand over Industry Automation. Because a PLC where its user draws up a algorithm can execute arithmetic operation, logical operation and data control, a PLC extends its application field to the Water Treatment System, Building Automation System etc and due to the universality of open network construction and the technology of connecting opened general-purpose technology to senior system, it also applies to DCS(Digital Control System) and HMI(Human Machine Interface) system field.

An IMM (Injection Molding Machine), which was researched in this paper, was also controlled by PLC. Since injection molding is a processing method of injecting melted plastic pellets to mold by pressure, it can quickly produce many variations of complex shapes. It has researched and developed hydraulic, electronic and hybrid types and due to the improvement of minute processing technique and the advent of new injection molding methods, it seems that injection molding can be used in many other fields and its application is likely to be expanded.

The trend today is that, the control system of PC based PLC is raised in the industrial field. Compared to a PLC, PC based control has a clear advantage of connection to the internet technology and integration with an IT system. In case that a user operates an open fieldbus, if it has the same protocol, we can use a PC based controller irrelevant of the manufacturing company of hardware and we can combine both equipment control and HMI with a PC. Thanks to the functions of a PC, it is easy to network senior, the same level or junior system. In the past, IMM used a PLC as a controller but it has changed to the application of a PC based Control by the increase in use of PC-based control systems in the industrial automation field. The objective of this research is ultimately in the development of a PC based IMM controller and an IMM was controlled by wiring the PLC of a PCI card type and industrial PC to an IMM via the I/O module of CANopen protocol. Presently, the clamping unit of a toggle-type IMM is controlled by an open-loop control method but in this paper, closed-loop control is applied to mold close and open by a feedback **value** of a position sensor, which is mounted on a moving dies and finally in the complementation of the total automatic injection process applied to the fuzzy algorithm in the close and open velocity control. We expect to product lower cost IMM than the process effects maximization which is developed through this research. We expect to be formed the basis of the maximized process efficiency for the PC based automation on the basis of the total process control of IMM and controlled the moving die velocity in using closed loop control and be able to product the lower IMM as improving the control performance by use of a proportional valve which is lower in cost than a servo valve.

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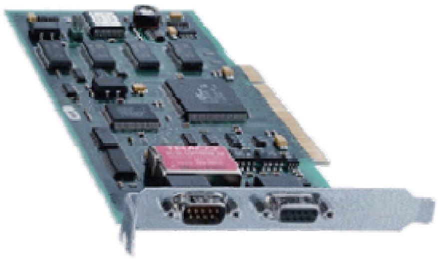
2. The configuration of a system

2.1 PC based Controller

By equipping the BT150 of BOSCH's industrial PC with the PCL (Personal computer Control Logic) of PCI card type PLC, a development is accomplished for PC based Control. The appearance of a BT150 and a PCL are shown in Fig. 1 (a) and (b), respectively.

(a)



(b)

Fig.1 (a) The BT150 of a BOSCH's industrial PC
(b) The PCL of a BOSCH's SoftPLC

To derive fast response time and reliability from its usage, PCL is based on the combination of VxWorks and Windows, which are on a parallel structure. The reliability of PCL depends on the stability of Windows. Because Windows doesn't satisfy real-time, it is associated with VxWorks, a real-time OS and this combination enables PC based controller to guarantee a real-time. Both OS communicate with TCP/IP protocol. Whenever a system needs a real-time, A VxWorks interrupts the operation of Windows. This interrupt guarantees a response time of about 30μs. As soon as the system starts, the data of a present project is transferred from the PC's hard disk to the memory of a PCL. With this method, the important feature of existing PLC, the function of saving data safely and continuously, is guaranteed.With this, system is ensured a safe restart from system error or down. PCL visualize important system and process state to PCs directly with WinPanel, which operates a PCL and reads a file. Other components, which need to exchange data with PCL, are connected with it by TCP/IP protocol. Communication with WinSPS, BOSCH's PLC programming tool, is performed by TCP/IP protocol and WinPanel, which has the function of operation and display related to PCL, is connected with run-time environment through TCP/IP protocol also. TCP/IP based transmission protocol of PCL enables simple networking via PC network and open communication with Windows application enables Microsoft's COM (Component Object Model) and PCL supports standardized OPC (OLE for Process Control) data exchange for separated application interface as well. Because peripheral units are connected with standardized fieldbus, its I/O is distributed and it doesn't need complex wiring. The possible choices of fieldbus standard are PROFIBUS-DP, InterBus-S, CANopen and DeviceNet and in this paper, the CANopen method is used. Each of the distributed modules, K-CAN16DO, K-CAN32DI and so on, is wired and communicated by this method. (Fig. 2)

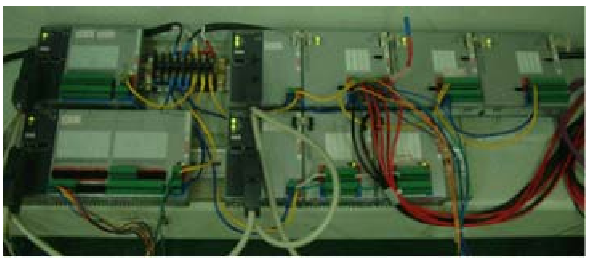


Fig .2 Distributed I/O modules

Each of modules is able to expand and wired to IMM. An IMM is controlled through modules as of electrical signal. The process of PLC programming and commissioning are divided into three steps of ①drawing up I/O configuration using WinCAN, ②the creation of control program using WinSPS, ③commissioning of PCL by the declaration of variables and the operation of WinPanel. Finally, by gearing into WinStudio, BOSCH's HMI software, IMM is controlled and observed. To configure control logic to PCL using WinSPS, PLC programming language, IL (Instruction List), LD (Ladder Diagram), FBD (Function Block Diagram), SFC (Sequence Function Chart) and ST (Structured Text), are used and each language is different in described form but their meanings is the same and cross-communication is possible within a program. Generally, IL and LD are used frequently and in the present development process, they are also used. The module types of WinSPS program are OM (Organization Module), PM (Program Module) and DM (Data Module) and an engineer can declare variables and assign addresses to symbol file. The structure of a call is represented to Fig. 3.

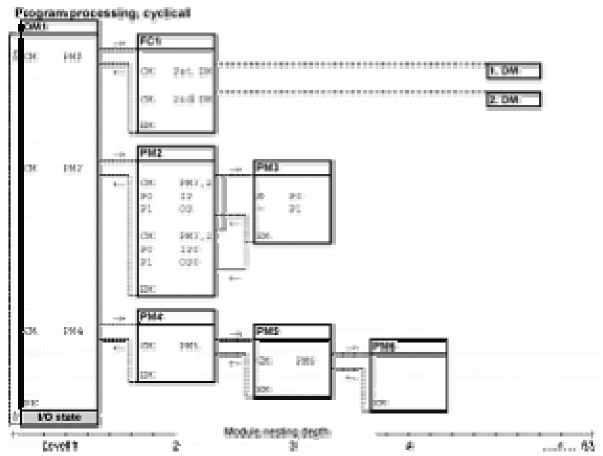


Fig.3 The structure of module call

The OM1 takes charge of calling overall modules by executing cyclic processing and the parallel operation of the OM1 and the OM18~OM25 executes control logic by calling DM and PM, which are stored data. The OM18 is prior to the OM25 and minimum interrupt time is 10ms. In this method, the program, which was drawn up, is uploaded to the PCL and the HMI program in the BT150, which was developed by the WinStudio, controls and observes IMM finally.

2.2 Injection Molding Machine

In this paper, the PRO-MC150 of the DHC (DongShin Hydraulics) is used and it, which has a clamping force of 150 ton, and is of a horizontal, hydraulic and screw type. Its clamping unit is toggle-type.(Fig. 4)

Fig.4 PRO-MC150

As of a hydraulic pump, which is the power source of IMM, variable, piston type hydraulic pumps of the REXROTH were used in this development. The flow rate and pressure of this pump is controlled by the signal of 0V through 10V and as a power transmission apparatus, a three-phase induction motor is used. BOSCH's NG16, proportional valve of a pilot operation, is used in the clamp cylinder for mold close and open process and injection cylinder for injection process and other process is controlled by solenoid valves, a general directional control valve(1-2). The trend today is the mold close and open velocity control of a toggle-type IMM, which has a strong clamping power and is suitable for fast production, controlled by a open-loop control method in accordance with the user's percentage input of flow rate (max 100%). In this paper, by comparing desired velocity with the error and error change of velocity, which was calculated by position sensor data, a feedback control was applied and the development is accomplished by applying fuzzy algorithm to consider system change, which is caused by a mold change or the installation of additional apparatus.

2.3 Fuzzy control algorithm

In this paper, the clamping unit of an IMM is a nonlinear system and as state variables, selectable angular displacement and velocity components are coupled with one another. In the process of linearizing the nonlinear dynamic equation, most state variables are deleted except the second order derivative elements of state variables so we can't find a state equation(3). To control the nonlinear system, fuzzy algorithm, which is more robust than linear controller, was applied and this application was the choice of considering system change like mold change or the installation of additional apparatus in the future(4). The fuzzy controller used the velocity error and error change of the moving dies of the clamping unit as input variables and the block diagram of the controller is represented to Fig. 5. The control rule table of a total of 49 is shown to Table Ⅰ and control rule is represented beneath.

$$R^1 : IF\ \ E\ \ is\ \ NB\ \ and\ \ \Delta E\ \ is\ \ NB,\ THEN\ \ \Delta U\ \ is\ \ NB$$

$$R^2 : IF\ \ E\ \ is\ \ NB\ \ and\ \ \Delta E\ \ is\ \ NM,\ THEN\ \ \Delta U\ \ is\ \ NB$$

$$\vdots$$

$$R^{48} : IF\ \ E\ \ is\ \ PM\ \ and\ \ \Delta E\ \ is\ \ PB,\ THEN\ \ \Delta U\ \ is\ \ PB$$

$$R^{49} : IF\ \ E\ \ is\ \ PB\ \ and\ \ \Delta E\ \ is\ \ PB,\ THEN\ \ \Delta U\ \ is\ \ PB$$

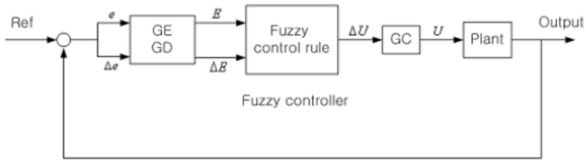
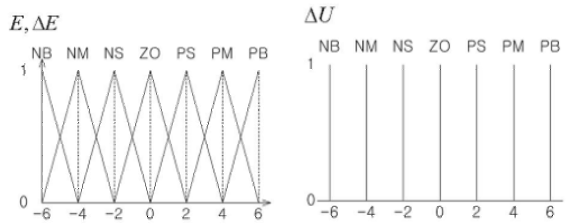


Fig.5 Block diagram of system

Table Ⅰ Rule table

E \ ΔE	PB	PM	PS	ZO	NS	NM	NB
PB	PB	PB	PB	PB	PM	PS	ZO
PM	PB	PB	PB	PM	PS	ZO	NS
PS	PB	PB	PM	PS	ZO	NS	NM
ZO	PB	PM	PS	ZO	NS	NM	NB
NS	PM	PS	ZO	NS	NM	NB	NB
NM	PS	ZO	NS	NM	NB	NB	NB
NB	ZO	NS	NM	NB	NB	NB	NB

Fig. 6 show the membership functions of input variables and output variable. The relation for the inference of each rule and final inference are represented next(5).



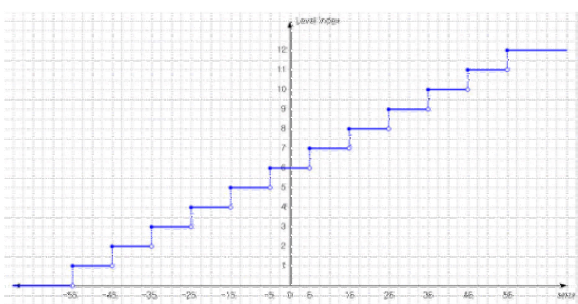
(a) (b)

Fig.6 (a) Membership Function of input variables
(b) Membership Function of output variable

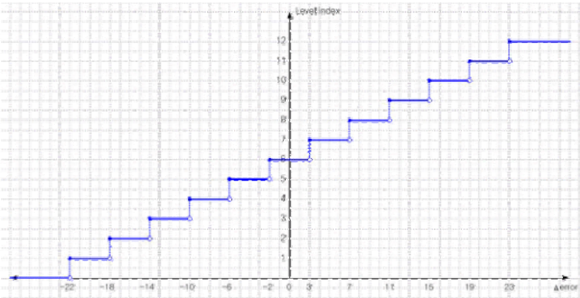
$$\Delta U \wedge (E \wedge \Delta E)$$

$$R^1 \vee R^2 \vee \cdots \vee R^{49}$$

To realize the theory on micro controller, the process of discretization is needs and the discretization of input variables and the result of the quantification of their membership function for error and Δerror are shown in Fig. 7 (a) and (b), Table. Ⅱ and Table. Ⅲ respectively(5). Table. Ⅳ shows the look-up table of these result. Like this, the discrete fuzzy control rule depends on Mamdani's inference and real time control and fast response control is possible and memory is economized(6-7).



(a)



(b)

Fig.7 (a) Discretization of error
(b) Discretization of Δerror

Table Ⅱ Quantization of Membership Function for Error

Level Index	Error Range	Membership Function of Error						
		NB	NM	NS	ZE	PS	PM	PB
0	error < -55	1.0	0.3	0.0	0.0	0.0	0.0	0.0
1	-55 ≤ error < -45	0.7	0.7	0.0	0.0	0.0	0.0	0.0
2	-45 ≤ error < -35	0.3	1.0	0.3	0.0	0.0	0.0	0.0
3	-35 ≤ error < -25	0.0	0.7	0.7	0.0	0.0	0.0	0.0
4	-25 ≤ error < -15	0.0	0.3	1.0	0.3	0.0	0.0	0.0
5	-15 ≤ error < -5	0.0	0.0	0.7	0.7	0.0	0.0	0.0
6	-5 ≤ error < 6	0.0	0.0	0.3	1.0	0.3	0.0	0.0
7	6 ≤ error < 16	0.0	0.0	0.0	0.7	0.7	0.0	0.0
8	16 ≤ error < 26	0.0	0.0	0.0	0.3	1.0	0.3	0.0
9	26 ≤ error < 36	0.0	0.0	0.0	0.0	0.7	0.7	0.0
10	36 ≤ error < 46	0.0	0.0	0.0	0.0	0.3	1.0	0.3
11	46 ≤ error < 56	0.0	0.0	0.0	0.0	0.0	0.7	0.7
12	56 ≤ error	0.0	0.0	0.0	0.0	0.0	0.3	1.0

Table Ⅲ Quantization of Membership Function for ΔError

Level Index	ΔError Range	Membership Function of ΔError						
		NB	NM	NS	ZO	PS	PM	PB
0	Δerror < -22	1.0	0.3	0.0	0.0	0.0	0.0	0.0
1	-22 ≤ Δerror < -18	0.7	0.7	0.0	0.0	0.0	0.0	0.0
2	-18 ≤ Δerror < -14	0.3	1.0	0.3	0.0	0.0	0.0	0.0
3	-14 ≤ Δerror < -10	0.0	0.7	0.7	0.0	0.0	0.0	0.0
4	-10 ≤ Δerror < -6	0.0	0.3	1.0	0.3	0.0	0.0	0.0
5	-6 ≤ Δerror < -2	0.0	0.0	0.7	0.7	0.0	0.0	0.0
6	-2 ≤ Δerror < 3	0.0	0.0	0.3	1.0	0.3	0.0	0.0
7	3 ≤ Δerror < 7	0.0	0.0	0.0	0.7	0.7	0.0	0.0
8	7 ≤ Δerror < 11	0.0	0.0	0.0	0.3	1.0	0.3	0.0
9	11 ≤ Δerror < 15	0.0	0.0	0.0	0.0	0.7	0.7	0.0
10	15 ≤ Δerror < 19	0.0	0.0	0.0	0.0	0.3	1.0	0.3
11	19 ≤ Δerror < 23	0.0	0.0	0.0	0.0	0.0	0.7	0.7
12	23 ≤ Δerror	0.0	0.0	0.0	0.0	0.0	0.3	1.0

Table Ⅳ Look-up table

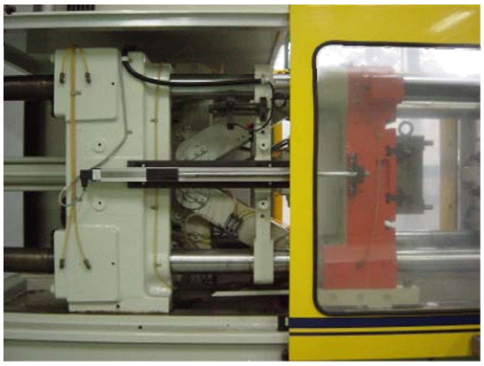
e \ ec	0	1	2	3	4	5	6	7	8	9	10	11	12
0	-54	-52	-54	-52	-47	-45	-39	-36	-27	-24	-13	-4	0
1	-52	-52	-52	-52	-45	-43	-36	-33	-24	-20	-10	0	4
2	-54	-52	-47	-45	-39	-36	-27	-24	-13	-10	0	10	13
3	-52	-52	-45	-43	-36	-33	-24	-20	-10	0	10	20	24
4	-47	-45	-39	-36	-27	-24	-13	-10	0	10	13	24	27
5	-45	-43	-36	-33	-24	-20	-10	0	10	20	24	33	36
6	-39	-36	-27	-24	-13	-10	0	10	13	24	27	36	39
7	-36	-33	-24	-20	-10	0	10	20	24	33	36	43	45
8	-27	-24	-13	-10	0	10	13	24	27	36	39	45	47
9	-24	-20	-10	0	10	20	24	33	36	43	45	52	52
10	-13	-10	0	10	13	24	27	36	39	45	47	52	54
11	-4	0	10	20	24	33	36	43	45	52	52	52	52
12	0	4	13	24	27	36	39	45	47	52	54	52	54

3. Results

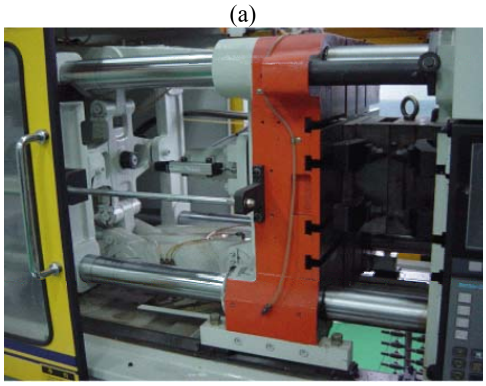
Fig. 8 (a) and (b) show the before and after figure of each repetitive process. Fig. 9 shows the desired velocity profile and the real velocity of the moving die and Table. Ⅴ shows the desired position and velocity of each step. In Fig. 9, the first rising graph is the velocity of mold open process per each step and continuously the second rising graph is the velocity of mold close process per each step. Each step, which is divided into five steps, was set up for position and velocity and the pressure of the last step of the mold close and open process was set up with 30bar and the pressure of the other step was set up with the same 60bar. After the control inputs, there was a response delay until the dies moved and the delay time of mold close and open process was about 0.1sec and 0.14sec, respectively. As a whole process, the response was slower than control input time. These response errors increased in the accelerated section, which is shown in the each step 1 process(8).

Table Ⅴ Desired velocity and position

process \ step	1	2	3	4	5
mold close velocity[mm/s]	940	1088	1190	772	465
mold close position[mm]	280	200	150	50	3
mold close pressure[bar]	60	60	60	60	30
mold open velocity[mm/s]	1100	1142	1419	900	530
mold open position[mm]	50	100	180	240	320
mold open pressure[bar]	30	60	60	60	60



(a)



(b)

Fig.8 (a) Mold close
(b) Mold open

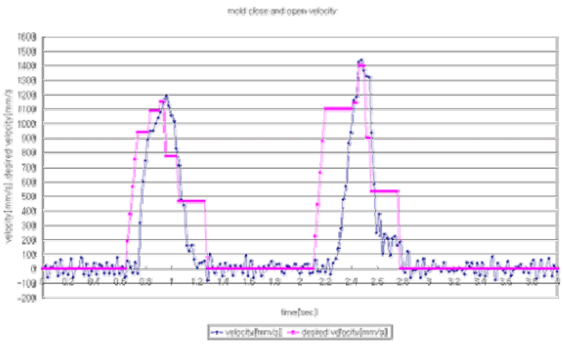


Fig.9 Mold close and open velocity

4. Conclusion

In this paper, to control the velocity of the mold close and open, the controller was configured by using PC based PLC, I/O modules, Industrial PC and HMI(Human Machine Interface) software and velocity is calculated with the data received from position sensor, which is mounted on a clamping unit, compared to the desired velocity of the moving die. From these comparison, feedback control is applied to the velocity control of the mold close and open process of toggle-type IMM and control method is improved from the existing open-loop control to the closed-loop control. As of control algorithm, Fuzzy control is applied and to realize this on PLC with the IL (Instruction List), a PLC programming language, fuzzy PI control is coded using look-up tables. Strictly speaking, the unit process controller, like a PLC as of main controller, only takes part in the whole process control and exclusive controllers like a motion controller, which operates at high speed, are installed in a unit machine and then reduce the burden of a main controller is the best control method by the distributed control under fieldbus but the PCL, a main controller, is only used in this paper. Therefore we can see in the result graph of experiment, that there exists an overshoot and undershoot but the whole trend of a velocity profile is traced and considered hydraulic actuator and nonlinearity of the clamping unit, it is acceptable result. Also, the practical operation of the IMM was reasonable. In this way today, from the growth rates of PC industry, we estimate that fieldbus is faster and the performance of a microcontroller also improved rapidly. We ensured that these factors also improve the control performance of IMM controller, which is developed through this paper.

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