A new approach in Industrial automation application "Embedded system design for Injection Molding Machine".

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Abstract- **This paper reports a successful project that modified old technology i.e. Relay control panel based injection molding machine in to more economical, reliable and efficient micro controller based control system. In this paper we discuss electro-hydraulic controlling systems of injection molding machine by using a simple Micro controller based embedded system that provides an effective and easy way to control the sequence of the hydraulic actuators movement and the states of hydraulic system. The project of a specific controller for Injection Molding Machine application join the study of automation design and the control processing of Hydraulic systems with the electronic design based on micro controllers to implement the resources of the controller.**

The micro controller based embedded system and its associated interfacing peripherals with the machine are described. The software including the control and interactive program is written in basic language for the sequence control of the machine and the closed-loop control of the injection speed process.

Keywords: Embedded system, Basic-X Microcontroller, Analog to digital converter (ADC), Digital to analog converter DAC, Liquid Crystal display (LCD), Injection Molding Machine (IMM), Solenoid valves, Hydraulic system, Close loop system.

I. INTRODUCTION

In the last few years, improvements have been made in the field of injection molding with respect to control system of injection molding machine, which directly affects the quality of the product being molded.

For obtaining a good quality of the plastic molded product several factors such as the injection speed, injection pressure, temperature of molten plastic and injection time are involve in Injection molding process [1]. The work described here has sought to simplify these requirements by controlling the injection pressure and speed during the molding cycle, which makes use of the digital and proportional hydraulics. An injection molding machine with a simple electrical/hydraulic control system has been modified by introducing hydraulic proportional control valves and machine sequence control [2] using a standalone embedded system i.e. micro controller base control system. This embedded system also provides an open-loop control of injection pressure profile and closed-loop control of injection speed. This project has demonstrated the feasibility of upgrading a conventional injection molding machine to an embedded control system i.e. micro controller base controlled one at reasonable cost.
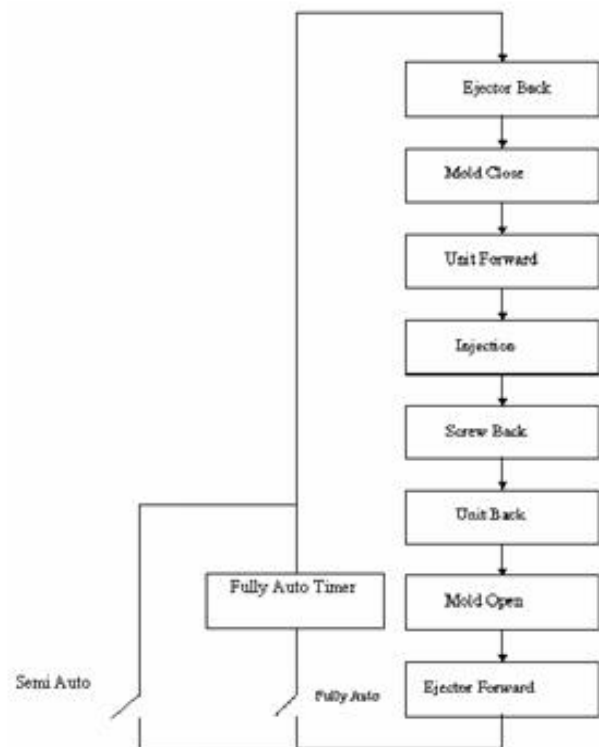

Figure. 1. The Injection Molding Machine working cycle stages.

II. THE INJECTION MOLDING MACHINE

Injection molding machine is the machine used to make plastic accessories. In this project an automatic type in-line screw plastic injection-molding machine was used. An in-line screw is utilized for the molding of high quality product with any thermoplastic material. The machine working cycle stages are shown in Figure 1.
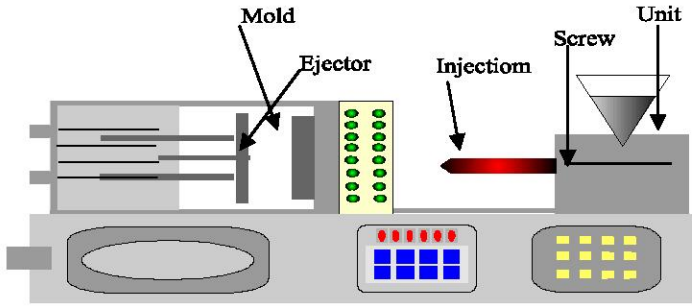
Figure 2: Injection Molding Machine.

The construction of the machine is simplified and shown in Figure 2. Two cylinders are used, one is for the mould clamping and opening, the other is for injection. An A.C. motor drives the plasticizing screw [3]. For the purpose of this project, the original electrical & hydraulic control circuit was abandoned and circuit modifications were introduced. For machine sequence controlling micro-controller based embedded system was used [4]. The mold close/open cylinder is controlled by a 4-way 3 position directional control valve. The position of the screw is sensed by two limit switches. Two proportional control hydraulic valves have been introduced into the hydraulic circuit for the control of the injection cylinder. The injection speed is adjusted by applying a voltage between zero and ten volts to either solenoid of the proportional directional and flow control valve. A proportional pressure relief valve is used to regulate the back pressure of the injection cylinder. The input voltage to the valve is also of range zero to ten volts to drive its solenoid. The displacement of plasticizer screw is measured by a rotary potentiometer. Voltage output from the potentiometer is digitized by the A/D in side the embedded system and the velocity is obtained from the digitized data by a difference algorithm stored in the micro controller. Any deviation from the pre-set velocity is fed to the proportional-plus-integral controller. The controller output is sent to the solenoid of the proportional and flow control valve which regulates the oil flow. The proportional pressure relief valve is closed at this stage. The injection cylinder back pressure measured by the pressure transducer is continuously fed to the micro-controller, the inbuilt A/D convertor digitize this signal and if the digitized pressure exceeds a preset value as required by the mould filling, the velocity control stops and pressure control still exists. During the holding stage, the injection cylinder pressure is varied according to a set pressure by applying the appropriate voltage signal to the pressure relief valve. The oil flow through the direction and flow control valve is maintained constant at that stage. The pressure control stops after a preset holding time, then injection is completed. When injection completes plasticizing and cooling of the molded object is started simultaneously. The screw motor is switched on by the controller. The screw rotates and plasticized material is fed ahead of the screw so that a force tending to retract the injection piston is generated. The proportional directional and flow control valve is then closed. A constant voltage is applied at the pressure relief valve to keep the back pressure constant. After the screw has moved back to the start position, plasticizing stops and when the cooling time has over and done, this stage ends. Finally, the mold is opened.

III. THE CONTROL SYSTEM

The block diagram of this embedded system shown in the Figure 3, which comprised on main control unit i.e. Basic X microcontroller and other peripheral devices. The screw displacement and the cylinder back pressure are measured by a potentiometer through a rack and pinion assembly and a pressure transducer coupled with an amplifier, respectively. The two analog signals are digitized by the 10-bit A/D convertor which is inside the micro controller.
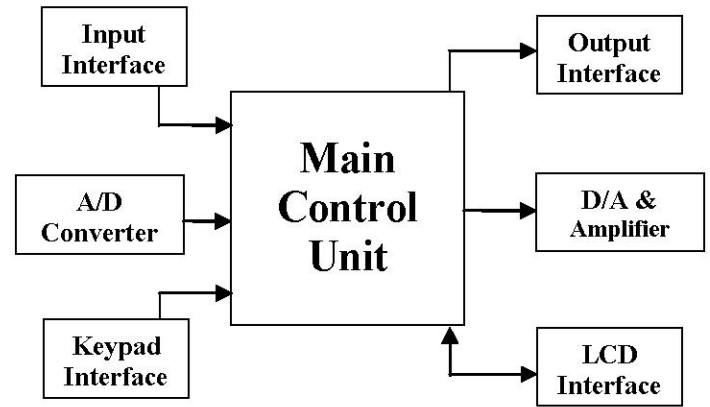

Figure 3: Block Diagram of Micro controller based embedded System.

The micro-controller first computes the screw velocity by the first-order finite difference method and takes the difference between calculated value and desired value on the velocity profile that is stored in the form of velocity/displacement. The resultant control signal is sent to the directional and flow control proportional solenoid valve regulating the oil flow via the D/A convertor. For the open loop pressure control, a set of digital values is output to the solenoid of the pressure relief valve via the D/A convertor and the amplifier at the predetermined time intervals.

A. Input interface:

The signal which comes from limit switches first goes to input interface (shown in figure 4) where it step down to 5V and then it fed to microcontroller.
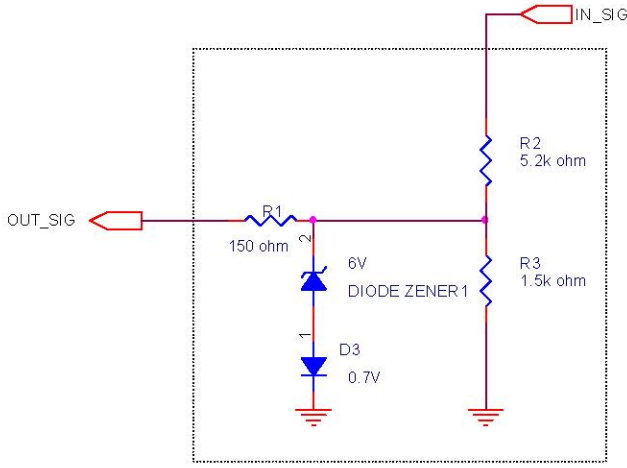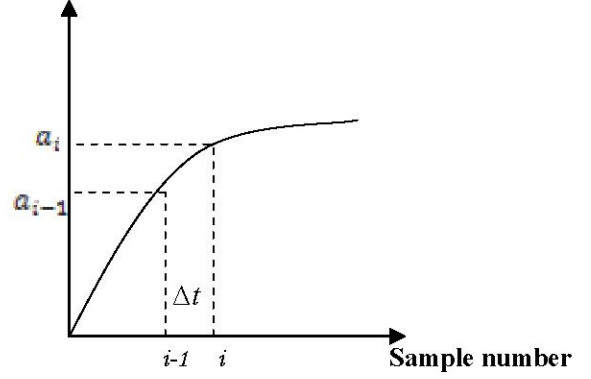
Figure 4: INPUT INTERFACE

Figure 6: Velocity Calculation.

B. Output Interface

The microcontroller generates a command signal which is feed to output interface (shown in figure 5) through opto- isolator. The output interface converts this signal to 24V D.C which is use for operating of solenoid valves of injection molding machine.
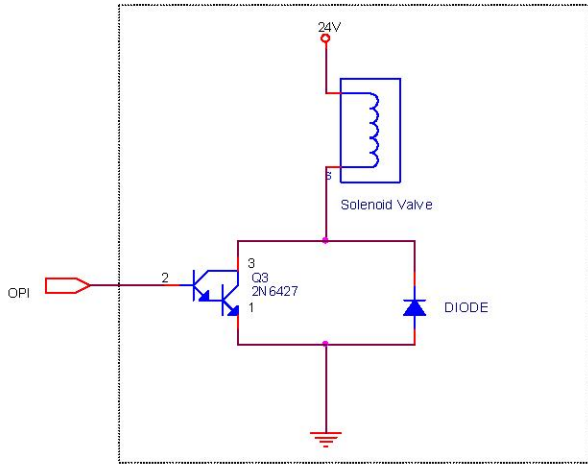

Figure 5: OUTPUT INTERFACE

IV. INJECTION SPEED CONTROLLING ALGORITHM

The screw displacement versus sample number is shown in Figure 6 "a_i" denotes the screw displacement at the ith sample and "Δt" is the sampling period.

Using Newton's Backward Difference formula, velocity at the ith sample is given by
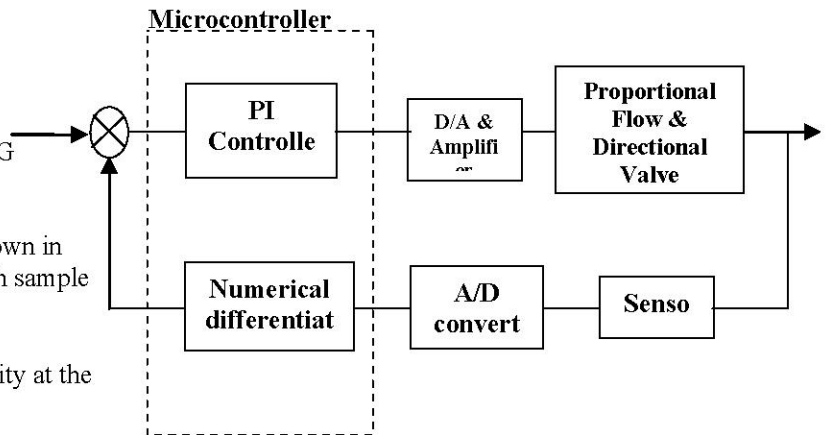
$$V_i = \frac{a_i - a_{i-1}}{\Delta t}$$

Proportional-plus-integral action is applied for the closed-loop control of injection speed (shown in Figure 7), i.e.

$$\frac{C_f}{E_i} = k_p\left(1 + \frac{1}{T_{iS}}\right)$$

Where

C_f is the Laplace transform of control signal to flow valve amplifier

E_i is the Laplace transform of velocity error at the ith sample

K_p is the proportional gain.

T_i is the integral action time.

Figure 7: Block Diagram of close loop control of injection speed.

In time domain, the following difference equation can be obtained:

$$C_f = K_p\left(r_i - v_i\right) + K_I \Delta t \sum_{i=1}^{t}\left(r_i - v_i\right)$$

Where

C_f and r_i are the control signal and desired velocity at the ith sample respectively.

K_1 is the integral gain.

In order to minimize the truncation error when calculating the integral term, the following expansion is used:

$$\sum_{t=1}^{t}\left(r_i - v_i\right) = \sum r_i - \left[\frac{a_i - a_{i-1}}{\Delta t} + \frac{a_i - a_{i-2}}{\Delta t} + \ldots\ldots + \frac{a_i - a_0}{\Delta t}\right]$$

Since

$$a_0 = 0$$

$$\sum_{i-1}^{i}\left(r_i - v_i\right) = \sum_{i=1}^{i} r_i - \frac{a_i}{\Delta t}$$

Hence

$$C_f = k_p\left(r_i - v_i\right) + k_i\left[\sum_{i=1}^{i} r_i - \frac{a_i}{\Delta t}\right]$$

$$= k_p\left[r_i - \frac{a_i - a_{i-1}}{\Delta t}\right] + k_i\left[\sum_{i=1}^{i} r_i - \frac{a_i}{\Delta t}\right]$$

The program only needs to store the last screw Displacement " a_{i-1} " and the sum of desired velocity ($\sum_{i-1}^{i} t$) for the calculation of control signal (C_f).

For the finer calculation of velocity, a second-order method is employed, which yields $G = (3a_i - 4a_i + a_{i-1})/(2\Delta t)$. The present study discards the more accurate expression because it will increase the computer storage and, more important, lengthen the calculation time.

V.   The EMBEDDED SYSTEM

The Embedded system based on Basic X micro-controller called BX-24 [5] (show in figure 8) and some other Peripheral devices. In the BX-24 system [6] there is a fast core processor with a ROM to store the Basic X Operating System, 400 bytes of RAM, 32 K Bytes of EEPROM, and lots of I/O devices such as timers, UARTs, ADCs, digital I/O pins and more. The BX-24 uses an Atmel AT90S8535 as its core processor. The timer can be programmed to generate periodic interrupts to the main processor so that the sampling period in the digital control of injection speed can be adjusted. The peripheral input & output Interface Adaptor, which provides numerous Input / Output ports, is used to interface the main controller with the external devices such as the limit switches for the mould open/closed, screw position and the safety door open/closed as well as the relays for the opening and closing of mould and the screw motor.
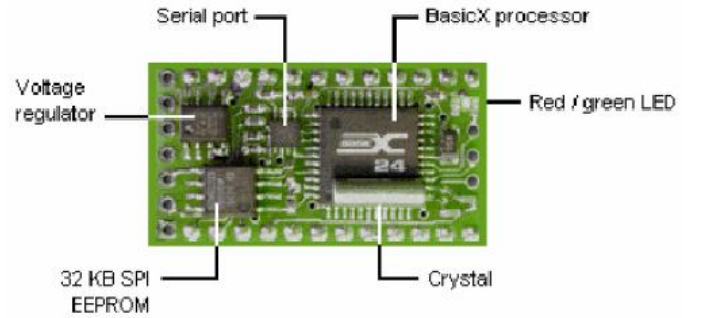

Figure 8: Basic X 24 Micro controller Chip.

A.   Interaction components:

The embedded system also have user interface that offer a complete monitoring of the system resources:

• Interactive mode of work; function available on the main program for didactic purposes, the user gives the signal to execute the step.

• LCD display, which shows the status of the system, values of inputs, outputs, timer and statistics of the sequence execution.

• Beep to give important alerts, stop, start and emergency.

• LEDs to show power on and others to show the state of inputs and outputs.

B.   Security:

To make the final application works property, a correct configuration to execute the steps in the right way is needed, but more then that it must offer solutions in case of bad functioning or problems in the execution of the sequence. The controller offers the possibility to configure two internal virtual circuits that work in parallel to the principal. These two circuits can be used as emergency or reset buttons and can return the

system to a certain state at any time. There are two inputs that work with interruption to get an immediate access to these functions. It is possible to configure the position, the buttons and the value of time-out of the system.

C. User interface:

The sequence of strings can be programmed using the interface elements of the controller. A computer interface can also be used to generate the user program easily. With a good documentation the final user can use the interface to configure the strings of bytes that define the steps of the sequence. But it is possible to create a program with visual resources that works as a translator to the user; it changes his work to the values that the controller understands. To implement the communication between the computer interface and the controller a simple protocol with check sum and number of bytes is the minimum requirements to guarantee the integrity of the data.

D. Firmware:

The main loop works by reading the strings of the steps from the EEPROM memory that has all the information about the steps. In each step, the status of the system is saved on the memory and it is shown on the display too. Depending of the user configuration, it can use the interruption to work with the emergency circuit or time-out to keep the system safety. In figure 9, a block diagram of microcontroller main program is presented.
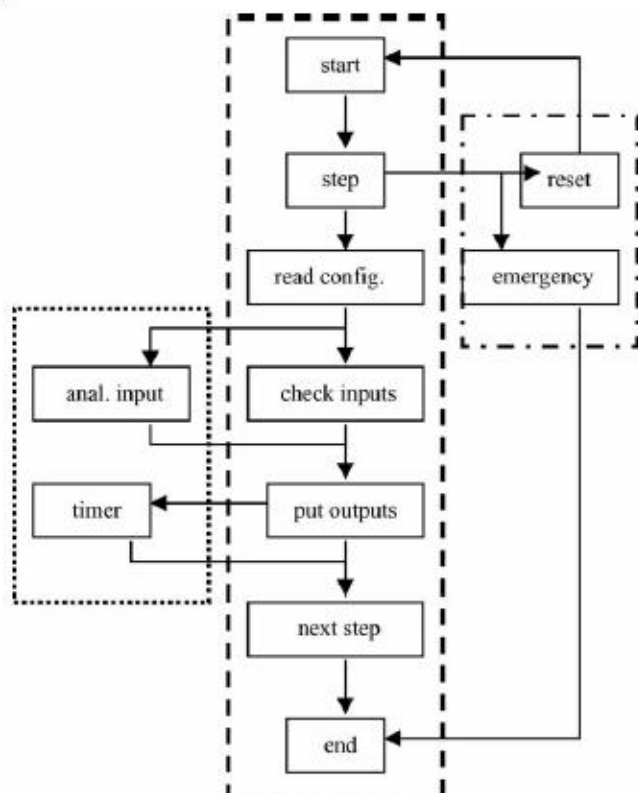
Figure 9: Block diagram of Firmware.

VI. CONCLUSION:

This paper has briefly described the upgrading of a conventional injection molding machine in to an embedded control system i.e. micro controller base controlled one at reasonable cost. Introducing a hydraulic circuits and micro controller based embedded system provides an effective and easy way to control the sequence of injection molding machine and after implementing this electro hydraulic system the performance and productivity of this injection molding machine was increased. So we can conclude that by using this embedded system and adding some hydraulic circuit we can increase the performance and productive of conventional injection molding machine at reasonable cost.

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About the author:

Syed Faiz Ahmed received Masters degree in Computer Controls & Automation from Nanyang Technological University, Singapore, in 2006. This research work was conducted as a part of his thesis. Currently, he is affiliated with the faculty of engineering science and technology, Hamdard University (HIIT), Pakistan, as Assistant Professor.