CONTROL SYSTEM FOR SMALL INJECTION MOLDING MACHINE

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Abstract: This paper deals with design and realization of control system in application for small injection molding machine. The small injection molding machine is intended to serve as a substitute for 3D printers in company, thus reducing producing time and improving mechanical properties of final product. The main goal was to design its own control system, which will be more cost-effective than using a PLC. An integral part was also the assembly, commissioning and programming of its own control system.

Keywords: control system, PLC, ARM, MCU, thermocoupler, injection molding machine, ATSAME70, Atmel, Microchip

1 INTRODUCTION

3D printers are very popular and famous with DIY people (DIY - "Do it yourself"), because it's very low cost in 2021. 3D printers allow to do any shape (in technical possibilities) made of a plastic string, which have different properties depending on the material. The company, for which it this control system is designed, is printing small and specific components. FDM 3D printed part has inconsistent mechanical properties in many ways. The main differences are evident in the elasticity and tensile strength.

The main idea of the work is realize control system as one unit instead of control unit and lots of converters and control cards. The own control system can save place and be low cost.

This paper deals with the design and implementation of a control system for a small injection molding machine. The project is developed in cooperation with the company `ELZACO spol. s r.o.`.

2 REQUIREMENTS FOR IMPLEMENTATION

The aim was to design and create a control system for a small injection molding machine at an affordable price and size. Because I am not the implementator of the control algorithm, all peripherals of control system must be implemented for the implementator who does not understand peripheral programming.

2.1 IMPORTANT PRINCIPLES OF INJECTION MOLDING MACHINE

For designing a specific control system it is important to know the main principle of injection molding machine to tailor-made all peripherals. On figure 1 there is a 3D model of small injection molding machine, which I get from a developer of mechanical design.

A simplified principle is the melting of the plastic granulate to the plasticization temperature. Melting is performed in a long tube with heaters. It is important to mention that there are several heaters that

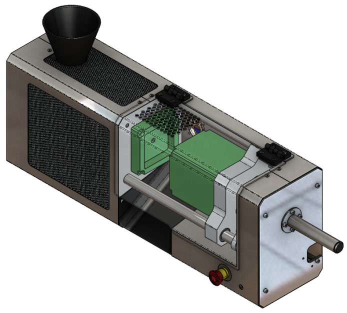

Figure 1: 3D model of small injection machine.

ensure the correct course of the melting process. This means that we have to measure the temperature in several places. The time constant of the heater is in the order of tens of seconds and this is reason, why we don't need extra fast PWM outputs.

The injection of the plastic is realized by extruder feed screw. For rotating the extruder screw is used a stepper motor, which has a driver controlled by impulses and digital inputs for enable and direction. Plastic is injected into mold, where one half of mold is moving. The movement of the mold is performed by the lead screw and a stepper motor. [1]

Other important peripherals are digital inputs from sensors and buttons, or digital outputs for signaling.

3 CONTROL SYSTEM SELECTION

Chapter 2.1 and 4 describes the design of the control system, from which the requirements for a suitable control system (minimum requirements) are drawn.

3.1 PLC

The own control system will be compared with a PLC from the company `Unitronics`, `UniStream`, because this PLC offer an integrated display. Modular PLC with 7" display starts at 18000 *CZK* which need a processor for 8000 *CZK*. Other necessary items are **I/O** modules. In same count of peripherals, it was a modul of digital inputs and outputs, which can offer stepper motor signal (usually marked as PTO), analog inputs for current loop (ranging 0..20 *mA*) or voltage (0..10 *V*), thermalcoupler input (type K). The communication module for `RS485` is sold separately. The price of the one module ranges between 3000 *CZK* and 8000 *CZK*.

The second option is to use a compact PLC, which offer an integrated display (5", 7" and 10.1") and several `I/O`. PLC with 5" diplay, 24 digital inputs, 2 analog inputs and 16 digital outputs is starting at 23000 *CZK*. For another module connection, it is necessary to buy a module extension and other modules can be added, like in the modular PLC.

All prices are only indicative and without VAT. The prices of PLC are taken from `SCHMACHTL` eshop[5].

3.2 OWN CONTROL SYSTEM

Given the requirement to minimize the cost, an alternative to a PLC control system was considered. The price of the own control system is estimated at 10000 *CZK*. This price is only for material per one piece. The final price is reduced by higher productions.

3.3 Other solution

During the market research, no product was found to be suitable as a cleaning system for injection molding machines. There are several companies that design control systems for large injection molding machines, which is an unsuitable solution in terms of price and size. At the time of the survey, there were some open-source projects for CNC, but it would be difficult to adapt or they were built with the idea of assembling arduino modules.

3.4 Conclusion

The analysis revealed that with the proposed control system, the price could be a third compared to a solution with a PLC. The savings do not only lie in the price of the control system, but also in the implementation of the specific peripherals like thermocouplers input into the control system itself. The price of a PLC can be justified by the simplicity and speed of implementation, for one manufactured piece. The own control system would be used in the production of multiple pieces, where the cost of development would be divided (the price of PLC will still be the same).

Mass-produced injection molding machines usually have their own control systems or designed to order.

4 DESIGN OF CONTROL SYSTEM

From the requirements described in Chapter 2.1 was created the block schematic on figure 2.

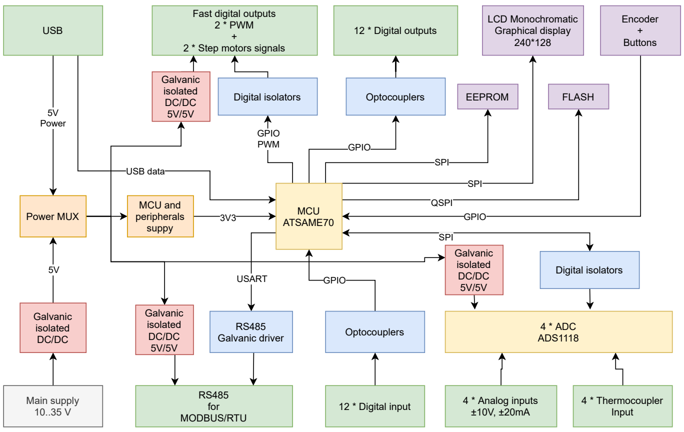

Figure 2: Block diagram of the control system.

4.1 Peripherals of the control system

I/O peripherals have been designed according to industrial requirements (similar to PLC). Thus, digital `I/Os` are designed with levels of 24 V and analog I/Os have ranges 0...10 V or 0...20 mA. For wide range use, the digitals peripherals and supply is designed to wide voltage range (10..32 V). And for safety all peripherals and supply is galvanic separated from processor.

The control system contains the following peripherals:

- **12 digital inputs** designed with common ground (`SINK`). An optocoupler is used for logic level conversion and galvanic isolation.
- **12 digital outputs**, which are solved as an open collector using the circuit `VNI4140`. Subsequently, the outputs are equipped with a fuse on the power input.

- **4 fast digital outputs** differ from normal digital output by speed and more option. All four digital output can use as PWM generator on high frequency. Two outputs can be use to generate specific number of pulses, that are using for control of drivers for stepper motors. Outputs is realized with circuit `DRV8844` (Quad indipended $\frac{1}{2}$ H-Bridge driver).
- **4 analog inputs** are switchable between voltage and current. Voltage inputs are possible as $\pm 10\,V$ and current inputs in the range $\pm 20\,mA$, where it is possible to convert range of $4 \ldots 20\,mA$ or any other in software. For measuring is used `ADS1118`, which is common for thermocoupler inputs.
- **4 thermocouplers inputs** are designed to primary use with K-thermocoupler. For converting is used the analog-to-digital convertor (`ADC`) ADS1188. The law of `cold junction compensation` [2] is used for calculating the resulting temperature.
- **Display** that is, for example, capable of displaying measured data, statistics or settings. Display is monochrome graphicals. Display has the resolution of $240 \cdot 128$ pixels. In combination with an encoder and buttons it allows the setting of parameters.
- **USB** will allow the setting or showing advanced parameters using a PC application or show basic terminal. The USB-C connector was chosen as the USB connector for its recent expansion.
- **RS485** is for communication with other devices. Primary this peripheraly is for another project, where I want to use this control system as a diplay for modular control system. `MODBUS/RTU` will be used as the communication protocol, which offer communication with other mass-produced devices such as `PLC`. This means that this control system can be a device of decentralized production.
- **Memory** - the control system have EEPROM (1 *Mbit* with `M95M01` over SPI) and FLASH (32 *Mbit* with `SST26VF032B` over QSPI) memory to save statistics and parametrs.

4.2 Realization

The control system (see figure 3), was designed as one four-layer printed circuit board. An ARM processor from Atmel (now is Microchip) `ATSAME70Q21` [3] was chosen as the main processor.

(a) Top side with display. **(b)** Bottom side.

Figure 3: Own control system

The HW was installed, revived, tested and SW equipment was created to operate all peripherals of the control system.

4.3 Software

The programming environment Microchip Studio 7 (renamed from Atmel Studio) was used for the development of the SW. The control system contains a program for the operation of peripherals, simple `GUI` and example of their using.

For easier implementation of the resulting control algorithm by the end-programmer, RTOS (Real Time Operating System) was chosen. FreeRTOS was chosen from a wide range of RTOS. The main advantage of using RTOS versus superloop are the tasks and their apparent parallelism. Another very useful advantage is the resource manager, semaphore, mux, queues, events and timers. In addition to the kernel itself, FreeRTOS also offers a package called FreeRTOS+, which it is a library of function. The packages are optional and can offer TCP or UDP stack, CLI (Command Line Interface), IO manage, JSON decoder or application protocols (HTTP, MQTT). [4]

The ASF3 library (Atmel Software Framework), which uses an offline configurator, was used for peripheral programming. ASF4 versus ASF3 uses ATMEL START (configurator in a web browser). However, this library is not lightweight (for universally use) and some functions had to be rewritten. With regard to the library used, the C programming language was chosen.

5 CONCLUSION

I managed to design, revive and test our own control system for a small injection molding machine. It is estimated that the cost of the proposed control system could be a third compared to using a PLC solution. From SW FreeRTOS with CLI extension was implemented. The implementation of drivers for all peripherals is also a matter of course in the SW. In the next version of the control system development, the design of the control system will be reworked. The main change will be the partition into several sub-boards to minimaze size and use the of colored graphical display. The use of the control system does not have to be limited to a small injection molding machine, as it has been designed universally, but its use is limited only by the number of IOs.

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