Műszaki Tudományos Közlemények vol. 20. (2024) 30–35.
DOI: Hungarian: https://doi.org/10.33895/mtk-2024.20.06
English: https://doi.org/10.33894/mtk-2024.20.06

DESIGN OF A CAVITY PRESSURE MONITORING SYSTEM FOR PLASTIC INJECTION MOLDING

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Abstract

This work aims to create an instrument that allows the measurement of cavity pressure during plastic injection molding. The designed device is intended to contribute to the equipment inventory of the Polymer Technology Laboratory at Sapientia EMTE, Faculty Târgu Mureș. The design criteria were the ease of mounting and use. The system was implemented with two load cells, two HX711 amplifiers, an ESP32-based microcontroller and a corresponding computer user interface. The user interface was developed using National Instruments LabVIEW program and finalized as a stand-alone application. During the design steps, attention was also paid to the practical applicability of the system.

Keywords: *injection molding, cavity pressure, microcontroller, LabVIEW, load cell.*

1. Introduction

Thanks to advances in polymer production technology in the 21st century, plastics are becoming increasingly prevalent in our everyday lives. This change is particularly noticeable in the automotive industry, where polymers are increasingly replacing traditional metal parts due to their low density, economical production, and excellent properties. The rapid growth in the industry shows that polymer processing is now one of the most important industry sectors, making production line quality control and its digitalisation essential.

1.1. The basics of plastic injection molding

Injection molding is based on the principle of injecting a low-viscosity plastic liquid into a closed mold through narrow channel (runner system). Low viscosity is essential to fill the mold quickly and completely. The nature of the injection molding process means that the cooling of the molten plastic takes place in a relatively short time and the process results in a product with excellent dimensional accuracy. Another advantage is that injection molding allows the production of parts with complex shapes that do not require further machining, except for the removal of plastic that has solidified in the ducts (sprues, runners). Injection molding technology can be used to produce parts of >50 kg with sufficiently large injection molding tools **[1]**.

1.2. The basics of microcontrollers

Microcontrollers are small stand-alone computers specialised in processing digital signals and controlling embedded systems. They are essential in industrial automation, home appliances, vehicles, medical equipment, etc. These microprocessors integrate the CPU, operational memory and peripherals on a single chip, take up little space, have low power consumption and can be economically produced in large quantities.

Microcontrollers can be programmed, developers can create their own software for their applications, customized solutions can be built. Peripherals, such as Analog to Digital Converters (ADCs), Digital to Analog Converters (DACs), timers and communication interfaces. These allow communication with the outside world and the management of inputs and outputs.

They are available in different architectures and performance levels, programming them requires special development tools or development boards. The development boards contain the components needed to program the microcontroller [2].

1.3. Measuring injection cavity pressure

The ability to measure cavity pressure during injection molding is extremely useful. Load cells, strain gages and piezoelectric sensors are widely used in industrial applications for this role.

The role of a sensor is to establish a known relationship, in our case between the applied force and the emitted signal. In the case of load cells, this relationship is linear over a large measurement range, making calibration relatively simple.

Cavity pressure measurement systems can be divided into two major categories depending on the way the sensors are installed: direct and indirect method (Fig.1).

The direct method, although simpler (because of the absence of the transfer rod), yields less accurate results, requires more maintenance and more durable sensors. The indirect method uses a transfer rod to transmit the force from the injection pressure to the sensor, which allows the sensor to operate at a lower temperature because it is located further away from the tool cavity [3]. In both methods, the sensors are used to detect the change in pressure over time.

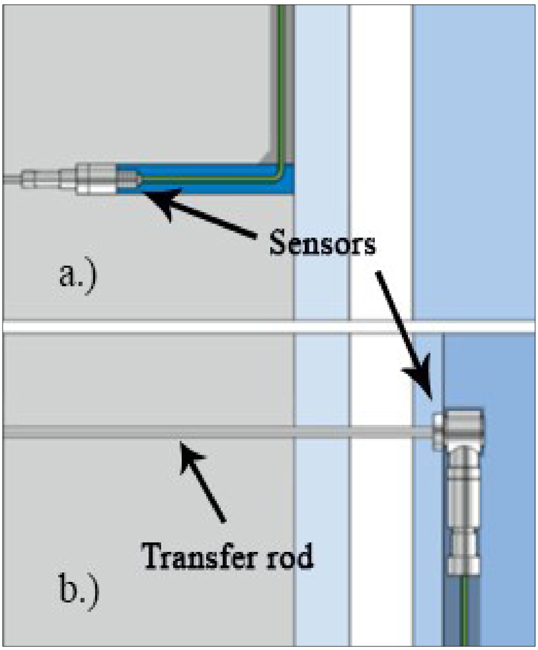

Fig. 1. *a.) Direct and b.) Indirect (transfer rod) pressure measurement method* [3]

2. Objective

The aim of my research is to design and create a device suitable for measuring the injection molding pressure of thermoplastics. The system is intended to extend the equipment inventory of the Polymer Technology Laboratory at Sapientia Hungarian University of Transylvania, faculty of Târgu Mures. The system aims to enable the analysis of pressure in the cavity over time, as well as the visualization and recording of the measured data.

3. System diagram

The system, in terms of its structure (Fig. 2) and operation, can be divided into Hardware and Software:

- Hardware: sensors, amplifiers, the microcontroller, and the wires connecting them.
- Software: the program running on the ESP32 microcontroller, and the user interface developed in the LabVIEW environment.

4. Hardware

4.1. ESP32

The development board selected for this project is a device with an ESP32 microcontroller (Fig. 3). Its computational capabilities are excellent for our purposes and its physical size is an advantage

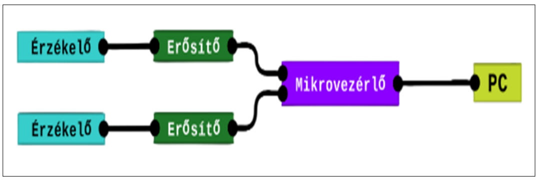

Fig. 2. *Construction diagram of the system.*

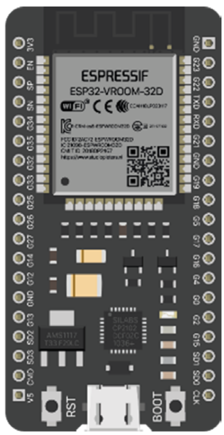

Fig. 3. *ESP32 microcontroller* [4]

also, as it helps to reduce the final size of the device.

The chosen microcontroller is equipped with a number of ADCs. In the first phases of the project, we tried to use these to read the analogue signals from the sensors, but their resolution was too low for this application, as it is only 12 bits. Furthermore, the linearity of the ADCs in the microcontroller is far from perfect and would have affected the accuracy of the measurements. For these reasons, an amplifier circuit with a higher resolution ADC was used between the sensors and the microcontroller.

Since data is transferred between the amplifiers and the microcontroller via synchronous serial communication, 4 digital inputs were used in addition to the power and ground. Of these, 2 were for the data and 2 for the clock signal.

4.2. RC15-5 load cells

The used sensors are bridge-type load cells. CavityEye Ltd. supported our research by providing the sensors.

The RC15-5 load cell's (**Fig. 4**) name is an abbreviation of "Ring Cell". The numbers refer to the outer diameter and the maximum load capacity, which in this case are 15 mm and 5 kN. The operating temperature range is –40 °C to +150 °C **[5]**.

The sensors need to be supplied with a voltage in the range of 5 - 12V and the output signal ranges from 10 to 20 mV. There is a linear correlation between the force applied to the sensors and the signal they emit, which can be read to determine the magnitude of the applied force.

4.3. HX711 amplifiers

Since the signal emitted by the sensors is in the millivolt range, measuring it with sufficient accuracy requires an amplifier. By using the HX711 circuit's instrumentation amplifier (**Fig. 5**) , which was developed specifically for this purpose, the signal can be sufficiently amplified to produce measurable results. The gain multiplier can be set to 128, 64 or 32 (in our case 128). In addition, the HX711 circuit has an ADC with a resolution of 24 bits

Thanks to its on-board voltage regulator, the HX711 can be supplied with a voltage range of 2.6 - 5.5 V. As a result, it can be supplied from both the 3.3 V and 5 V (VIN) pins of the microcontroller, further simplifying its system **[6]**.

4.4. 3D printed case

Given that it is not advisable for electrical components to rely solely on wiring for connection, 3D printing technology has been used to create a compartmentalized storage unit to ensures proper storage and safe utilization of hardware components (**Fig. 6**) .

5. Software

The Arduino integrated development environment (Arduino IDE) was used to write the program for the microcontroller, while the user interface was written in LabVIEW.

Fig. 4. *RC15-5 load cell (5000 N).*

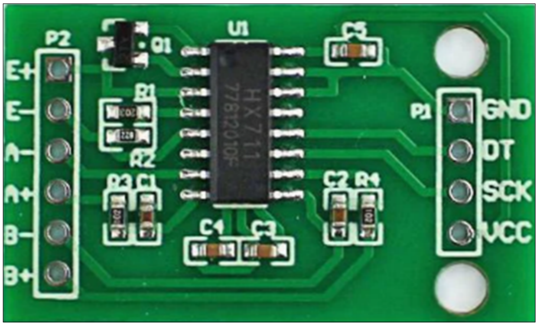

Fig. 5. *HX711 amplifier circuit board.*

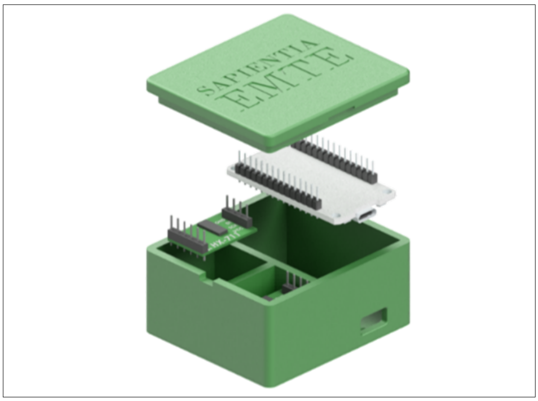

Fig. 6. *Storage case with the system components.*

5.1. Determining the sampling rate

In order to optimize the program developed in LabVIEW, it was necessary to estimate the time required to run the main loop of the microcontroller program.

The time to run the program cycle, which is also the sampling period, was determined by a test program. It incorporates not only the necessary code for sampling but also the code essential for measuring the time interval between two sampling points.

5.2. Calibrating the load cells

A separate program has been developed to calibrate the lead cells. Its role is to output the digitized value from the signals of the sensors. This is the value that is generated by the ADC of the HX711 and sent to the microcontroller.

The program outputs the raw value from both sensors to the Serial Monitor (Arduino IDE), which can then be read by the user. During calibration, the outputs of the sensors were recorded in several iterations:

– Unloaded state
– Loaded with a known force
– After 10 s of load

The reason for reading the value 10 s after the load has been applied is to minimize the so-called "creep" effect of the sensors, which causes the emitted signal to decrease over time, even under constant load.

The calibration measurements were evaluated to ensure that the relationship between the signal from the sensors and the force acting on them is linear over the measurement range. The square of the regression coefficient (R^2) is 0.9997 and 0.9996 respectively for the sensors.

5.3. ESP32 program

During measurement, it is necessary to perform some arithmetic operations in order to make sense of the signal from the sensors. While these calculations are obligatory, there is no strict rule dictating that the microcontroller must be the entity performing them. It is preferable to shift the burden of the more time-consuming calculations from the microcontroller, so that the sampling period can be minimized. For these reasons, the program shown in Fig. 7 has been uploaded to the microcontroller to manage the sampling of the load cells.

5.4. LabVIEW user interface

The LabVIEW program user interface (Fig. 8) shall provide the following functionality:

– Select serial communication port
– Select the transfer pin diameter
– Start calibration
– Start or stop the measurement
– Saving data
– Start recalibration

The user interface has been designed with an emphasis on intuitive placement of controls.

5.5. LabVIEW Block Diagram

The LabVIEW development environment is fully graphical. It allows the user to implement common programming structures such as *while* and *for* loops.

```
void loop() {
  if (scale1.is_ready() && scale2.is_ready()) {
    long rawValue1 = scale1.read();
    long rawValue2 = scale2.read();

    Serial.print(rawValue1);
    Serial.print(", ");
    Serial.println(rawValue2);
  }
}
```

Fig. 7. *Sampling program using the HX711 library.*

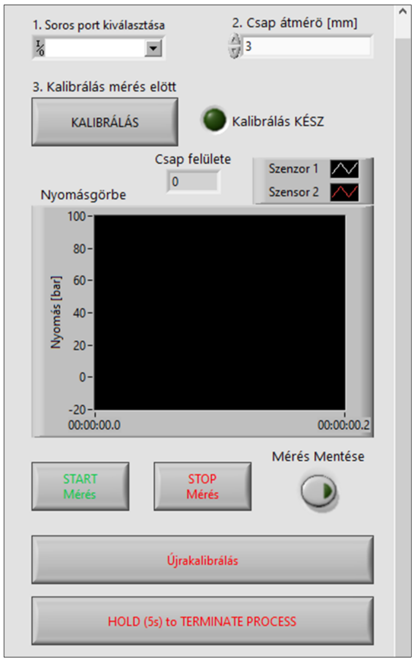

Fig. 8. *LabVIEW program user interface.*

The serial communication between the microcontroller and the PC was realized using the VISA protocols included in the LabVIEW software package.

For the reasons explained in chapter 5.3, the signal processing was done by the LabVIEW program running on a separate computer.

The first step of the main program cycle is the determination of the reference value (initialization) of the load cells (Fig. 9). This must be done while the sensors are unloaded. The calibration process automatically runs each time the program is started, but it can also be performed manually should the need arise (re-initialization). This has proved to be a particularly useful feature during the testing stages of the system.

Receiving the measurement data from the microcontroller and executing the required arithmetic calculations are also carried out within the main cycle of the program.

6. Assembly of the system

The electrical components of the system were initially connected using pins and wires. Subsequently, once the connections were set up, the components were placed within a 3D printed case. This case served as a means for organizing the wiring of the power supply, data communication, and sensor connections (Fig. 10).

7. Results

The system was tested in order to assess its practical applicability. Sensors were installed in an injection molding tool, adhering to the principles of indirect pressure measurement method (chapter 1.3). Test measurements were conducted at the Polymer Technology Laboratory of Sapientia University. Injection molding operations were executed using a pneumatic injection molding machine.

The created parts were tensile test specimens and were made of polypropylene and polyethylene.

The polyethylene pieces were made using recycled HDPE, while the polypropylene pieces used pure granules. The pneumatic injection molding machine was run at 6 bar pressure. The injection molding cylinder temperature was 265°C for polyethylene and 280°C for polypropylene.

8. Conclusions

It can be affirmed that the development of a device for measuring injection pressure has been successfully concluded. The circuit elements and

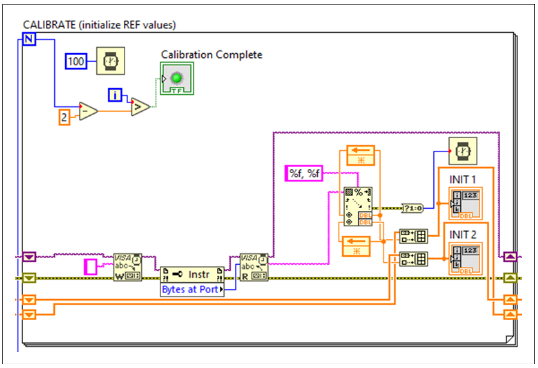

Fig. 9. *Calibration cycle in LabVIEW graphical interface.*

Fig. 10. *The assembled system placed in its storage case.*

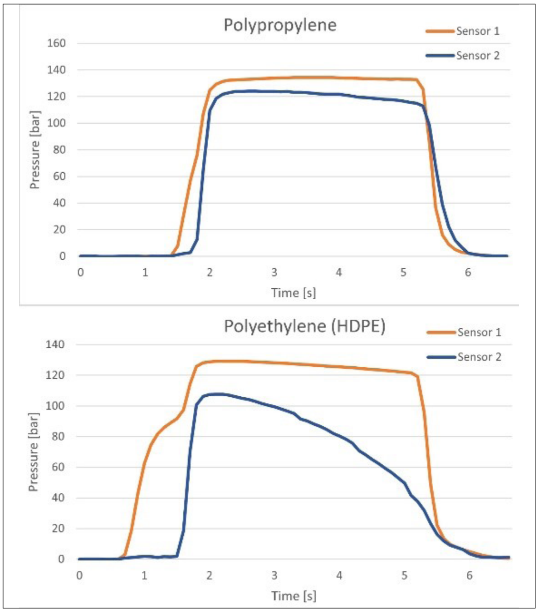

Fig. 11. *Injection molding pressure curves of Polypropylene and Polyethylene with the signals of sensor 1 (orange) and sensor 2 (blue).*

requisite programs for both the microcontroller and the user interface have been effectively designed. We were also able to realize practical measurements with the system.

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