Temperature control for rotomolding machine.

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***Abstract*– One of the most commonly used plastic modeling methods is rotational (rotomolding). Where, hollow pieces are produced from pouring plastic powder or liquid into a mold that rotates in two axes while heating. This is a temperature highly dependent process, due to any temperature variation can cause inaccuracies in the final product. For this reason, in the present work a control is proposed to keep the temperature stable regardless of the disturbances that may appear. For this, an Arduino-based dynamic closed loop control system was designed. By adjusting the burners temperature values of the system by using servo valves. The proposed system was validated in the production process of 750-liter domestic water tanks. Taking into account the burners response to achieve the operation point, as well as the quality of the resulting tinacos.**

Keywords: Dynamic closed loop control systems, automated temperature control, embedded systems.

I. Introduction

There are currently many applications in the industry, of control systems for the different production areas. Such as food processing, in the metal-mechanical industry, pulp and paper processing, mining, dairy, polymer processing and transformation, etc. The study of these industries or the problems with which they have faced lead the engineer to delve into the subject. It is the case to generate prototypes or experimental plants that when perfecting their control system are scaled and implemented for the production. One of the main problems of roto molding equipment is its manual control which produces many types of defects in the manufacture of water tanks, this is the main reason why this work is developed looking to implement in the equipment a system of automatic control that allows maintaining a stable temperature regardless of the external agents or disturbances that may alter it, all this in accordance with the production requirements already established in the process manuals that the company has.

For this paper a prototype is presented which has the design of a PID controller of a temperature control system for a roto molding machine that manufactures tanks of three layers of polymers for water storage with a capacity of 750 liters. It also shows the results obtained from the investigation that include the experiments carried out in the equipment to obtain the correct transfer function and the PID design to improve the response of the system.

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2020.1.1.133
ISBN: 978-958-52071-4-1 ISSN: 2414-6390

The system has the capacity to constantly monitor the temperature of the flame of the machine burner using temperature sensors type *K*; also it has as an actuator an experimental valve that is controlled by a 15 kilos servomotor which is linked by their central axis. Given the conditions and requirements of hardware, the Arduino oversees running the control algorithm thus allowing to associate both the sensors to monitor the temperatures as the actuator that is the servomotor to generate an opening angle and thus allows the gas to pass.

Due to hardware requirements a major advantage in the prototype is the reduced cost with which it can be implemented, compared to industrial-type hardware such as a PLC. This article describes the design and construction of a thermal system for heating a stainless-steel mold for a roto molding machine, showing the temperature control that is obtained by means of the prototype controller.

II. Rotational Molding

The rotational molding process is unique among molding methods for plastics in the plastic at room temperature is placed in a mold at approximately room temperature and the whole assembly is heated up to the melting temperature for the plastic. Both the mold and the plastic are then cooled back to room temperature. Normally, the only controls on the process are the oven temperature, the time in the oven, and the rate of cooling. Each of these variables has a major effect on the properties of the end product. At this stage it is useful to be aware that if the oven time is too short, or the oven temperature is too low, then the fusing and consolidation of the plastic will not be complete. This results in low strength, low stiffness, and a lack of toughness in the end product. Conversely, if the plastic is overheated then degradation processes will occur in the plastic and this result in brittleness. In a commercial production environment, the optimum "cooking" time for the plastic in the oven often has to be established by trial and error. In recent years it has been shown that if the temperature of the air inside the mold is recorded throughout the molding cycle, then it is possible to observe in real time many key stages in the process.

It is important to understand that rotational molding does not rely on centrifugal forces to throw the plastic against the mold wall. The speeds of rotation are slow, and the powder undergoes a regular tumbling and mixing action. Effectively the powder lies in the bottom of the mold and different points on the surface of the mold come down into the powder pool. The regularity with which this happens depends on the speed ratio that is the ratio of the major (arm) speed to the minor (plate) speed. The most common speed ratio is 4:1 because this gives a uniform coating of the inside surface of most mold shapes, the importance of the speed ratio in relation to the wall [1]. Figure 1 shows the Rotational molding process.

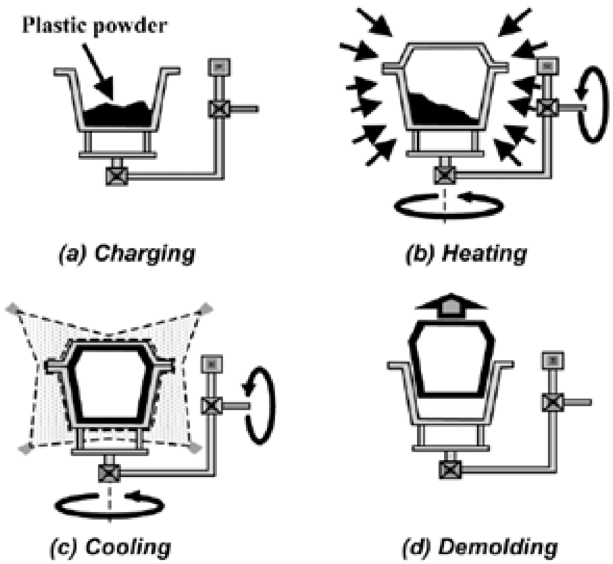


Fig. 1 Rotational molding.

When the mold rotates in the oven, its metal wall becomes hot, and the surface of the powder particles becomes tacky. The particles stick to the mold wall and to each other, thus building up a loose powdery mass against the mold wall. A major portion of the cycle is then taken up in sintering the loose powdery mass until it is a homogeneous melt. The irregular pockets of gas that are trapped between the powder particles slowly transform themselves into spheres and under the influence of heat over a period of time they disappear. These pockets of gas, sometimes referred to as bubbles or pinholes, do not move through the melt. The viscosity of the melt is too great for this to happen, so the bubbles remain where they are formed and slowly diminish in size over a period of time Molders sometimes use the bubble density in a slice through the thickness of the molding as an indication of quality. If there are too many bubbles extending through the full thickness of the part then it is undercooked. If there are no bubbles in the cross section then it is likely that the part has been overcooked. A slice that shows a small number of bubbles close to the inner free surface is usually regarded as the desired situation.

Other indications of the quality of rotationally molded polyethylene products relate to the appearance of the inner surface of the part and the smell of the interior of the molding. The inner surface should be smooth with no odor other than the normal smell of polyethylene. If the inner surface is powdery or rough then this is an indication that the oven time was too short because insufficient time has been allowed for the particles to fuse together. If the inner surface has a high gloss, accompanied by an acrid smell then the part has been in the oven too long. Degradation of the plastic begins at the inner surface due to the combination of temperature and air (oxygen) available there.

Even if the oven time is correct, the method of cooling can have a significant effect on the quality of the end product. The most important issue is that, in rotational molding, cooling is from the outside of the mold only. This reduces the rate of cooling and the unsymmetrical nature of the cooling results in warpage and distortion of the molded part. The structure of the plastic is formed during the cooling phase and rapid cooling (using water) will result, effectively, in a different material compared with slow cooling (using air) of the same resin. The mechanical properties of the plastic will be quite different.

In each case, slower cooling tends to improve the strength and stiffness of the plastic but reduces its resistance to impact loading. Fast cooling results in a tougher molding but it will be less stiff. The shape and dimensions of the part also will be affected by the cooling rate.

III. Prototype Description

Figure 2 shows the detail of the structure of the hardware that manages the prototype; it is possible to appreciate the individual elements and their interconnections with the Arduino.

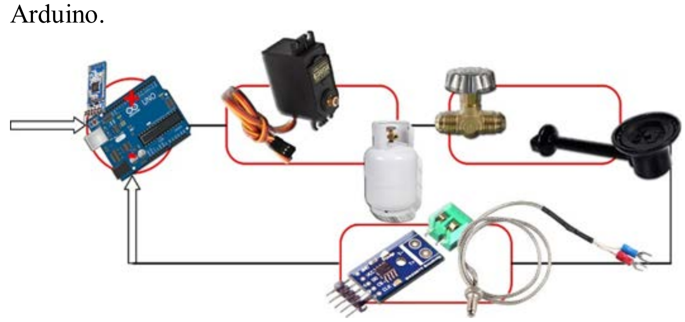


Fig. 2 Prototype elements.

The closed loop is formed by these elements initiating by the census of the temperature that is processed and evaluated by the Arduino in that way controls the actuator that consequently actuates the valve placing it with the appropriate opening degrees and thus regulating the system independently.

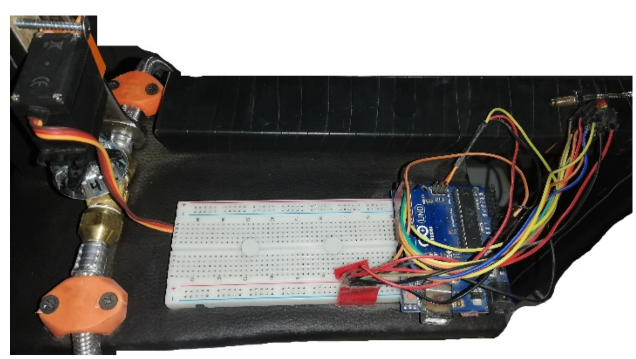


Fig. 3 Assembly of prototype elements.

The prototype consists of a temperature control system consisting of two temperature sensors thermocouple type K with the module Max6675 that are sensing the temperature of the flame and the ambient temperature, both signals are sent to the Arduino; the servomotor is controlled by the Arduino and its Servo library; this servo motor controls directly the valve that allows the flow of the gas to the burner that generates the flame. In Figure 3, the physical elements that make possible the closed loop system are shown.

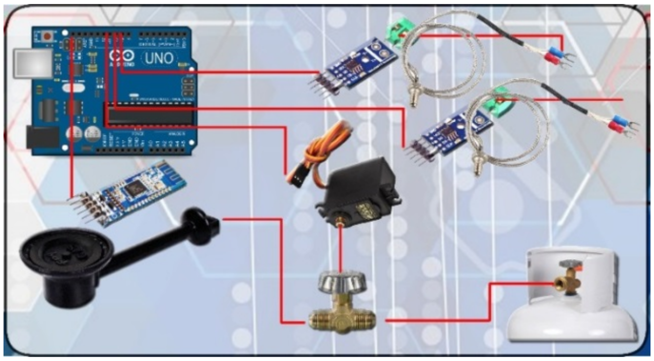


Fig. 4 Prototype connections diagram.

Figure 4 represents the Arduino schematic connection diagram. Specifying the pin numbers where the sensors were connected as well as, the connection with the physical elements that make up the system.

1. Type *K* Thermocouple and Max6675 Module. When designing a prototype, you must choose the most suitable components that meet the needs of the system at a better cost and that offer greater performance at the time of work.

In the choice of temperature sensors several tests were carried out with similar sensors that carried out an equivalent work, regarding the heat measurement that was being tested, after repeated laboratory tests, the thermocouple type *K* is selected with the Max6675 module [2], because of its best operation in high temperatures operating in a range of action ranging from 0 to 1024 degrees Celsius, with a functioning between 3 to 6 volts; the output interface is SPI, see Table 1.

Temperature measurement involves the use of transducers which convert this physical phenomenon into another, such as voltage or current, the transducer used is the thermocouple type *K*, which is a device widely used in the industry.

A thermocouple is a device formed by the union of two different metals that produces a voltage (Seebeck effect), which is function of the temperature difference between one of the ends called "hot spot" or hot or measuring union and the other called "cold spot" or cold or reference union.

TABLE 1.
MAX6675 MODULE ELECTRICAL CHARACTERISTICS

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.0V to +5.5V, T_A = -20°C to +85°C, unless otherwise noted. Typical values specified at +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Temperature Error		$T_{THERMOCOUPLE}$ = +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-5		+5	LSB
			V_{CC} = +5V	-6		+6	
		$T_{THERMOCOUPLE}$ = 0°C to +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-8		+8	
			V_{CC} = +5V	-9		+9	
		$T_{THERMOCOUPLE}$ = +700°C to +1000°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-17		+17	
			V_{CC} = +5V	-19		+19	
Thermocouple Conversion Constant					10.25		µV/LSB
Cold-Junction Compensation Error		T_A = -20°C to +85°C (Note 2)	V_{CC} = +3.3V	-3.0		+3.0	°C
			V_{CC} = +5V	-3.0		+3.0	
Resolution					0.25		°C
Thermocouple Input Impedance					60		kΩ
Supply Voltage	V_{CC}			3.0		5.5	V
Supply Current	I_{CC}				0.7	1.5	mA
Power-On Reset Threshold		V_{CC} rising		1	2	2.5	V
Power-On Reset Hysteresis					50		mV
Conversion Time		(Note 2)			0.17	0.22	s
SERIAL INTERFACE							
Input Low Voltage	V_{IL}					0.3 x V_{CC}	V
Input High Voltage	V_{IH}			0.7 x V_{CC}			V
Input Leakage Current	I_{LEAK}	V_{IN} = GND or V_{CC}				±5	µA
Input Capacitance	C_{IN}				5		pF

2. Servomotor MG995. In order to generate the desired control, the actuator response is required from the temperature measurement signals obtained, the Arduino produces the required opening angle, which in turn will be sent to the actuator to position and consequently set that angle on the gas valve. The specific element of actuator for this prototype is the MG995 model [3], which has a transmission box with metal sprocket so it is more resistant to weight and workloads; operating voltage from 4.8 to 7.2 volts with an operation speed of 0.2 s/60º (4.8 V), 0.16 s/60º (6 V). This actuator is operated from the Arduino via a library named Servo. Figure 5 shows the servo motor coupled to the gas valve.

Fig. 5 Valve prototype (actuator) for the gas control.

3. Arduino. Arduino contains Atmel AVR microcontrollers. These cards make it easier to handle peripherals by controllers [4].

Similarly, Arduino offers a development environment (IDE) where users program the microcontroller of the board. The Arduino architecture is the tool used in this prototype, this board oversees processing both the input signals and generating the output signals, as well as running the algorithms that allow to maintain a closed loop in the system. The control libraries running the Arduino in addition to the mentioned before is the Arduino PID Library that will be responsible for running the main algorithm control system.

IV. Libraries

The temperature sensors, the servomotor and the Arduino are hardware, which alone cannot perform the specific tasks desired. To do this you have to do the programs, which are a set of instructions, and in this way, you can control the Arduino with your inputs and outputs. There are open source tools that make it easier to work by using these programs. These tools are called libraries, which are just collections of code that facilitates the interconnection of sensors, actuators such as servomotors, screens, electronic modules among others. The libraries reside in a file with extension *.h* and for Arduino are open source.

1. Max6675.h Library. The code in the library, which is of public domain, helps to read the temperature through the Max6675 sensor. The process is illustrated in Figure 6.

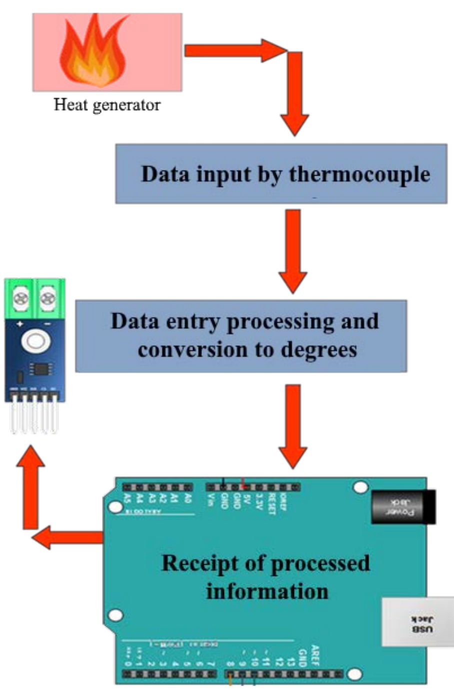


Fig. 6 Block Diagram Max 6675.h library

2. Servo.h Library. Figure 7 shows a block diagram with the servo controller operating the MG995 servomotor [5].

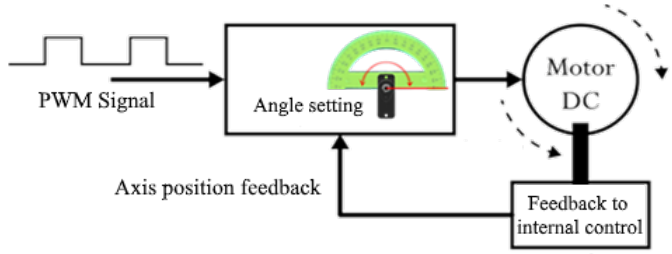


Fig. 7 Block Diagram of servo library.

3. PID Controller. A PID is a feedback control system, which calculates the deviation or error between a measured value and a desired value. This control algorithm consists of three different parameters. Proportional, Integral and derivative, proportional gain is applied to the current error, the integral gain is applied to the past values of the error, and the derivative gain is a prediction of future errors. The sum of these three actions is used to adjust the process by means of a control element; in the case of this prototype is the position of a valve, see Figure 8.

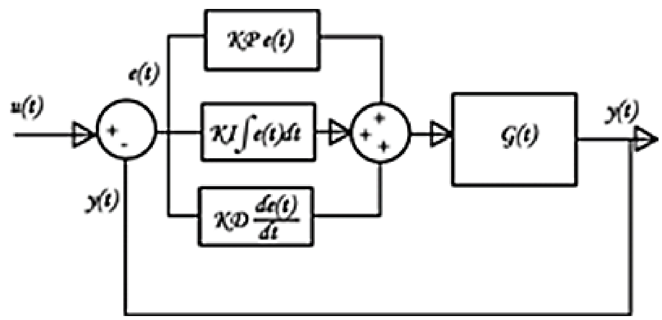


Fig. 8 Diagram of the PID function.

4. PID.h Library. When the PID library [6] [7] was programmed on the Arduino software an important process called discretization was performed; it was figured with the help of the Z transform.

Equations (1) to (3) are showing the Z-transform of the PID action [8]-[11].

$$Z\{K\_p\ (e(t))\} = K\_p\ E(z) \qquad (1)$$

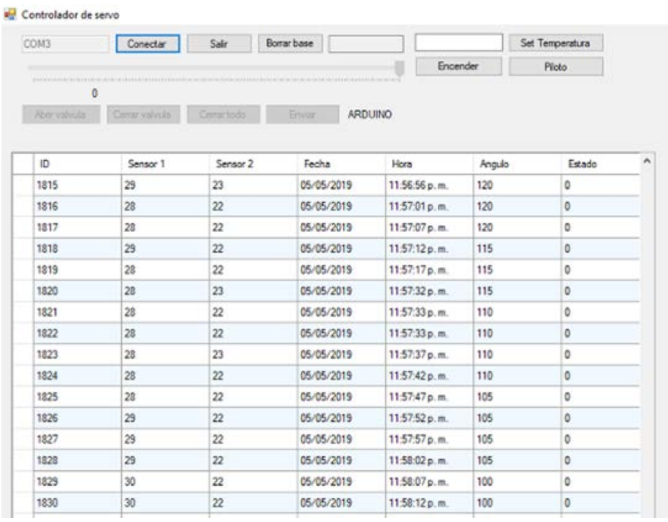
$$Z\{K_i(\int e(t)dt)\} = K_i \frac{z}{z-1} E(z) \qquad (2)$$

$$Z\left\{K_d\left(\frac{de(t)}{dt}\right)\right\} = K_d \frac{z-1}{z} E(z) \qquad (3)$$

5. IoT. Additionally, a software was developed that allows the connection with the prototype from external devices. With this, the process acquires greater functionality since the software constantly obtains information from the embedded system, it is stored in a database and is useful to perform a deeper analysis, as well as to better understand the behavior of the process; the process temperatures are obtained

continuously, as well as the opening angle in which the servo valve is located. The connection can be made via USB for connection to PC, by means of Bluetooth for Tablet with Android operating system. The advantages increase considerably since with these adjustments the system can be monitored remotely by means of WEB services which concentrates the information in the Cloud and can later be consulted remotely. In the same way, the plant can be controlled remotely by means of an Android App and a WEB Application, thus creating a connection to the internet of things (IoT), all this is based on the Realtime Database concept since the information is stored in the so-called FireBase Platform, which is a free Google service that provides instant access to information.

Our proposal can be considered as an Internet of Things (IoT) system. It is due to the system can be monitored and controlled in real time from Internet. Figure 9 shows an emptied of data collected from the prototype and made it available from internet.



ID	Sensor 1	Sensor 2	Fecha	Hora	Angulo	Estado
1815	29	23	05/05/2019	11:56:56 p.m.	120	0
1816	28	22	05/05/2019	11:57:01 p.m.	120	0
1817	28	22	05/05/2019	11:57:07 p.m.	120	0
1818	29	22	05/05/2019	11:57:12 p.m.	115	0
1819	28	22	05/05/2019	11:57:17 p.m.	115	0
1820	28	23	05/05/2019	11:57:32 p.m.	115	0
1821	28	22	05/05/2019	11:57:33 p.m.	110	0
1822	28	22	05/05/2019	11:57:33 p.m.	110	0
1823	28	23	05/05/2019	11:57:37 p.m.	110	0
1824	28	22	05/05/2019	11:57:42 p.m.	110	0
1825	28	22	05/05/2019	11:57:47 p.m.	105	0
1826	29	22	05/05/2019	11:57:52 p.m.	105	0
1827	29	22	05/05/2019	11:57:57 p.m.	105	0
1828	29	22	05/05/2019	11:58:02 p.m.	105	0
1829	30	22	05/05/2019	11:58:07 p.m.	100	0
1830	30	22	05/05/2019	11:58:12 p.m.	100	0

Fig. 9 Internet of thongs (IoT) response of the prototype.

V. System Performance

The prototype must respond correctly according to the requests that the operator or user establishes, meaning that, if the user sets a temperature set-point in *N* degrees Celsius, the prototype must respond as fast as possible and stay in the desired value. The closed loop system performs its calculations and positions the servo-valve in the tilt angle that keeps the desired temperature and when there is a source of disturbance, the system reacts to maintain the established set-point. Figure 10 shows the system performance when a 34°C set-point was established. Our system begins to converge in approximately 40 seconds. Which is considered really successful, especially if we consider the nonlinearity of the system.

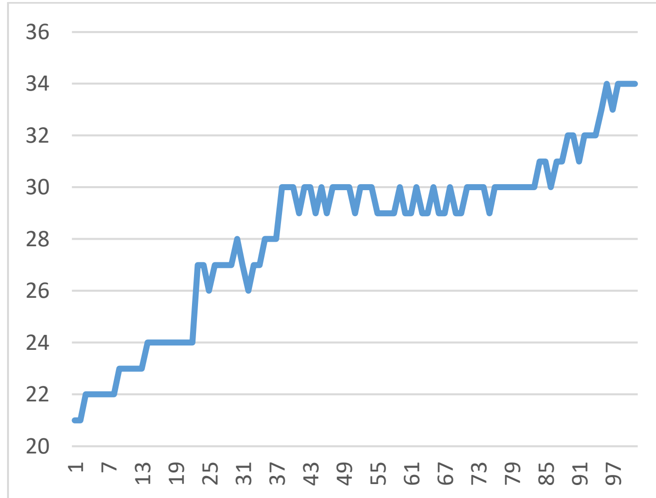


Fig. 10 System response when establishing a set-point.

In Figure 11 the whole prototype is visualized operating at full valve opening.

Fig. 11 Prototype in operation.

VI. Conclusions

The main objective of the project was the design and construction of a controller for a closed loop system to control the temperature in a roto molding machine. With the results obtained and the response that the prototype has thrown in its tests the planted objective is fulfilled, and it is expected to apply the control to the production process, fulfilling the requested specifications for the production of the water tank by means of roto molding. It is also considered to improve the performance of the control, applying other algorithms and thus reduce the response times of the system.

ACKNOWLEDGEMENTS

The authors thank to Reimer Group for the facilities granted for this project.

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[5] Servo Reference. Consulted from the URL https://www.arduino.cc/en/Reference/Servo
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