Temperature controls for plastic injection machine based on PID controller

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Abstract

Injection machines are already on the market with varying prices based on its capacity. Even the smallest machine on the market has a capacity starting from around 100 grams per second, with an expensive price starting around USD 13,000. Furthermore, the machine also has a large power consumption as well. This condition is unfavorable to the start-up business from the lower middle market, which has limited resources and budget. In this work, the design of the plastic injection molding, which is smaller and cheaper compared to the one available in the market is proposed. This proposed machine is available in the middle production capacity. In this work, the temperature of the heater and the pneumatic electronically are controlled in order to melt resin plastic perfectly. The PID control algorithm is applied to control the heater and the pneumatic of the system. The component used to control the heater until it reaches certain temperature condition according to the feedback from the temperature sensor. Moreover, once the temperature has reached the certain degree that makes the plastic material into a semi-liquid condition, then the pneumatic active to push the barrel. During the experiment, the temperature measured by the sensor on the heater. The result shows in accordance with the desired target temperature to melt the resin plastic perfectly without exceeding the temperature limit of the system. The temperature system is 90% to 95%.

Keywords

PID controller, temperature control, injection machine

1. Introduction

The raw plastic material is the most common material and widely used for various needs. Therefore, the business opportunity in the field of plastic injection is still wide open (Endarwati, 2017). The price of the plastic product depends on the type of material and size. The larger the size of the product the greater the size of the injection machine. However, the production of a small-sized product with relatively low quantity using a large injection machine is significantly not efficient.

One way to produce the plastic product is by using an injection machine. This machine will process plastic material into the plastic product with the desired shape. Plastic injection machine consists of several parts. One of them is the heated cylinder which melts the plastic material (Martinez, 2018). In this part, the temperature is greatly affecting the melting process. This is because the temperature stability affects the quality of plastics to be produced. Therefore, the temperature needs to be kept stable in order to improve the quality of plastic. If the temperature is not stable, then the plastic can be hardened or brittle. The faster the temperature is stable at the desired temperature the better the quality of the plastic produced (Dubay, Pramujati, & Hernandez, 2005). The stability of the temperature in the

injection machine has an important role, in determining the quality of the plastic to be produced. Therefore, the temperature needs to be maintained stably. The stability of the temperature accelerate the process of plastic injection and increase the quality of plastics produced by injection machines(Maries, 2013).

Some research on temperature stability control has been done using various control methods (PI Controller, PID Controller, Fuzzy Logic Controller, and ANFIS Controller) with different results, but many studies have a result of setting time 2.5 seconds (Ling, 2013; Mahto & Murmu, 2015). Some of the research is also using Artificial Neural Network method or better known as Neural Network method (ANN) to improve the performance of the temperature controller(Kangaranifarahani & Mehralian, 2013). However, the temperature control which based on ANN or Fuzzy, need longer computer calculation the temperature control based on PID(Fatma, Karim, Jamaludin, Abdullah, & Talib, 2017).

In this project, the injection machine which priority for lower middle market plastic production, is developed. The temperature of the melting process and the pneumatics are controlled, in order to have good and effective plastics production. The injection machine in this project is developed for middle-lower business which has middle size production. In this paper, the prototype of the plastic injection machine for middle-low size business is described. Next, the model of the proposed system used in the proposed system discusses in detail. Finally, the performance of the proposed injection machine is evaluated experimentally.

2. Literature review

Injection moulding process is widely used to produce plastic products that have complex shapes. One of the benefits of injection moulding is the ability to mass products with speed and low cost (Kong, Application, & Data, 2011). The whole injection machine is divided into three important parts, mechanical, electrical and controller, respectively. The mechanical part consists of several mechanical components, namely mould, heated cylinder, hopper and injection cylinder. The electrical section contains about electronic parts such as a microcontroller, heater, thermocouple, and power supply. Finally, In the controller part, the PID controller is applied to control the temperature of the injection machine.

2.1. Mechanical Part

This injection machine consists of many components one of which is a component of this mechanic that support the injection process will be done. Component-component mechanic in this machine is mould, band heater, heated cylinder/barrel, hopper, injection cylinder pneumatic(Bannister, Jones, & Bagwell, 1963). Figure 2.1 shows the complete array of plastic injection machines (Rosato, Rosato, & Rosato, 2000).

Injection machine is divided into several parts, as shown in Figure 2.1. The important parts of the injection machine are as follows:

i. Mould

Mould is the part that receives the plastic liquid that has been melted by the band heater. This section serves to print the plastic in accordance with the desired shape (Teklehaimanot, 2011).

ii. Band heater

Band heater is the part that serves to heat the cylinder that contains the plastic material until the plastic material becomes semi-liquid form. Once the plastics material in the form of semi-liquid form, the pneumatic is then pressed into the mould for printing (Jansen, 1995).

iii. Heated cylinder

A heated cylinder is the process of heating the plastic into a liquid form("Injection Molding Machine," 2016).

iv. Hopper

The hopper is the part to put the plastic resin to be processed to melt into the desired shape.

v. Injection cylinder pneumatic

Injection cylinder pneumatic is an actuator to push the plastic resin in order to fully fit the room inside the mould(Sheikh & Sharma, 2015).



Figure 2.1. The overall mechanical part of the existing injection machine(Dyneon GmbH, 2013).

2.2. Electrical part

In addition to mechanical components, there are also electronic components. The function of these electronic components is controlling the mechanical components. Here are some of the electronic components used in the manufacture of plastic injection machines:

Microcontroller

The microcontroller is the control centre of a plastic injection machine to control the temperature of the heater according to the data input of the sensor and to move the pneumatic up and down(Mohamed, Abdalaziz, Ahmed, & Ahmed, 2017). One of the microcontrollers which used in this project is Arduino, as shown in Figure 2.2. Arduino consists of many pins, which configure as either inputs or outputs in the system(Kibria, 2013).



Figure 2.2 Arduino(Sanjaya, 2016)

• Power supply

Power supply, provide supply DC electrical source, which supplies the electronic components. The electricity will be distributed microcontroller and pneumatic.

• Relay

Relay serves to disconnect or connect electronic devices automatically by providing voltage then the components in the relay can disconnect and connect the flow of electricity.

2.3. Controller Part

PID controller is the most widely used control strategy in the industry (Control Station, 2015). It is used for various control problems such as automated systems or plants. A PID Controller consists of three different elements: P for the proportional controller, I for Integral controller and D for derivative controller. PID controller can be implemented to meet various design specifications for the system. Proportional control, pure gain adjustment acting on the error signal to provide the driving input to the process. Integral control is implemented through the introduction of an integrator (KI/s). Integral control is used to provide the required accuracy for the control system. Derivative control will have the effect of increasing the stability of the system, reducing the overshoot and improving the transient response. PID equation as shown in Equation 1(Ogata, 2010):

$$K_p + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_p s + K_I}{s}$$
(1)

Where K_P is contant for the proportional controller, K_I is contant for Integration controller and K_D is the contant for derivative controller.

In this work, Temperature control is carried out in a heated cylinder area with a band heater. The band heater that heating the cylinder will be controlled by using a microcontroller that has an input from a temperature sensor mounted on the cylinder nozzle. After input received by the microcontroller, it will be processed using PID control method(Jiang & Jiang, 2012; Stopford, Darling, Arthur, Priest, & Awbery, 2016). Arduino is controlling the band heater according to the input of the sensor.

This work, PID control method to control the temperature is applied(Isermann, 1989; Parkale, 2012; Vieirat, Dias, & Mota, 2003). This method is very convenient to use because this method is the lesser in calculation cost because the other method like ANN or fuzzy logic controller is very heavy in computing the data.

3. Research methodology

This project will design and manufacture of the plastic injection machine since the existing problems cannot be solved with existing plastic injection machines. Therefore, this experiment will prove the stability and the mobility of this small-scale injection machine is the same as the large-capacity injection machine. Furthermore, the price of this injection machine is also cheaper than the existing injection machines. Therefore, this experiment has a result of data that will prove the temperature stability of this machine. Based on that reason, this experiment is included in the quantitative approach(Gulo, 2000; John W. Creswell, 2017).



Figure 3.1 overall of the proposed system.

Figure 3.1 shows the overall proposed system in order to achieve the objective of this project, the following procedures will be considered:

- 1. This project will start with the study literature injection plastic machine, and control system of PID Study Literature is a process by which learning and collecting data from journals and books related to research methods can be done to support the design of this plastic injection machine.
- 2. Development of Mechanical design.

This stage, the size and material that will be used to design the plastic injection machine, is determined. Since the machine is designed using pneumatic, therefore the strength of the material should be calculated, which sustains the body pneumatic in order to avoid bending or damaged its components of the injection machine

The mechanical design of the machine has been upgraded for the better result by adding a pneumatic automation to the booster of the plastic material. The advantages of using pneumatic, s the pressure on the plastic material is constant, so that the product which is produced has a good quality. The motion mechanism also maximized using only vertical movement only. This machine can also be upgraded by adding other machines such as feeder machine that serves to insert the resin automatically. Also a machine for automatic mould replacement.

3. Development of electronic design

From the data collected can be determined what electronic components will be used to design this plastic injection machine ranging from the type of sensor that will be used to the electronic circuit to connect all electronic components also determine what components will be used to connect the input and output from the microcontroller.

Generally, PLC controller is used as a control system in the engine design. However, by using PLC, the price becomes expensive, which affected to the overall price of this machine. Therefore, on this project, the controller is replaced by using a microcontroller, since it has a cheaper price and easier in the application. This machine

has several sensors that connected with the microcontroller, such as temperature sensors. The machine also able to add a reed sensor to know the position of the pneumatic.

4. Fabrication of the mechanical design

Based on the results of the mechanical design that has been done previously there are some mechanical components that already exist in the market must be modified to fit the mechanical design that has been determined before. This modification aims to strengthen the structure of this machine so strongly to hold the burden that is given by the pneumatic to the barrel.

The fabrication process begins with determining the pneumatic size to be used. After the size has been set, the next is the selection of barrels. The barrel size should match the diameter and pneumatic length. Once specified the fabrication process can be started by positioning the pneumatic and barrel in the middle position. This should be done with great precision to prevent damage to the barrels and pneumatics if the pneumatic and barrel are not in the middle position. Once the pneumatic position has been aligned, then the skeleton can be coupled to push the pneumatic and barrel by a welding method. After all the welding process is complete then done the total painting.

5. Installation of the electrical component

After mechanical fabrication is completed. The next stage is the installation of electronic components which have been designed will be applied to the sensor and pneumatic. After all installed, then the pneumatic test process can be done by using the switch manually. The proposed of to know that the pneumatic runs in accordance with the position. In the band, heater is also tested whether it can function normally or not by using a digital thermometer. If the thermometer shows that the temperature indicates the temperature rise, then it can be ensured that the heater band is functioning normally.

6. Development of a hybrid integrated system for injection machine system by using programming

After the mechanical and electronic components are installed, the next step is programming. In this step. The installation of the libraries that will be used to read the sensor and display through the LCD to be installed. After that design algorithm to control system/injection machine. Programming will use the Arduino program using C language.

7. Evaluate the performance of the proposed system.

After all, the process has been passed for the design of this machine, it will be tested algorithms that have been implemented in the C language. Some tools that can be used to perform testing are:

- Serial monitor Serial monitor is a feature of Arduino software that can know the input of the sensor. And display the input in the window
- Thermometer digital

This tool works for the standard of certainty of the heater band temperature. Serves as a comparison of the sensors that have been installed in the barrel

• Oscilloscope The oscilloscope is required in order of knowing the actual output signal from the Arduino.

4. Experimental work

This section discussed the experimental setup, the result of the experiment and the analysis of the experiment. The experiment setup discussed the specification of the hardware of the mechanical and electrical parts. The result of the experiment is discussed in the next section. In this section consist of the experimental result of the changing temperature and pneumatics. Finally, the result of the experiment analyses in the final section of the experimental work.

4.1. Experimental setup

This chapter will explain the specifications of the mechanical and electronic components that will be used in this experiment. Figure 4.1 shows the result of mechanical fabrication of the injection machine.



Figure 4.1 mechanical overview

4.1.1. System specification

The specification of the injection machine will be explained in detail below:

a. Pneumatic

In this experiment pneumatic serves, as shown in Figure 4.2, the cylinder pneumatic function is to push the plastic resin that has been melted by the band heater into the mould. In this experiment, the pneumatic used has a stroke length of 150 mm and has a diameter of 10 mm.



Figure 4.2 Cylinder pneumatic

b. Band heater

Figure 4.3 shows the Band Heater, band heater is a very important role in this machine. Because this component holds full control in melting the material so it can fit in the mould space, therefore the heater band in use in this experiment is 150 Watts. That can reach around 300°C in 5 seconds.



Figure 4.3 band heater

c. Barrel

In this experiment, the barrel must constrain the plastic resin from leaking so that the pneumatic can fully push the plastic resin to the mould chamber. This barrel has a 160 mm long, 21 outer diameter, 19 inside diameter, and the material is brass, as shown in Figure 4.4.



Figure 4.4 Barrel

d. Nozzle

Nozzle serves to deliver a plastic resin driven by pneumatic to fit into the mould. Its large hole to be able to drain plastic resin is 3 mm, 5cm long and 7cm in diameter and has a brass material, as shown in Figure 4.5.



Figure 4.5 Nozzle

e. Hopper

Figure 4.6 is the Hopper. Hopper is a funnel for plastic resin so it can be channelled to the injection chamber



Figure 4.6 Hopper

4.1.2. Overall system work

The process of the whole system as can be seen from Figure 4.7. as shown in the block diagram below, that first pours plastic resin on the barrel and setting the temperature according to the inserted material. After the plastic resin is inserted into the barrel the microcontroller waits for input from the sensor indicating that the temperature has reached x $^{\circ}$ C then the microcontroller activates the relay to push the pneumatic to the melted plastic resin is ready to be pushed into the molding chamber after all ingredients have entered the mold available then the relay is turned off then pneumatic back to starting position.



Figure 4.7. the overall system work

4.2. Experimental Result

This experiment was done under two conditions. The first condition is the condition of the open loop, it means that the band heater is on without temperature limit. So the temperature keeps increasing, to the maximum. From figure 4.8 shows two lines, the blue line indicates the sensor near the heater, and the orange coloured line shows the sensor in the die/nozzle. The second condition is the closed loop condition shown in Figure 4.8 In this condition the system has been limited or has been controlled with the PID control system.

On the blue and colored lines show two different sensors. The blue one is the sensor that is attached to the engine and the orange line is an additional sensor to test whether the sensor installed on the machine has good accuracy or not. From the graph below shows that there is a temperature difference on the sensor and the additional sensor is 21 $^{\circ}$ C

The graph shown in figure 4.8 is an open loop system, this condition is very dangerous to the engine because the temperature generated by the heater band can damage the barrel or material because the temperature is too hot therefore the temperature needs to be controlled. In graph 4.9 shows a graph of a system that is controlled (closed loop). Can be seen on the highest temperature graph is $199 \degree C$ degree, this is the optimal condition desired from the system. The temperature measurement graph on the die is not smooth results, as shown in Figure 4.8 and 4.9 with the red circle. This condition happened since the temperature sensor is not attached to the perfect die. The slight shift leads to measurement error at the temperature tool. However, in the thermocouple, this condition does not happen, because the sensor remains permanent in the barrel.



Figure 4.8 Open loop system temperature analysis



Figure 4.9 Closed loop system temperature analysis

4.3. Experimental analysis

An injection machine is a machine for melting a plastic resin so that the liquid form of it can move and can enter the moulding chamber. Surely this machine definitely requires to temperature stability. Therefore, this experiment will focus on temperature control of this machine in order to melt the plastic resin perfectly.

In the experiments conducted have obtained a graph showing the results of the two systems. The first does not use any system control and the second uses the PID control system. The results can show that the system is not controlled, the temperature continues to grow indefinitely. This condition is very dangerous because it can damage the components contained in this injection machine can also damage the product to be produced, therefore the control system is in need in this experiment.

Therefore, the PID controller is installed in the system, in order to control the Temperature of the system to behave as the desired material. The coefficient PID is determined based on the experiment. The chosen coefficient is the one with the best performance of the temperature to achieve the desired temperature based on the material.

Figure 4.9 shows that the system can be stable in the temperatures of 199 $^{\circ}$ c. This proves that the temperature is in accordance with the desired. Once the system has been controlled, then the system will be stable at a certain temperature. Because the temperature is stable in that condition then the components can be maintained condition and the resulting product also has good quality.

5. Conclusions

In this work, the injection machine which priority for lower middle market plastic production, is developed. The temperature of the melting process and the pneumatics are controlled, in order to have good and effective plastics production. The injection machine in this project is developed for middle-lower business which has middle size production. The prototype of the plastic injection machine for middle-low size business is developed. The model of the proposed system used in the proposed system discusses in detail. Finally, the performance of the proposed injection machine is evaluated experimentally.

The result shows that the system which not applied PID control system is cannot be controlled, the temperature continues to grow indefinitely. This condition is very dangerous because it can damage the components contained in this injection machine can also damage the product to be produced, therefore the control system is in need in this experiment. The condition which applied PID will be stable at a certain temperature. Because the temperature is stable in that condition then the components can be maintained condition and the resulting product also has good quality.

6. Future Work

In the future, it is needed to evaluate the safest and the comfort of the injection machine, since it is related to a very high temperature which could be more than 100°C.

References

- Bannister, E. L., Jones, R. N., & Bagwell, D. W. (1963). *Heat Transfer, Barrel Temperatures and Thermal Strains in Guns*.
- Control Station. (2015). Common Industrial Applications of PID Control. Retrieved June 26, 2018, from https://controlstation.com/pid-control/
- Dubay, R., Pramujati, B., & Hernandez, J. (2005). Cavity temperature control in plastic injection molding. *IEEE International Conference Mechatronics and Automation*, 2005, 2(July), 911–916. https://doi.org/10.1109/ICMA.2005.1626673

Dyneon GmbH. (2013). Injection Moulding Handbook. Injection Moulding Book, 40.

- Endarwati, O. (2017). Peluang Investasi Industri Plastik Masih Terbuka.
- Fatma, S., Karim, A., Jamaludin, A., Abdullah, Z., & Talib, N. (2017). Comparison Effectiveness of PID, Self-Tuning and Fuzzy Logic Controller in Heat Exchanger. *Journal of Applied Environmental and Biological Sciences*, 7, 28–33.
- Gulo, W. (2000). Buku Metodologi Penelitian. Penerbit Universitas Negri Malang (UM Press).
- Injection Molding Machine. (2016) (p. 66).
- Isermann, R. (1989). Digital Control Systems. https://doi.org/10.1007/978-3-642-86417-9
- Jansen, K. M. B. (1995). Heat transfer in injection moulding systems with insulation layers and heating elements. *International Journal of Heat and Mass Transfer*, 38(2), 309–316. https://doi.org/10.1016/0017-9310(95)90021-7
- Jiang, W., & Jiang, X. (2012). Design of an intelligent temperature control system based on the fuzzy self-tuning PID. *Procedia Engineering*, 43, 307–311. https://doi.org/10.1016/j.proeng.2012.08.053
- John W. Creswell. (2017). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. *Journal of Social and Administrative Sciences*. https://doi.org/10.1453/jsas.v4i2.1313
- Kangaranifarahani, M., & Mehralian, S. (2013). Comparison Between Artificial Neural Network and Neuro-Fuzzy

for Gold Price Prediction.

Kibria, S. (2013). Speech Recognition for Robotic Control (Vol. 3). Umea University.

- Kong, S., Application, F., & Data, P. (2011). (12) United States Patent. United States Patent. https://doi.org/10.1016/j.(73)
- Ling, W. (2013). PID Control of Hybrid Injection Molding Machine Temperature. *Advanced Materials Research*, 753–755, 2607–2611. https://doi.org/10.4028/www.scientific.net/AMR.753-755.2607

Mahto, P. K., & Murmu, R. (2015). Temperature Control for Plastic Extrusion Process, 5748–5758. https://doi.org/10.15680/IJIRSET.2015.0407052

- Maries, G. R. E. (2013). The influence of the injection processing temperature on the thermal stability of polymers used in the manufacture of items in the automotive and sports industry. *Machine Design*, 5(1), 37–42.
- Martinez, I. (2018). Thermal effects on materials. ETSIAE-UPM, Ciudad Universitaria.
- Mohamed, N. M. A., Abdalaziz, A. A. A., Ahmed, A. A., & Ahmed, A. A. (2017). Implementation of a PID control system on microcontroller (DC motor case study). *Proceedings - 2017 International Conference on Communication, Control, Computing and Electronics Engineering, ICCCCEE 2017*, (1), 2–6. https://doi.org/10.1109/ICCCCEE.2017.7866088

Ogata, K. (2010). Modern Control Engineering. https://doi.org/10.1109/TAC.1972.1100013

- Parkale, Y. V. (2012). Comparison of ANN Controller and PID Controller for Industrial Water Bath Temperature Control System using MATLAB Environment, 53(2), 1–6.
- Rosato, D. V., Rosato, D. V., & Rosato, M. G. (2000). *Injection molding handbook* (3rd ed.). Kluwer Academic. https://doi.org/10.1007/978-1-4615-4597-2

Sanjaya, M. W. S. (2016). Robot Cerdas berbasis Speech Recognition. Andi OFFSET.

Sheikh, M. S., & Sharma, P. (2015). Design Analysis for Components of Pneumatic Injection Moulding Machine Using Pro-E. *International Journal of Innovation in Engineering Research and Technology (IJIERT)*, 2(7), 1–8.

- Stopford, C. W., Darling, C. R., Arthur, G., Priest, J. H., & Awbery, J. H. (2016). Research on temperature control with numerical regulators in electric resistance furnaces with indirect heating Research on temperature control with numerical regulators in electric resistance furnaces with indirect heating. https://doi.org/10.1088/1757-899X/106/1/012014
- Teklehaimanot, S. (2011). Simulation and Design of a plastic injection Mold.
- Vieirat, J., Dias, F., & Mota, A. (2003). Comparison Between Artificial Neural Networks and Neuro Fuzzy Systems in Modelling and Control: A case Study. *Intelligent Components and Instruments for Control Applications*, 249–255. https://doi.org/10.1016/S1474-6670(17)32543-0