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Design of feed rate control system on loss in weight feeder using programmable logic controller

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Abstract

In the industrial world where there is a material process or solid product, it definitely requires a consistent material distribution process to be used in the next process. And to move material from the main storage area, it is necessary to use a tool commonly called a feeder machine or loss in weight feeder. This tool has a feeder system consisting of a hopper and a feeder mounted on a load cell with high accuracy. So in this study, a feed rate control system was designed on the loss in weight feeder to keep the feed rate process at the desired value, so there is a controller to regulate the motor speed in the feeder. To run the control system, a parameter control is needed, namely PID. In this study, in designing the PID controller using direct synthesis tuning which will be carried out using two methods in producing a plant model, namely the process model, the proportional gain (K_p) value is 38.7, integral gain (K_i) is 0.6, and derivative gain (K_d) is 0.6. K_d of 8.12. And the plant structure model of the Auto Regressive eXogenous (ARX) model, the proportional gain (K_p) value is 13, the integral gain (K_i) is 0.78, and the derivative gain (K_d) is 12.85. Based on direct testing, the PID controller parameter that is suitable and reliable with the desired process response from the feed rate output from the loss in weight feeder prototype is the PID controller parameter using direct synthesis tuning based on the plant process model. In the system test without disturbance, it produces a time constant (τ) of 3 seconds, settling time (t_s) of 5 seconds, delay time (t_d) of 1.5 seconds, overshoot (M_p) of 79.92% and steady state error (ess) of 0%. And when testing the prototype by providing interference, it shows a fairly good interference rejection.

Keywords:

Loss in weight feeder, feed rate, PID controller, direct synthesis.

1 Introduction

Loss in weight feeder is a device with a feeder system consisting of a hopper and a feeder installed on a load cell that is often used to deliver goods or products at the specified feed rate with great precision. The motor of the loss in weight feeder must be regulated in order to achieve the desired feed rate [1]. A Loss in weight feeder is an alternative to a weight feeder conveyor for businesses that wish to supply materials or goods with a high feed rate precision and greater tool durability. Consequently, we want a controller that successfully controls the feed rate on the loss in weight feeder and meets the specified performance

parameters. Loss in weight feeder is utilized extensively in industries. In the pharmaceutical business, for instance, loss in weight feeder adjusts the feed rate of a mixture of chemicals A and B [2]. In the cement business, the loss in weight feeder regulates the feed rate of raw cement during the blending process [3], whereas in the plastics industry, it regulates the feed rate of plastic seeds before entering the pelletizing process. Because the loss in weight feeder is a feeder whose performance is unaffected by the density of the regulated material or product, it has several applications in industry.

The Programmable Logic Controller (PLC) is one of the most popular control systems [4], [5]. PLC is an electronic system with the digital operation. It can hold internal instructions that accomplish specialized functions like as logic, sequencing, timing, counting, and arithmetic operations to control machines or processes via digital or analog I/O modules [6]. According to a survey, 97% of industries that engage in control employ PID for their control. The simplicity of the PID control framework, where only three primary parameters must be modified or tuned to achieve the desired system performance [7]. According to Gozali (2005), direct synthesis is one of the ways for building a PID controller. Only the actual and intended plant models are required for this method [8]. The Direct Synthesis (DS) method is used to design or tune controller parameters based on the correlation between plant parameters and the closed-loop system. This technology has been utilized for steam temperature control in superheater in power plants and yields a satisfactory performance response, with an inaccuracy of 0.41 percent. Tuning using direct synthesis is frequently used for tuning the PID controller because it can provide a PID controller with a good response and has a good capacity to keep the response at the target value if a disturbance occurs. Utilizing PLC Outseal for motor speed control with 92.7% efficiency on conveyors can be simple [9]. PLC Outseal is an automatic sorting device that separates things based on their size [10].

In this study, a feed rate control system was built for the loss in weight feeder to maintain the feed rate process at the appropriate value; consequently, the motor speed in the feeder is regulated by a controller. To operate the control system, PID parameter control is required. In this study, the Auto Regressive eXogenous (ARX) model and the process model will be used to create a plant model to build a PID controller using Direct Synthesis tuning. Based on direct testing, the PID controller parameter utilizing direct synthesis tuning for the plant process model that is suitable and reliable with the intended process response from the feed rate output of the loss in weight feeder prototype is the PID controller parameter. In the disturbance-free system test, the time constant (τ) is 3 seconds, the settling time (t_s) is 5 seconds, the delay time (t_d) is 1.5 seconds, the overshoot (M_p) is 79.92%, and the steady state error (ess) is 0%. And when the prototype is tested by introducing interference, it exhibits a reasonable level of interference rejection. In addition, the human-machine interface has been created for real-time process monitoring.

2 Research Methods

2.1 Prototype Design

Loss In Weight (LIW) feeder is a tool with a feeder system consisting of a hopper and a feeder installed on a load cell that is often used to deliver goods/products at the appropriate feed rate with great accuracy. When the LIW feeder is in continuous operation, correct gravimetric functioning can be obtained by regulating the feeder speed to give a steady decrease in hopper weight. The setting of the feed rate is mostly determined by closed-loop control in order to deliver the product at the specified feed rate. The purpose of the design is to determine the PID controller's output. Based on the Outseal Mega V1.2 PLC, the

controller was created using direct synthesis and may be used to the feed rate control system on the loss in weight feeder. Regarding the design of this research, both hardware and software design are included.

Fig. 1 depicts a prototype of the loss in weight feeder 3D design's feed rate control mechanism. Where the product or substance utilized is pulverized sand. A calibrated load cell sensor determines the weight of the product when it is loaded into the hopper.

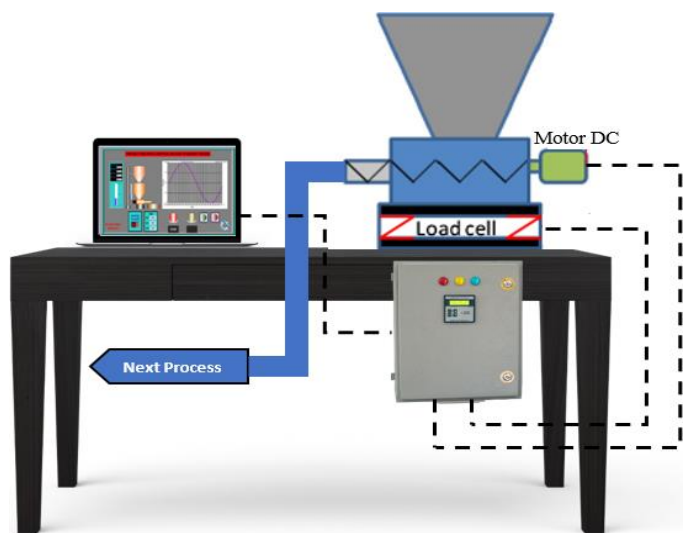


Fig. 1. Loss in weight 3D design.

If the start button is clicked, the PLC Outseal Mega V1.2 will receive three raw data to be converted into process variables: the beginning weight, the actual weight per second, and the running time. Then, this raw data are transmitted to Haiwell Cloud Scada. Develop on PC to calculate the value of the feed rate. The findings of the feed rate value are transmitted back to the Outseal Mega V1.2 PLC for incorporation into the PID controller ladder diagram. In order to regulate the output feed rate of the loss in weight feeder prototype, a PID controller is incorporated in the Outseal Mega V1.2 PLC to regulate the rotational speed of the DC motor so that the output feed rate process matches the specified set point. Electric motors are commonly employed in small companies, such as onion-chopping machines [11]. Fig. 2 depicts the loss in weight feeder prototype hardware implementation.



Fig. 2. Loss in weight feeder prototype.

Fig. 3 is a wiring diagram of the loss in weight feeder's feed rate control system. The installation of component wiring must adhere to the specified design shown in Fig. 3. Errors in the wiring system might lead to malfunctioning components. In the loss in weight feeder prototype, the PLC Outsell Mega V1.2 serves as the

principal controller. PLC Outsell Mega V1.2 functions to provide a signal to the BTS7960 module driver for driving a DC motor and to receive PV signals from the output of the weight transmitter. The Outseal Mega V1.2 PLC interfaces with a PC running the Haiwell Cloud Scada Develop program through a USB cable via the Modbus RTU protocol. The master will be Haiwell Scada Cloud Develop and the slave will be PLC Outsell Mega V1.2. Haiwell Cloud Scada Develop can not only monitor PLC Outsell Mega V1.2, but also issue commands to it [9, 10].

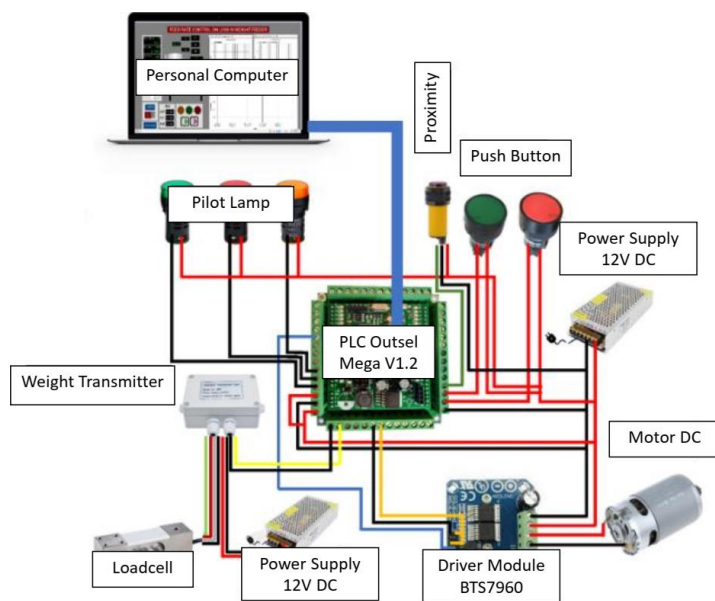


Fig. 3. Wiring diagram.

This research utilizes two applications, namely Outseal Studio and Haiwell Cloud Scada Develop. Outseal Studio is used to program the Outseal Mega V1.2 PLC to load controller operations, such as accepting input from push buttons, raw data signals from load cell sensors, and transmitting MV signals from the PID controller algorithm computation to DC motors. Utilizing the Haiwell Cloud Scada Develop software, a temperature software interface is developed. The interface or monitoring system is implemented via the Haiwell Cloud Scada Develop software, which reads addresses adapted to the ladder diagram of the Outseal Nano V5.2 PLC controller. On the monitoring display, the data received by the controller is displayed as numbers and reaction graphs from set points, process variables, and manipulated variables in real-time trends, and the user can view the past on the historical trend.

2.2 PLC Outsell Mega V1.2

PLC Outsell Mega V1.2 is a CPU Atmega128a-based tool with extra devices that are safe for usage in industrial settings. The utilized bootloader is of type optiboot. The digital input of the Outsell PLC Mega V1.2 is optically isolated using an optocoupler and conforms to the technical requirements of International Standard IEC 61131-2. Digital output in the form of NPN transistors with current management to prevent issues caused by overloading or short-circuiting.

For PLC Outsell Mega V1.2, the external power supply voltage can range from 9 to 24 Volts. As a replacement for a linear regulator, the Outsell Mega V1.2 PLC includes a switching buck converter that generates less heat than a linear regulator and can accept a power supply voltage of up to 24 Volts. In the loss in weight feeder feed rate control system study project utilizing a single power supply, the GIN must be connected to the PLC ground to activate the digital input because it is of the sinking variety. This input device functions as a current drain (negative provider), and since the digital output on the PLC Outsell Mega V1.2 is an open collector NPN type, X1+ must be connected to a positive power source via a 0.75 mm jumper connection.

2.3 Sensor load cell 50 Kg

The sensor is the first measurement equipment to make direct contact with the process. The measurement system comprises of instruments that detect environmental activities and turn them into data that can be recorded or saved. The primary role of the sensor is to detect the measured process value with precision. PLC Outseal Mega V1.2 may connect or detect a variety of sensors, enabling the presentation and monitoring of sensor data via a display or HMI. PLC Outseal Mega V1.2 can detect the sensor's value and indicate that it falls within the higher and lower thresholds.

A load cell sensor is a common form of load sensor that converts a load or force into an electrical voltage change. Variations in electric voltage are dependent on the pressure caused by loading. The sensor of the load cell incorporates a strain gauge, an electrical component used to monitor pressure. The strain gauge circuit is designed as a Wheatstone bridge. If the pressure on the load cell varies, it will have an effect on the Wheatstone bridge's resistance, causing the mV output on the load cell to vary based on the pressure applied to the load cell. The Wheatstone bridge consists of four series and parallel resistors.

2.4 Weight Transmitter

In creating a prototype feed rate control system for a loss in weight feeder, a 50 kg load cell sensor and a JY-S60 weight transmitter are utilized to measure the weight of the hopper's product. The weight transmitter JY-S60 amplifies the load cell's mV output signal to V so it may be processed by the Outseal Mega V1.2 PLC. There are ten pins on the weight transmitter JY-S60, five for input and five for output. This weight transmitter requires a 24 V DC power supply from an external source. On the weight transmitter JY-S60, you can additionally specify zero and span for the output voltage or current. The output voltage of the feed rate control system prototype for the loss in weight feeder will be between 0 and 5 Volts.

2.5 Driver Module BTS 7960

In the prototype feed rate control system for the loss in weight feeder, the author needs additional tools to drive the MY6812 12 V DC Motor because the MY6812 12 V DC motor cannot be controlled directly by the Outseal Mega V1.2 PLC. Since the electrical power requirement on the MY6812 motor is quite high while the output power on the Outseal Mega V1.2 PLC is very low, the Outseal Mega V1.2 PLC requires a driver module that can increase the power.

The author uses the BTS 7960 driver module as a result. The BTS 7960 driver module offers various features, including an input voltage range of up to 27 Volts, the ability to output up to 43A, and a compact form that allows for easy mounting, driver, and the user has the option of driving the DC motor forwards or backwards. The BTS7960 driver module features an integrated driver IC in a single package, which works to simplify microcontroller interface in order to show microcontroller input.

2.6 Motor MY6812 12VDC

A motor is a device that converts electrical energy to mechanical energy. The motor consists of two major components known as the rotor and stator. The rotor consists of an anchor coil, whereas the stator consists of a field coil and a frame and cannot revolve. Electromagnetism is the underlying principle of the device's performance.

A DC motor operates on the idea that torque will be generated when a conductor carrying an electric current is put in a magnetic field. When the electric current in the wire is moving away from us (forward), a clockwise magnetic field is created around the wire. In contrast, when the electric current travels in the direction of the wire approaching us (backward), the magnet forms counterclockwise around the wire. In designing a prototype feed rate control system, the loss in weight feeder's output feed rate is adjusted using the MY6812 12 V DC motor.

2.7 Pulley

In the prototype of the loss in weight feeder's feed rate control system, the belt pulley transmission system serves as a reduction in rotation. The electric motor shaft's rotation is gradually slowed by the belt pulley transmission. Slow rotation and movement are best for this machine's operation, hence a low rotational speed is desired. The ratio of the employed pulleys is 1:5, with 1 on the motor pulley and 5 on the screw pulley shaft feeder.

2.8 Power Supply

The power supply is an electronic device that can generate the power necessary for an electronic circuit. The primary function of the power supply or power supply is to convert the AC power to input via cable (alternating). Uninterrupted Power Supply (UPS) applications are examples of frequently used applications. The prototype of the loss in weight feeder feed rate control system needs 12V DC and 24V DC power sources to operate electrical equipment within and outside the panel box.

2.9 Haiwell Cloud Scada Develop

Haiwell Cloud Scada Develop is a framework based on Xiemen Haiwell Technology Co., Ltd.'s industrial automation monitoring and management platform. Using the data link tool from Haiwell, real-time and historical data may be stored in databases like MySQL and SQL server, and data can be transmitted. Haiwell Cloud Scada Develop supports JavaScript, which is a more potent programming language than traditional SCADA, and all resource configurations will be exploited to a greater extent. Haiwell Cloud Scada Develop provides built-in drivers for a variety of industrial equipment and today's prevalent PLC and inverter tools. In this study, Haiwell Cloud Scada Develop is utilized for the monitoring and control of the control system.

2.10 Plant Transfer Function

The transfer function can be determined through data collection utilizing the bump test method. The bump test method involves manually managing the control action of the controller in a stable state and then observing changes in the response process variable until the product in the hopper reaches its minimum limit. In the Matlab system identification tools, the bump test is performed in two different ways [12]. The initial plant bump test data in the form of PV and MV data altered the MV value for 20 trials from 60% to 90%. Fig. 4 shows the outcome of the bump test.

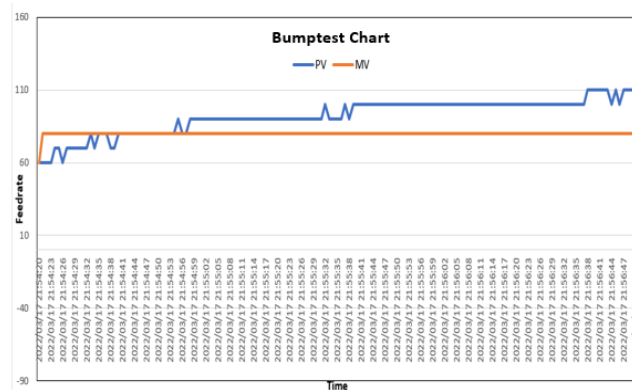


Fig. 4. First bump test result.

From the bump test data, we can obtain the plant transfer function (G_{Plant}):

$$G_{Plant} = \frac{1.3555}{13.0632555s^2 + 61.56293s + 1}$$

Moreover, we do a second bump test by changing the MV value several times as a comparison. The second bump test results can be seen in Fig. 5.

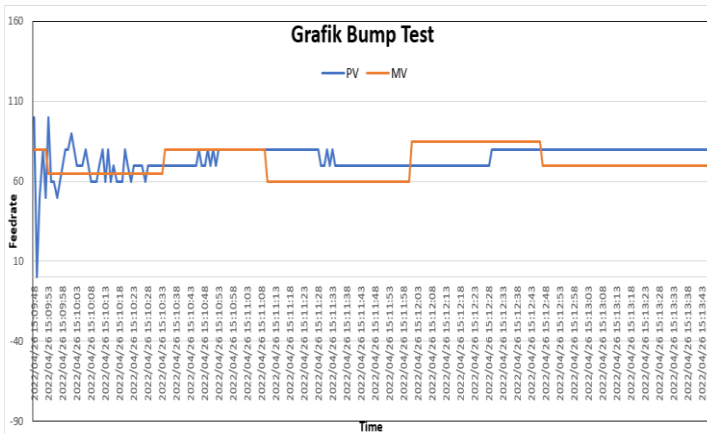


Fig. 5. Second bump test result.

Also, for this second bump test data, we can obtain the plant transfer function (G_{Plant}):

$$G_{Plant} = \frac{1.05523}{16.28442s^2 + 16.46518s + 1}$$

The two transfer functions obtained show that the plant transfer function is a second-order system. So, by using the direct synthesis method [8], [13], [14], the controller needed is a PID controller.

2.11 Sensor Transfer Function

The prototype of the loss in weight feeder employs a 50 kg load cell sensor. The PLC is incapable of analyzing this sensor data. Therefore, a weight transmitter is added to this measurement device in order to increase the sensor output. Utilize the Eq. 1 to determine the model of the load cell sensor and weight transmitter or Gain Transmitter (GT).

$$G_T = \frac{Span_OutputLoadcell}{Span_InputLoadcell} \times \frac{Span_OutputWeightTransmitter}{Span_InputWeightTransmitter} \quad (1)$$

By substituting the sensor and transmitter parameters into the Eq. 1, we can obtain:

$$G_T = \frac{2mV - 0mV}{50kg - 0kg} \times \frac{5V - 0V}{2mV - 0mV}$$

$$G_T = \frac{2mV}{50kg} \times \frac{5V}{2mV} = 0.1$$

2.12 PID Controller Design

From the previous section, we have two transfer function that is obtained from different data as:

1. The first plant transfer function

$$G_{Plant} = \frac{1.3555}{13.0632555s^2 + 61.56293s + 1} \cong \frac{C(s)}{U(s)} = \frac{K}{\omega_n^2 s^2 + \frac{2\zeta}{\omega_n} s + 1}$$

Desired time constant: $\tau^* \approx 1.2$ seconds

Based on the equation below, the values of ζ , ω_n and K can be determined:

$$K = 1.3555$$

$$\frac{1}{\omega_n^2} = 13.0632555$$

$$\omega_n = 0.2766$$

$$\frac{2\zeta}{\omega_n} = 61.56293$$

$$\zeta = 8.514$$

Determine the time integral, time derivative, proportional gain, integral time, and derivative time [15]:

$$\tau_i = \frac{2\zeta}{\omega_n} = 63.06 \text{ seconds}$$

$$\tau_d = \frac{1}{2\zeta\omega_n} = 0.21 \text{ seconds}$$

$$K_P = \frac{\tau_i}{\tau^* K} = 36.7$$

$$K_I = \frac{K_P}{\tau_i} = 0.6$$

$$K_D = K_P \times \tau_d = 8.12$$

2. The second plant transfer function

$$G_{Plant} = \frac{1.05523}{16.28442s^2 + 16.46518s + 1} \cong \frac{C(s)}{U(s)} = \frac{K}{\omega_n^2 s^2 + \frac{2\zeta}{\omega_n} s + 1}$$

Desired time constant: $\tau^* \approx 1.2$ seconds

Based on the equation below, the values of ζ , ω_n and K can be determined:

$$K = 1.05523$$

$$\frac{1}{\omega_n^2} = 16.28442$$

$$\omega_n = 0.247807$$

$$\frac{2\zeta}{\omega_n} = 16.46518$$

$$\zeta = 2.04$$

Determine the time integral, time derivative, proportional gain, integral time, and derivative time [15]:

$$\tau_i = \frac{2\zeta}{\omega_n} = 16.464 \text{ seconds}$$

$$\tau_d = \frac{1}{2\zeta\omega_n} = 0.989 \text{ seconds}$$

$$K_P = \frac{\tau_i}{\tau^* K} = 13$$

$$K_I = \frac{K_P}{\tau_i} = 0.78$$

$$K_D = K_P \times \tau_d = 12.857$$

2.13 Simulation Results

Determine the response characteristics of the feed rate control system on the loss in weight feeder utilizing the two PID parameter techniques derived from the calculations. Next, a simulation is performed using Simulink Matlab by entering the known parameters into the block diagram depicted in Fig. 6.

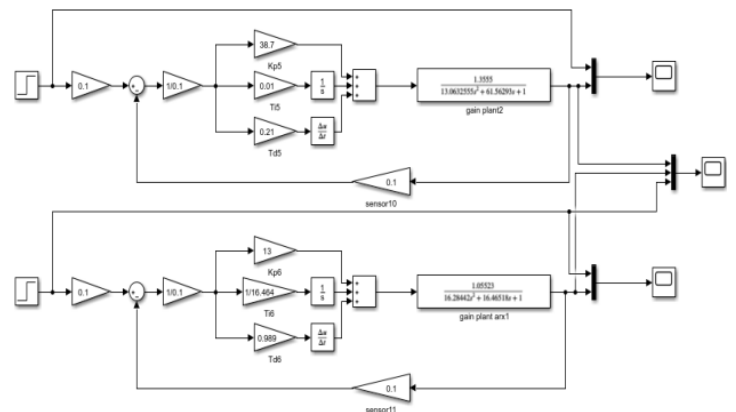


Fig. 6. Block diagram simulation using Simulink in Matlab without disturbance.

Fig. 7 shows the simulation result on feed rate control system without disturbance. The input signal used to test is a step signal with a final value of 1.

From Fig. 7 or the simulation results, it can be seen that the comparison between the two specifications of the feed rate control system response can be seen in Table 1.

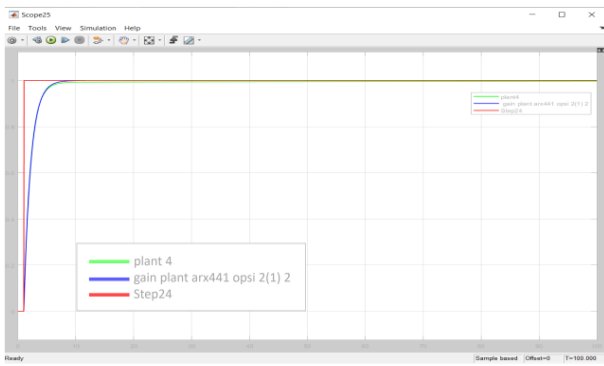


Fig. 7 Control system simulation results without disturbance.

Table 1. Simulation response specification

Specification	Value	
	Gain plant process model	Gain plant structure model ARX
Time constant (s)	2.175	2.956
Settling time (s)	5.6237	5.7166
Delay time (s)	1.8156	1.831
Overshoot (%)	-	-
Error steady state (%)	-	-

The responses of the feed rate control system are susceptible to perturbations, such as a failed filling hopper valve or a change in DC motor voltage. Also, the simulation of the control system was conducted by introducing the disturbance signal. It must be performed to determine whether or not the designed PID controller can manage disturbances. Fig. 8 depicts the block diagram for this simulation test.

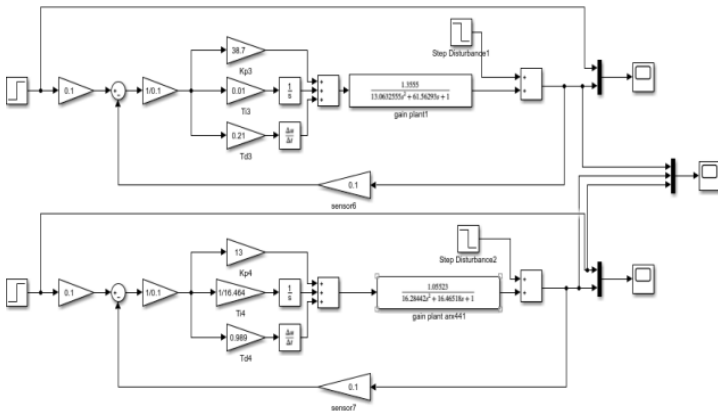


Fig. 8. Block diagram simulation using Simulink in Matlab with disturbance.

The final value of a step signal representing a disturbance was -0.2. Fig. 9 demonstrates that the feed rate control system employing the first PID controller has an undershoot of 20% and a settling time of 85.5 seconds following the disturbance. In the meantime, the feed rate control system, which employs the second PID controller, yielded identical results: a 20% undershoot and a settling time of 85.5 seconds.

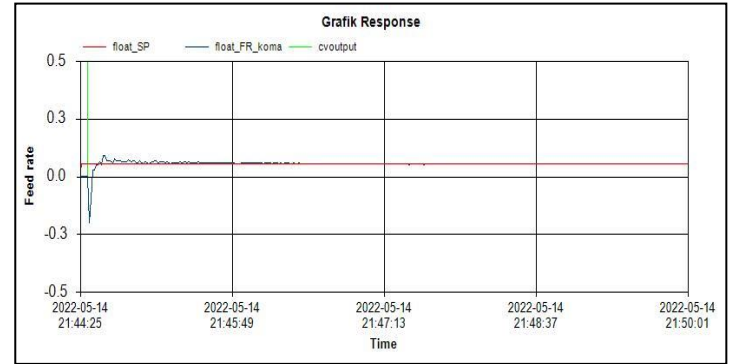


Fig. 9. Control system simulation results with disturbance.

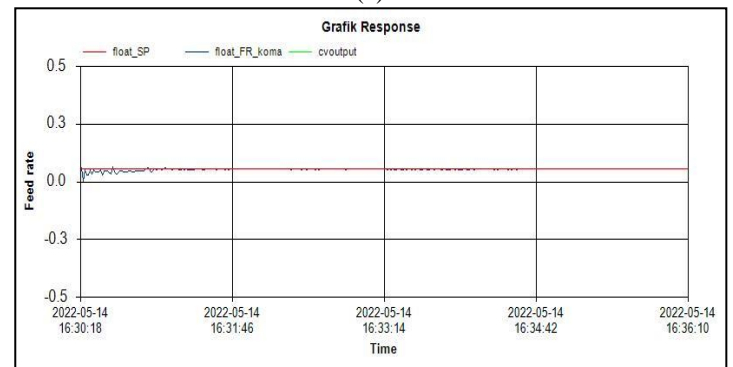
3 Results and Discussion

After simulation testing, prototype testing immediately follows. The two planned PID parameters were entered alternately into the PLC, and a test signal was sent to see the subsequent responses. To ensure the robustness of the PID controller, we had conducted five experiments utilizing different set point values. The initial test was conducted using a fixed set point of 0.052 kg/s. Fig. 10 displays the acquired results, with description:

1. float FR koma is the process variable's change graph
2. float SP is a graph of the specified or desired value
3. cv output is a graph of changes from the final control element or, in this instance, a suction fan.



(a)



(b)

Fig. 10. Prototype first test results by using: (a) first PID parameters, (b) second PID parameters.

From the two experiments conducted separately, it appears that the process variable can match the set point when the experiment is conducted at the set point or desired value of 0.052 kg/s.

The second test was carried out by increasing the set point value from 0.052 kg/s to 0.070 kg/s. The results obtained are shown in Fig. 11, with description:

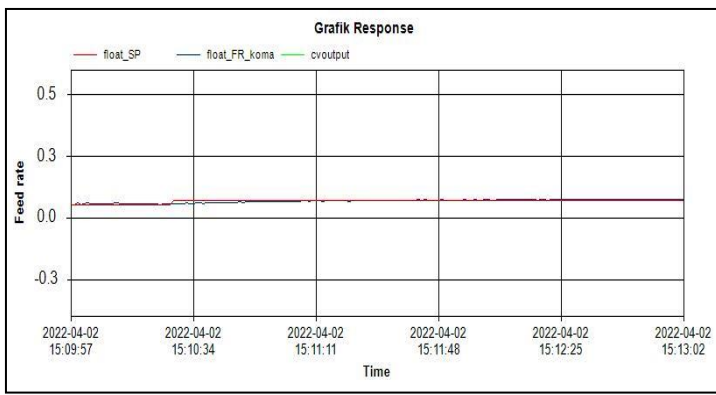
1. float FR koma is the change graph for the process variable float
2. float SP is a graph of the specified or desired value
3. cv output is a graph of changes from the final control element or, in this instance, a suction fan.

From the two experiments conducted separately, it appears that the process variable can match the set point when the experiment is conducted at the set point or desired value of between 0.052 kg/s and 0.070 kg/s.

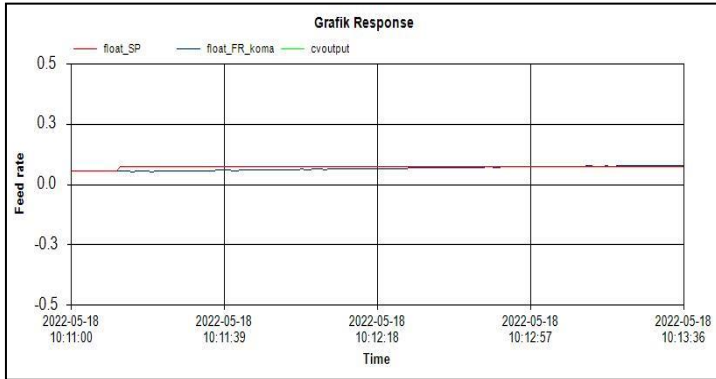
The third test was carried out by lowering the set point value from 0.082 kg/s to 0.070 kg/s. The results obtained are shown in Fig. 12. It is describes:

1. float FR koma is the process variable's change graph
2. float SP is a graph of the specified or desired value
3. cv output is a graph of changes from the final control element or, in this instance, a suction fan.

From the two tests conducted separately, it appears that the process variable can match the set point when the experiment is conducted at the set point or intended value between 0.082 kg/s and 0.070 kg/s.

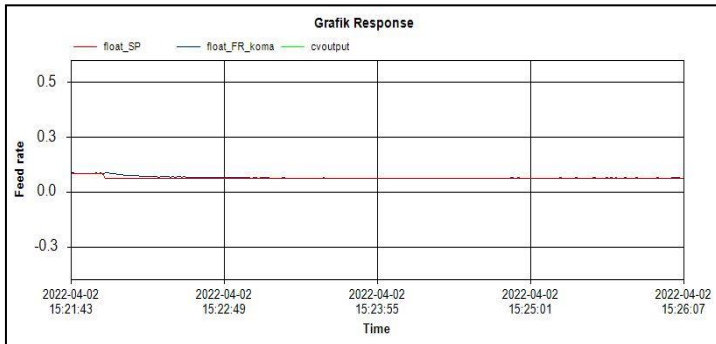


(a)

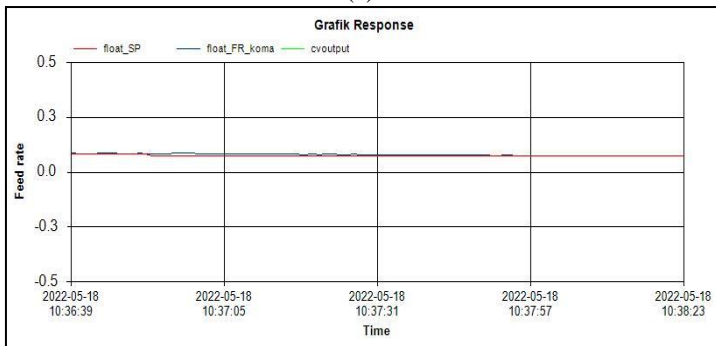


(b)

Fig. 11. Prototype second test results by using: (a) first PID parameters, (b) second PID parameters.



(a)



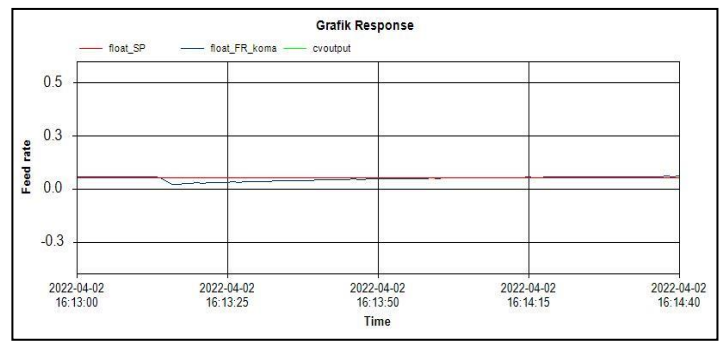
(b)

Fig. 12. Prototype third test results by using: (a) first PID parameters, (b) second PID parameters.

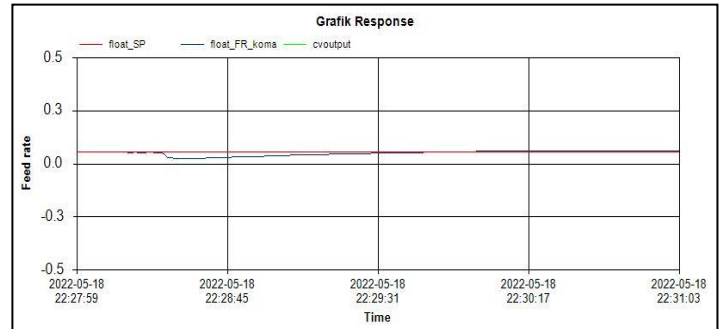
The fourth test was conducted by interfering with the procedure. To create the disturbance, a weight of 4.0 kg of the product was added to the hopper to simulate a filling valve error that caused the product to fall into the hopper. Fig. 13 illustrates the results achieved.

It is described:

1. float FR koma is the process variable's change graph
2. float SP is a graph of the specified or desired value
3. cv output is a graph of changes from the final control element or, in this instance, a suction fan.



(a)



(b)

Fig. 13. Prototype fourth test results by using: (a) first PID parameters, (b) second PID parameters.

Based on the two studies conducted at different times, the process is disrupted when the experiment is conducted. The disturbance was made by adding 4.0 kg of product to the hopper to imitate a tiny filling valve fault that causes the product to fall back into the hopper so that the process variable can match the set point.

The fifth test was conducted by introducing another process disturbance. This disturbance was produced by decreasing the input voltage of the DC motor to simulate a voltage drop. Fig. 14 depicts the achieved outcomes.

It is described:

1. float FR koma is the process variable's change graph
2. float SP is a graph of the specified or desired value
3. cv output is a graph of changes from the final control element or, in this instance, a suction fan.

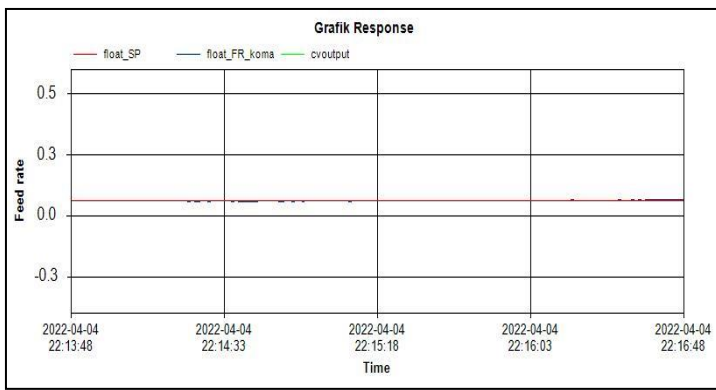
From the two tests conducted at different times, it appears that when the experiment is conducted, another disturbance is introduced into the process. This disturbance was generated by lowering the input voltage of the DC motor to simulate a voltage drop; thus, the process variable can meet the set point.

In chapter 2.2, the plant transfer function model was built from two sets of data gathered from different bump tests. The first model was generated using the data from the process model, while the second model was created using the data from the ARX model. The two plant models were generated using distinct bump testing. Using the direct synthesis approach, two PID parameters are derived from the two plant models using the same tuning results. The first model yielded the PID parameters: $K_p = 38.7$, $K_i = 0.6$, and $K_d = 8.2$. The second gave us $K_p = 13$, $K_i = 0.78$, and $K_d = 12.85$. With these two PID parameters, simulation and prototype testing have been conducted.

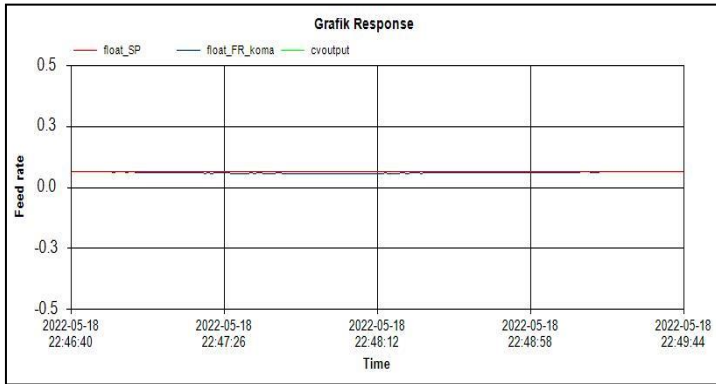
Various PID parameter settings will result in distinct process responses. The prototype feed rate control system operates based on the specified set point feed rate output. The value of the feed rate is derived from the calculation of the lost weight divided by the running time of the tool, using the Eq. 2 [16].

$$\text{Feedrate} = \frac{dw}{dt} \quad (2)$$

To accomplish the set point, the PID controller in the PLC will calculate the feed rate error. The PID controller uses this error value to adjust the DC motor's MV value.



(a)



(b)

Fig. 14. Prototype the fifth test results by using: (a) first PID parameters, (b) second PID parameters.

According to chapter 3, multiple tests have been conducted to identify which PID parameter is the most appropriate and reliable for the plant. Based on a comparison of these data, it has been determined that the reaction of the two PID controllers built can modify the MV such that the PV feed rate can catch up and meet the set point, as depicted in Table 2.

According to the basic design, Table 2 reveals that the response of the first PID controller has superior performance specifications: zero offsets, faster settling time, and faster delay time. However, the time constant is longer than anticipated, and there is a 79.92% overshoot when the prototype begins to run. In the meantime, the response of the second PID controller has lower performance characteristics than the initial design: the time constant, settling time, and delay time are longer than the initial design, and an overshoot of 19.23% arose when the prototype was beginning to run. The initial pulse of the DC motor rotating to adjust the PV at the set point creates an overshoot, which disturbs the load cell reading [17]. So that peaks on the PV feed rate graph appear up or down. On average, the prototype feed rate control system requires between 10 and 15 seconds to respond to this scenario. The PLC is set to increase MV by 32% in the first three seconds of the prototype's initial run to lessen the peak.

Table 2. Responses characteristics

Specification	Value	
	Gain plant process model	Gain plant structure model ARX
Time constant (s)	3	3
Settling time (s)	5	9
Delay time (s)	1.5	2
Overshoot (%)	79.92	19.23
Error steady state (%)	-	-

When a disturbance was introduced to systems using the initial PID parameters, a 57.6% undershoot was observed. Nonetheless, the PID controller can handle the situation and returns the response to a steady state value for 33 seconds. The second PID

parameters have an undershoot of 57.69% and a settling time of 56 seconds under identical conditions. To test the systems, a unique disturbance was added. It is a dip in voltage. To replicate a voltage drop, the DC motor input voltage was lowered to 1.97 V. The initial PID parameters result in a response with an undershoot of 8.06 percent and a settling time of 35 seconds. The second set of PID parameters produces a response with an undershoot of 12.9% and a settling time of 136 seconds.

According to these test results, the first PID settings are more appropriate and trustworthy than the second. The PV response generated by the first PID is superior to the second, regardless of the presence of disturbances.

4 Conclusion

The first PID settings are more appropriate and dependable based on prototype testing than the second. Both tests with and without disturbance were conducted. The initial PID parameters generate a response with a time constant (τ) of 3 seconds, settling time (t_s) of 5 seconds, delay time (t_d) of 1.5 seconds, overshoot (M_p) of 79.92%, and stable stated error (ess) of 0% in the absence of disturbances. The disturbances were generated by adding some product to the hopper to simulate a minor filling valve fault and by decreasing the DC motor input voltage to simulate a voltage loss. The findings of the prototype tests for these two disturbances indicate a reasonable level of disturbance rejection.

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