Designing and Static Performance Testing of Auger Type Fertilizer Metering Device with PID Control

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Abstract. The rapid development of technology has brought a positive impact on the agricultural sector, primarily through the concept of precision agriculture. Precision fertilization is critical to improving agricultural quality and productivity by adapting the right actions to the right place at the right Time according to land variability. One approach that is considered successful is fertilization based on nutrient adequacy levels, which can provide optimal fertilization recommendations. The purpose of this study is to obtain an auger-type variable rate mating device that can control the dose of granular fertilizer. The results showed that the variable rate metering device auger type that had been tested could work quite well in controlling the dose of granular fertilizer. This can be seen from the static calibration of the auger-type metering device producing a linear correlation of each motor with a correlation equation y = 0.0041x – 0.025 with a coefficient of determination R^2 = 0.9543 and the results of testing stair step response and step response both without fertilizer and with fertilizer show that the system can follow the set point commands given.

1 Introduction

The rapid development of technology has a positive impact on agricultural development. The problem of precision agriculture opens up many possibilities for improving the quality and productivity of agriculture. Precision agriculture is an agricultural concept based on the variability of agricultural land, determining the proper action in the right place at the right Time in the right way.

Fertilization refers to the practice of adding substances to the soil to increase its fertility. Fertilization with the concept of nutrient adequacy level is considered the most successful in predicting fertilization recommendations. Applying the correct dose of fertilizer to soil nutrient conditions will provide maximum production results and can reduce the occurrence of environmental pollution. Manual application of fertilizer results in diverse fertilizer applications and requires much labour, resulting in damaging soil fertility and unbalanced plant growth [1].

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Non-uniform treatment technology, also called VRT, is one of the technologies that has the potential to replace URT (Uniform Rate Technology) uniform treatment technology, especially in VRT (Variable Rate Technology) fertilization treatment. Both variable rate technology (VRT) and integrated application systems provide knowledge that fertilizer application occurs only in specific amounts or doses determined by the location where required. The variable-level system makes it clear, from an agronomic point of view, that fertilization targets are determined by soil test findings and are connected to information systems related to soil nutrient content. The variable tariff system is related, from an economic point of view, to the costs that must be incurred to fertilize an agricultural region. A variable-rate system that considers the environment helps prevent over-fertilization, which can lead to environmental problems [2].

This technology is a component of the precision farming system (also known as precision farming), which is an agricultural system that is now widely developed in countries that are considered developed. VRT technology will be able to produce the proper treatment according to the needs of the plant. Providing the correct application at the right Time, the correct dosage, and the right location are the three critical components involved in delivering the proper treatment. Analysis of soil and plants is necessary for timely application because it is necessary to determine the type and level of nutrients contained in plants, as well as the types and levels of nutrients contained in the soil that plants can still absorb. This is done so that both data sets can be used as a basis for determining the dose that needs to be given [2].

To reduce the negative impact of uniform fertilization, variable rate fertilizer applicator technology that can provide fertilization doses according to plant needs is needed. One part of this technology is a variable rate mating device that functions to ration fertilizer as instructed. In general, the metering device used is the edge cell type, but this type of edge cell has several disadvantages, including fertilizer being easy to accumulate and coagulate. Clumping that occurs continuously leads to clogging and unbalanced application of fertilizers to plants. To reduce the buildup and clumping that often occurs in eddge cell types, an auger-type metering device made of polyline plastic and PVC pipes was developed. Auger-type mating devices can reduce buildup and clumping in fertilizers [3].

Therefore, research was carried out to design a variable rate mating device of the auger type using PID control as a component of precision fertilization so that the application of fertilizer is by the portion or dose needed.

2 Methods

2.1 Place and time

This research will be carried out at the Agricultural Tools and Machinery Workshop Laboratory, Agricultural Engineering Study Program, Faculty of Agriculture, Hasanuddin University from January 2023 to December 2023.

2.2. Materials and tools

The materials used in this study were urea fertilizer, PVC pipe, acrylic, and polyethene plastic.

The tools used in this study are classified into two parts, namely hardware and software. The hardware used includes Arduino Uno, digital scales, an L298N motor driver module, a 12V DC motor With a Rotary Encoder, a laptop, and workshop equipment. The software used includes Fritzing software, Arduino IDE software, and Microsoft Excel software.

2.3. Research procedure

2.3.1 Planning Level

This stage is the stage in designing the design drawings of the tools to be made. The tool design process is carried out by designing roughly on drawing paper, which is then continued by designing the machine using SolidWorks Software. The parts of the auger type Variable Rate Fertilizer Metering Device are as follows,

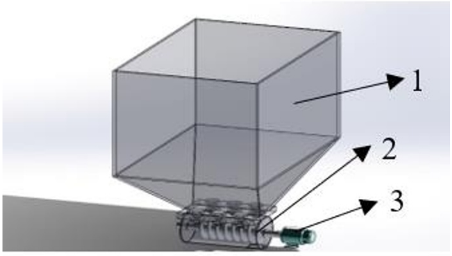

Fig. 1. Design variable rate fertilizer auger type metering device.

Information:
1. Hopper serves to accommodate fertilizer.
2. Auger-type Metering Device serves to distribute fertilizer from the hopper through the auger rotation.
3. DC motor serves to rotate the auger-type mating device.

2.3.2 Functional plan

Functional design is the determination of components in making tools. The following components and functions are made in this study, namely:

Table 1. Component names and their functions.

No	Component	Function
1	Hopper	To contain fertilizer
2	Auger	Serves to distribute fertilizer through the auger rotation
3	Arduino Uno	It functions as a microcontroller that can control the rotation of the motor according to the set point.
4	Modul driver motor DC L298N	It makes it easier to determine the direction of rotation of a DC motor and also precision in controlling the motor so that the motor is easier to control.
5	DC Motor	Serves to rotate the auger-type mating device.
6	Rotary Encoder	Functions to change the angle of position or movement so that it can be processed into information in the form of digital code by the rotary encoder to be forwarded by the control circuit.

2.3.3 Structural plan and technical analysis

Structural Design and Technical Analysis have a function to determine the components and structures of the tool and analyze the materials to be used so that they can be based on the criteria of the tool to be designed. The structural components of the auger-type Variable Rate Fertilizer Metering Device are as follows,

a. Hopper

In the hopper design, there are two parts, namely the trapezoidal prism section and the square part, as seen in Figure 2. Acrylic material was chosen as the material for making hoppers with several considerations, including strong, corrosion-resistant, and translucent. The thickness of acrylic used is 2 mm. In determining the size or dimensions and slope (angle of repose) of the hopper, you must first know the volume of fertilizer to be used.

The dimensions of the hopper include the length, width, height, and slope of the base. Dimensions: The length, width, and height are determined based on the volume of the hopper you want to make. Theoretically, the volume of the hopper can be determined by the equation:

$$V_{hp} = \frac{D_p \times A_p \times 10^3}{n_p \times \rho_p} \tag{1}$$

Information:

Vhp = Volume hopper (cm3)

Dp = Fertilization dose (kg/ha)

Ap = Area of fertilizing land once filling (ha)

n_p = Number of fertilizing machine units

ρp = Bulk density Fertilizer (kg/cm^3)

In determining the dimensions of the hopper, it is necessary to find the volume of the square and the volume of the decapitated prism. Because the hopper part I is square shape to find the volume using the formula:

$$V_I = p\ x\ l\ x\ h \tag{2}$$

Where:

V_I= Square volume

p = Panjang

l = Wide

h = Tall

Because the Hopper part II is in the form of a decapitated prism, to find Volume (V) using the formula:

$$V_{II} = \frac{1}{3} h\left(A_1 + A_2 \sqrt{A_1 \times A_2}\right) \tag{3}$$

Where:

V_{II} = Volume of decapitated prism

A1 = Cover Area

A2 = Base Area

H = Tall

The basis for determining the slope (angle of repose) is to find the smallest tilt angle of the three fertilizers used, namely urea fertilizer [4].

Fig. 2. Hopper design.

b. Auger Type Metering Device

In the design of the Metering Device, this is in the form of an auger, as seen in Figure 3. PVC pipe material and polyethene plastic were chosen as auger manufacturing materials with several considerations, including strength and corrosion resistance. The thickness of PVC pipes in the manufacture of augers is 1 mm and the diameter of polyethylene plastic is 1 cm.

According to [5], the theoretical volumetric capacity of an auger is formulated in Equation 1 as follows:

$$Q_t = \frac{\pi}{4}(d_{sf}^2 - d_{ss}^2) l_p n \tag{4}$$

Where:

Qt = theoretical volumetric capacity (m^3/s)
d_{sf} = Auger outer diameter (m)
dss = Auger shaft diameter (m)
lp = pitch length (m)
n = rotating speed Auger (rev/s)

Determination of the inner diameter and outer diameter is an essential step before determining the volumetric capacity of the auger. To measure the volumetric capacity of the auger, information about the inner diameter and outer diameter is needed using the formula:

Diameter:

$$D = \sqrt{(\pi \times dss)^2 + (lp)^2}: \tag{5}$$

Where:

d = inner diameter (m)
dss = Auger shaft diameter (m)
lp = Auger pitch length (m)

Outer Diameter:

$$D = Ddaun\,auger + d - dss \tag{6}$$

Where:

D = outer diameter (m)
$D_{\text{daun auger}}$ = auger leaf diameter (m)
d = inner diameter (m)
dss = Auger shaft diameter (m)

Fig. 3. Auger type metering device design.

c. Arduino UNO
Arduino Uno is an ATmega328 (datasheet) based microcontroller board. It has 14 input pins of digital output, of which 6 input pins can be used as PWM output and 6 analogue input pins, a 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and reset button. In this study, Arduino Uno functions as a microcontroller brain that can control motor rotation according to the set point. The advantages of Arduino include no need for a programmer chip device because there is already a bootloader in it that will handle uploading programs from the computer. It is enough to connect the USB cable from Arduino UNO to the computer [6].
d. Modul driver motor DC L298N
The L298N motor driver is used to control the speed and direction of rotation of the DC motor. IC L298 is an H-bridge type IC that will be used to control the DC motor load. The L298 IC consists of logical transistors (TTL) with NAND gates that function to make it easier to determine the direction of rotation of a DC motor or stepper motor. The advantage of the L298N motor driver module is in terms of precision in controlling the motor, so the motor is easier to control [7].
e. Motor DC
The DC motor used in this study is a 12V DC motor with a 100:1 gearbox; the maximum rotational speed before the gearbox is 10,000 rpm, the maximum rotational speed before the gearbox is 100 rpm, and the torque is 20 Kgcm. DC gearbox motors are used because they have a working speed that is easily set in a wide speed range and have ample torque that will be used to rotate the auger [8].
f. Rotary Encoder
Rotary encoders use optical sensors to produce a series of pulses that can be interpreted into motion, position, and direction so that the angular position of the motor shaft against the rotating auger can be processed into information in the form of digital code by the rotary encoder to be forwarded by the control circuit [9].

2.4. Stages of tool making

2.4.1 Hopper making

The hopper tool has been successfully made through a series of stages. First of all, it starts with the determination of the volume of fertilizer to calculate the dimensions of the hopper by utilizing equations (1), (2), and (3), which become the basis for accurate design. Next, the bulk angle (Angle of Repose) of urea fertilizer is measured, and the smallest Bulk angle is selected to determine the slope of the hopper, ensuring optimal material flow. After the dimensions and slope of the hopper are known, the next step is to carry out the hopper assembly according to the pre-arranged design. This assembly process ensures the fit of all components for the hopper to function efficiently. Lastly, the hopper has undergone functional testing to see if its performance is according to the desired standards.

2.4.2 Auger making

The process of making the auger has been completed with steps. First of all, it starts with determining the volume of fertilizer as a basis for calculating the dimensions of the auger, following equations (4), (5), and (6) to guarantee the accuracy of the calculation. The next step involves assembling the auger by making sure all components are installed according to the pre-conceived design. After the assembly phase is complete, the tool has undergone functional testing to see its performance.

2.4.3 Control system assembly

The control system assembly process has been successfully implemented through structured steps. The initial stage begins with the creation of a microcontroller design using Fritzing software, ensuring that all components are optimally integrated. After the design is completed, proceed with the assembly of the control system based on the previously prepared design. This assembly process involves precision-assembling and connecting electronic components to ensure continuity of functionality. Furthermore, the assembled control system undergoes meticulous functional testing to see if its capabilities are according to the desired specifications. With the completion of these steps, it can be ensured that the assembly of the control system has been successfully carried out systematically and is ready to be used to control the system effectively.

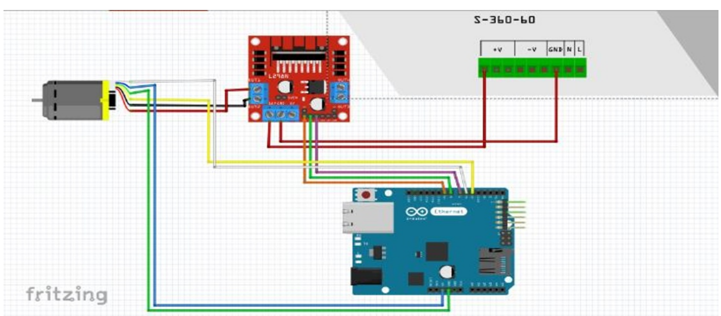

Fig. 4. Control system assembly design.

2.4.4 Tool calibration

The calibration process has been successfully carried out to determine the relationship between the speed of the DC motor and the mass of fertilizer coming out of the metering device. The steps carried out systematically involve the installation of test components as an initial stage. Next, the programming language that is required to set up open-loop controls by using PWM controls is created. The test was carried out by feeding urea fertilizer into the hopper according to its capacity and running PWM controls with varying values (50, 100, 150, 200, 250) for 20 seconds each. This process allows monitoring of the relationship between PWM (Pulse et al.) and RPM (revolutions per minute) DC motors. Next, data analysis was carried out using regression methods to understand the relationship.

2.4.5 Tuning PID (proportional, derivative from integral)

The PID tuning process has been successfully implemented using the Ziegler-Nichols I method on open-loop control without fertilizer. The initial stage involves the installation of testing components to ensure proper setup. Next, a motor control program language using PWM was created to compile open-loop controls. The DC motor is run by a step response method at rotational speeds of 0, 2000, 4000, 6000, and 8000 rpm for 20 seconds, and then the data is measured by a rotary encoder. Analysis of rotational speed data was carried out using the Ziegler-Nichols I method, which allowed the identification of optimal PID parameters. PID tuning is done with precision, ensuring efficient and stable motor response in the face of different rotating speed variations.

The Zigler-Nichols method summarized in Table 2 determines KP, Ti, and Td from an open loop response using the S. Ti and Td curves must be transformed with Equations 7 and 8 to obtain KI and KD for PID control [10].

Table 2. PID Parameter tuning with reaction curve method.

Controller Type	Kp	Ti	Td
P	T/L	~	0
PI	0.9 T/L	L/0.3	0
PID	1.2 T/L	2L	0.5L

$$Ki = Kp/Ti \tag{7}$$

$$Kd = Kp \times Td \tag{8}$$

2.4.6 Tool testing

Tool testing is carried out with urea fertilizer using the stair-step response method, which involves several stages. First of all, the necessary tools and materials for testing are prepared. Next, urea fertilizer is fed into the hopper according to the hopper capacity to ensure suitable test conditions. The metering device is then run at different rotary set-points (0, 2000, 4000, 6000, 8000, 0, 8000, 6000, 4000, 2000 rpm) for 20 seconds at each stage. Data on DC motor speed, Time, and mass of collected fertilizer are then processed to obtain accurate information regarding the response of the tool to variations in rotation and mass of fertilizer.

3 Result

3.1 Tool planning outcomes

The metering device is a component of Variable Rate Fertilizer (VRF) designed to ration granular fertilizer with doses as needed. Therefore, we selected materials from acrylic, polyethene plastic, and PVC pipes. The metering device consists of two main parts, namely the hopper and auger where the hopper is made of acrylic, while the auger is made of polyline plastic and PVC pipe.

Based on the design results, a hopper was made with dimensions of length, width, and height of 30 cm, 20 cm, and 21.96 cm, respectively, as shown in Figure 5. The dimensions of the auger design in Figure 6 are shaft diameter, outer diameter, inner diameter, and pitch length of 10 mm, 28 mm, 11.08 mm, and 15 mm, respectively.

Based on the test results, all components and parts of the machine functioned adequately. The most important parts of the tool are the 12 V DC motor, auger, and hopper.

Table 3. Specification of components.

No	Components	Parameters	Performance
1.	Motor DC	• Tegangan	12 V
		• Maximum speed	10000 Rpm
		• Gear Ratio	100: 1
		• Torsi maximum	34 kg·cm
		• Resolution	64 CPR
2.	Hopper	• Capacity	13 kg

		• Hopper top volume	13175 cm3
		• Hopper bottom volume	3953 cm3
		• Volume total hopper	17128 cm3
3.	Auger	• Theoretical volumetric capacity	0,0029417 m3/s
		• Auger outer diameter	29,08 mm
		• Diameter porous Auger	10 mm
		• Pitch length	15 mm
		• Diameter in Auger	11,08 mm

3.1.1 Hopper

Hopper is a component of variable rate fertilizer that functions to collect fertilizer. The Area of land to be fertilized for 1 allotment is used as the basis for the hopper capacity to be designed at 1300 m2, then the capacity that can be accommodated is 13 kg so that the total volume of the hopper is 17,128 cm3. The basis for determining the dimensions of the hopper size with several considerations is the weight of fertilizer that can be loaded by variable rate fertilizer with a urea density of 0.759 kg / l. Determination of the hypotenuse of the hopper is done using the angle of repose. The seed reservoir (hopper) is made of acrylic material with a thickness of 2 mm. The size of the hopper dimensions can be seen in the following table:

Table 4. Hopper dimensions

Dimension section hopper	Length (cm)	Wide (cm)	Tall (cm)	Hypotenuse length (cm)
Above	30	20	21,96	-
Below	10	3	15,87	31,74

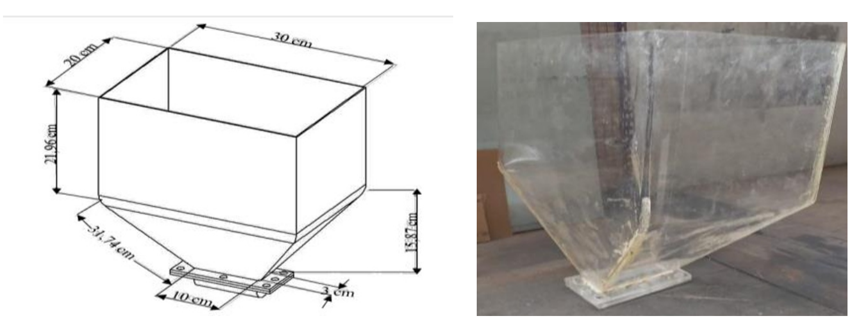

Fig. 5. Results of hopper and hopper design on tools.

3.1.2 Auger

Fertilizer rationing is a component of fertilizer equipment that functions to regulate the dropping of fertilizer in a certain amount and the desired fertilization distance. The type of metering device used is a thread-shaped auger type with material from polyline plastic and PVC pipe.

The primary determination of the dimensions of the metering device is to take the initial dimensions of a pre-existing auger-type metering device with an auger shaft diameter of 10 mm, an auger inner diameter of 11.08 mm, an auger outer diameter of 29.08 mm and a pitch length of 15 mm as the initial basis for designing dimensions as well as the size of the metering device. Then, it is mounted on the lower hopper and rotates along the metering device shaft.

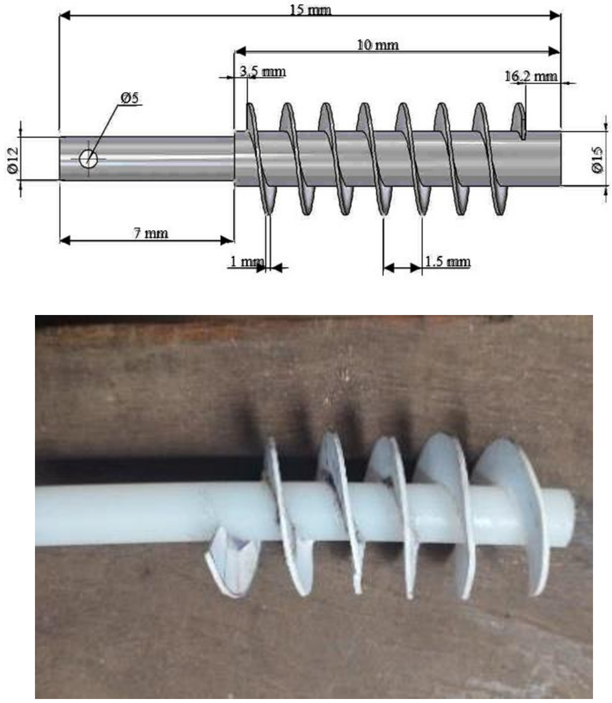

Fig. 6. Auger and auger design results on tools.

3.1.3 Control system assembly results

The design results of the DC motor speed control system can be seen in Figure 7. The hardware system in the plastic container is the control centre that sends control instructions to the DC motor. The actual speedreading results will be displayed on the serial monitor, and setting the speed set point is done by giving a value to the serial monitor. The input voltage given to the motor is a voltage of 12 Volts obtained from the power supply. The rotating motor will send speed data to the microcontroller through a rotary encoder sensor placed on the small axle shaft from the top of the motor.

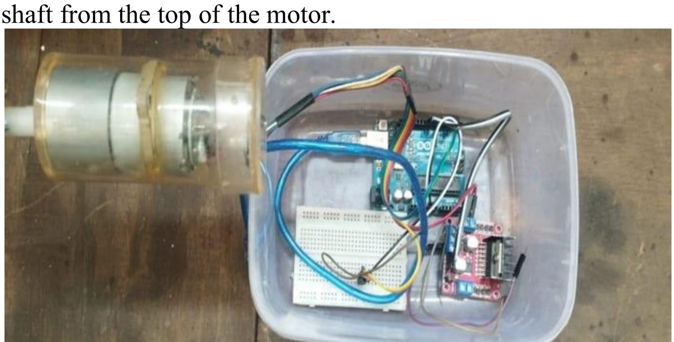

Fig. 7. The results of the assembly of the control system.

The difference in speed read will be the difference in set points, so the control system will send a command to calculate the voltage with the help of the L298N motor driver. This process will continue as long as the motor is working. The DC motor used has a maximum rotational speed of 10000 rpm. Giving different PWM values will provide varying speeds so that this can be used to adjust the speed of the motor.

3.2 Tool test results

This auger-type variable rate fertilizer metering device can be seen as the success rate based on the amount of uniformity of fertilizer that comes out on the hopper. The metering device can rotate according to the set point without fertilizer, and the metering device can rotate according to the set point with fertilizer.

3.2.1 Functional Test

A functional test is a set of activities performed to ensure that a software or system behaves according to predefined needs and functional specifications. To ensure that all desired features and functions work correctly.

3.2.1.1 Tuning PID

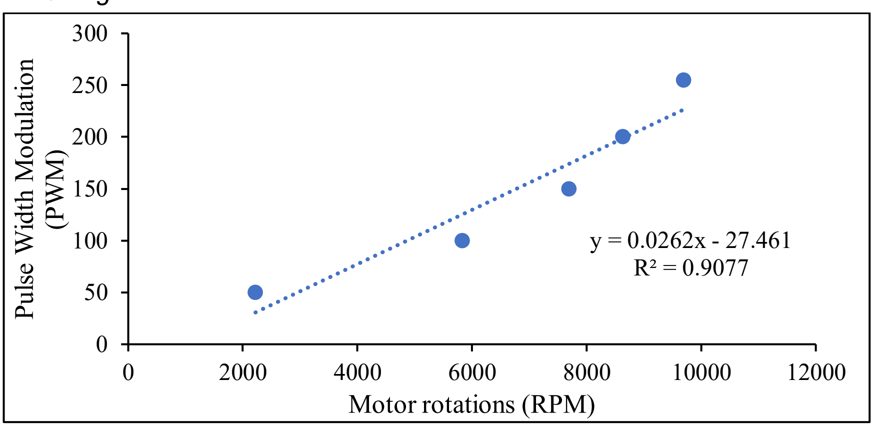

Fig. 8. Graph of PWM's relationship with RPM.

Initially, the Pulse Width Modulation (PWM) value was given to see how the effect of giving PWM values on the speed of this motor can be seen in Figure 8. The appropriate PWM value is given to adjust the speed of the moton. The initial data collection gives PWM between and -255 with an interval of 50 so that the PWM values given are 50, 100, 150, 200, and 250. The test carried out is running the motor that has been installed on the tool frame without loading. The speed of the motor is measured using a rotary encoder speed sensor with a pulse output of 64 per rotation. The data obtained is comparative data between PWM and motor speed which is then reused to find PID constants, namely L (dead Time) and T (delay time).

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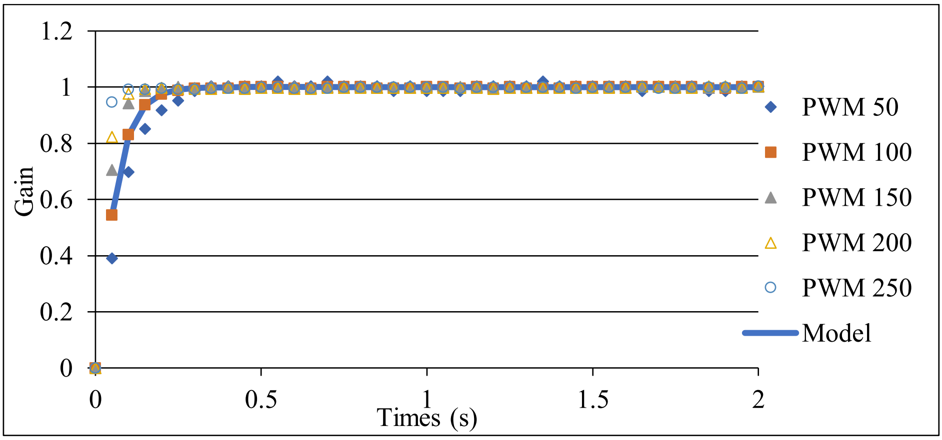

Fig. 9. DC Motor Testing Chart with PWM 50, 100, 150, 200 and 250.

The higher the PWM value given, the greater the speed value produced. The results in Figure 9 of this graph will later be used to obtain the constants Kp, Ti, and Td based on parameter search using the Ziegler Nichols method. In addition, the results of motor speed testing with PWM are also used to perform optimization testing with solvers that help obtain the required PID constants. Based on the test, PWM 100 is the best value to get the desired constant value. The L and T values obtained for the motor are 0.01 and 0.202, respectively. The obtained L and T values are reused to determine the values of Kp, Ki, and Kd using the Ziegler Nichols method with the equations in Tables 1, (1), and (2). The results of these calculations obtained the values of Kp. Ki and Kd, respectively, 0.10966, 0.08876, and 0.05184.

The PID tuning process that has been carried out produces PID constants, which include K, $_P$, KI, and KD. The proof is carried out through a test to see the performance of these constants. In this study, testing was carried out using DC motors.

The test results of the PID constants obtained are shown in Figures 10 and 11. Figure 10 shows the results of testing the speed of a DC motor with a set-point of 2000 rpm. Figure 10 shows a graph of test results with K_P, KI, and KD values of 0.10966, 0.08876, and 0.05184, respectively. The graph shows that the value of the PID constant is quite good in controlling the speed of the DC motor at 2000 rpm, which is characterized by a reasonably fast motor response with a short time delay of about 0.1 milliseconds. However, a swift response has the potential to result in an overshoot. This can be seen in Figure 10, where there is a relatively high overshoot of 71.5% at time t = 0.15 milliseconds. These results show that the overshoot only lasts for 0.15 milliseconds. After that, oscillations occur around the set point for 0.25 milliseconds. After that, the motor speed becomes constant at the set-point value.

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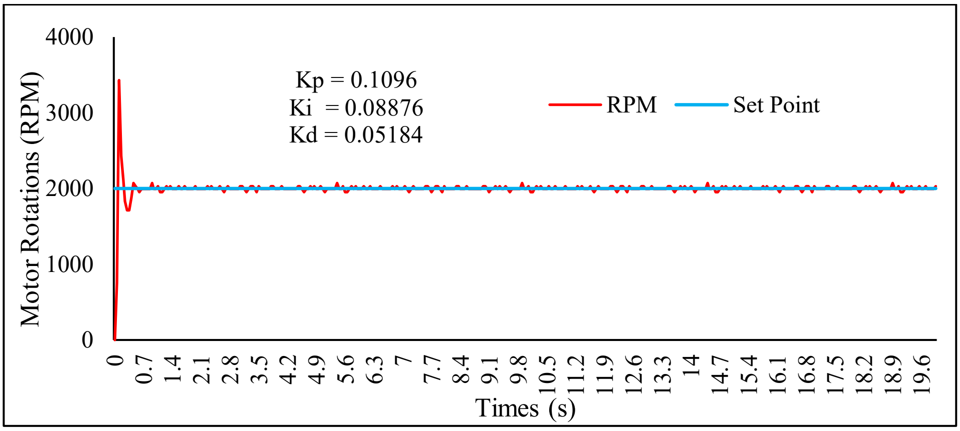

Fig. 10. Control system test chart at set point 2000 RPM.

From testing, the PID constant does not produce steady state error. The results of this test show that changes in the values of the PID constant will significantly affect the control results. The use of a considerable K value will cause an overshoot,t, which is high and increases oscillations. Hence, the use of the K value, the proper KI, and KD will reduce overshoot, eliminate error offset and oscillations, and reduce lag or lag time [11].

Test results with 8000 rpm set-point treatment are shown in Figure 11. Figure 11 is the test result with PID constants of 0.10966, 0.08876, and 0.05184, respectively. The graph shows that the resulting overshoot is smaller than the previous test results, where the overshoot occurred by 2.59% at t = 0.35 milliseconds. Conversely, the speed of the DC motor is not able to reach the set-point value until it is t = 0.3 milliseconds. Two things likely cause this. Namely, the first is that the K_P value used is still tiny for 8000 rpm treatment, so the K_P needs to be increased. However, the use of a more considerable K_P value has the opportunity to increase overshoot and oscillations. The second cause is the initial power of the motor that is not strong enough to reach the set-point value.

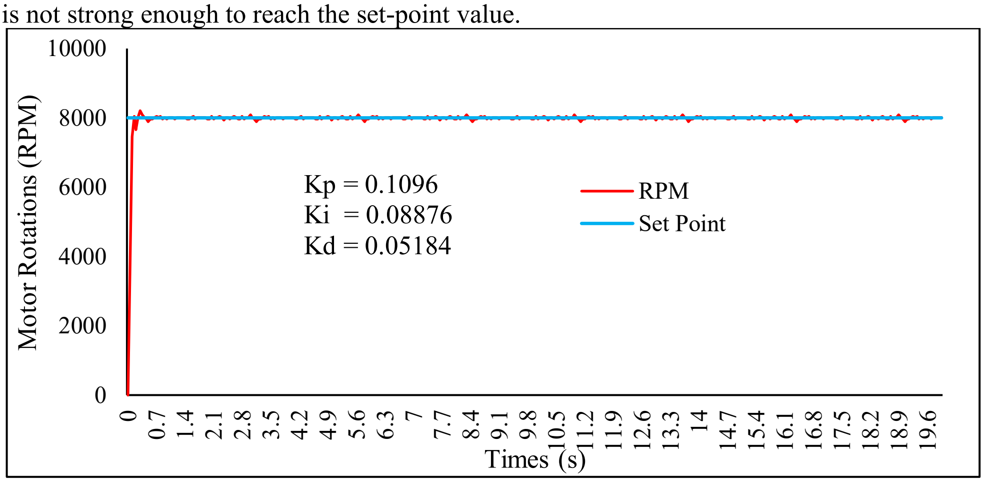

Fig. 11. Control system test chart at set point 8000 RPM.

Both test results also show that the control response to DC motor speed varies for the exact value of PID constants. So, one of the difficulties in the PID tuning process is finding the right combination of PID constants that has the same performance for every change in speed or set-point command.

Table 5. System response testing with pid control on metering device.

Response System Kp = 0.1096 Ki = 0.08876 Kd = 0.05184				
Set point (RPM)	**Rise Time (ms)**	**Settling Time (ms)**	**Overshoot (%)**	**Error Steady State (%)**
2000	0,11	0,34	71,50	-
4000	0,13	0,47	32,90	-
6000	0,15	0,25	11,55	-
8000	0,20	0,5	2,59	-

The test results of the PID constant generally show good performance in controlling the speed of the DC motor. However, the test results also show that the response produced varies for different motor speeds. The performance of the PID constant at a speed of 2000 rpm rise Time produced is excellent but has a very high overshoot. At a speed of 4000 rpm, the resulting rise time is perfect, too, but oscillations occur so that it takes longer to reach settling Time. At 6000 rpm, the resulting overshoot is lower than the previous speed but takes longer to reach the settling Time. At a speed of 8000 RPM, it can be seen that the motor speed does not overshoot and is fast to reach settling Time, but it takes longer than the previous speed to reach rise time. Therefore, it is still necessary to modify the PID constants of the tuning results so that an appropriate combination of PID constants that can control the performance of the DC motor for all set-point values is obtained.

3.2.1.2 Control system testing

The test of this system aims to see the controllability to maintain motor speed at various speed variations against a given set point. Tuning is carried out by closed system testing and is carried out using 11 set points, namely 0, 2000, 4000, 6000, 8000, 0, 8000, 6000, 4000, 2000, and 0 rpm. The test was conducted without using a load; motor darı speed data was recorded on a serial monitor and inputted to a Microsoft Excel PC. The test results can be seen in the following graph:

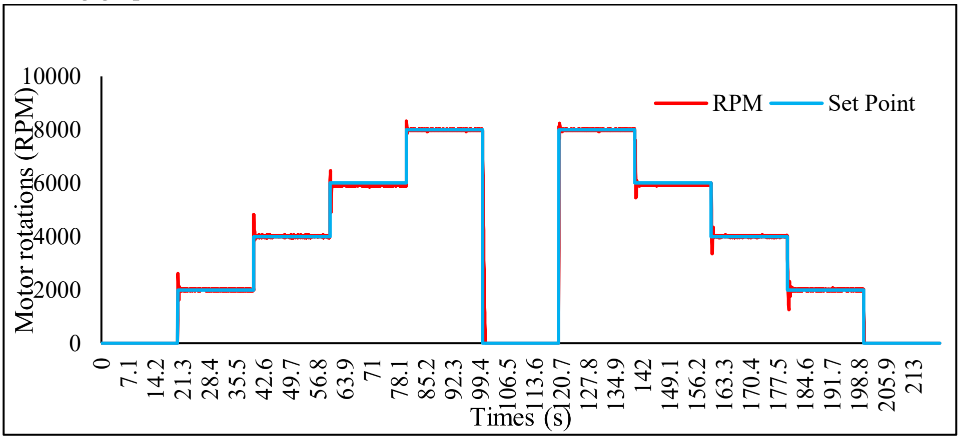

Fig. 12. Graph of DC motor speed test results stair-step response method.

Figure 12 shows the speed of the DC motor concerning Time. It can follow the set point given by the motor response when controlled with PID control, and it gives a good response. When the set point goes up, or the set point goes down, the speed remains stable. When the average rising set point changes overshoot, the response rises more slowly compared to other speed set points.

The results, obtained using the PID control method of the Ziegler-Nichols, provide PID parameter values that can correspond to all desired velocity varıası. Control results show better results without having to tune parameters again. This is to the research of Salim and Pambudi (2014), based on the Ziegler-Nichols method can be applied to the PID parameter tuning process; the PID parameter tuning process can be done shorter without the need for trial and error of Kp, Ki, and Kd parameters Other parameter tuning methods cannot provide a better response when there is a change in speed Need to do further tuning when there is a change in the speed set point. This is undoubtedly a problematic activity because there must be changes in the value of the PID constant, changing the value of the programming language and re-entering the programming language into the microcontroller.

3.2.1.3 Testing tools without fertilizer

Performance testing of tools without fertilizer is carried out with variations in the desired rotation speed divided into 11, namely 0, 2000, 4000, 6000, 8000, 0, 8000, 6000, 4000, 2000, and 0 rpm recorded every 20 seconds. A time of 20 seconds is considered that the system has experienced a stable state. Performance test results tool without fertilizer is shown in Figure 13—testing stair step response without fertilizer for the metering device. The test results show that the speed of the DC motor can follow every command set-point given speed, suitable for step-up and step-down, rapid response to changes in value set-point, and not happen steady-state error. From the chart, it can also be seen that it happens overshoot and oscillations for testing metering devices. Overshoot The highest occurs in each of them metering on value set-point 2000 rpm at t = 0.20 ms, 4000 rpm at t = 0.15 ms, and 6000 rpm at t = 0.20 ms. This is due to the previous position of the motor from the stationary position, so a fast response causes the motor speed to pass the value set-point. In addition, the role of proportional control is to speed up the response of the system but leave overshoot and oscillations. This is to the statement by Bolton (2004) that oscillations occur due to the time lag that occurs in the system so that it gets bigger KP then the more significant the control action for a value error specific so that the chances of the system to pass the value will be even greater.

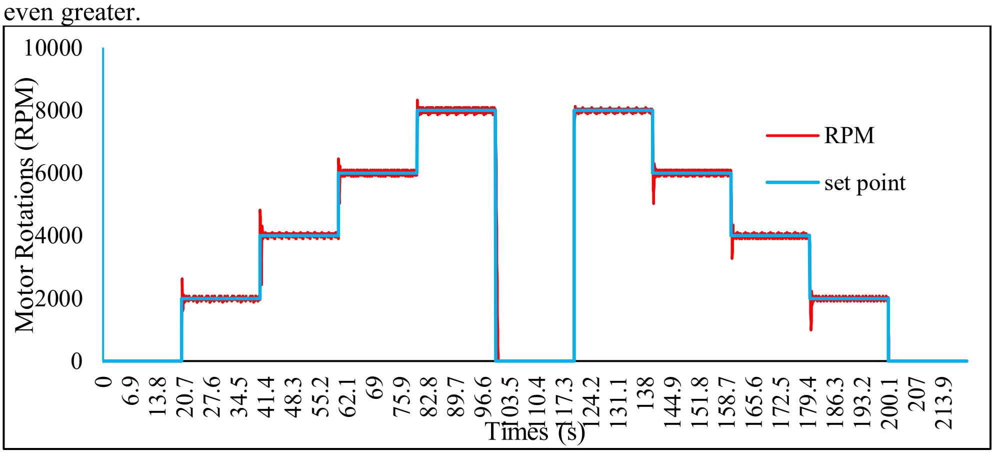

Fig. 13. Graph of metering device test results stair-step response method without fertilizer.

Oscillations that occur in each test range from 0.2% - 1.55%. Oscillations occur not only because of the use of the PID constant but also because of the influence of friction between the auger shaft and the bearing and friction between the outer diameter of the auger and the auger housing.

3.2.2 Performance Test

Testing the performance of the tool carried out with fertilizer is carried out to determine whether the auger-type metering device can adjust the fertilizer flow rate and pay attention to PID control can rotate the auger dose of fertilizer remains stable at the set point, even in the presence of fertilizer load.

3.2.2.1 Metering device calibration

Calibration is carried out to determine the relationship or correlation between the speed of the DC motor and the mass of fertilizer coming out of the metering device. Tests are carried out on metering devices. The metering device calibration results are shown in Figure 14 metering calibration results. The X-axis represents the speed of the DC motor in rpm, while the Y-axis represents the mass of fertilizer coming out of the metering device in grams.

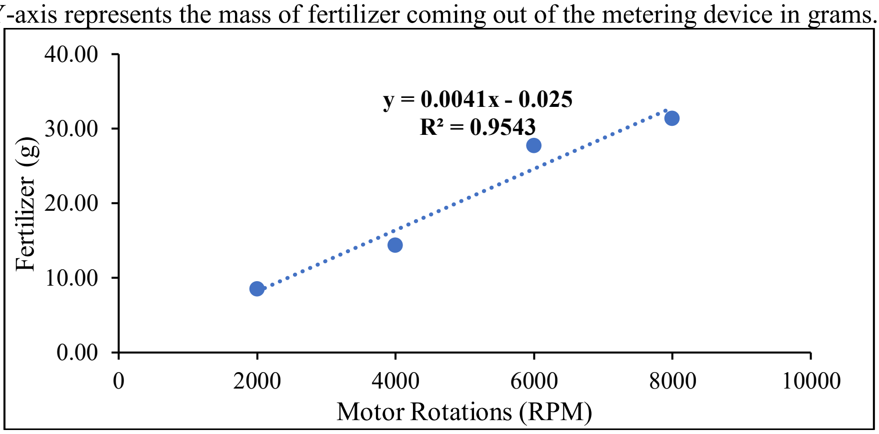

Fig. 14. Graph of the relationship of motor speed with fertilizer output.

The graph of the calibration results shows that the speed of the DC motor and the mass of fertilizer coming out of the metering device are linearly correlated with the correlation equation y = 0.0041x – 0.0255 with the coefficient of determination R^2 = 0.9543. These results show that controlling the fertilization dose can be done by controlling the speed of the DC motor attached to the auger shaft.

3.2.2.2 Step Response Testing on Tools with Fertilizer

The results of step response testing on the tool with the fertilizer obtained are shown in Figures 15 and 16. Figure 15 shows the results of step response testing on a tool with a 2000 rpm set-point fertilizer. The graph shows that the speed of the motor can reach the set-point at 2000 rpm, which is characterized by a reasonably fast motor response with a short time delay of about 0.10 milliseconds. However, a swift response has the potential to result in an overshoot. This can be seen in Figure 15, where there is a relatively high overshoot of 53.5% at time t = 0.15 milliseconds. These results show that the overshoot only lasts for 0.05 milliseconds. After that, there were oscillations around the set point, averaging 7.4% during the test. This is caused by several things, including DC motor power that is not strong enough to handle large enough fertilizer loads, fertilizer sizes that are not uniform and large enough to range from 1 mm – to 2 mm, and the pitch distance on the auger is only 1.5 mm. As a result, when fertilizer with a large size accumulates in the auger gap, the load will become more prominent so that the motor rotation becomes hampered.

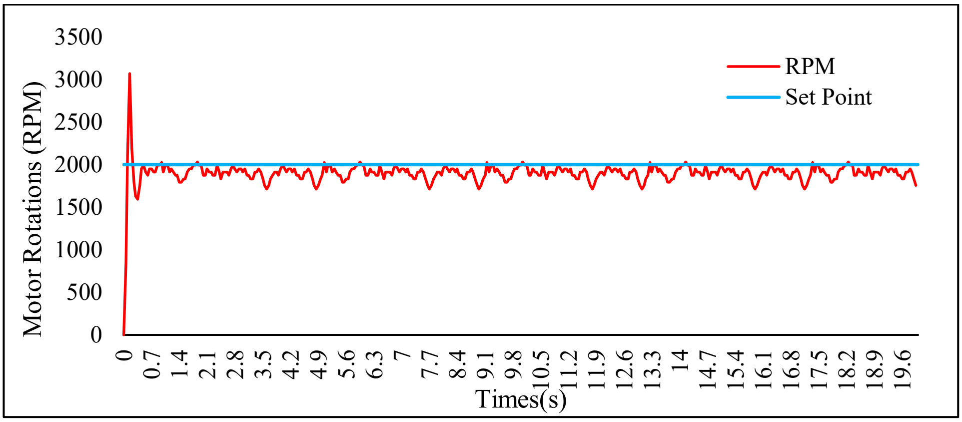

Fig. 15. Results of step response testing on tools with fertilizer (2000 RPM).

The results of step response testing on a tool with 8000 rpm set-point fertilizer are shown in Figure 16. The graph shows that step response testing on a tool with fertilizer can reach a set-point at 8000 rpm, which is characterized by a reasonably fast motor response with a short time delay of about 0.15 milliseconds. The graph shows that the resulting overshoot is smaller than the previous test results, where the overshoot occurred by 2.59% at t = 0.15 milliseconds. After that, there was an oscillation around the set point averaging 1.15% during the test; this test is quite good because it is still within tolerance limits. This is in accordance with Rahamdwati's statement (2015) that although there are oscillations, the movement is still within the predetermined tolerance limit, which is around 2%-5%. This indicates that the system can maintain its stability despite fluctuations, and the observed oscillation values remain within acceptable ranges according to previously established tolerance standards.

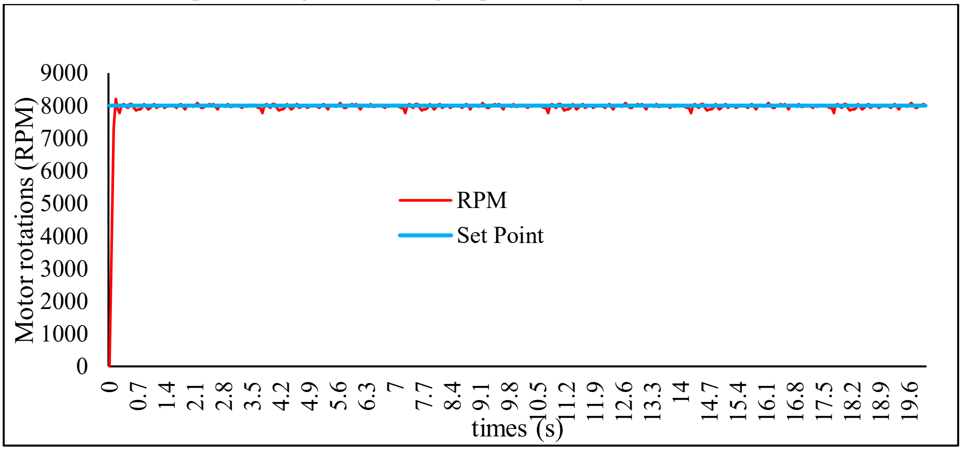

Fig. 16. Results of Step Response Testing on Tools with Fertilizer (8000 RPM).

Both test results also show that step response testing on tools with fertilizer is different for the exact value of PID constants. So, one of the difficulties in the PID tuning process is finding the right combination of PID constants that has the same performance for every change in speed or set-point command.

Table 6. Step response testing with fertilizers.

Set point (RPM)	Rise Time (ms)	Settling Time (ms)	Overshoot (%)
2000	0,10	0,45	53,5
4000	0,13	0,65	34,7
6000	0,11	0,45	7,51
8000	0,15	0,3	1,15

The test results of the PID constant generally show good performance in controlling the speed of the DC motor. However, the test results also show that the response produced varies for different motor speeds. The performance of the PID constant at a speed of 2000 rpm rise Time produced is excellent but has a very high overshoot. At a speed of 4000 rpm, the resulting rise time is perfect, too, but oscillations occur so that it takes longer to reach settling Time. At 6000 rpm, the resulting overshoot is lower than the previous speed but takes longer to reach the settling Time. At a speed of 8000 RPM, it can be seen that the motor speed does not overshoot and is fast to reach settling Time, but it takes longer than the previous speed to reach rise time. Therefore, it is still necessary to modify the PID constants of the tuning results so that an appropriate combination of PID can control the performance of the DC motor for all set-point values.

3.2.2.3 Stair-step response testing on tools with fertilizer

Testing with fertilizers is still on the scale of laboratory testing and has yet to reach the stage of field testing. Testing was carried out using Urea fertilizer with the stair step response method. Performance testing of tools without fertilizer is carried out with variations in the desired rotating speed divided into 11, namely 0, 2000, 4000, 6000, 8000, 0, 8000, 6000, 4000, 2000, and 0 rpm recorded every 20 seconds. A time of 20 seconds is considered that the system has experienced a stable state.

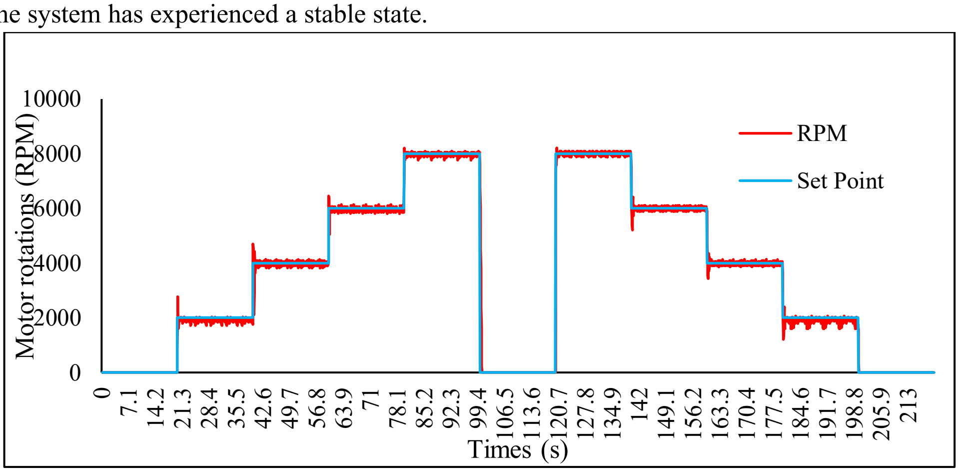

Fig. 17. Graph of metering device test results stair-step response method with fertilizer.

The test results shown in Figure 17 are successive graphs of the test results on the tool. The test results show that, in general, the system can still respond well and follow every set-point command given, both at step up and step down, but there are considerable oscillations. This is caused by several things, including DC motor power that is not strong enough to handle large enough fertilizer loads, fertilizer sizes that are not uniform and large enough to range from 2 mm to 4.75 mm, and the pitch distance on the auger is only 1.5 mm. As a result, when fertilizer with a large size accumulates in the auger gap, the load will become more prominent so that the motor rotation becomes hampered. A decrease in motor speed will undoubtedly reduce the amount of fertilizer released. However, the decrease in speed will be compensated by subsequent laps that exceed the set-point value.

The test results described show that the auger-type metering device with its control system has good performance and can be recommended for use in precision fertilization machines. Based on the results of metering device performance testing, the stair-step response method shows that overshoot and isolation occur highly due to DC motor power that is not strong enough to handle large enough fertilizer loads. This can be overcome by using a DC motor with greater power.

4 Conclusion

Based on the results of this study, it can be concluded that:

1. It has been successfully designed to build an auger-type variable rate metering device to control fertilizer output.
2. Static calibration of the auger-type mating device produces a linear correlation between fertilizer and RPM with the correlation equation $y = 0.0041x - 0.025$ with determination coefficient $R^2 = 0.9543$.
3. The results of stair step response testing, both without fertilizer and with fertilizer, show that the system can follow the set point commands given.

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