Solution Stirring Design Using Magnetic Stirrer on DC Motor with PLC-Based PID Method

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ABSTRACT

Along with the development of the times, the industrial and manufacturing world also develops. One of the activities that is widely carried out in the industrial and manufacturing world is stirring production raw materials, either in the form of solutions or liquids. The purpose of the stirring process is to get a perfectly mixed (homogeneous) stirring. For this reason, a device is needed that can stir the solution as desired. One type of tool that can be used is a magnetic stirrer placed on a DC motor. However, when the DC motor is given a load, the DC motor tends to become unstable so a controller is needed. To solve this problem used PID controller. PID controllers use control constants in the form of PB, Tick, and Tdk. To obtain the controlling constant, a process of trial and error is carried out. The most stable results obtained from the testing process were PB = 600%, Tik = 1.2 s, and Tdk = 0.2 s. With system response in the form of rise time 0.7778 s, peak time = 5s. settling time 5.4286 s, overshoot = 2.8571 RPM and steady state error = 0%. The setpoint used is 700 RPM with a sampling time of 60 ms. The developed system successfully achieves stable and well-controlled stirring. The results of this research contribute to the improvement of solution stirring processes in the industrial and manufacturing domains. The developed system can be effectively utilized for stirring solutions, enhancing the efficiency and quality of production processes.

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1. INTRODUCTION

Magnetic stirrer is one type of stirrer that is widely used in laboratories [1]–[3]. Magnetic stirrers are used to stir various types of liquids and solutions [4]–[6]. Stirring is done with the aim of mixing a material with other materials or making a solution have certain characteristics. The solution is perfectly mixed into a homogeneous solution. Magnetic stirrer has two parts, namely magnetic bars and stir bars. Magnetic bars are usually placed on a drive. While the stir bar is a magnet placed on the wada that contains the solution to be stirred. The drive used is a DC motor with type JGA25-370 [7]. This motor is a DC motor with a speed of 1000 RPM, which has various advantages. However, this DC motor also has a drawback, that is, when given a load, the DC motor becomes unstable for that a controller is needed. Common controller types used are fuzzy logic [8]–[11], integral state feedback [12]–[15], sliding mode control [16]–[19], and PID [20]–[23]. In this study, PID controllers were used.

PID controllers are used because they can make the system have a good system response [24]–[26]. In the form of fast rise time, reducing error values and eliminating overshoot and undershoot. PID controllers consist of 3 types of controllers, namely proportional controllers, integral controllers and derivative controllers [27]–[31]. Each controller has advantages and disadvantages. The three controllers complement each other.

PID controllers are used simultaneously to obtain good control results. PID controller is applied to a controller in the form of PLC (Programmable Logic Controller) [32]. The PLC used is OMRON CP1E-NA20DRA [33], [34]. This PLC can be used to run logical, timing and sequential functions [35]–[37]. The solution stirring system using a magnetic stirrer on a DC motor using a PLC-based PID controller aims to obtain stable stirring results with a low error value. So that the stirred solution becomes homogeneous.

In previous research, Ashadi Setiawan and Alfian Ma'arif have implemented the use of PLC in stirring coffee drinks at a speed of 600 RPM. The automatic control system using the PID algorithm on the PLC managed to achieve stable speed with low overshoot. Test results show that this system can stir coffee drinks effectively with optimal PID parameters [38]. Other studies discuss the use of PID (Proportional Derivative) controllers in DC motors to overcome the drop due to load. The trial and error method is used to control DC motors with Arduino UNO software. The parameters Kp=1.5, Ki=0.87, Kd=0.27 are applied in the test. The system response shows rise time = 0.9925, Time = 2.7368, Overshoot = 1.3333, and Steady State Error = 0 [39].

In addition, a simulation model of DC Motor PID controllers at variable and constant speeds using Matlab has also been studied by Zainab *et al* [40]. Through two tested cases, it was found that the parameters kp=5, ki=3, and kd=5 on the PID controller can improve the performance of DC servo motors in speed response, rise time, and upper and lower bypass ratios. This simulation proves the effectiveness of repair procedures in the performance of electric motors. Then, other researchers have also used Matlab in DC Motor simulations. Abdul Latif *et al* developed a PID control system on DC motors for mini conveyor drives [41]. The hardware configuration uses a hollow steel frame and two copies of roller belts. The PID control system is implemented using Matlab and Arduino, with a Rotary Encoder speed sensor to measure and control speed. The results showed proportional gain value = 0.94624747, integral gain = 51.4023958, and derivative gain = 0.01941504. The PID control successfully achieved the set point value and reduced steady state error to 1.015188 percent (no load) and 2.2020751 percent (loaded) in actual DC motor response.

The research contribution of this research is to provide an effective solution for stirring solutions using magnetic stirrers placed on DC motors with PLC-based PID controllers. This research focuses on developing a solution stirring system that is stable and produces homogeneous solutions.

2. METHODS

The method used in this study is an experiment to make a solution stirring system. In making the system, design is carried out on the parts to be made. The design carried out includes several parts, namely the design of the solution stirring system, the design of the PID controller and the magnetic stirrer model.

2.1. Solution Stirring System Design

The input part consists of a rotary encoder sensor with type C38S6G5-600B-G24N. The sensor will read the rotational speed of the DC motor. After getting the DC motor rotation speed data, the sensor will send a pulse signal to the controller. In the controller section, the pulse signal will be read and translated by calculation so that the rotational speed can be observed in RPM units. Furthermore, control of the rotational speed of the DC motor is carried out in order to get rotation in accordance with the given setpoint value. Then the controller will give a control signal and will rotate according to the control. But before the control signal can be received by the DC motor, a change is made from the control signal in the form of voltage converted into a PWM signal. This process is carried out on the voltage to PWM module. The system block diagram is shown in Fig. 1.

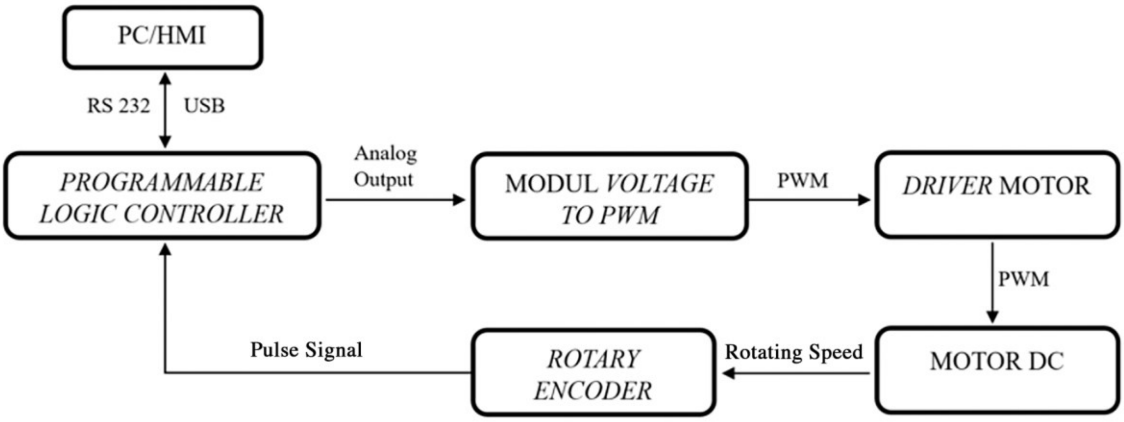

Fig. 1. System block diagram

Wiring diagrams are made with the aim of observing how components are connected. Wiring diagrams can be a reference material for assembling and compiling a system. So as to minimize errors that will occur. The system wiring diagram is shown in Fig. 2.

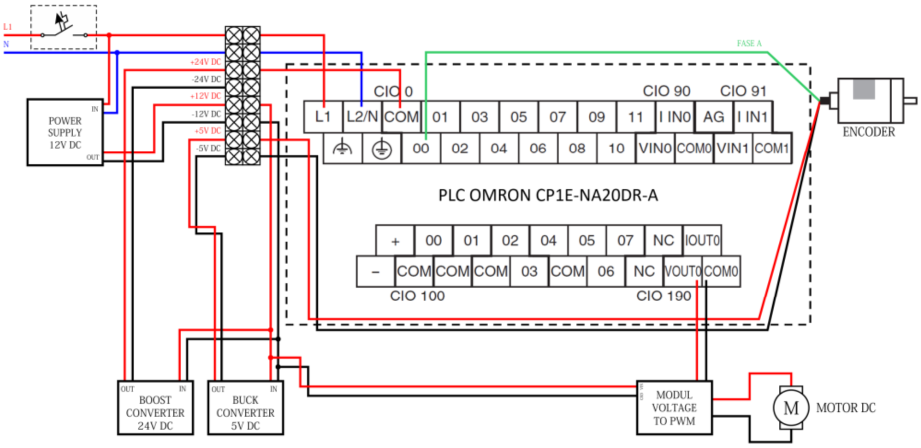

Fig. 2. System wiring diagram

The wiring diagram shows that the PLC and power supply get power from AC power of 220 V. while the voltage to PWM module gets power of 24 V DC. Each component gets input from other components. Input and Output components are more complete as in Table 1.

Table 1. System inputs and outputs

No	Component	Input	Output
1	**Rotary Encoder**	**Power supply**: VCC: 5 VDC; **Gnd:** 0	Pulse 24 V DC
2	PLC	**Power supply**: 220 VAC; **CIO:** 24 V DC	CIO 190: analog 0 – 5 V DC
3	**Modul voltage to PWM**	**Power supply**:12 V DC; **Input signal** 0 – 5 V DC	PWM 0 -100 %
4	Motor DC	PWM 12 V	Rotating speed

2.2. PID Controller Design

Control of the rotational speed of the DC motor is carried out using a PID controller. PID controllers are used to obtain optimal DC motor rotation speed. Therefore, the PID control system was made. With the PID controller, the DC motor can produce a stable rotating speed with a low error value. The way the PID controller system works is by entering the setpoint and the value of the controlling constant so that the DC motor will rotate and then the DC rotation will be compared with the entered setpoint value. The difference between the setpoint value and the rotational speed value results in an error value. The error value will be passed to the controller for controller calculations. After calculation, the controller will provide the controller value to the voltage module to PWM to be converted into a PWM signal. This PWM signal will be forwarded to the motor driver. The motor driver will regulate the speed of the DC motor. This process will run continuously. The PID control block diagram is shown in Fig. 3.

The process that occurs in the solution stirring system using a magnetic stirrer is formulated on the flow chart. Flow charts serve to document the processes running on a system. It starts with the system starting until the system is finished. The processes occurring in the system can be observed in the flow chart in Fig. 4.

The stirring system begins by entering control parameters in the form of setpoint values, proportional control values, integral controllers, and derivative controllers. When the controller parameters are entered, the DC motor will move and produce a rotational speed with RPM units. The setpoint value and DC motor rotation value will be compared to determine the error value. The error value is used to perform the PID controller calculation process. After the PID controller calculation process is carried out, the PLC will issue a control signal in the form of an analog output value which is then converted into PWM voltage. If the error value equals 0 then the system will finish. If the error is not equal to 0 then the process will complete.

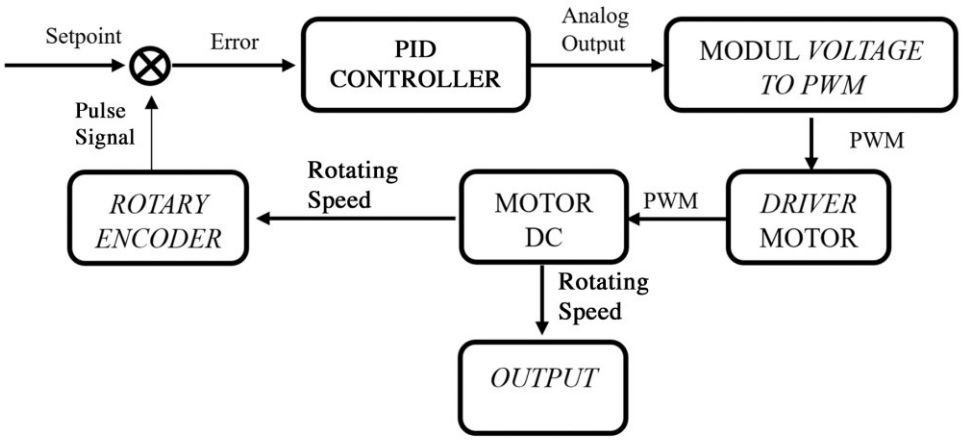

Fig. 3. PID control block diagram

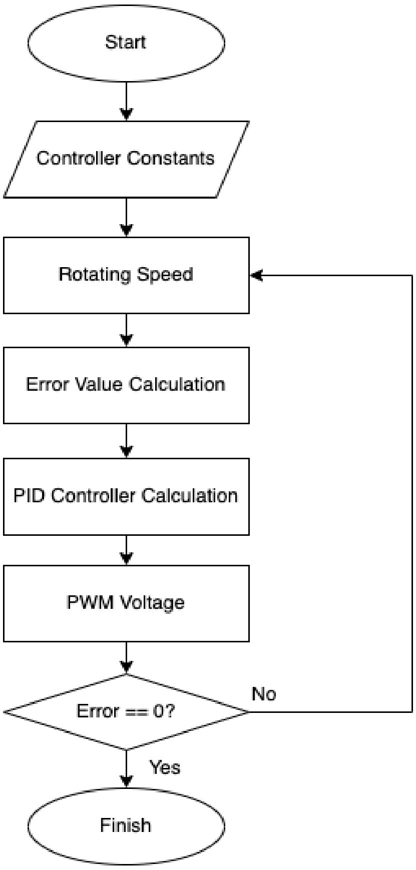

Fig. 4. System flow chart

2.3. Design of Magnetic Stirrer Models

The stirrer used in this study was a magnetic stirrer. Magnetic stirrer consists of magnetic bar and stir bar. The magnetic bars are connected to the DC motor by a coupling. Then the rotary encoder sensor is also installed coupling. Both couplings are belted so that when the DC motor rotates, the rotary encoder sensor can read the number of revolutions of the DC motor. The DC motor and encoder are placed parallel to a box made of cube-shaped acrilyc material with dimensions of 16cm×12.5cm×13cm. On top of this box, a measuring cup is placed as a container for the solution to be stirred, then placed the stir bar into the measuring glass, then the stir bar will rotate following the rotation of the magnetic bar so that the solution will be stirred properly. The magnetic stirrer image can be seen in Fig. 5.

Fig. 5. Solution stirrer (magnetic stirrer)

3. RESULTS AND DISCUSSION

The results and discussion of this study consisted of testing DC motors without load, stirring water solution and stirring oil solution. Each test was carried out 5 times with various variations. The Solution stirring system circuit is shown in Fig. 6.

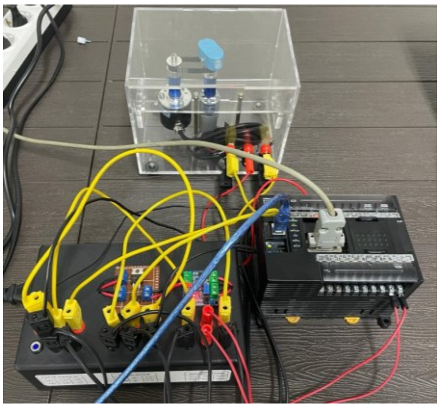

Fig. 6. Solution stirring system circuit

3.1. No-load DC Motor Control

Testing of DC motor control with the PID method is carried out with the aim of obtaining a stable DC motor speed in accordance with the entered setpoint value. Control is carried out carefreely. Controller parameters are obtained from trying or better known as trial and error. The no-load PID controller test is performed with 5 variations of controller constants as shown in Table 2.

Table 2. No-load DC motor controller parameters

No	Setpoint	Sampling Time (ms)	Proportional (PB)	Integral (Tik)	Derivatives (Tdk)
1	700	60	400	0,4	0,1
2	700	60	350	0,8	0,2
3	700	60	400	1,2	0,2
4	700	60	500	0,8	0,2
5	700	60	600	1,2	0,2

Controller parameters are entered sequentially with various variations. The results of the control process are shown on the chart as can be seen in Fig. 7. No-load DC motor control results in fairly stable DC motor rotation. With a fairly low error value. The response of each experiment can be seen in Table 3. The system response obtained shows that the system is running quickly and stably also produces low errors. With this, the control of the no-load DC motor has been successfully carried out.

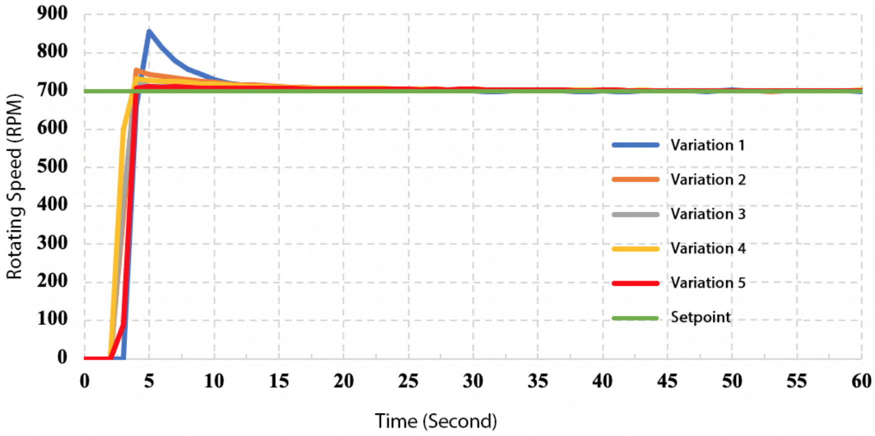

Fig. 7. No-load PID motor control chart

Table 3. No-load DC motor control system response

No	Control	Rise time (s)	Peak time (s)	Steady state error (%)	Overshoot (RPM)	Settling time (s)
1	Variation 1	0.8485	6	0	22.2857	13.2
2	Variation 2	1.4829	5	0	7.8571	15
3	Variation 3	1.5255	5	0	3.5714	5.8426
4	Variation 4	1.1180	5	-1	4.4286	12.75
5	Variation 5	1.0875	6	0	1.7143	4.9645

3.2. Stirring of the Aqueous Solution

The aqueous solution stirring test is carried out by inserting water in a measuring glass as much as 300 ML. The controller used is a PID controller with 5 variations of the control constant. The control parameters of stirring the aqueous solution are shown in Table 4.

Table 4. Aqueous solution stirring control parameters

No	Setpoint	Sampling Time (ms)	Proportional (PB)	Integral (Tik)	Derivatives (Tdk)
1	700	60	400	0.4	0.1
2	700	60	350	0.8	0.2
3	700	60	400	1.2	0.2
4	700	60	500	0.8	0.2
5	700	60	600	1.2	0.2

Controller parameters are entered sequentially with various variations. The results of the control process are shown on the chart as can be seen in Fig. 8. No-load DC motor control results in fairly stable DC motor rotation. With a fairly low error value. The response of each experiment can be seen in Table 5.

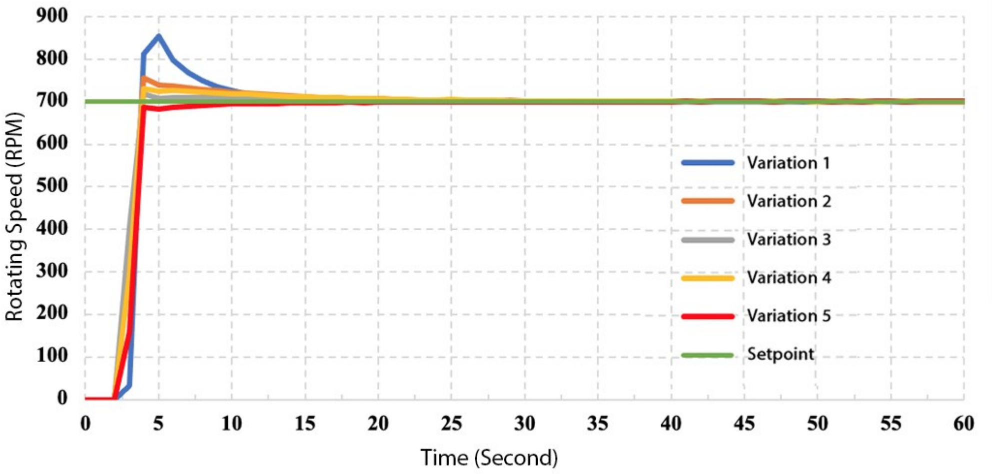

Fig. 8. Aqueous solution stirring test graph

Table 5. Response of aqueous solution stirring system

No	Control	Rise time (s)	Peak time (s)	Steady state error (%)	Overshoot (RPM)	Settling time (s)
1	Variation 1	0.7179	6	1	22.0	12.8
2	Variation 2	1.4922	5	0	8.0	15
3	Variation 3	1.5465	5	-1	2.5714	5,4
4	Variation 4	1.5311	5	-1	4.4286	14
5	Variation 5	1.5311	5	-1	4.4286	14

3.3. Oil solution stirring

The aqueous solution stirring test is carried out by inserting oil in a measuring glass of 300 ML. The controller used is a PID controller with 5 variations of the control constant. The control parameters of stirring the oil solution are shown in Table 6. Controller parameters are entered sequentially with various variations. The results of the control process are shown on the graph as can be seen in Fig. 9. No-load DC motor control results in fairly stable DC motor rotation. With a fairly low error value. The responses of each experiment can be seen in Table 7.

Table 6. Oil solution stirring control parameters

No	Setpoint	Sampling Time (ms)	Proportional (PB)	Integral (Tik)	Derivatives (Tdk)
1	700	60	400	0.4	0.1
2	700	60	350	0.8	0.2
3	700	60	400	1.2	0.2
4	700	60	500	0.8	0.2
5	700	60	600	1.2	0.2

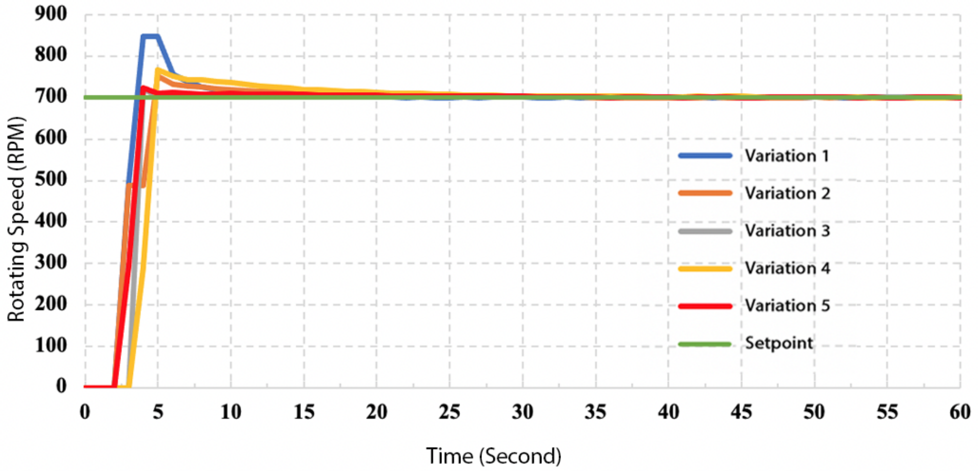

Fig. 9. Oil solution stirring test graph

Table 7. Responses of No-load DC Motor Control

No	Control	Rise time (s)	Peak time (s)	Steady state error (%)	Overshoot (RPM)	Settling time (s)
1	Variation 1	1.2410	5	0	21.1429	11
2	Variation 2	2.3950	6	-2	7.2857	13
3	Variation 3	0.7778	5	0	2.8571	5.4286
4	Variation 4	1.4697	6	0	9.7143	19
5	Variation 5	1.5454	5	-1	3.2857	5.75

The results showed that this system is capable of producing stable solution stirring with fast system response and low error rate. To control the no-load DC motor, the control parameter values PB=500%, Tick=0.8s, and Tdk=0.2s are entered. As a result, the system responded in the form of an increase time of 1.180 s, a peak time of 5 s, an error in steady state of -1%, an overshoot of 4.4286 RPM, and a completion time of 12.75 s. Next, stirring the water solution as much as 300 ml using the parameters PB = 400%, Tik = 1.2 s, and Tdk = 0.2 s. The resulting system response was a rise time of 1.5465 s, a peak time of 5 s, a steady state error of -1%, an overshoot of 2.5714, and a completion time of 5.4 s. As for stirring the oil solution as much as 300 ml, the parameters used are PB = 400%, Tik = 1.2 s, and Tdk = 0.2 s. The resulting system response was an up time of 0.7778 s, a peak time of 5 s, a steady state error of 0%, an overshoot of 2.8571 RPM, and a completion time of 5.4286 s. These results show that the solution stirring system using a magnetic stirrer on a DC motor with a PLC-based PID method results in stable solution stirring with fast system response and low error rate. Recorded system responses include up time, peak time, steady state error, overshoot, and completion time. In stirring aqueous and oil solutions, the control parameters used provide a system response appropriate to the purpose of the study.

Comparison of the results of this study with previous studies shows some differences and similarities. Previous research by Ashadi Setiawan and Alfian Ma'arif implemented the use of PLC in stirring coffee drinks and managed to achieve stable speeds with low overshoot using the PID algorithm. This system effectively stirs coffee drinks with optimal PID parameters [38]. Another study by other researchers used trial and error method by using Arduino UNO software to control DC motors [39]. The PID controller parameters used are Kp=1.5, Ki=0.87, and Kd=0.27. The system results showed promising results with an uptime of 0.9925, a completion time of 2.7368, an overshoot of 1.3333, and an error in steady state of 0. In addition, Zainab *et al* . conducted a simulation study using Matlab to evaluate the performance of DC motor PID controllers at variable and constant speeds [40]. Their results showed that the use of PID parameters kp=5, ki=3, and kd=5 improved the speed response, ride time, and upper and lower payout ratios of DC servo motors. This simulation shows the effectiveness of repair procedures in improving the performance of electric motors. In another study, Abdul Latif *et al* . developed a PID control system for mini conveyor drives using DC motors. They use a hardware configuration with a hollow steel frame and two roller belts. The PID control system, implemented using Matlab and Arduino, successfully achieved set point values and reduced steady state errors to 1.015188 percent (with no load) and 2.2020751 percent (with load) in actual DC motor response [41].

Based on the comparison with previous studies, it can be seen that all such studies have been successful in implementing PID controllers to achieve stable control and minimize errors in various applications. This research focused on solution stirring systems using magnetic stirrers in DC motors, while previous research explored applications such as coffee stirring, load management in DC motors, and mini conveyor drives. Each study used different controlling parameters and experimental settings. However, all of these studies achieved favorable results in terms of system responsiveness, error reduction, and stability.

4. CONCLUSION

The solution stirring system using a magnetic stirrer on a DC motor with the PLC-based PID method produces stable solution stirring, with fast system response and low error. Controlling a no-load DC motor is carried out by entering the value of the control parameter in the form of PB = 500%, Tik = 0.8 s, and Tdk = 0.2 s. Controlling the DC motor without load produces system responses in the form of rise time = 1.180 s, peak time = 5 s, steady state error = -1 %, overshoot = 4.4286 RPM, and settling time = 12.75 s. Stirring the water solution as much as 300 ml, the parameters used are PB = 400%, Tik = 1.2 s, and Tdk = 0.2 s. The resulting system response is rise time = 1.5465 s, peak time = 5 s, steady state error = -1 %, overshoot = 2.5714, settling time = 5.4 s. Stirring the oil solution as much as 300 ml, the parameters used are PB = 400 %, Tik = 1.2 s, dan Tdk = 0.2 s. The resulting system response is rise time = 0.7778 s, peak time = 5 s, steady state error = 0 %, overshoot = 2.8571 RPM, and settling time = 5.4286 s. Based on these results, this study concluded that the solution stirring system using a magnetic stirrer on a DC motor with the PLC-based PID method is able to produce stable solution stirring with fast system response and low error rate. No-load DC motor control, aqueous solution stirring, and oil solution stirring all give satisfactory results with minimal error rates. However, this research still has room for further development. For future research, it is recommended to conduct experiments with wider variations in control parameters to explore the potential of more optimal stirring systems. In addition, system testing on solutions with different compositions and properties also needs to be carried out to expand the application of the system and understanding of its performance. Furthermore, research can involve the influence of external disturbances on the stirring system and compare the performance of the PID method with other control methods. The development of real-time monitoring and data collection systems is also important to gain a deeper understanding of system performance. By continuing this research and applying these suggestions, it is hoped that knowledge of solution stirring systems can be expanded and their performance and application can be improved in various industries and fields that require stable and efficient solution stirring.

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