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Performance Process of Coil Winding Machine Based on Accuracy and Speed for Water Pump Motor

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A B S T R A C T

A coil winding machine for water pumps using a monitoring system is a development of conventional winding tools. In regular coil winding tools, the coil winding process is done manually by rotating the handle as many times as the desired number of turns. The conventional winding tools have problems consisting of inconsistent working speed and operator-dependent winding continuity. Undesirable windings can occur with conventional winding tools, and the winding process requires close supervision. Therefore, the automatic coil winding machine was developed to optimize the coil winding process. The machine utilizes a DC motor to rotate the coil rolls, replacing the conventional roller handle function. This machining method uses an optocoupler sensor. The sensor serves to identify and evaluate the rotation of the roller. In addition, the ATmega8 microcontroller was applied to develop a system that can work automatically. Data collection involves varying the number of wire turns and the wire diameter dimension. The variation is necessary because the number of windings and wire diameter affect pump efficiency and performance. The data testing showed a machine accuracy rate of 98%, with a maximum difference of 1 coil winding in the results. This data confirms that the coil winding machine meets the tool's accuracy standards.

INTRODUCTION

Small-scale industries or electrical machine workshops often use manual systems, specifically dynamo rollers operated by human power, to repair transformers or dynamo windings because automatic winding machines are significantly more expensive. The process of winding enamel wire using manual tools is time-consuming and often results in inaccuracies in the calculation of the number of wire turns and the inability to adjust the machine rotation speed as necessary. Maintaining processes and repairing industrial machines requires both speed and accuracy in the work results. For instance, when repairing an electric water pump, it is often necessary to replace the motor coil, which involves a new bobbin winding process. The accuracy of the number of windings is crucial in ensuring the replacement of water pump coils [1]. Email wire winders use a coil winder as an auxiliary tool to achieve the necessary speed and accuracy when winding water pump coils. This tool utilizes Arduino as a control input, allowing the winding roller to operate automatically. Arduino is a commonly used option due to its accessibility and affordability, making it a practical and cost-effective solution for the coil winder.

Using a wire coil winder when repairing water pumps is crucial, as the wire winding affects the efficiency and performance of the pump. The pump's performance relies on the accurate number of wire turns, wire diameter size, and spacing between windings, which can impact the torque and power needed to drive the pump rotor. The number of coils wound on the pump wire affects the speed of the water flow and generates high pressure in the produced water. Accurate winding of the required number of turns is not feasible when done manually. Therefore, the production of winding rollers with an effective winding speed is necessary. Although the open-end wire winding machine is highly reliable in the industrial field, it is not immune to weaknesses that can cause a decline in its performance efficiency, such as electrical and mechanical issues. Therefore, proper maintenance and periodic checks are required to ensure the machine's smooth operation. In addition, engineers are developing a multifunctional machine as an attractive option to increase the machine's variable speed [2], [3].

Increasing the efficiency of engine performance is accompanied by the use of automation on industrial machines. Automation is a realization of technological developments that can produce alternatives to improve work systems that are fast, accurate, effective, and efficient to obtain optimal work results. The use of Arduino Uno R3, proximity sensor E18-D80NK, and smartphone data communication via Bluetooth HC-06, as well as an automation control system via MIT App Inventor on a 220 volt

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AC motor produces 100% actual readings and 50% input accuracy. The rotational speed of the number of coils in 60 and 120 turns takes 8.12 seconds and 18.88 seconds [4], [5]. The result of coil winding using automation and equipped with an active voltage system is that it can operate at high speed without causing the wire to break and reduce the coil size [6]. In other words, the size of the coil windings becomes tighter to increase the coil's function in its use in tools. Other rollers utilize a rotation counter sensor and a PIC microcontroller. The manufacture of the winding machine lowered the production cost of the machine enormously. However, in the manufacture of these tools, the wire coil is widening due to an increase in voltage. The rolling process also generates hot friction on the pulleys, causing insulation damage. The error also results in an inaccurate number of turns [7]. Therefore, to increase efficiency with low production costs, research on the design of a wire coil winding machine is carried out by utilizing a microcontroller. The resulting wind coil is prioritized for its application to water pumps.

METHODS

Machine Design Method

The machine's design is fabricated by using SketchUp software. This software allows for a comprehensive evaluation of the machine design through 3-dimensional drawings. The construction of the winding machine incorporated a length of 40 cm, a width of 30 cm, and a diameter of 5 cm. Meanwhile, the rectifier and rotating parts are 20 cm and 26.5 cm long, respectively.

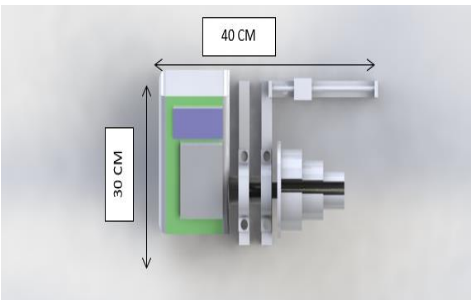

Figure 1. Top View Design Of The Coil Winding Machine

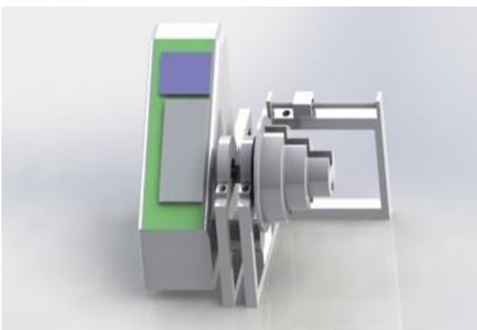

Figure 2. Side View Design of the Coil Winding Machine

Component concatenation Design

In the winding machine system, the components are linked together in a concatenation where a keypad is applied to input the desired number of turns, and an optocoupler sensor is placed on the number of turns counter to monitor the actual number of turns made by the machine. When the number of windings matches the input on the optocoupler sensor keypad, it will send a signal to the Arduino Atmega 8 to stop the rotation of the DC motor. In addition to ending the DC motor rotation, the Arduino Atmega 8 will activate the buzzer to sound an alarm when the winding process is complete and display the number of formed coils on the LCD screen.

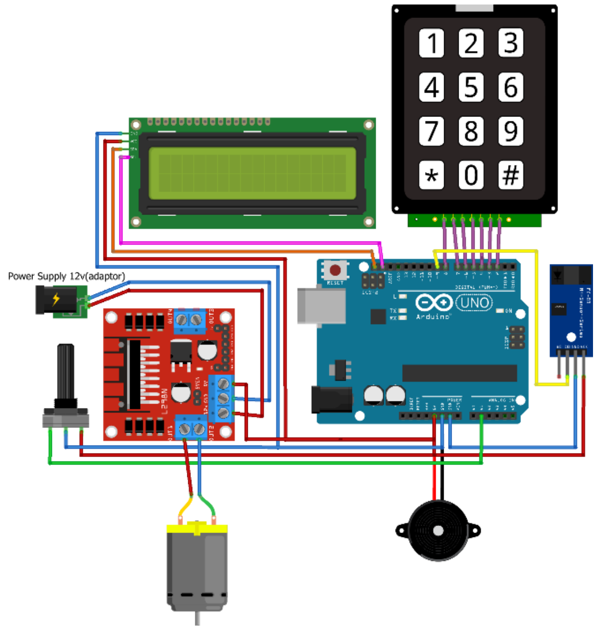

Figure 3. Complete Concatenation Of Coil Winding Machines

The coil winding machine process starts working when the user connects the power cable to the socket and presses the "ON" button. After pressing the "ON" button, the LCD display will light up and show the limit and counter. To input a new amount, the user can press the (*) button on the keypad. Pressing the (*) button on the keypad will cause the LCD display to show the text "value is 10 to 9.999.999". This point indicates that the minimum limit is ten coils, with 9,999,999 coils as the maximum.

Then the machine will display the text "insert limits" in this section. The user provides instructions for entering the expected amounts of coils by pressing the characters on the keypad. Furthermore, pressing the hash button (#) would automatically make the machine process work, so the optocoupler sensor would count the amount of winding coil rotation.

The LCD display will show the amount of the winding limit and counter process. During the winding process, the motor DC would rotate equally to the number of coils inserted on the keypad. When the expected coils are complete, the motor will automatically stop.

Testing Coil Winding Machine

Optocoupler sensor testing is accomplished by calculating the accuracy of the ratio of the number of turns successfully identified by the sensor to the expected actual winding rotation. The test was conducted five times with a different total number of winding coils. The variations test the expected coils of 10, 20, 30, 40, and 50 rotations wound with five repetitions to observe the accuracy of the optocoupler sensor's calculating precision.

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Therefore, the difference between the number of coils detected by the sensor and the actual number of wound coils is adjusted to ensure accurate results and to match the expected number of windings. The coil winding speed was computed by calculating the total windings created for each diameter of the roll and the time needed to complete each winding.

The coil winding machine has been designed with five rolls of varying sizes, enabling tests to facilitate all winding processes on each roll. The dimensions of the wire diameter used in the winding process are categorized into three different types based on their size. The wire diameter used in the coil winding process is 0.25 mm, 0.35 mm, and 0.55 mm. A variation in wire diameter was conducted to test the difference in time needed by the coil winding machine for each variant type of wire. Therefore, twenty-five tests conducted on each variant calculated the required time for winding each wire.

RESULTS AND DISCUSSION

In general, coil winding is a process that creates wires that are crucial and suitable for a wide range of machines and technological requirements. Research over the last 13 years has discussed a lot about the reduction factor that occurs in the working process of the coil, the machine that uses the coil, and the field that appears around the coil. In addition, many studies discuss single-coil induction machines, detection, and errors caused by discrepancies or coil inefficiencies.

There are approximately five research clusters related to coils, namely, a discussion of the factors that cause the ineffectiveness of a technology or machine, research discussing synchronous machines that use coil types of various types and variations, and research with a focus on the discussion of dynamos. In addition, there is also a cluster that discusses machine modeling and technology systems. Finally, many research groups related to the use of coils appear in the research cluster, with discussions about machine errors and fault diagnosis [8]–[12].

Nonetheless, a limited amount of research that delves into the intricacies of coil-winding machines is available. The existing discourse predominantly focuses on the magnetic field and electric field aspects associated with coil winding. However, a comprehensive examination of coil-winding machines encompassing other critical factors remains relatively scarce in scholarly literature [13]–[16].

Based on the research network in Figure 4, coil-winding influences many things in a complex way in the latest research development. Nevertheless, there is a noticeable dearth of comprehensive research addressing the intricacies of the winding process, resulting in a limited ability to optimize the production of coil-winding machines on an industrial scale at a cost-effective rate. The coil winding process, which finds extensive application in synchronous machines, relies on carefully tailored winding parameters to generate a magnetic field that undergoes rotational movement over time, synchronized with electric current oscillations. The type of synchronous machine is also in line with the wire-winding process carried out in this study [17], [18]. The majority of research on coil winding machines discusses permanent magnets, so the focus of discussion on simple coil winding machines becomes difficult to find [19]–[23]. Exploration of manufacture and failure An observation of the winding shows that coil winding failure is caused by bearing failure, increased electrical resistance, insulation failure, and short circuits, which can cause catastrophic failure during operation. Coil winding machine failure can also be caused by machine life and the operating environment. The operating environment and machine tasks can accumulate damage and faults through system contamination, moisture ingress, high-temperature cycling, vibration, and partial discharge of high-frequency inverter voltage [24], [25].

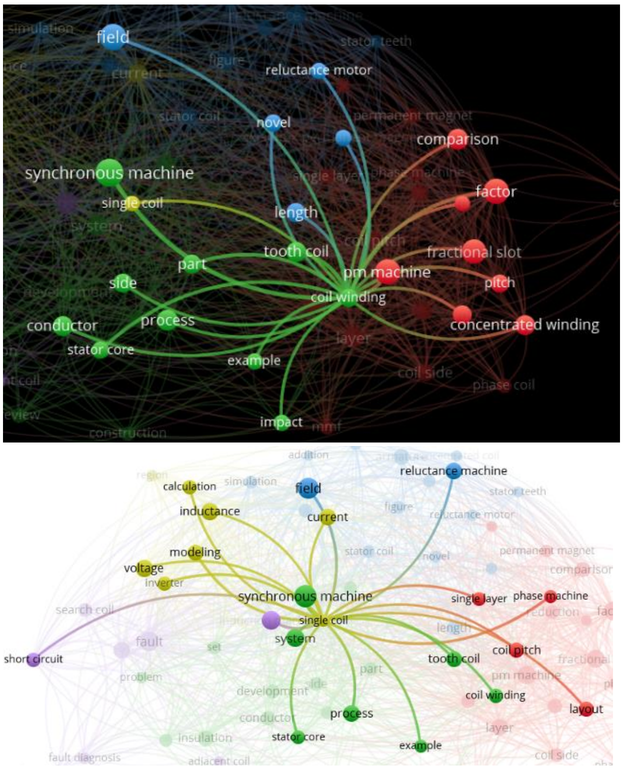

Figure 4. Influence network of coil winding process

The coil winding machine made in this study is a water pump's motor coil winder. The electrical component box on the coil winding machine was constructed using wood and positioned on the left side of the machine. The electrical box contains several electronic components, including the ATmega 8 microcontroller, buzzer, potentiometer, and power supply.

Moreover, the roll-turning iron on the coil winding machine is connected to a gear that can move the roller to roll the wire on the winding machine. The rollers are divided into five variant sizes, namely 24.5 cm, 27 cm, 31.5 cm, 36.5 cm, and 41 cm, as can be seen on Table 1. The testing of the optocoupler sensor was carried out by winding the coils for 25 repetitions. This test was to determine the accuracy of the coil winding machine.

Based on multiple experiments conducted on the coil winding machine in Table 1, it has an accuracy rate of 98% and an error rate of 40%, which means that further improvements are necessary to enhance its performance for practical applications. The experiment was repeated five times with a different number of coils in each experiment. Furthermore, the experimental results show that the fewer winding processes are expected to produce, the smaller the percentage of errors that occur in the winding process. Meanwhile, if the desired number of windings increases, the inaccuracy will occur more frequently.

Table 1. Accuracy of Coil Winding Machine

Experiment	Target	Result					Error	Accuracy
		1	2	3	4	5		
X_1	10	10	10	10	9	10	20%	90%
X_2	20	20	20	19	20	20	20%	95%
X_3	30	30	29	30	30	30	20%	97%
X_4	40	40	39	40	39	40	40%	98%
X_5	50	50	49	50	49	50	40%	98%

Only one inaccuracy was discovered in the winding process for 10, 20, and 30 coils during the first to third experiments. Meanwhile, in more numbers, namely in the fourth and fifth experiments, there were two inaccuracies out of the five experiments conducted. The higher percentage of errors for each expected number of coils could indicate that a considerable potential error may occur in any winding process with more than 50 coils. However, even though these errors occur more often, the construction of the coil winding machine is capable of achieving 98% accuracy in the coil winding process. The small amount of winding error that occurs shows the high percentage of accuracy of the coil winding machine. There is only one gap in the coil for the whole winding process.

The winding process of wire windings using a coil winding machine carried out in this study was varied using three variants of wire dimensions. The winding process for the three variants of wire dimensions was carried out using five different roll diameters. Different wire dimensions and coil diameters will affect the efficiency and performance of the water pump. Based on these experiments, it is known that the rotational speed of each wire size in each roll diameter is as follows: Tabel 2 until Tabel 6.

Table 2. Duration for 10 Coils Winding Process

Wire	Duration (s)				
	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
0,25 mm	3,51	3,54	3,86	4,17	4,18
0,35 mm	3,52	3,54	3,89	4,19	4,21
0,55 mm	3,53	3,54	3,95	4,20	4,22

Table 3. Duration for 20 Coils Winding Process

Wire	Duration (s)				
	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
0,25 mm	7,37	7,63	7,68	7,81	7,82
0,35 mm	7,38	7,64	7,71	7,85	7,85
0,55 mm	7,61	7,64	7,85	7,87	8,06

Table 4. Duration for 30 Coils Winding Process

Wire	Duration (s)				
	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
0,25 mm	11,44	11,45	11,58	11,81	11,83
0,35 mm	11,46	11,48	11,61	11,83	11,85
0,55 mm	11,57	11,59	11,67	11,86	11,89

Table 5. Duration for 40 Coils Winding Process

Wire	Duration (s)				
	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
0,25 mm	15,21	15,31	15,37	15,58	15,68
0,35 mm	15,23	15,32	15,61	15,76	16,00
0,55 mm	15,28	15,38	15,75	15,77	16,03

Table 6. Duration for 50 Coils Winding Process

Wire	Duration (s)				
	Roll 1	Roll 2	Roll 3	Roll 4	Roll 5
0,25 mm	19,19	19,20	19,29	19,48	19,71
0,35 mm	19,21	19,22	19,31	19,61	20,18
0,55 mm	19,23	19,23	19,32	19,63	20,36

The variation in the dimensions of the coil wire aims to determine the speed of the winding process with different types of wire thicknesses. This variation intends to calculate the acceleration of the winding process if the water pump motor requires another coil of wire to increase its efficiency and performance. Besides that, each dimension variation of the wire rolling has a different diameter roller size. The roller diameter sizes from smallest to largest are 24.5 cm, 27 cm, 31.5 cm, 36.5 cm, and 41 cm. The difference in the circumference of the roller causes a time difference in the rolling process. The number of windings of wire varies by ten coils, twenty coils, thirty coils, forty coils, and fifty coils. A visualization of the wire winding duration data is shown in Figures 5 and 6.

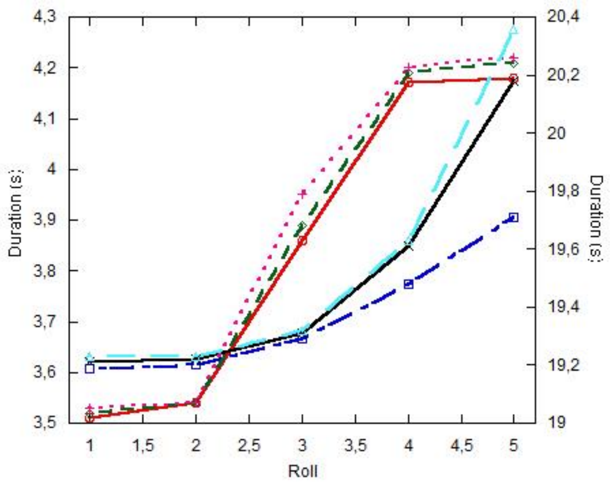

Figure 5. The Effect Of Roll Diameter On Various Wire Dimensions

Figure 5 shows a comparison of the time increase in the winding process. The winding duration time for each type of wire coil on the diameter of the roller varies. The increase in the coil winding process duration occurs due to the increasing number of coil wires expected in the winding process. The winding process on the same roller diameter tends to have a time duration that is not much different. However, the winding process using different sizes of reel diameters results in a very high expansion in the duration of the coil winding process. The difference in the increasing duration of rolling time occurred significantly from roller 3 to roller 5. The increase arises due to the considerable difference in diameter between roll 3, roll 4, and roll 5. The difference in the diameter of roller 3, roller 4, and roller 5 was 31.5 cm, 36.5 cm,

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and 41 cm. Meanwhile, the diameters of roller 1 and roller 2 are 24.5 cm and 27 cm, respectively. So, the size of roller 1 and roller 2 diameters does not significantly affect the duration of the winding time in the coil winding process. Figure 4 shows an increase in winding duration for each wire variation, as indicated by the blue, black, and light blue lines. The blue, black, and light blue lines also revealed an increase in the winding processing time at the highest winding process of 50 coils.

The blue, black, and light blue graphs in Figure 5 also provide information that the larger the wire dimensions used in the coil winding process, the longer the duration of time required. According to the blue graph, using a 0.25-mm-diameter wire for the coil winding process takes less time than using a wire with a larger diameter. The black line shows a significant increase in coil winding time when using a 0.35 mm wire dimension compared to a 0.25 mm wire dimension. Whereas in the observing winding process, using a 0.5 mm diameter wire shows a very high rolling duration. The change in time significantly occurred in the diameter of roll 3 to roll 5. The graph indicates that using a larger wire dimension results in a longer duration for the wire winding process. Increasing duration times for the coil winding process means the speed of the winding process slows down as the wire dimension gets bigger and heavier.

Figure 5 also visualizes a comparison graph for each wire dimension. The red, green, and pink lines represent the comparison of winding duration times at the coil winding process with the same number of expected coils. The graph visualizes a comparison of winding duration times for a fixed number of spirals. The comparison represents ten coil windings. The rolling process, which refers to the process of shaping the wire into a coil, involves using five different roll diameter sizes.

Based on the graph, the duration of the rolling process tends to be stable in rolls 1 and 2. The stability of the duration time also arises in the rolling with rolls 4 and 5. Meanwhile, there is a significant increase in rolling time duration when using roll sizes 2, 3, and 4. Based on the two types of graphs observed through a comparison of the winding times on the two different numbers of coils, As the number of coils increases, the duration of the winding process tends to increase steadily. Meanwhile, if the number of coils is small, there will be a significant increase in the duration of the winding process, but it does not increase steadily.

Meanwhile, based on Figure 6, the graphical analysis is divided into three parts. At first, the linear line is at the top of the graph. The linear lines show the increase in winding time required for each type of wire at the same roll diameter and a different number of coils. Second, the blue, pink, and black graphs reveal the comparison of the increase in duration time at different roll diameters and the same number of coils. The number of coils winding in the experiment is 50 coils. The discussion of graph analysis occurs in Figure 5. Third, the green, red, and blue graphs are at the bottom. The line at the bottom is a ratio of the winding process duration time for each wire with the same number of coils and roll diameter.

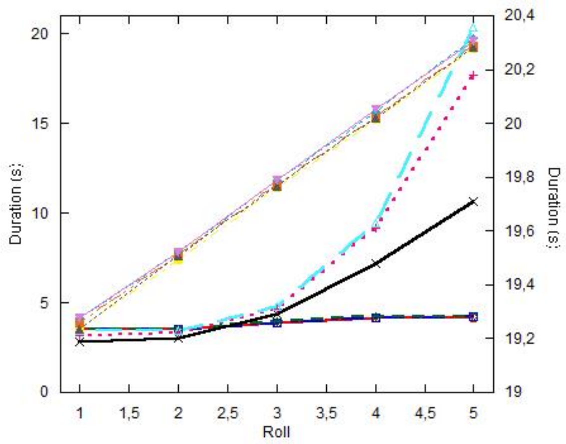

Figure 6. Effect of the number of turns and roll diameter on duration winding process.

Figure 6 shows that the duration of the coil winding process consistently increases with the expected number of coils. So, the display shows that for every increase in the number of coils, there is an increase in the duration of winding time within the range of 3 to 20 seconds. The number of spirals that cause an increase in the duration of the winding time is 10, 20, 30, 40, and 50 coils. The lines in the graph indicate that the winding duration for each additional number of spirals does not differ significantly for each variant wire dimension. It can be observed from the data from Table 2 to Table 5 that the difference in time needed for different wires on the same roll diameter differs only between 0.01 seconds and 0.3 seconds. In contrast, the increase in time due to changes in the roller diameter for the same number of coils is significantly different.

The graph at the bottom of Figure 6 visualizes the increase in the duration of time in the macro coil winding process. Overall, the lines do not indicate any significant difference in the duration times of the coil winding process using an automatic coil winding machine with the ATmega 8 microcontroller. The low duration of the coil winding process occurs because the difference in winding time of each wire on the same roll is only 0.01 to 0.3 seconds different. A comparison of the duration of the winding time required by each wire dimension is displayed in Figure 7.

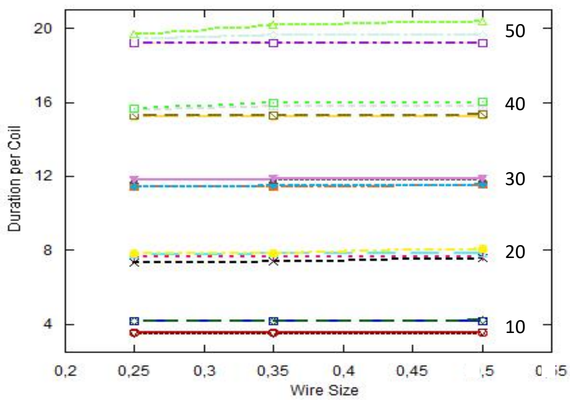

Figure 7. Comparison Of The Duration Time In The Winding Process For Different Wire Dimensions With Various Roll Diameters.

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The graph in Figure 7 shows a contrast in the duration of the coil winding process for different wire dimensions and roll diameters. Each line in the graph represents a different combination of wire dimension and roll diameter, with the x-axis showing the number of wire dimensions and the left y-axis indicating the duration time in seconds. Also, the right side of the y-axis indicates the number of coils. The increase in the duration time shown in each graph is a consequence of the increasing number of coil windings. As the number of coils increases, the coil winding process takes longer to complete. The graphs in Figure 7 show that as the number of coils increases, the duration of the coil winding process also increases. This trend can be seen in all graphs, regardless of the wire dimension and roller diameter worn. Whereas for the same number of coils, the increase in time duration on each wire dimension has no significant impact.

The comparison of the winding duration becomes most remarkable as the number of spirals increases to 50 coils. The graph clearly indicates a difference in time required for the coil winding machine using wire dimensions of 0.25 mm, 0.35 mm, and 0.50 mm. The increasing trend is strengthened by the data in Table 6, which shows an increase in the rolling duration of up to 0.3 seconds for each increase in the number of coils. Based on these results, we can conclude that an automatic coil winding machine utilizing the ATmega 8 as a microcontroller can work efficiently. Automatic coil winding machines do not require different duration times, even if the roller diameter or wire dimensions change according to user needs.

CONCLUSIONS

The ATmega 8 microcontroller functions well for processing on a water pump coil winder. The component wiring and device design indicate a potential for one coil error. The accuracy of winding the number of coils reaches 98%. The size of the wire used in the winding process does not affect the tool, does not reduce the effectiveness or accuracy of the tool, and does not reduce the efficiency of winding the coils to be used in water pumps. The optocoupler sensor connected to the ATmega 8 counts the number of turns and can carry out the winding process with precision. The larger the number of coils desired, the higher the accuracy of the number obtained by this winding roller. The stable rotational speed of the reels makes the number of coils even more perfect. There is only one winding in the machine where the error is made. This causes this tool to be used as a simple winding winder for pump motors.

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