COPPER WINDING VOICE COIL SPEAKER MICROCONTROLLER BASED

[1*]ADI KURNIAWAN SAPUTRO, [2]HANIFUDIN SUKRI, [3]ANDRE PUTRA PRATAMA, [4]KOKO JONI, [5]ACHMAD FIQHI IBADILLAH, [6]MONIKA FASWIA FAHMI

Department of Electrical Engineering, Faculty of Engineering, Universitas Trunojoyo Madura

Jl. Raya Telang, Perumahan Telang Indah, Kec. Kamal, Kabupaten Bangkalan, Jawa Timur, Indonesia 69162

e-mail: [1]adi.kurniawan@trunojoyo.ac.id, [2]hanifudinsukri@trunojoyo.ac.id, [3]190431100083@student.trunojoyo.ac.id, [4]kokojoni@trunojoyo.ac.id, [5]fiqhi.ibadillah@trunojoyo.ac.id, [6]monika.faswiaf@trunojoyo.ac.id

[*]Corresponding author

ABSTRACT

The voice coil is a vital speaker component, producing sound through electromagnetic vibrations. Generally, commercially available voice coils do not meet standard quality specifications, especially in terms of copper quality and adhesive strength. This problem often leads to issues such as coil burning or breakage during operation. On the other hand, ordering custom voice coils through manual winding processes requires considerable time. This study aims to address these limitations by designing an automated coil winding device that employs Pulse Width Modulation (PWM) techniques to control the speed of a DC motor, enabling the production of voice coils with specifications and durability tailored to specific needs. An Arduino Nano microcontroller controls the system and consists of a BTS 7960 motor driver, a Direct Current (DC) motor, an optocoupler sensor, a rotary encoder, a 4x4 keypad, and an LCD display with an I2C interface. Coil durability testing was conducted using an ohmmeter and an amplifier with a transformer ranging from 20A 45V to 30A 45V. The testing results indicate that coils produced with the automated winder can be adjusted to approach the 8-ohm specification, with a tolerance of 0.1 to 0.3 ohms, suitable for speaker requirements. The comparison results show that commercial voice coils exhibit resistances below 8 ohms, with the lowest resistance measured at 4.9 ohms for larger coils. During power testing, coils with a diameter of 35.5 mm and copper wire diameters of 0.20 mm and 0.23 mm broke when tested with a 20A 45V amplifier. In contrast, commercial coils remained stable up to an input power of 372 W and output power of 273 W, although a burning odor was detected. These findings indicate that the copper quality in commercial coils is superior in resisting amplifier power up to 30A 45V compared to coils produced with the automated device.

Keywords: *Voice Coil, Pulse Width Modulation, Arduino Nano, Motor Direct Current*

1. INTRODUCTION

A speaker, or loudspeaker, is a crucial electronic device that converts electrical signals into sound waves audible to the human ear. This process occurs through primary components, such as the voice coil, cone paper, and suspension, which work together to focus the movement of each element to produce optimal sound output [1]. The voice coil itself is a copper wire coil that generates a variable magnetic field to drive the cone paper and create sound vibrations [2]. To prevent errors in the coil, the winding of the voice coil requires high precision in terms of both the number of turns and the quality of materials used. However, in the current market, the quality of voice coil windings is often inconsistent, resulting in component durability issues and an increased risk of damage, such as burning or breakage, when used at high power levels [3].

Most small industries or electronics workshops still rely on manual winding tools for copper voice coil winding. As explained by Meilia Dwi Suryani and Moses Laksono Singgih, Voice Coil Touch (VCT) defects frequently occur due to a lack of precision during the installation process, such as inaccuracies in positioning, negligence in the gluing process, and failure to meet standard specifications in materials and equipment used. This indicates challenges in manual coil production, which can lead to products with reduced durability and increased susceptibility to damage when used over the long term [4].

Previous studies related to automation in coil winding have been conducted, such as the work by Yusuf Nur Rohmat et al., who designed a semi-automatic winding device for dynamo winding processes, allowing the replacement of manual labor with a more efficient and faster tool. Nur Rohman and her colleagues also developed an automatic winding system to increase production speed and improve the neatness of results, which proved effective in enhancing efficiency [5]. However, these studies primarily focus on the development of dynamo winding machines and have not yet addressed the specific challenges involved in voice coil winding for speaker applications. The main weaknesses of conventional methods are the lack of accuracy and speed in the manual winding process, present challenges that must be addressed. As described in the research by Dedi Setiawan and colleagues, the use of Pulse Width Modulation (PWM) has proven effective in controlling the speed of DC motors. Therefore, this study employs PWM techniques to develop an adjustable automatic voice coil winder, aiming to overcome the limitations of manual tools, which are prone to inaccuracies in the number of turns and variability in coil component quality [6].

This study aims to develop an automatic copper coil winding device using PWM control to enhance the accuracy and efficiency of voice coil production. Additionally, an ohmmeter feature is incorporated to facilitate the adjustment of the number of turns and to ensure that the voice coil resistance reaches 8 ohms, aligning with speaker specifications, within a tolerance of 0.1 to 0.3 ohms. Therefore, this research not only improves the durability and quality of the produced voice coils but also offers a more affordable alternative for small-scale industries previously limited by the high cost of commercial automatic winding machines.

2. RESEARCH METHODOLOGY

2.1 Pulse Width Modulation (PWM)

The primary methodology used in this study is Pulse Width Modulation (PWM), a technique commonly employed to control power in electrical devices. PWM is a modulation method that regulates power by rapidly switching the power source on and off [7]. This technique enables direct current (DC) to be converted into a square wave signal, where the "on" state reaches peak voltage and the "off" state drops to zero volts. By adjusting the ratio of "on" time to "off" time—referred to as the duty cycle—PWM can control the effective power supplied to a load. The PWM duty cycle ranges from 0% (fully off) to 100% (fully on), allowing precise power control [8].

In this study, PWM is utilized to regulate the speed of a DC motor that drives the coil winding (voice coil) system. The PWM duty cycle is set based on program input to control motor speed precisely. This enables the system to adjust the winding speed to the desired specifications, where the PWM signal's duty cycle is converted into the motor's rotational speed. The frequency of the PWM signal also affects how quickly the motor responds to speed adjustment changes [9].

2.2 Block Diagram

This system is designed with three main components: input, processing, and output. The block diagram in Figure 1 illustrates each component and its flow within the overall system. The input section consists of a 4x4 keypad that allows users to enter the desired number of motor rotations, either manually or automatically. This input serves as a control parameter that defines the required number of turns for the coil winding process. The processing section is managed by an Arduino Nano, which functions as the control system for the entire circuit. The Arduino Nano reads input from the keypad and processes this data to control the speed and number of rotations of the DC motor. The processing section also includes a rotary encoder and an optocoupler sensor. The rotary encoder provides feedback on the motor's position and rotational speed, while the optocoupler sensor accurately counts each rotation, ensuring the motor stops once the specified number of turns has been reached [10]. The output section consists of the DC motor and an LCD display. The DC motor, controlled by a PWM signal from the Arduino Nano, performs the winding of copper wire onto the voice coil. The motor's speed and number of rotations are controlled and adjusted in real time according to the PWM duty cycle. The LCD display provides real-time information, such as the completed number of turns, allowing the operator to monitor the process and ensure that the winding proceeds as expected [11][12]. Overall, this system enables precise control in the voice coil winding process, enhancing speed, accuracy, and consistency through PWM-controlled DC motor operation.

The main microcontroller governing the entire system is the Arduino Nano, which receives input from sensors and the keypad, and controls the DC motor and servo based on the specified settings. The LCD displays information such as the desired number of turns, motor speed, and the winding process status. The 4x4 keypad serves as an input tool for entering parameters, including the number of turns and other specifications required for the winding process.

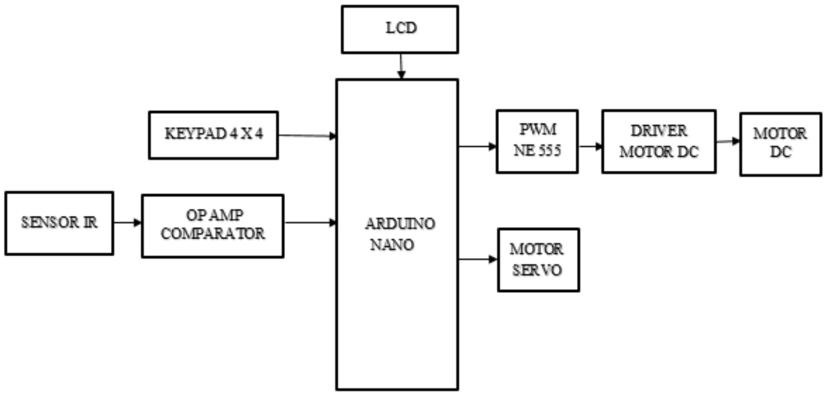

Figure 1. System Block Diagram

An IR sensor detects the motor's rotational period, while an Op Amp Comparator processes the signal from the IR sensor and sends it to the Arduino to ensure accurate turn counting. The NE555-based PWM module generates a PWM signal to control the speed of the DC motor [13][14]. This PWM signal is sent to the DC motor driver, which then drives the motor at the specified speed. The motor is used to wind copper wire onto the voice coil, with its speed controlled by the motor driver that receives the PWM signal from the NE555 [15]. The servo motor functions to position or guide certain components in the winding process, such as cutting the wire once the desired number of turns has been reached.

2.3 System Flowchart

The flowchart of the system is presented in Figure 2. The process begins with the preparation of the tools and materials to be utilized, including the configuration of the initial parameters for the voice coil and the winding machine. At this stage, the operator determines the diameter of the voice coil and the diameter of the copper wire to be used. These parameters are essential as they dictate the required number of turns and the power capacity that the voice coil can handle. The operator inputs the desired number of turns based on the speaker's requirements or specifications. This number of turns must be calculated according to the previously established diameter sizes of the voice coil and the wire to achieve optimal winding results.

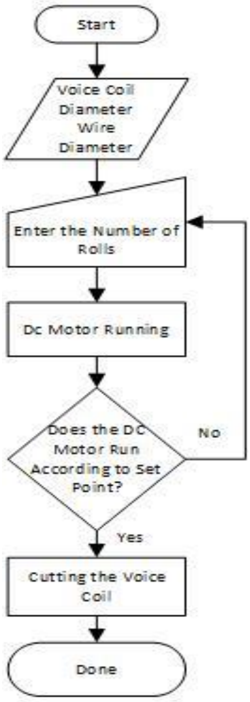

Figure 2. System Flowchart

Once the number of turns is determined, the DC motor begins to rotate and wind the wire to form the voice coil. The DC motor is controlled using PWM to adjust the speed as necessary, ensuring that the wire winding is conducted neatly and consistently. At this stage, the system checks whether the DC motor is operating at the defined speed and number of turns, referred to as the set point. If the desired number of turns has not yet been reached, the process will repeat until the target is achieved. Once the specified number of turns is completed, the process will continue.

After reaching the required number of turns according to the set point, the machine will cut the copper wire to finalize the winding process. This step can be performed either automatically or manually, depending on the design of the cutting system used. With the voice coil winding process completed, the voice coil is prepared for the next stage or for installation into the speaker. Each step in this process is crucial to ensure that the resulting voice coil meets the desired specifications and can operate optimally within the speaker.

3. RESULTS AND DISCUSSIONS

3.1 Hardware Result

The machine utilizes a DC motor for the winding system and is equipped with a keypad for input. Users can specify the number of turns for the DC motor, with an automatic selection option available by pressing specific letters on the keypad. This feature allows users to input the diameter of the voice coil and the size of the wire to calculate the required number of turns. The input is displayed on an LCD screen. To set the diameter of the voice coil, the machine is equipped with a mold, while a switch is provided to start the machine. A potentiometer is used to adjust the speed of the DC motor, and a button allows for slow motor rotation, ensuring accuracy in counting each turn. The system is further enhanced with a rotary encoder and an optocoupler sensor for precise processing. This configuration ensures that the winding operation is efficient and accurate, contributing to the overall effectiveness of the voice coil manufacturing process. The hardware is presented in Figure 3.

An integrated cutter is utilized to cut the copper wire once the winding process is completed. For automated operation, the cutter will activate automatically at the end of each session. After winding, the user can remove the voice coil from the mold, scrape or burn the ends of the copper wire, and then measure the resistance using an ohmmeter. The components involved include a buzzer, LCD, keypad, potentiometer, servo, cutter, ohmmeter, clamps, DC motor, bearings, pillow blocks, optocoupler, mold, and a switch. The switch indicates when the winding is complete, signaling that the winding has reached the halfway point and serving as a marker on the timer.

3.2 Revolution Per Minute (RPM) Testing

The Table 1 presents the calculation results for determining the RPM values based on the sizes of the large and small gears utilized in the tool. By employing the optocoupler component, the number of revolutions can be accurately measured without manual calculations. When the DC motor is operated at maximum speed (100%) for a duration of one minute, the number of revolutions made by the large gear, which has 28 teeth, is recorded as 178.

Figure 3. Voice Coil Equipment

Table 1 Large Gear and Small Gear RPM Experiments

No	Presentase	RPM (Large Gear)	RPM (Small Gear)
1	100%	178	415
2	75%	133,5	311,25
3	50%	89	207,5
4	25%	44,5	103,75

Gear ratio equation, R:

$$R = \frac{RPM_{\text{Small}}}{RPM_{\text{Large Gear}}} \quad (1)$$

Utilizing equation (1), the gear ratio is calculated by dividing the RPM of the small gear (415) by the RPM of the large gear (178), yielding a gear ratio of 2.33.

To calculate the RPM of the dynamo driving the large gear, it is necessary to determine the gear ratio between the dynamo and the large gear. The dynamo is connected through a gear ratio to the large gear, as expressed in the following equation:

$$R = \frac{RPM_{Dynamo}}{RPM_{\text{Large Gear}}} \quad (2)$$

The RPM of the dynamo can be determined by dividing the number of revolutions of the large gear by the number of revolutions of the small gears attached to the DC dynamo, resulting in a gear ratio of 2.333. With this ratio, the RPM of the DC dynamo can also be calculated by multiplying the gear ratio by the RPM of the large gear. This calculation yields an RPM of approximately 415.274 for the small gear, representing the maximum speed (100%) of the DC dynamo.

3.3 Voice Coil Voltage Testing

The Table 2 presents the voltage testing result on the voice coil. Based on the testing result, it is observed that the theoretical calculations for achieving a resistance of 8 ohms generally exceed the values obtained from the experiments, with the exception of the voice coils utilizing a diameter of 35.5 mm and 0.2 mm copper wire. In this particular case, the experiment recorded 136 turns, whereas the theoretical calculation indicated 131.16 turns. Conversely, the factory-manufactured voice coil of the same dimensions employed only 86 turns, resulting in a resistance of 7.5 ohms.

For other voice coil sizes, it is noteworthy that none of the experimental turn counts achieved the corresponding theoretical values. This discrepancy may be attributed to variations in the type of resistance or the quality of the copper used; higher purity copper necessitates more turns, consequently requiring a longer length of copper wire to attain the targeted 8-ohm resistance. Manufacturers might deliberately design the resistance to be slightly below 8 ohms to prevent the copper windings from contacting the bottom iron plate of the speaker and to ensure compatibility with a variety of speaker types utilizing the same voice coil size. Furthermore, minimizing the number of copper windings serves as a cost-saving strategy.

Table 2 Testing the Voltage on the Voice Coil Using an Ohmmeter and Multimeter

Testing	Voice Coil Diameter	Copper diameter	Lots of twists	Copper wire length (meters)	Voltage (ohmmeter on tool)	Voltage (multimeter)	Barriers Copper type
1	99,2 mm	0,42 mm	184	57,224 m	8,2Ω	8,2Ω	1,984 × 10^{-8}
2	99,2 mm	0,40 mm	178	55,358 m	8,2 Ω	8,2Ω	1,860× 10^{-8}
3	75,5 mm	0,35 mm	178	42,186 m	8,2 Ω	8,2Ω	1,869× 10^{-8}
4	75,5 mm	0,30 mm	136	32,232 m	8,1 Ω	8,2Ω	1,775× 10^{-8}
5	49,5 mm	0,28 mm	176	27,28 m	8,1 Ω	8,2Ω	1,827× 10^{-8}
6	49,5 mm	0,25 mm	138	21,39 m	8,3 Ω	8,4Ω	1,903× 10^{-8}
7	35,5 mm	0,23 mm	156	17,784 m	8,2 Ω	8,2Ω	1,914× 10^{-8}
8	35,5 mm	0,20 mm	136	15,504 m	8,1 Ω	8,1Ω	1,640× 10^{-8}
9	99,2 mm (manufacturer)	0,40 mm	86	35,454 m	4,9 Ω	4,9 Ω	2,402×10^{-8}
10	75,5 mm (manufacturer)	0,30 mm	115	24,648 m	6,4 Ω	6,4 Ω	2,146 × 10^{-8}
11	49,5 mm (manufacturer)	0,25 mm	104	17,285 m	7,8 Ω	7,7 Ω	1,834× 10^{-8}
12	35,5 mm (manufacturer)	0,20 mm	114	9,804 m	7,5Ω	7,5Ω	1,735× 10^{-8}
13	99,2 mm (theory)	0,42mm	131,161	65,94 m	8Ω	-	1.68× 10^{-8}
14	99,2 mm (theory)	0,40mm	173,460	59,809 m	8 Ω	-	1.68× 10^{-8}
15	75,5 mm (theory)	0,35mm	150,729	45,791 m	8 Ω	-	1.68× 10^{-8}

Testing	Voice Coil Diameter	Copper diameter	Lots of twists	Copper wire length (meters)	Voltage (ohmmeter on tool)	Voltage (multimeter)	Barriers Copper type
16	75,5 mm (theory)	0,30mm	189,075	33,642 m	8 Ω	-	1.68×10^{-8}
17	49,5 mm (theory)	0,28mm	141,952	29,306 m	8 Ω	-	1.68×10^{-8}
18	49,5 mm (theory)	0,25mm	193,213	23,363 m	8 Ω	-	1.68×10^{-8}
19	35,5 mm (theory)	0,23mm	192,311	19,774 m	8 Ω	-	1.68×10^{-8}
20	35,5 mm (theory)	0,20mm	212,025	14,952 m	8 Ω	-	1.68×10^{-8}

The test results clearly indicate discrepancies among the theoretical, experimental, and factory-made voice coils, particularly concerning the number of windings, which directly affects the resulting resistance. By determining the number of turns, the length of copper wire (P) utilized can be calculated using the following equation:

$$P = (\text{number of turns}) \times (\text{circumference of the voice coil}) \quad (3)$$

To determine the resistance of the type of copper used in winding voice coils and manufacturers can use the following equation:

$$\rho = \frac{R \times A}{L} \quad (4)$$

Where ρ is the resistance of the type of copper wire, R is the resistance of the copper wire, L is the length of the copper wire and A is the cross-sectional area of the copper wire

3.4 Input and Output Power Testing

According to the Table 3, the power ratios for a 35.5 mm voice coil with copper diameters of 0.2 mm, 0.23 mm, and 0.2 mm (manufacturer), as well as for a 49.5 mm voice coil with copper diameters of 0.25 mm, 0.28 mm, and 0.25 mm (manufacturer), indicate that both the input and output power exceed the specified power targets. This excess is attributed to the amplifier's capacity, which is sufficient to meet the power target requirements.

In the case of the 75.5 mm voice coil with a copper diameter of 0.35 mm, the input power exceeds the target due to the voice coil jumping, which is caused by a collision between the voice coil and the bottom iron plate. This issue arises because the adhesive used has not fully cured, preventing the secure placement of the voice coil and causing the copper winding not to sit entirely within the magnetic field. Consequently, the amplifier's power indicator shows a high reading immediately after the voice coil lifts, while the output power fails to reach the target. A similar issue occurs with the 0.30 mm (manufacturer) coil size, where the input power nearly meets the target, but the output power remains significantly below it.

For the remaining sizes, specifically, the 75.5 mm voice coil with a 0.30 mm copper diameter and the 99.5 mm voice coils with copper diameters of 0.4 mm, 0.42 mm, and 0.4 mm (manufacturer), neither the input nor output power reaches the target. This shortfall is due to the amplifier's inability to provide the necessary power, as the high specifications of these speakers exceed the amplifier's capabilities.

The diagram illustrates a significant disparity between input and output power, which can be attributed to the connections or cables used, resulting in a reduction of the current transmitted from the amplifier's output. Additionally, the efficiency of the transformer and amplifier contributes to the output power variation, as some power is lost as heat rather than being effectively delivered as output power to the speaker.

Table 3. Comparison of the Input and Output Power

Voice coil diameter	Copper Diameter	Resistance	Travo Current	Voltage Travo	frequency	Output Current	Output Voltage	Output Power	Input Power	Power Target	information
35,5mm	0,2mm	8,1 Ω	20A			3,28 A	49,05 V	160,88 W	247,3W	100 W	broken wire
	0,23mm	8,2 Ω				3,82 A	52,17 V	199,2894 W	256,9W	175 W	broken wire
	0,2mm (manufacturer)	7,5 Ω				4,5 A	60,71 V	273,195 W	372 W	175 W	burnt
49,5mm	0,25mm	8,3 Ω				3,49 A	57,79 V	201,6871 W	349,8W	100W	hot

	0,28mm	8,1 Ω				3,95 A	54,8 V	216,46 W	345 W	200 W	hot
	0,25mm (manufacturer)	7,8 Ω				4,29 A	60,67 V	260,2743 W	422,5W	200 W	hot
75,5mm	0,3mm	8,1 Ω	30A	45 V	50 Hz	2,98 A	57,47 V	171,2606 W	270 W	300 W	hot
	0,35mm	8,1 Ω				5,79 A	59,02 V	341,7258 W	458 W	450 W	hot
	0,3mm (manufacturer)	6,4 Ω				5,63 A	59,61 V	335,6043 W	449 W	450 W	hot
99,5mm	0,4mm	8,2 Ω				1,52 A	60,39 V	91,7928 w	178 W	500 W	hot
	0,42mm	8,2 Ω				2 A	63,7 V	127,4 W	207,4W	650 W	hot
	0,4mm (manufacturer)	4,9 Ω				2,96A	61 V	180,56 W	290,2W	650 W	hot

4. CONCLUSION

This study successfully designed and tested an automatic voice coil winding machine based on PWM controlled by an Arduino Nano. This machine is capable of producing voice coils with specifications approaching 8 ohms, in accordance with the requirements of the speaker, with a resistance tolerance of 0.1 to 0.3 ohms. In comparison to factory-made voice coils, the automatically wound coils demonstrate more accurate resistance values but exhibit lower durability under high current conditions. During power testing, the automatically wound coil of a specific size failed when tested with a 20A 45V amplifier, whereas the factory-made coil was able to withstand up to 30A 45V, despite a noticeable odor indicating heating. This suggests that the quality of the copper used in factory-made coils is superior in terms of heat and high current resistance.

Overall, this automatic winding machine can produce voice coils of acceptable quality and specifications, although there are differences in material durability compared to factory-made voice coils. This device has the potential to address issues in the manual production of voice coils, which is time-consuming and could serve as a more efficient alternative for producing voice coils that meet specific requirements.

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