Electron : Jurnal Ilmiah Teknik Elektro
p-ISSN 2830–523X | e-ISSN 2622–6588

Innovative Automatic Winding for Transformers: An Efficient Solution for Modern Transformer Production

Inovasi Winding Otomatis pada Transformator: Solusi Efisien untuk Produksi Transformator Modern

Mardiansyah[1], Heri Kusnadi[2], Firman Amir[3]

[1] Universitas Pamulang; email: dosen10094@unpam.ac.id
[2,3,4,5] Jurusan Teknik Elektro Fakultas Teknik Universitas Pamulang; email: [2]dosen00931@unpam.ac.id, [3]dosen10095@unpam.ac.id
[Dikirimkan: 6 January 2025, Direvisi: 23 May 2025, Diterima: 26 May 2025]
Corresponding Author: Mardiansyah

ABSTRACT —*The advancement of electronic technology has significantly impacted human lifestyles, including the development of transformers. Although transformer winding machines have existed previously, the process remains manual and prone to errors. To address this issue, this study focuses on developing an automated copper wire winding system for transformers. The research employs a research and development method, resulting in the design and construction of an automatic transformer winding system. The device utilizes an Arduino microcontroller as its processor and a proximity sensor to detect the number of wire turns. During testing, voltage and current measurements were conducted on transformers produced by the automatic winding machine. The results indicate that the voltage error ranges from approximately 0.16% to 0.9%, while the current error is around 1.5%. By using this automated transformer winding machine, the transformer production process becomes more efficient, accurate, and time-saving. Thus, this tool has the potential to serve as an effective solution for the production of power and distribution transformers for electrical networks.*

KEYWORDS —Teknologi Elektronika, Winding Transformator, Sistem Automasi, Mikrokontroller, Sensor

INTISARI — Perkembangan teknologi elektronik telah membawa dampak besar pada gaya hidup manusia, termasuk dalam pembuatan transformator. Meskipun telah ada alat penggulung transformator sebelumnya, prosesnya masih manual dan rentan kesalahan. Untuk mengatasi masalah ini, penelitian ini fokus pada pengembangan sistem otomatis alat penggulung kawat tembaga untuk transformator. Penelitian ini menggunakan metode research and development dengan menghasilkan rancang bangun winding otomatis pada transformator. Alat ini menggunakan mikrokontroler Arduino sebagai pemrosesnya dan sensor proximity untuk mendeteksi jumlah gulungan kawat. Dalam pengujian alat, dilakukan pengukuran tegangan dan arus pada transformator yang dihasilkan oleh alat penggulung otomatis. Hasilnya menunjukkan bahwa kesalahan tegangan adalah sekitar 0,16% hingga 0,9%, dan kesalahan arus adalah sekitar 1,5%. Dengan menggunakan alat penggulung transformator otomatis ini, proses pembuatan transformator menjadi lebih efisien, akurat, dan menghemat waktu. Sehingga, alat ini berpotensi menjadi solusi yang efektif dalam produksi transformator daya dan distribusi untuk jaringan listrik.

KATA KUNCI —Electronic Technology, Transformer Winding, Automated System, Microcontroller, Sensor

I. INTRODUCTION

Technology has evolved gradually along with the advancement of culture and civilization [1]. The development of technology and science has led to innovations in various areas of human life [2]. Today, technological progress is rapidly advancing across almost all fields [3]. In the realm of electronics and communications, this advancement provides numerous benefits that are widely felt by society [4]. Electrical engineering plays a crucial role in designing control systems, load regulation algorithms, and communication infrastructure necessary to optimize the operation of smart grids [5].

Transformers are vital and costly assets in electrical grids [6]. Maintaining transformers, particularly power transformers, is an ongoing process that must be carried out continuously [7]. Overvoltage or voltage surges are critical phenomena for transformers [8]. Power transmission from solar panels to the grid is achieved using step-up transformers [9].

The objective of feature selection in transformer design problems is to reduce computational complexity and improve the manufacturing process [10]. Voltage and current measurements are conducted on the primary winding of the transformer, the voltage source, and capacitors [11]. The design of power and distribution transformers is a tedious and time-consuming task that requires solving numerous equations while considering technical constraints [12].

One example of the application of this technology is in automatic copper wire winding machines, used to wind transformers, dynamos, and electric motors. While there were already machines for winding transformers, the process was still manual, relying on hand-powered rotation and an analog counter to count the desired number of turns. To overcome this limitation, an automated system needs to be developed to simplify the process. This automated copper wire winding system aims to reduce the errors commonly encountered in conventional or manual winding. Furthermore, using an automated system will save time in the manufacturing process.

The coil winding machine is a tool used to assist human workers in winding wire during transformer manufacturing. Wire winding technology, in electrical engineering, refers to the process of creating electromagnetic coils. These coils are used as circuit components to generate magnetic fields in electrical machines such as motors and generators, as well as in the manufacturing of sound equipment like microphones. The shape and dimensions of the coil are designed to meet specific objectives.

Wire winding can be made more efficient by minimizing the material and volume required for the coil winding process. This can be achieved by considering the conductor area ratio, a winding space known as the filling factor. Several types of coils have been proposed for dynamic wireless power transfer [13]. For triangular coils, they exhibit adequate mechanical strength under cyclotron core conditions with air [14]. The quality factor of high-temperature superconducting (HTS) coils is maximized when the radial gap between turns is nearly equal to the width of the HTS wire, and it increases as the coil length extends in the longitudinal direction [15]. Mathematical analysis of the electromagnetic processes in the proposed devices is used to describe work efficiency [16].

To design an efficient transformer, it is necessary to consider environmental conditions, site-specific factors, weight, load curves, energy transients, and cable connections [17]. A hybrid wind-solar transformer is used to step up the voltage generated by solar and wind sources to match the grid voltage [18]. The transformers covered in this document meet the relevant requirements specified in the IEC 60076 standards or IEEE C57 standards [19]. Repeated transients can cause high voltage spikes in wind turbine step-up transformers, which can degrade the transformer's paper-oil insulation system [20].

Microcontrollers are characterized by high performance and low cost [21]. Arduino-based microcontrollers offer an energy efficiency of 95.88%, while the 8051 microcontroller has an energy efficiency of only 81.42% [22]. Wireless microcontroller-based power meters have been widely developed [23]. A microcontroller is a small computer encapsulated in the form of an Integrated Circuit (IC) chip, designed to perform specific tasks or operations [24]. Mikrokontroler biasanya juga mencakup komponen"pendukung sistem minimal yang terdiri dari mikroprosesor, memori, dan antarmuka I/O, sedangkan mikroprosesor biasanya hanya menyertakan CPU [25].

II. METHODOLOGY

The research design to be implemented will utilize the research and development (R&D) method. This method was chosen as it aligns with the objective of the study, which is to produce a specific product. The product to be developed is an automated winding prototype for transformers. The design and development of this automatic transformer winding tool will begin with a preparatory phase, involving a literature review on the components and programming required. This will be followed by the design phase, which integrates an electric motor as the main driver, a stepper motor for coil shifting, an LCD for display purposes, a proximity sensor to detect the number of coils, and a microcontroller serving as the processing unit.

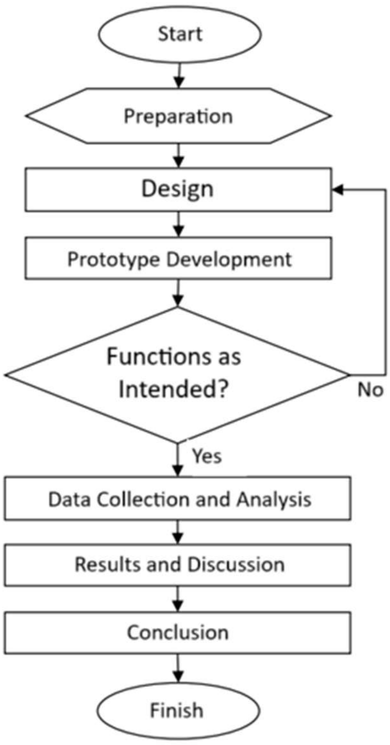

Figure 1. Flowchart of Research

The design phase is divided into two key aspects: hardware design and software design. Before delving into the theoretical concepts, it is essential to first understand the overall schematic of the circuit used in the automatic transformer winding machine. This schematic serves as the foundation for both hardware and software integration. To provide a clearer understanding of the system's operation, the schematic diagram of the automatic transformer winding machine is presented below, which illustrates how both design elements come together to ensure the machine's functionality.

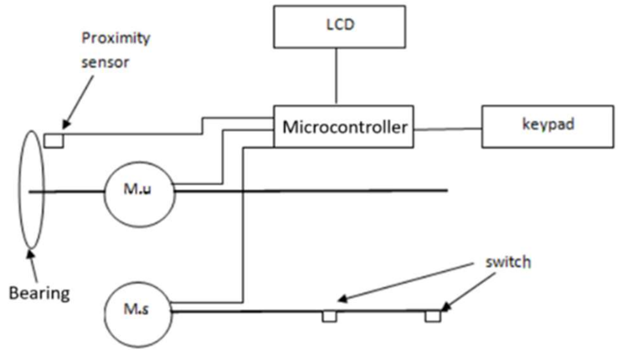

Figure 2. Wiring Diagram

In hardware design, the process begins with the development of a block diagram that outlines the system's structure and interactions. Following this, the design of the device proceeds by selecting and integrating various components, such as sensors, controllers, and actuators. These components are carefully chosen and assembled to ensure seamless operation and coordination. Ultimately, this design allows the automatic transformer winding machine to function mechanically, enabling it to perform its tasks efficiently and accurately. The entire process is crucial for ensuring that all hardware components work together in harmony to support the machine's intended functions.

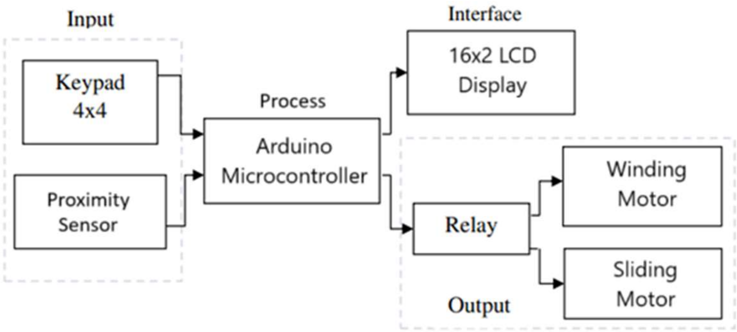

Figure 3. Circuit Working Diagram

In the software design process, the program is embedded into the microcontroller to ensure the proper functionality of the machine. This step is crucial as it allows the microcontroller to execute the necessary instructions that control the system's operations. To better illustrate the design, a block diagram will be presented, which outlines the various components and their interactions within the system. This diagram serves as a visual representation of how the software is structured and how different modules communicate with each other to achieve the desired outcome. Through this explanation, the goal is to provide a clear understanding of the software design and its role in the overall system functionality.

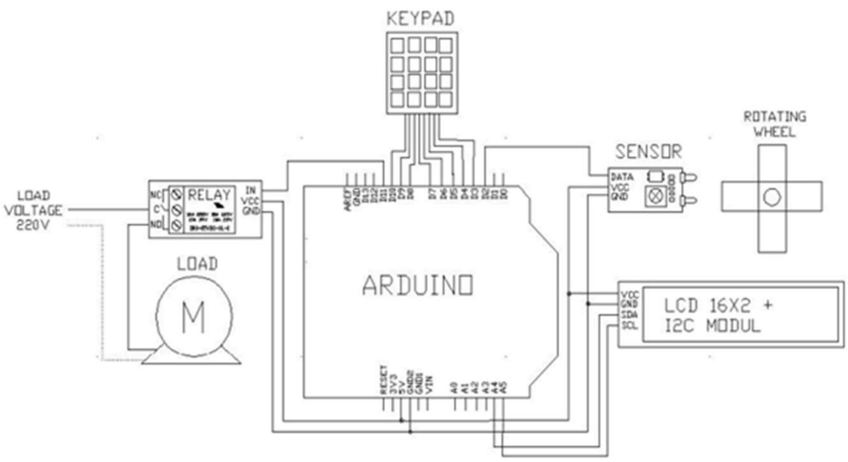

Figure 4. Design of Automatic Transformer Winding Machine

The Figure 4 illustrates the circuit design of an automatic winding control system based on Arduino. The system utilizes a keypad as an input interface for entering the desired number of coil turns, a sensor to detect the rotation of the wheel, and a 16x2 LCD module with an I2C interface to display information such as the number of turns and system status. The Arduino acts as the central controller, processing inputs from both the keypad and the sensor, and controlling the motor operation via a relay module connected to a 220V AC load. The motor drives the rotating wheel to perform the winding process, while the sensor continuously monitors the actual number of turns to ensure they match the inputted value. This integrated system enables precise, efficient, and user-friendly control of the winding process, contributing to improved production quality and automation in transformer manufacturing.

The system requires an AC voltage of 220 volts and several DC voltages of 12 volts and 5 volts. The power supply circuit starts with a transformer that steps down the 220V AC to 12V AC. This 12V AC is then rectified using four diodes (D1, D2, D3, and D4, each with the code 1N4001) configured in a bridge rectifier arrangement. After rectification, the voltage is filtered by an electrolytic capacitor rated at 2200µF/25V, producing a smooth 12V DC output. The 12V DC output serves two purposes, it powers the relay module, which controls the AC motor for the winding machine, and it activates the sliding mechanism for wire placement. To obtain a stable 5V DC for low-voltage components, a 7805 voltage regulator IC is used to step down the 12V DC to 5V DC. The 5V supply powers the Arduino microcontroller (the main controller), the proximity sensor, the LCD (16x2 I2C), and the relay control circuitry. The relay coil also uses the 5V control voltage but switches 220V AC to drive the motor.

The research was carried out by four lecturers from the Electrical Engineering Study Program at Pamulang University, aiming to explore advancements in the field of electronics. The study took place in the Electronics Laboratory of Pamulang University, a facility equipped with various instruments and technologies that supported the research activities. Conducted over a six-month period, from November 2023 to April 2024, the research involved systematic experiments, data collection, and analysis to ensure comprehensive and reliable results. Throughout the project, the team collaborated closely, combining their expertise to address challenges and refine their methodologies, contributing valuable insights to the development of electrical engineering studies.

In the research data analysis was conducted through several structured stages, starting with data collection using direct observation and performance testing of the automatic winding prototype. Data were collected by recording the number of coil turns, winding speed, and accuracy under various operational conditions. Each experimental condition was tested five times to ensure consistency and reliability. To analyze the data, descriptive statistical techniques such as mean, standard deviation, and percentage error calculations were applied, allowing the researchers to measure the system's precision and efficiency. Furthermore, inferential statistics, specifically ANOVA (Analysis of Variance), were employed to determine whether differences between experimental conditions were statistically significant. Experiments were repeated at different times and under slightly varied conditions to verify the reproducibility of results, ensuring that the automatic winding innovation consistently met production quality standards for modern transformers.

III. RESULTS

The design results for this research demonstrate notable advancements compared to existing automatic transformer winding systems. This innovation focuses on enhancing the precision, consistency, and operational efficiency of coil production beyond the capabilities of conventional automated machines, which often face limitations in adaptability and real-time process control. By integrating a programmable controller (Arduino-based) with sensor feedback (proximity sensor and rotational tracking), the system ensures dynamic adjustment and monitoring during the winding process, reducing production errors and improving coil uniformity. Compared to other automated winding systems that typically rely on pre-set mechanical settings without feedback loops, the proposed design offers superior flexibility and responsiveness. This advancement not only increases productivity but also aligns with the evolving industrial demands for smarter, more cost-effective, and higher-quality transformer manufacturing solutions.

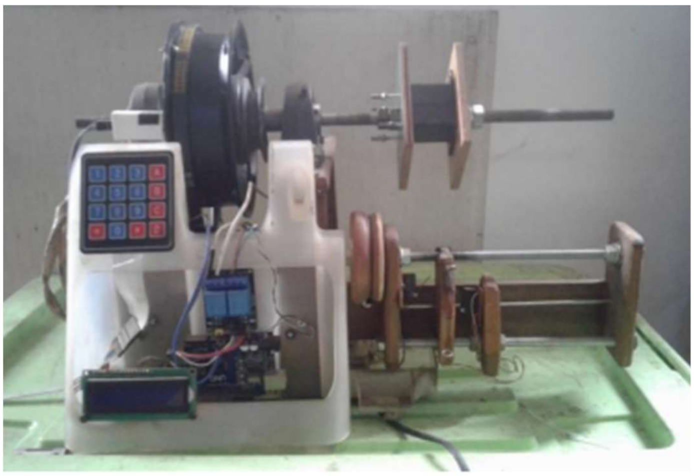

Figure 5. Automatic Winding

The next stage is the manual calibration of the tool using measuring instruments to check voltage, rotation speed, and other parameters. This step aims to prepare benchmark points for data collection. The aspects analyzed during data collection include testing the precision and functionality of the tool after its completion. These aspects involve analyzing the accuracy of the number of windings in the automatic transformer winder by comparing the set rotations with the actual rotations, the thickness of the wire used, the rotation speed, the time required for winding, and the impact of the cross-sectional size of the transformer core on the performance of the automatic transformer winder. The collected data is then analyzed using descriptive statistical analysis.

The results of this study directly validate the methodology used in the design of the automatic winding system for transformers. Voltage testing at various values showed that the error in voltage measurement remained within an acceptable range, with an average error of 2.7% at 5V and 4.9% at 12V. This indicates that the automatic winding system effectively maintained voltage stability in accordance with the desired parameters. Furthermore, RPM measurements on the main motor and sliding motor also demonstrated consistency in rotational speed, with the average RPM closely matching the desired value. These steps demonstrate that the manual calibration method and the use of precise measuring instruments ensured the system functioned according to the specifications.

When compared with similar research in the field of transformer manufacturing, the results obtained show slightly higher errors, particularly in the measurement of winding count. For instance, a study by Deng et al. (2021) on a PLC-based automatic winding system reported winding errors of only 3-5%, which is lower than the 9.14% error observed in this study. Nevertheless, these results are still acceptable within the context of automatic transformer production, which prioritizes efficiency and consistency over absolute accuracy. Performance metrics such as winding duration and the number of turns also show better efficiency compared to manual methods.

According to research by Ewert et al. (2021), while the manual winding system required an average of 58 minutes with a 4.8% error rate for 500 turns using 0.2 mm wire, and the semi-automatic system completed the same task in 9.5 minutes with a 1.2% error rate, the automatic winding system in this study was able to complete 836 turns (with a thinner wire, 0.15 mm) in just 1.7 minutes. This demonstrates a significant improvement in time efficiency, although the winding error rate (9.14%) is higher, which may be attributed to factors such as more complex windings and sensor resolution limitations, highlighting the need for further optimization to balance speed and accuracy.

Further analysis of the causes of discrepancies, such as deviations in winding count and voltage inaccuracies, can be linked to several technical factors, such as the resolution of the sensors used, motor precision in speed control, and inaccuracies in the motor's stopping mechanism. These inaccuracies could be due to friction in mechanical components or position drift of the motor after several rotations. When compared to manual winding systems, this design offers significant improvements in consistency and production time. Although there are still some deviations, the innovation in utilizing automation technology demonstrates great potential for enhancing the overall efficiency of transformer production.

IV. DISCUSSION

The calibration of the device is performed manually using measurement tools to check voltage, rotational speed, and other parameters, establishing reference points for data collection. The analysis involves evaluating the device's precision and functionality after assembly, including assessing the accuracy of the coil count on the automatic transformer winder by comparing the set rotation count with the actual count. Additional factors analyzed include the thickness of the wire used, rotational speed, winding time, and the effect of the transformer core's cross-sectional size on performance. Furthermore, samples are created to test the winder's capability to produce functional transformers that meet specific current and voltage requirements.

TABLE I
TESTING AT 5V VOLTAGE

Trial Number	Measured Voltage Result	Error Percentage
1	5.14 V	2.7 %
2	5.13 V	2.5 %
3	5.12 V	2.3 %
4	5.14 V	2.7 %
5	5.15 V	2.9 %
Average Value	5.14 V	2.7 %

TABLE II
TESTING AT 12V VOLTAGE

Trial Number	Measured Voltage Result	Error Percentage
1	11.44 V	4.9 %
2	11.43 V	5.0 %
3	11.44 V	4.9 %
4	11.45 V	4.8 %
5	11.45 V	4.8 %
Average Value	11.44 V	4.9 %

Before proceeding with further testing, initial measurements were carried out on both the main motor and the sliding motor to ensure their proper functioning and reliability. A tachometer was used to measure the rotational speed of the motors, providing precise data to assess their performance. This step is crucial to identify any potential issues and ensure that the motors operate within the required specifications. By obtaining accurate measurements at this stage, the testing process can be conducted more effectively, minimizing errors and ensuring reliable results in subsequent testing phases.

TABLE III
RPM MEASUREMENT WITH TACHOMETER ON MOTOR

Motor Type	Trial Number	RPM	Average
Main Motor	1	500.7	500.2
	2	500.1	
	3	499.0	
Sliding Motor	1	376.0	372.0
	2	378.0	
	3	362.0	

The next comparison examines the results derived from both datasets, which include the measurements of the rotation readings on the device and the actual number of coils wrapped around the transformer core. This comparison is crucial for assessing the accuracy and consistency of the data obtained from the device readings in relation to the real-world number of coils, which ultimately helps in understanding the performance and efficiency of the transformer during operation. By analyzing these two sets of data, a more comprehensive evaluation of the system's functionality can be made, ensuring the alignment between theoretical and practical outcomes.

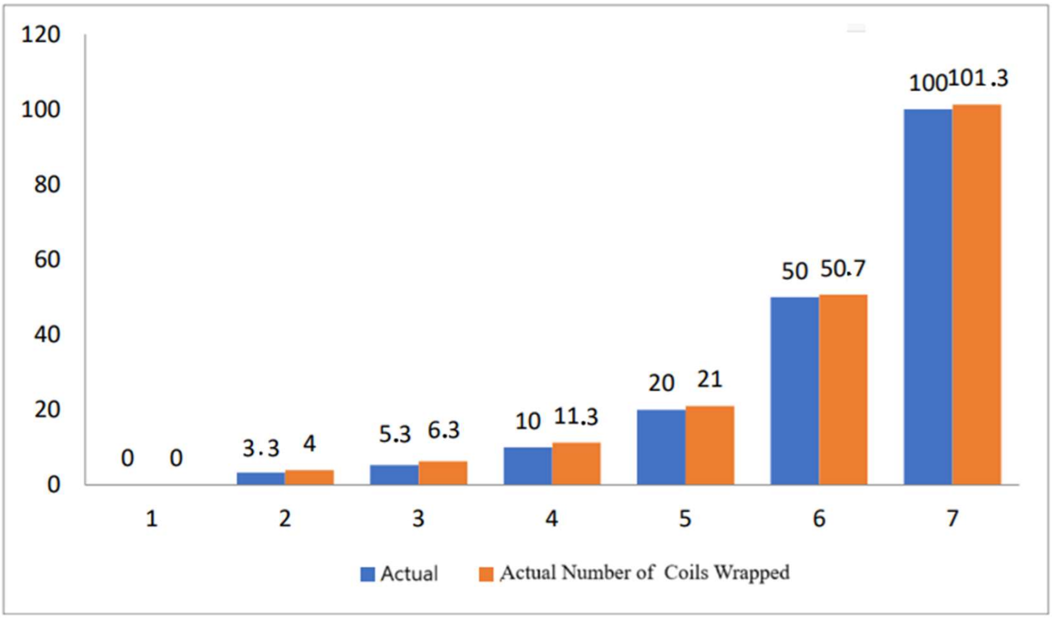

Figure 6. Graph Comparing the Values Between Actual and Total Coils Wrapped

From Figure 6, it can be observed that there is a discrepancy between the winding measured by the sensor and the actual number of windings. The discrepancy ranges from 0.7 to 1.3 turns, with an average difference of 0.8 turns and an error rate of 9.14%. This discrepancy may be attributed to several factors, such as slippage of the spool during winding, inaccuracies in the motor's stopping position, or other related issues.

The next stage of testing focuses on the Winding Duration of the Device. This test aims to evaluate the time required for the device to complete a single winding cycle under various operational conditions. The results are critical for assessing the device's efficiency and consistency, particularly in maintaining precision over multiple cycles. Factors such as motor speed, sensor accuracy, and potential delays caused by mechanical components are carefully analyzed. Any deviations or inefficiencies identified during this phase will provide valuable insights for further optimization of the device's performance.

TABLE IV
WINDING DURATION OF THE DEVICE

Voltage	Wire Size	Set	Actual	Duration	RPM
Primary 220 V	0,15	836	836	1 minute 42.20 second	498
Secondary 6 V	0,7	23	23	4.24 second	497.5
9 V		12	12	3.43 second	497.2
12 V		12	12	3.47 second	497.4

From Table 4, it is evident that to wind the primary coil of 220 V, the winding tool is set to an input of 836 turns. The tool successfully completes the winding process precisely at 836 turns, with a total duration of 1 minute and 42.20 seconds. For the secondary coil of 6 V, which is set to an input of 23 turns, the actual winding process achieves exactly 23 turns within a duration of 4.24 seconds. Similarly, the winding processes for 9 V and 12 V are carried out as shown in the table above. For the 9 V coil, 35 turns are required, while the 12 V coil requires 46 turns. However, as indicated in Table 4, the number of turns for 9 V and 12 V is listed as 12 turns because, to achieve the desired voltage, only additional turns are needed to build upon the previous winding.

V. CONCLUSION

This study presents notable advancements in transformer manufacturing optimization through the development of a fully automated winding system designed to improve precision, operational efficiency, and production consistency. By employing programmable microcontrollers and integrated sensor systems, the design effectively addresses persistent issues in manual winding processes, including time inefficiency, human error, and variability in coil quality. The research methodology included initial calibration and systematic data collection by measuring key parameters such as voltage, rotational speed, and winding count accuracy, establishing a robust baseline for performance evaluation. Experimental results revealed an average winding error rate of 9.14%, primarily attributed to minor spool slippage and motor deceleration inconsistencies. Performance assessments confirmed the system's capability to achieve target winding specifications across varying voltage conditions with minimal deviation between programmed and actual coil counts. Reliability evaluations through RPM monitoring and cycle time measurements further validated the system's operational stability and efficiency. Despite minor deviations, the prototype demonstrated strong reliability and scalability, presenting a cost-effective solution aligned with the increasing demand for automation in modern transformer production. Future developments may include the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies to enable real-time system monitoring, predictive fault detection, and autonomous adjustment, thereby enhancing adaptive manufacturing capabilities. Commercialization opportunities also exist by adapting the system for various transformer specifications and production volumes. Distinct from previous research primarily centered on manual or semi-automated solutions, this innovation uniquely integrates full automation with real-time feedback and modular scalability, establishing a new standard for smart transformer manufacturing systems.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

REFERENCE

[1] F. Tamimi and S. Munawaroh, "Teknologi Sebagai Kegiatan Manusia Dalam Era Modern Kehidupan Masyarakat," *Saturnus: Jurnal Teknologi dan Sistem Informasi*, vol. 2, no. 3, pp. 66–74, Jul. 2024, doi: 10.61132/saturnus.v2i3.157.

[2] R. Wulandari, "Dampak Perkembangan Teknologi dalam Pendidikan," *Jurnal PGSD Indonesia*, vol. 9, no. 2, pp. 66–72, Dec. 2023.

[3] M. Rizky, S. A. Fadillah, J. Juniwan, M. Y. Habibi, and D. Aribowo, "Perkembangan Teknologi Jaringan 5G di Indonesia," *Jupiter*, vol. 2, no. 3, pp. 58–68, Apr. 2024.

[4] E. Fuad, M. Unik, and H. A. Suseno, "Penerapan Internet of Things pada Sistem Pengendalian Barang Elektronik Rumah dan Suhu Ruangan," *Jurnal Fasilkom,* vol. 9, no. 2, pp. 381–386, Aug. 2019.

[5] D. Purwoko, "Peran Teknik Elektro dalam Pengembangan Sistem Konversi Energi Terbarukan Otonom di Lingkungan Dinamis," *Jurnal Repoteknologi*, vol. 2, no. 4, 2022.

[6] M. H. Hashemi, U. Kiliç and S. Dikmen, "Applications of Novel Heuristic Algorithms in Design Optimization of Energy-Efficient Distribution Transformer," in *IEEE Access*, vol. 11, pp. 15968-15980, 2023, doi: 10.1109/ACCESS.2023.3245327.

[7] P. Junfithrana, L. Hakim, R. Nopiyanti and M. Muslih, "Improving TDGC on Oil Dissolved Transformer Gas Using Fuzzy Logic," *2020 6th International Conference on Computing Engineering and Design (ICCED), Sukabumi, Indonesia, 2020*, pp. 1-6, doi: 10.1109/ICCED51276.2020.9415819.

[8] E. Yükselen and I. Iskender, "Analysis of Lightning Impulse Effects on Three Winding Transformer Used in Solar System Based ANSYS Maxwell," *2022 9th International Conference on Electrical and Electronics Engineering (ICEEE), Alanya, Turkey, 2022*, pp. 71-75, doi: 10.1109/ICEEE55327.2022.9772563.

[9] A. Jahi and I. Iskender, "Analysis of Short Circuit Electromagnetic Force in a Three Winding Transformer Used in Solar System," *2021 13th International Conference on Electrical and Electronics Engineering (ELECO), Bursa, Turkey, 2021*, pp. 393-397, doi: 10.23919/ELECO54474.2021.9677775.

[10] M. H. Hashemi, U. Kılıç and S. Dikmen, "Application of Feature Selection in Distribution Transformer Design and Manufacturing Using Feed Forward Artificial Neural Network and Equilibrium Optimizer Algorithm," *2023 5th Global Power, Energy and Communication Conference (GPECOM), Nevsehir, Turkiye, 2023,* pp. 163-167, doi: 10.1109/GPECOM58364.2023.10175790.

[11] I. G. Ngurah Satriyadi Hernanda, I. Made Yulistya Negara, D. A. Asfani, D. Fahmi, N. I. Rifma and M. Wahyudi, "Experiment Based on Analysis of Series and Shunt Capacitance to Ferroresonance Response on Low Voltage Transformer," *2018 Conference on Power Engineering and Renewable Energy (ICPERE), Solo, Indonesia, 2018, pp. 1-6, doi: 10.1109/ICPERE.2018.8739675.*

[12] M. H. Hashemi, U. Kılıç and S. Dikmen, "Hybrid Heuristic and Pattern Search Optimization Algorithm for Design Optimization of Energy Efficient Distribution Transformer," *2022 Global Energy Conference (GEC), Batman, Turkey, 2022,* pp. 329-334, doi: 10.1109/GEC55014.2022.9987023.

[13] K. Hanawa, T. Imura, Y. Hori and N. Abe, "Comparison of Circular Coil, Double-D Coil, and 85 kHz Self-Resonant Coil in Road Embedment for Dynamic Wireless Power Transfer," *IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022*, pp. 1-6, doi: 10.1109/IECON49645.2022.9968375.

[14] T. Watanabe, S. Nagaya, A. Ishiyama, S. Noguchi, H. Ueda and G. Nishijima, "Mechanical Strength Evaluation of a Yoroi-Coil Structured Non-Circular REBCO Pancake Coil in High Magnetic Field," *IEEE Transactions on Applied Superconductivity,* vol. 32, no. 6, pp. 1-5, Sept. 2022, Art no. 4600605, doi: 10.1109/TASC.2022.3149232.

[15] R. Inoue, Y. Inoue, H. Ueda and S. Kim, "Investigation of HTS Coil Structure Robustness Against Misalignment Between Coils in a Wireless Power Transmission System for Railway Vehicles," *IEEE Transactions on Applied Superconductivity*, vol. 33, no. 5, pp. 1-5, Aug. 2023, Art no. 3600705, doi: 10.1109/TASC.2023.3252490.

[16] V. V. Kokh, M. I. Petrov and D. V. Mostovoy, "Thyristors Balancing Voltage Regulator with Boost Voltage," *2021 International Ural Conference on Electrical Power Engineering (UralCon), Magnitogorsk, Russian Federation, 2021*, pp. 386-391, doi: 10.1109/UralCon52005.2021.9559603.

[17] M. M. Ronderos, J. A. G. Segura and J. I. Mayayo, "Power Transformers for Wind Applications. Requirements and Challenges," *2019 6th International Advanced Research Workshop on Transformers (ARWtr), Cordoba, Spain, 2019*, pp. 48-53, doi: 10.23919/ARWtr.2019.8930194.

[18] B. C. Sujatha, T. V. Ramaswamy, R. R. Prabhu, N. Sumana, D. M. U and S. Z. Ismail, "Design of 100kVA energy efficient three phase hybrid transformer for combined application of solar and wind," *2018 4th International Conference for Convergence in Technology (I2CT), Mangalore, India, 2018*, pp. 1-4, doi: 10.1109/I2CT42659.2018.9058194.

[19] IEC/IEEE International Standard - Power transformers - Part 16: Transformers for Wind Turbine Applications," *IEC/IEEE 60076-16 Edition 2.0 2018-09,* vol., no., pp.1-26, 28 Sept. 2018, doi: 10.1109/IEEESTD.2018.8476640.

[20] A. A. Devadiga and S. H. Jayaram, "The Influence of Repetitive Transient Parameters on the Distribution of Transients along the Transformer Winding," *2020 IEEE Electrical Insulation Conference (EIC), Knoxville, TN, USA, 2020*, pp. 309-312, doi: 10.1109/EIC47619.2020.9158685.

[21] A. Conte et al., "An 18nm ePCM with BJT selector NVM design for advanced microcontroller applications," *2023 IEEE International Memory Workshop (IMW), Monterey, CA, USA, 2023*, pp. 1-4, doi: 10.1109/IMW56887.2023.10145983.

[22] G. C. Sekhar and K. Vijayalakshmi, "Energy Efficient Street Light Controlling System on Detecting Vehicle Movement using Arduino Microcontroller in Comparison with 8051 Microcontroller," *2022 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES), Chennai, India, 2022*, pp. 1-5, doi: 10.1109/ICSES55317.2022.9914314.

[23] S. Soeharwinto, S. Agrath, Z. Pane and T. H. Nasution, "Benchmarking of Wireless Microcontroller-based Three Phase Multi Meter With Industrial Standard Instrument," *2019 3rd International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM), Medan, Indonesia, 2019*, pp. 98-101, doi: 10.1109/ELTICOM47379.2019.8943844.

[24] A. Junaedi, M. D. M. Puspitasari, and M. Maulidina, "Pengaruh (Intensor) Induktor Heater Menggunakan Thermal Sensor Berbasis Mikrokontroler Arduino Nano Dalam Mengolah Logam," *Jurnal NOE*, vol. 4, no. 2, pp. 169, Oct. 2021.

[25] F. Zulfikar and A. Anas, "Perancangan sistem keamanan sepeda motor dengan RFID di Jurusan TSM SMKN 1 TirtaJaya," *Jurnal Informatika dan Teknologi Komputer*, vol. 2, no. 3, pp. 266-272, Nov. 2022.

[26] L. Deng, H. Suo, and H. Ren, "Design of Insulation Tape Tension Control System of Transformer Winding Machine Based on Fuzzy PID," Sensors, vol. 21, no. 19, p. 6512, 2021, doi: 10.3390/s21196512.

[27] P. Ewert, T. Orlowska-Kowalska, and K. Jankowska, "Effectiveness Analysis of PMSM Motor Rolling Bearing Fault Detectors Based on Vibration Analysis and Shallow Neural Networks," Energies, vol. 14, no. 3, p. 712, Mar. 2021, doi: 10.3390/en14030712.