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A Development of a 2-Axis Filament Winding Machine for Glass-Epoxy Composite Fabrication of Long Fiber Material

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ABSTRACT

The glass-epoxy (G-E) composites are manually prepared utilizing either the hand lay-up technique or mechanised methods. Within this study, a 2-axis filament winding apparatus was specifically engineered and constructed to manufacture pipes and round-shaped specimens. This system enables the production of pipe specimens featuring internal diameters of up to 60 mm and lengths extending to 1000 mm. The winding angle configurations vary from 50o to 80o, contingent upon the mandrel diameter employed. The delivery unit's screw speed ranges from 1 to 250 revolutions per minute (rpm). A DC motor was selected for its superior capabilities and precision in this endeavors.
A dedicated control unit was devised to oversee the entire process, ensuring consistent and uniform winding. The resultant machine has potential applications in scientific research and educational contexts, especially in the realm of fabricating long fiber composite materials. Multiple specimens were manufactured to authenticate the functionality of the newly developed machine.

1. . Introduction

Composite materials are produced by combining reinforcement fibers within a thermoset polymer resin matrix. These reinforcement fibers possess an aspect ratio that facilitates efficient load transfer among fibers, thereby establishing a robust bond with the resin matrix. In essence, composites are formed through the amalgamation of two or more materials, giving rise to a novel material that generally demonstrates enhanced strength compared to its constituents. Notably, in comparison to metallic materials, composites present superior flexibility, resilience in highly corrosive environments, and a notable reduction in weight. [1].

The development of composite fiber winding machines has been spurred by technological advancements across various industries, including aerospace, marine, electrical, chemical, transportation, and piping systems. These **machines cater to** the specific requirements of fabricating composite **materials,** meeting the demand for enhanced structural integrity and performance in diverse applications. [2-4].

The fabrication of glass-epoxy (G-E) composites has traditionally involved manual methods such as hand lay-up or mechanised processes. In response to the growing demand for precise and efficient production of long fiber composite materials, this paper presents the development of a dedicated 2-axis filament winding machine. This machine is designed

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to streamline the fabrication process, particularly for pipes and round-shaped specimens, offering advantages in terms of consistency, uniformity, and versatility, and it has been conducted by Abdalla et al. [5,6]. Their studies reveal that the expenses associated with both the software and the substantial filament winding machines available in the market are notably high. Within the filament winding process, a winding machine is utilised to meticulously wrap resin-impregnated roving or monofilaments onto a rotating mandrel specimen, maintaining controlled tension and adhering to a predetermined geometrical pattern and commonly employed fiber materials in the industry including those of E-class. In the context of a two-degree-of-freedom filament winding machine, it is customary for the mandrels to exhibit a cylindrical shape. [7, 8].

The process where the layers are perpendicular to the axis is called hoop winding, and the layers at an angle to the axis are called the helical layers studied by Hazra [9] T. in which the properties of the finish composite products are dependent on the type of winding pattern. Typical winding patterns are hoop winding and helical winding.

Considering the importance of understanding the mechanical properties of filament-wound tubes for many applications, scholarly research on the subject has become important. Mechanical constants and characteristics are determined in the bulk of this research using a combination of mechanical tests and analytical investigations. Ref. [10-12] explores the impact of multi-axial filament winding on tubular structures with three distinct winding configurations. This exploration involves a comparative analysis of data obtained from [±45, ±60], [±30, ±60] with [±60], [±55], referred to as baseline data. The investigation specifically focuses on the effects under constant ratios of biaxial loads. In the investigation conducted by Krishnamurthy and Muralidhar [13], The filament winding machine is capable of generating cylindrical parts of various diameters using mandrels of various sizes and can construct small-sized specimens with any fiber and resin combination. Joanna et al. [14] investigated the motivation behind the development of this 2-axis filament winding machine stemming from the limitations of existing fabrication techniques. Manual processes are inherently labour-intensive and may lack precision, while mechanized methods may not provide the required flexibility for certain applications. In light of these challenges, the presented machine addresses the need for a reliable and adaptable solution to enhance the manufacturing of G-E composites.

The key features of the developed machine include its ability to produce pipe specimens with internal diameters of up to 60 mm and lengths extending to 1000 mm. The flexibility of the winding angle configurations, ranging from 50o to 80o, allows tailoring the fabrication process to specific requirements, contingent upon the mandrel diameter employed. The delivery unit's screw speed, ranging from 1 to 250 revolutions per minute (rpm), further contributes to the machine's versatility and capability to accommodate a variety of composite materials.

To ensure precision and consistency in the winding process, a dedicated control unit has been integrated into the system. This control unit oversees the entire manufacturing process, guaranteeing uniform winding and reliable production of high-quality specimens. The selection of a DC motor for this Endeavor is based on its superior capabilities, providing the necessary precision and control required for the fabrication of long-fiber composite materials.

The potential applications of the developed 2-axis filament winding machine extend beyond industrial settings, making it a valuable tool for scientific research and educational contexts. Its capabilities open up new possibilities for exploring the properties and applications of long-fiber composite materials, contributing to advancements in material science and engineering.

In the subsequent sections of this paper, we will delve into the design and construction details of the 2-axis filament winding machine, highlighting its key components and functionalities. Additionally, experimental results and validation studies will be presented to demonstrate the machine's effectiveness in the fabrication of G-E composite specimens. Through this comprehensive exploration, we aim to showcase the significance of the developed machine in advancing the field of composite material manufacturing.

Most of the published works appear to have been carried out using AC or servo motors for delivery systems. In contrast to this strategy, the current work employs a DC motor due to its superior capabilities and precision when running under heavy loading situations. The technique in glass fabric reinforcement would obviously offer apparent advantages in mechanical qualities, and this is regarded as a good alternative for pipe applications.

This paper presents the development of a specialized 2-axis filament winding machine tailored for the fabrication of glass-epoxy (G-E) composites, particularly focusing on long fiber material production. The current methods for creating G-E composites involve manual processes or mechanized techniques, each with its own set of limitations. In response to the need for precision, consistency, and versatility in composite material manufacturing, our research introduces a novel machine capable of producing pipes and round-shaped specimens.

The designed 2-axis filament winding machine exhibits notable features, including the ability to manufacture pipe specimens with internal diameters up to 60 mm and lengths extending to 1000 mm. Winding angle configurations, ranging from 50o to 80o, offer flexibility tailored to specific mandrel diameters. The delivery unit's screw speed, adjustable from 1 to 250 revolutions per minute (rpm), enhances the machine's versatility for accommodating various composite materials. A DC motor, selected for its precision, plays a pivotal role in ensuring the machine's superior capabilities.

To maintain control and consistency throughout the manufacturing process, a dedicated control unit oversees the winding operation. This integration guarantees uniform winding, contributing to the reliable production of high-quality composite specimens. Beyond industrial applications, the developed machine holds promise in scientific research and educational contexts, providing a valuable tool for exploring the properties and applications of long-fiber composite materials.

2. DESIGN AND MANUFACTURING OF WINDING MACHINE

The design of an automated composite fiber winding machine is an integration of mechanical and electrical. The PIC16F877A microcontroller controls the machine. This section discusses the details of mechanical and electrical design.

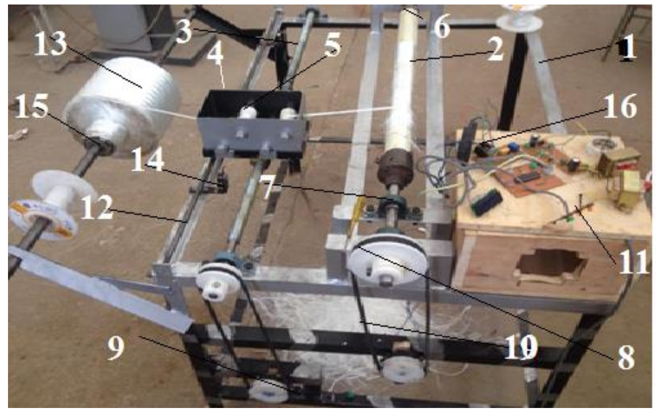
3. A. Mechanical system design

Figure 1 presents a schematic three-dimensional representation of the automated composite fiber filament-winding machine, while Figure 2 portrays the actual machine. In a comprehensive overview, the mechanical structure of the machine can be categorised into two primary constituents: the delivery unit and the rotary unit. Concurrently, the control unit represents an indispensable element within the overarching machine configuration. Figure 1: Schematic 3-D modelling of automated composite fiber Filament winding Machine

It is crucial to emphasize the pivotal role played by the delivery unit, a central module comprised of essential components including the fiber holder, limit switch, rollers guide, resin bath (featuring four rollers), carriage, lead screw, lead screw holders, and DC motor. The fiber holder serves as the repository for fiber roving, a fundamental element within the operational framework of the automated fiber winding machine. Employing the wet winding method, the fiber is guided through a resin bath before being conveyed onto the mandrel through the carriage.

Of particular significance is the limit switch, which plays a critical role in effecting the reversal of the motor's rotation, thereby propelling the carriage rod. Constructed from a low-friction polymer, the carriage incorporates a roller and two polished screw eyes, serving the dual purpose of guiding and providing tension to the wetted fiber before its application onto the mandrel. The lead screw, facilitating the conversion of rotary motion into linear motion transmission, stands as an integral component in the system [15].

As depicted in Figure 3, the resin bath is meticulously constructed from a steel container equipped with four rollers. Throughout the winding process, the resin bath serves as a reservoir for the epoxy or polyester resin mixture. Additionally, the eye functions as a guide for the fiber, directing it toward the resin bath while concurrently removing excess resin from the wetted fibers upon their passage through the rollers of the resin bath.



a) Manufactured winding machine

Item No.	Part name	Material	Item No.	Part name
1	Stand	Mild steel	9	motor DC
2	Mandrel	Steel	10	Belt
3	Lead screw	Mild steel	11	Control box
4	Frame Resin bath	Mild steel	12	Guide of roller
5	Roller	PVC	13	Pulley of fibergla
6	Chuck	Mild steel	14	Limit switch
7	Bearing	Steel	15	Stand of fiber
8	Pulley	Aluminum	16	The circuit

b) Table of parts names

Figure 2: Filament Winding Machine and the names of its parts

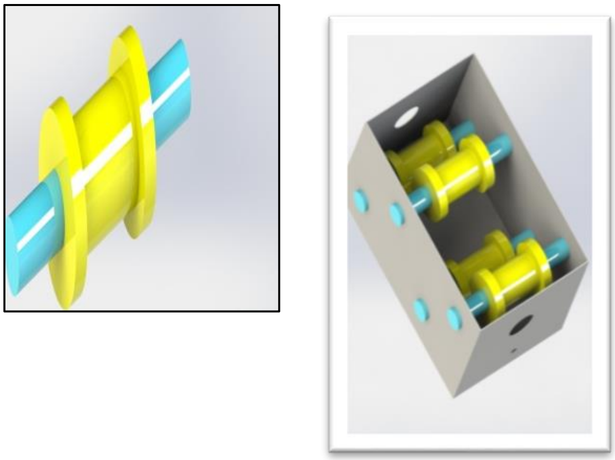


Figure 3: Resin bath

Figure 4 presents the rotary assembly unit, comprising a spindle (with chuck), tailstock, and mandrel, securely affixed to the horizontal frame. The mandrel is horizontally supported between a chuck and tailstock, as depicted in Figure 4. The tailstock remains free while the chuck is manipulated to the necessary angle and speed through the control unit. As the mandrel undergoes rotation, a carriage is engaged in the process. Travels along the mandrel and delivers fiber with a given position and tension.

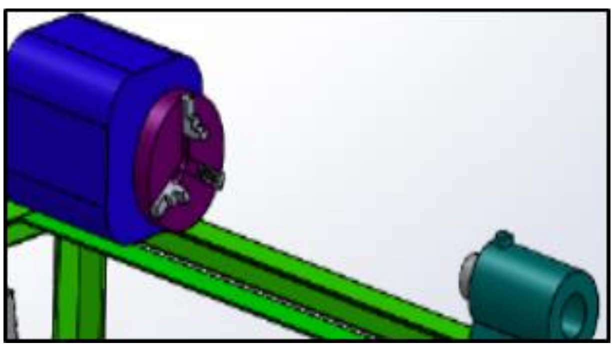


Figure 4: Rotary assembly unit

B. Electrical and electronic system design

The design of electrical and electronic circuits could be carried out into several fragmented circuits; the design of these fragmented circuits is discussed in the following sections

a) **Main circuit**

In the core circuit, also identified as the microcontroller circuit, a PIC16F877A microcontroller takes center stage, as depicted in Figure 5. This microcontroller plays a pivotal role in transmitting and receiving signals to and from the control circuits. It is noteworthy that the microcontroller functions as a miniature computer, featuring a central processing unit, read-only memory (ROM), random access memory (RAM), and various input and output devices.

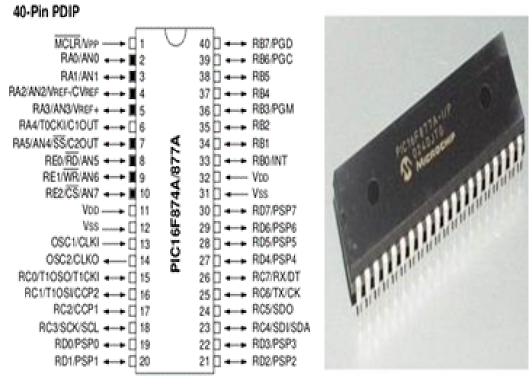
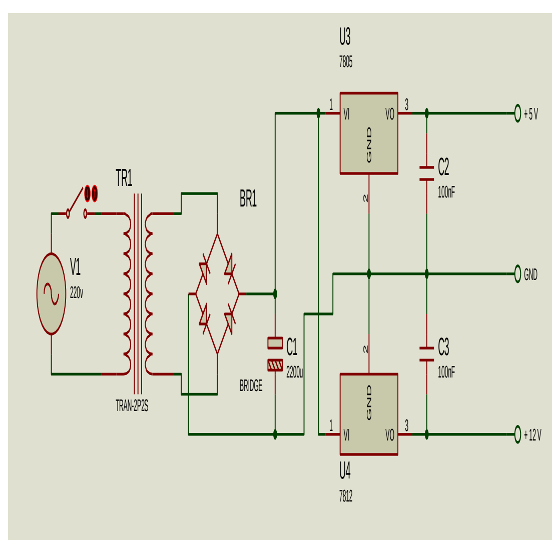


Figure 5: Microcontroller PIC16F877A

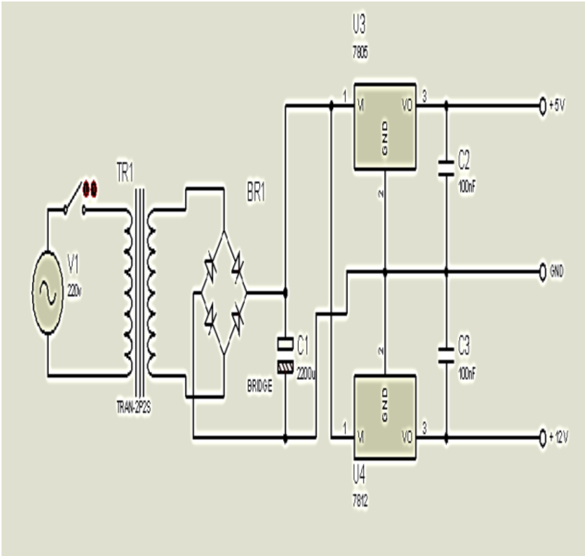
b) **Sub-circuits:**

Figure 6 illustrates one of the sub-circuits within this system, specifically the feeding/cutting-off circuit. This circuit comprises feeder and voltage regulation circuits. The feeder circuit, as depicted in Figure 6-a, integrates unification and voltage regulation circuits. The primary function of the voltage regulation process is to maintain a regulated (+5V) voltage supplying the microcontroller, along with the control of the (+12V) voltage governing the engine speed and the operational circuit of the engine. The second component of this circuit is the cutting-off voltage circuit, presented in Figure 6-b, from which the signals to control the motor speed are derived.

microcontroller to start the program to adjust the angles as well as switching - off the circuit and restart it. Figure 8 illustrates the practical circuits of this system.



a) Feeder circuits



b) Voltage cutting off circuit

Figure 6: a & b Feeding / cutting off circuit

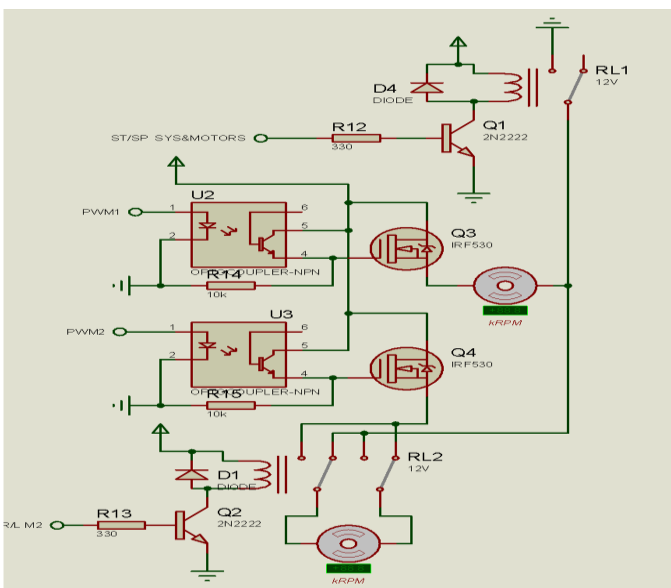


Figure 7: Circuit keys to send signals

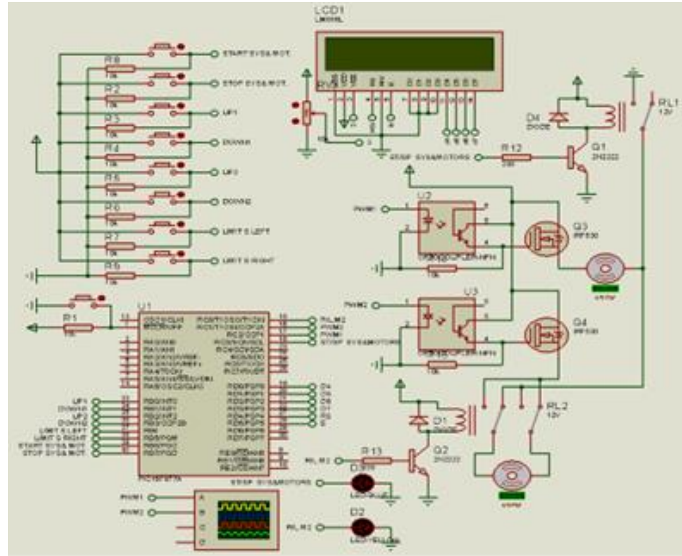


Figure 8: The practical circuits

II. SYSTEM WORKING THEORY

In the devised winding machine, the primary objective of the control circuit is to fine-tune the angles of lapping around the column. This intricate process is achieved through the application of the conclusive equation (1) governing the speeds of two engines. The initial engine is tasked with the rotation adjustments of the column, around which the product is wrapped. Simultaneously, the second engine is responsible for the continuous lateral movement of the box – the container within which the product undergoes processing. This operational configuration is visually depicted in Figure 9.

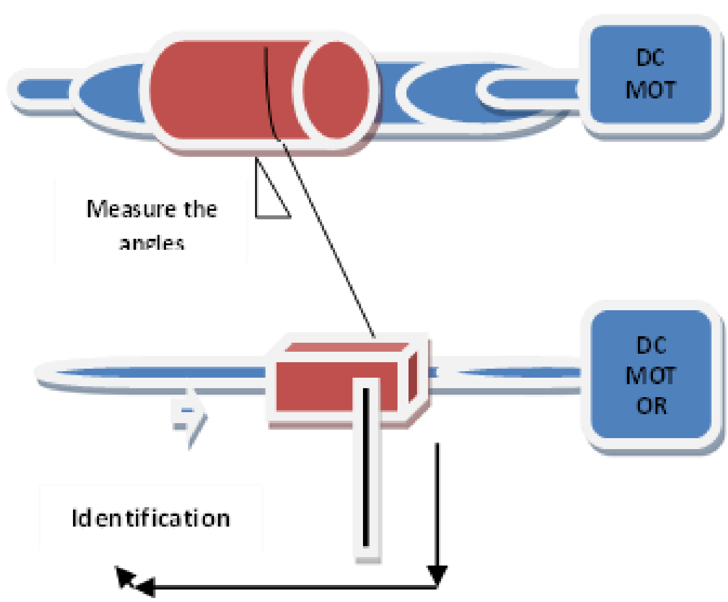


Figure 9: The first engine and the second engine

Persisting in the systematic encapsulation of the product through a harmonious static process,

Equations 1 and 2 encapsulate, through empirical insights, the variations in speed for the two engines. This involves employing fixed steps and measuring angles to determine the corresponding values based on the altering speeds. The control methodology adopted entails the utilisation of a PIC16F877A microcontroller, programmed and simulated using MICRO C and the PROTEUS simulator program, respectively. The calculations for t wnig ane anlucidated as follows [3]:

$$\theta = \frac{2\pi r N_m}{Vc} \qquad (1)$$

where θ: is the winding angle, r: is the Mandrel radius, Nm is the Mandrel speed, Vc is the carriage linear velocity which is calculated as follows:

$$VC = NS \times d \qquad (2)$$

Where NS is the screw speed, d is the screw thread distance.

During the Machine working, the pattern is considered complete and cover of glass on the mandrel at different values of angles. These angles range between 500 and 800.

Evidentially, the developed winding filament machine is used for research and educational purposes, however, a lot of specimens could be produced using it. Fig. (10) Shows samples of the final specimens of different dimensions after fabrication and machining.

Figure 10: The fabricated specimens

CONCLUSION

A Filament Winding machine has been successfully fabricated, and the performance evaluation has yielded the following conclusions:

1. The machine demonstrates effectiveness for educational and research purposes.

2. The Filament Winding machine proves to be capable of fabricating small-sized specimens with various fiber and resin combinations at a cost-effective level.

3. The attainment of winding patterns is achieved by independent control of the rotational speed of the mandrel and translational speed of the carriage block on the lead screw.

4. The machine exhibits the capability to produce cylindrical parts of varying diameters by utilizing mandrels of different sizes.

5. The range of the winding angle, or fiber orientation angle, spans from 500 to 800, contingent upon the mandrel diameter utilized.

6. The control methodology implemented involves the utilization of a PIC16F877A microcontroller.

7. The mechanical strength of filament-wound parts is contingent not only upon the composition of the component materials but also on critical process parameters such as winding angle, fiber tension, resin chemistry, and curing cycle.

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