DESIGN AND DEVELOPMENT OF LOW COST TWO AXIS FILAMENT WINDING MACHINE

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ABSTRACT: Composite materials are being used in many applications these days as they have demonstrated their competence and sustainability considerably. The present work focused on design and development of a low cost two axis laboratory size filament winding machine (FWM) capable of developing 50 mm minimum internal diameter and a maximum length of 1000 mm pipes. The speed control units developed in the present study facilitated in independently controlling the speeds and direction of the mandrel and the end-effecter in an attempt to achieve the winding angle ranging from 10º to 90º. The speed of the mandrel and the end-effecter could be varied from 0 – 480 rpm and 0 – 500 rpm respectively. A 16-bit RISC single-chip microcontroller was used to logically process the required control signals to achieve the required motion in the machine. Tubular samples of 50 mm internal diameter and 53 mm external diameter were prepared from the developed FW machine.

KEYWORDS: *GFRP; Filament Winding Machine; AVR Controller*

1.0 INTRODUCTION

Composite materials are considered as alternatives to the conventional materials for the engineers and designers during the material selection for the applications where the components weight to strength ratio is a significant parameter. These materials have been extensively used in many fields which include defense, aerospace, sports and pipes and pressure vessels in chemical industry. As weight and cost saving are the two essential factors for today's industry, the prime objective of process and manufacturing engineering is to integrate automation in manufacturing techniques used in preparation of advanced composite structures. Among the various manufacturing techniques employed in composite structure fabrication, filament winding is one of the most cost-effective production techniques employed [1]. The filament winding is a process or technique where fibers are accurately laid in particular orientations that are pre-planned on to a mandrel so as to achieve the finished component shape [2]. The fiber may made up of anyone of the following either a (a) wet winding or (b) laying up of pre peg tows. For the first case, the fiber is passed through the resin contained in a resin bath and later wounded onto the mandrel whereas for the second case the semi cured fiber tows are laid on the mandrel at required angle which are allowed to cure in an oven later. The desired thickness and strength of the composite geometry could be achieved by varying parameters such as, (a) winding tension, (b) winding angle and/or (c) resin content in each layer of reinforcement. There are three basic winding patterns employed namely (i) Hoop Winding, (ii) Helical Winding and (iii) Polar Winding and are found in extant literature [3-7]. The properties of the finished component depend on the type of winding pattern selected in fabrication.

The filament wound manufacturing technique was developed during 1950's [8] where there were two axis of rotations to be controlled. Later, by 1970's, the implementation of servo controller made the task very simple and now, with the drastic development in the computing, sensing and controlling systems, sophisticated computer controlled filament winding machines are available [9- 11]. These high end technologies are used to produce the sophisticated symmetric profiles, eventually, increasing the final cost of machine. The present work focused on Design and use of standard available materials and components for the construction of Filament winding (FW) machine with a 16-bit RISC single-chip microcontroller based control.

2.0 DESIGN AND FABRICATION OF FW MACHINE

A lathe type wet FW machine was proposed in the present study and the design was kept simple, so as to reduce the cost involved in huge machining process if some complicated designs were adopted. Based on the below mentioned requirements, the mechanical structure of the machine was designed based on strength and rigidity. The proposed

FW Machine consisted of a ridged base frame with three units namely (a) mandrel rotational unit, (b) apron assembly and (c) the control unit. Schematic outline of the hardware arrangement intended for the proposed FW machine are presented in Figure 1. The resin bath along with the tensionars was made as the separate units.

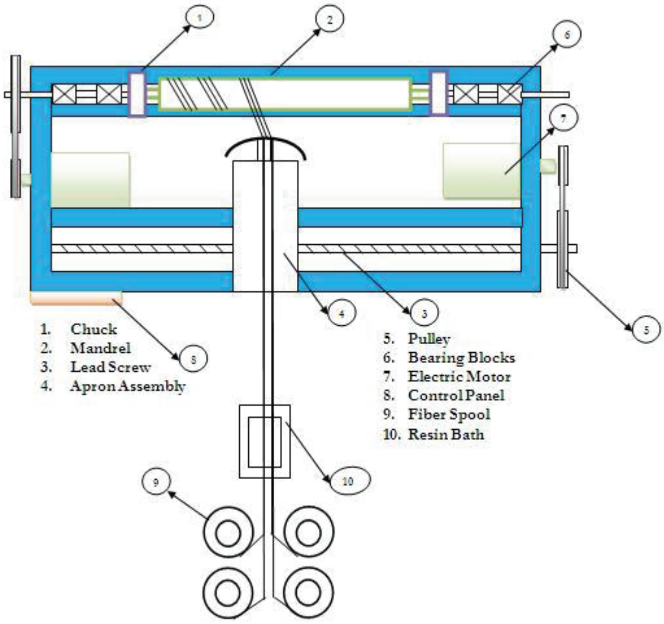

Figure 1: Schematic diagram of proposed filament winding machine

The structure to be developed was based on the requirement given as follows:

i. Maximum Load on the mandrel: 37 kg.
ii. Speed variation required for the mandrel: 0 - 480 rpm.
iii. Speed variation required for the lead screw: 0 - 600 rpm.
iv. Maximum Length of the lead screw: 1200 mm.
v. Maximum load on the resin bath: 15 kg.

2.1 Mandrel Rotational Unit

The mandrel rotational unit consisted of two bearing blocks of which one was fixed and the other is allowed to move along the plane of the bed, based on the required length of the mandrel. The bearing block comprises of two bearings through which a shaft runs. For both the bearing blocks on to one side a self centered chuck is fastened whereas on to the other side shaft of the fixed bearing block a motor is coupled via pulley. The schematic diagram of the bearing block is shown in Figure

2 where the pulley (A), bearing (C, D) and chuck (B) are represented. Based on the von-misses criteria the diameter of shaft was determined to be 30 mm with a factor of safety as 3 and based on the operating conditions and the loads acting on the bearing appropriated full journal bearings were selected. A one HP Dc Motor was selected to drive the mandrel based on which the above dimensions were determined.

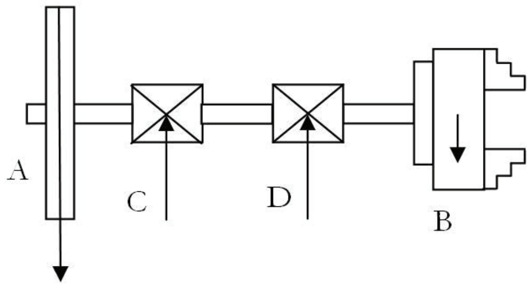

Figure 2: Block Diagram of bearing block assembly

Care has been taken during manufacturing to maintain the centres of both the bearing blocks were in line. The mandrel speed could be varied based on the requirements by the control logic. The mandrel is a hallow rotating cylindrical element around which the filament was wrapped. It was affixed to the base frame through bearing and a shaft which was driven by a belt drive connected to an electric motor which also served as a prop up for the composite cylinder. For a satisfactory performance, the mandrel had to meet several requirements. It must be solid and robust enough to sustain structural strength during operation at a maximum speed of 600 rpm approximately. The mandrel experienced not only the inertia load due to its self-weight but also the torsion load due to the drive unit and pressure due to the filament being wrapped. Based on the trial and error method, the mandrel dimensions were determined as the outer (d_o) and inner diameter (d_i) of mandrel, to be 50 mm and 40 mm, respectively considering the von-misses criteria.

2.2 Apron Assembly Unit

Apron assembly consisted of a resin bath and a fiber holder that slid on a guide way in the midst of the lead screw arrangement. Lead screw is a member powered to slide the end effector on the guide and is supported at the ends. A standard available lead screw of 28 mm mean diameter and 1150 mm length was selected. Considering the lead screw as a beam supported at two extreme ends which slides the end effector due to rotation, a bending load and twisting moment are experienced by the lead screw. It was found that the factor of safety for the lead screw selected was 3 based on von-misses criteria. The guides with perfect flat were fastened with great care on to the base frame so as to make the sliding guide a perfect flat. The fiber holder was powered by a dc motor coupled to the lead screw. A non-contact type distance measuring sensor was attached onto the sliding fiber holder to determine the distance traveled and control accordingly. The Resin bath consisted of a resin pool and a roller placed at the center half dipped in the resin pool and a band of fibers were allowed to pass on the roller. This ensures the proper impregnation of the resin in the fiber band. Specially designed tension pines and vertical creel pines were arranged before and after the roller so that the tension pin maintained the pre-defined tension in the fiber band and removed the excess resin. Vertical creel pines were placed as to guide the fiber. The amount of tension could be maintained by changing the angle of the tension pins as there is a considerable effect of fiber tension on the mechanical properties of the components produced [11]. The fabrication processes for all the mechanical components were simple but a wire cut EDM was employed to manufacture the tension pins so as to achieve the required dimensions.

2.3 Machine Control Unit

The control unit was the brain of the system which was used to perform the winding operations logically. There were two different motions to be controlled in the machine; one was a linear motion of the apron assembly whereas the other was a rotational motion of the mandrel. The angle of fiber that was to be wound depended on, (i) Diameter of the mandrel, (ii) Mandrel speed, and (iii) linear speed of apron assembly (lead screw speed). In other scene variation of any one or combination of parameters would change the winding angle and vice versa. The relation of winding angle (θ), mandrel diameter (d), mandrel speed (N_m) and lead screw speed (N_l) was by $\theta = (\pi d N_m / p N_l)$. A 16-bit RISC single-chip AVR microcontroller was used to logically control the filament winding machine motion. The control logic comprises two schedules, (i) determination of speed of either mandrel or apron assembly based on the user inputs and (ii) Winding sequence to be carried out. In the present design of FWM a choice was provided to users to vary either the mandrel speed or the lead screw speed. If users decided to control the mandrel speed, a constant value of lead screw speed of 75 rpm was selected or the control of lead screw speed was selected, then, the mandrel speed was constant and equal to 100 rpm. These values were considered in view of the geometric constrains of the present FWM. The mandrel and lead screw speeds were determined by fallowing the program sequence presented in Figure 3 and the values obtained were stored in the memory so as to be recollected when needed in winding sequence.

During the winding sequence, a user was asked to input the valid length and thickness of the sample to be fabricated based on which the number of pass required, for example, the circuit runs were determined from the sequence published elsewhere [4]. AVR board was coupled to the motor control unit, where an H bridge circuit was coupled to the lead screw motor as its direction had to be changed so as to place the fiber band on the mandrel along the length in both directions. Based on the non-contact distance measuring sensors, the track of the length required was determined. A PWM control technique was employed in the control process and Figure 4 describes the steps involved in the control during the winding sequence.

Figure 3: Speed determination sequence

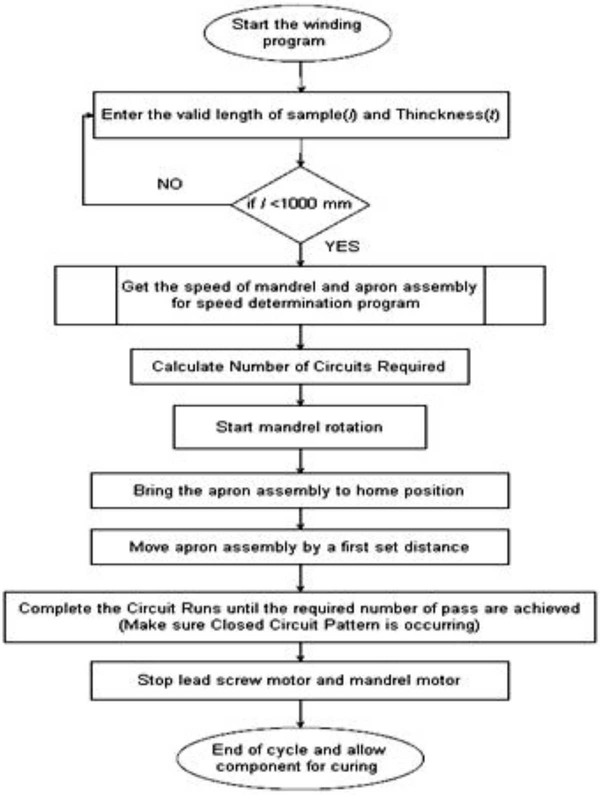

Figure 4: Winding sequence

3.0 RESULTS

The developed FW machine is presented in Figure 5 and the samples prepared with different orientation of fibers are presented in Figure 6. A series of tests were performed on the machine developed to assess the operation of the machine and the following results were observed.

i. To avoid the extra cost of getting a component machined, stranded available components were selected based on the standard design procedure for individual components where a huge factor of safety not less than 3 was provided to have a space for a sudden load change during operation.
ii. The FW Machine developed was operating as per the required specifications i.e. the mandrel speed varying from 0 – 480 rpm and the apron assembly containing the end effecter with a speed range of 0 – 500 rpm. Two DC motors with one horse power capacity were selected for the movement of mandrel and apron assembly.

iii. The pipes with 50mm internal diameter and 53 mm outer diameter with different angle of fiber orientation, $[\pm10^\circ]_4$, $[\pm20^\circ]_4$, $[\pm30^\circ]_4$, $[\pm45^\circ]_4$, $[\pm55^\circ]_4$, $[\pm58^\circ]_4$ were prepared from the FW Machine developed.

iv. There was slight slip during the dwell in the winding operation which could be rectified by slight adjustment in the program. The pay eye or the end effector design had to be modified as it could even affect the fiber alignment.

v. The components developed were of sound strength and appropriate volume fraction.

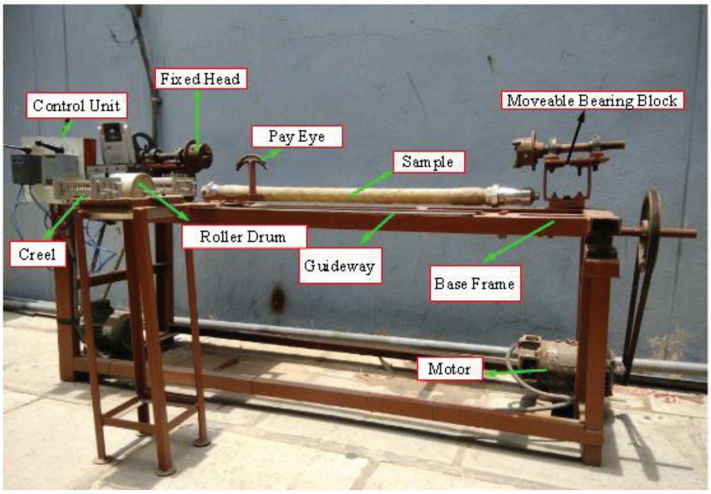

Figure 5: Filament winding machine

Figure 6: Filament wound pipe

4.0 CONCLUSION

An automated low cost two axis FW machine has been designed and fabricated that produces the product of reliable quality. The fabricated machine has a robust structure with no vibration and the controller used could effectively control various motions of the machine. The cost of the FW Machine could be reduced yet making it over designed. Use of roller in the impregnation system increases the production time and impregnation. The mandrel diameter was 50mm, 1000 mm long on to which the cylindrical components were made. The tensionars are able to maintain the appropriate tension in the fibers that could be found from the volume fraction of the fibers of the finished component. Six samples with fiber orientation being $[\pm10^\circ]_4$, $[\pm20^\circ]_4$, $[\pm30^\circ]_4$, $[\pm45^\circ]_4$, $[\pm55^\circ]_4$, $[\pm58^\circ]_4$ are prepared and a slight slip in fiber during winding is observed which could be improved by a slight change in end effector design.

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