DESIGN OF COMPACT PRE-PREGGER MACHINE FOR IN HOUSE PRODUCTION OF PRE-PREG MATERIAL

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ABSTRACT: The main idea of this project is to conceptually design and simulate a lab-scale pre-pregger machine for in house production of pre-preg material. The aim is to decrease the size of the existing machine and reduce the cost to fabricate it. The concept design of the machine focuses on four major components: drum, resin bath, guider and fiber spindle. The pre-pregger machine is designed with an adaptable drum parameter which can be installed and removed easily from the drum holder. In this project, Programmable Logic Controller (PLC) was used to control the pre-pregger machine. The CX-ONE OMRON PLC was chosen to design the ladder diagram of the controller. In order to simulate and test the correctness of the controller, a simple electrical setup has been made. The setup consists of three motors, few sensors and push button. The simulated setup proved that the proposed conceptual design of the pre-pregger machine is workable.

KEYWORDS: *Pre-pregger Machine; CAD; PLC; Design; Control Strategies*

1.0 INTRODUCTION

Pre-pregging process is widely used to produce a composite material in the composite industry as it allowing better control of the composite materials geometry and design to suit the designated application [1-4]. The first pre-pregger machine was developed in the late 1960s to support the production of carbon fiber tape for the manufacture of composite structures on a U.S. National Aeronautics and Space Admin. (NASA) lunar lander [5-7]. At that time, resin systems were, for the most part, difficult to mix, catalyze, process consistently and manage during production. Because of this, most pre-pregger manufacturing fell to large chemical companies and resin producers [8].

The use of lab-scale pre-pregger machine for in house production of pre-preg material is well-known in composite manufacturing plant due the ability of the technique to efficiently align the fiber that being impregnated with the resin. Often, the machines use a controller to control the movement of the machine so that not only the drum is rolled continuously but able to control the speed of the rotation in order to obtain desired amount of resin impregnated onto the fibre. Nonetheless, there are some issues that faced by the supplier to design and produce this pre-pregger machine. The main issue is the size of the pre-pregger machine and the amount of investment to produce the machine [8]. The larger the size of the machine, the higher the cost that is needed to produce the machine [9]. According to Japan-based Toray Industries, the size of the pre-preg machine makes it impossible for them to take advantage of economies of scale as they produce off-the-shelf material designed to meet a various specification [10-12]. Therefore it is essential that this project take place to support the needs.

In brief, this project explore with the conceptual design and the control strategy of the lab-scale pre-pregger machine for in house production of pre-preg material. The design process is applied through a combination of two CAD software, AutoCAD for detail drawing and SolidWork for the simulation purpose. The control process is programmed using CX-ONE OMRON Programmable Logic Controller (PLC) software and confirmed. The simulation utilize unidirectional movement which are either clockwise or counter clockwise rotation.

1.1 Preliminary Works

Commonly, the existing pre-pregger machine has a large size and very heavy to carry. The drum itself has a size range between 1000 mm to

2000 mm while the width has a diameter range between 300 mm to 1100 mm which lead to their high cost. This project is targeted to design a compact unit and provide competitive cost for manufacturing. The design is limited to two phases which are conceptual design and control strategies of the pre-pregger machine. This preliminary work will be used for further development of the lab-scale pre-pregger machine in the near future.

1.2 The Conceptual Design

The machine is designed with flexible concept. The design focuses on the drum part which is the main controller for the lab-scale pre-pregger machine. The drum can be change into two different sizes which is 600 mm and 300 mm in diameter. There were three designs initially developed. Each of the design has their drum's movement varies. Various factors were taken into consideration prior to choosing the final design to suit with the earlier objective.

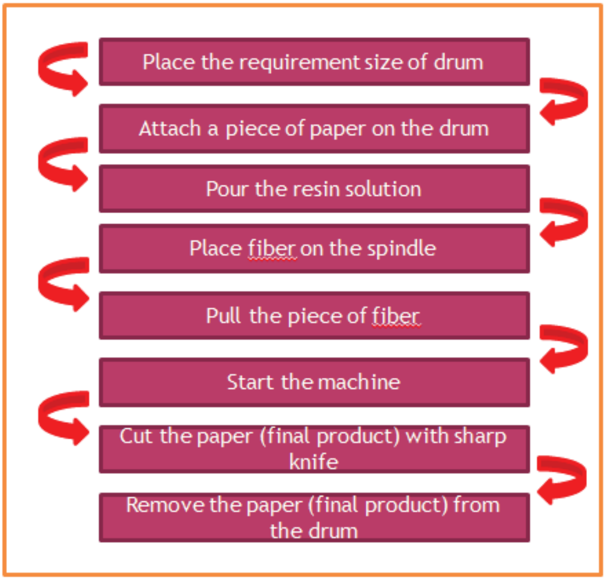

Figure 1: Flowchart of the Overall Process of Lab-Scale Pre-Pregger Machine

The flowchart in Figure 1 shows the detail of the process involved in the conceptual design of pre-pregger machine [13].

1.3 Programming Software (CX-ONE OMRON VER 4.34)

PLC is adopted to control the drum movement in pre-pregger machine. A PLC is an industrial computer that has a central processor unit, memory, input and output interface and a programming device [14]. The function involves logic controlling in sequencing, timing, arithmetic data manipulation and counting capabilities. PLC is commonly used in electromechanical automatic process and able to control a wide variety of manufacturing machines and systems in the plant [15-16]. The programming that is used by this software is relatively simple and easy to use. PLC also able to provide flexibility, error correction, visual observation and cost saving compare to other controller software.

In this project, a CX-ONE OMRON VER 4.34 is used. This choice is made due to the fact that OMRON PLC is a micro-PLC with the capability of becoming a modular type of PLC. Besides that, it is not only compact but it is scalable that has a faster processing speed and low cost than other controllers in the market. Naturally, it is compatible with all other devices in the Omron PLC line up.

2.0 METHODOLOGY

2.1 Hardware Setup

Figures 2 and 3 show the conceptual design that was drawn using AutoCAD. There are four main components in pre-pregger machine which are fibre spindle, resin bath, guider and collecting drum.

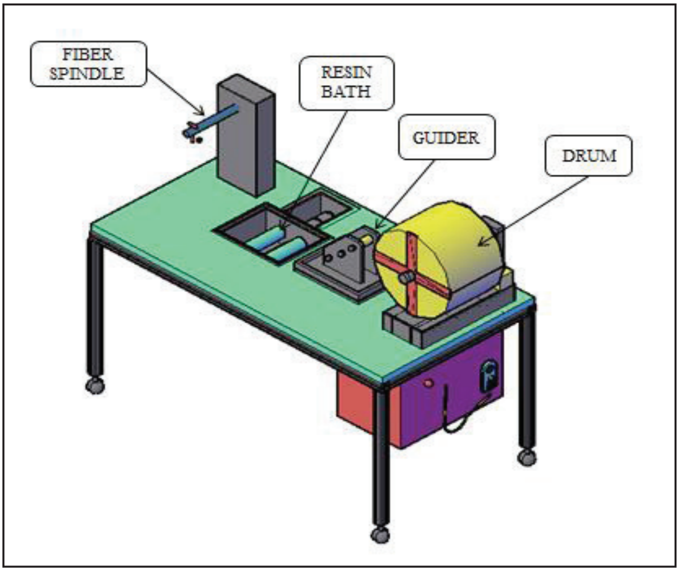

Figure 2: South West (SW) Isometric

The main function of the machine is to align fibers that are being impregnated with the resin out from the drum to produce unidirectional pre-preg material. The drum is required to be placed properly so that the drum can roll continuously while the roller of the pre-preg material does not roll at the same place.

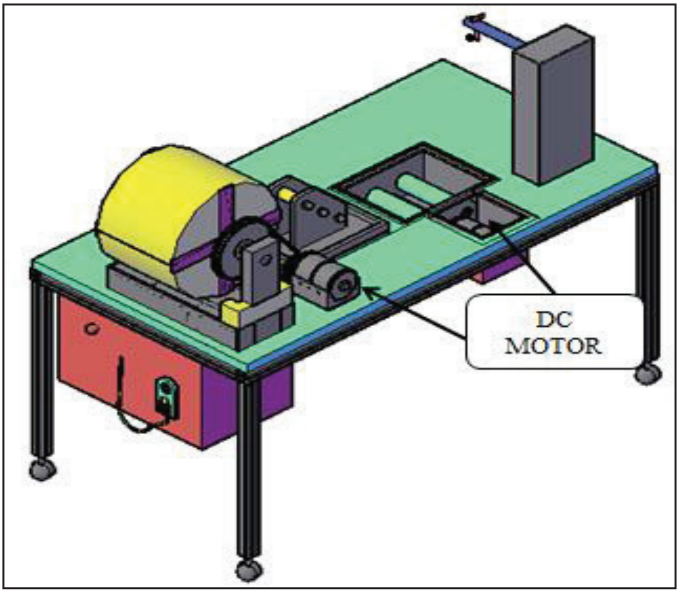

Figure 3: South East (SE) Isometric

2.2 Electrical Setup

In this project, a simple electrical wiring for the controller has been developed in order to give details knowledge about the concept of the controller for the lab-scale pre-pregger machine. Figure 4 shows the position of the electrical wiring.

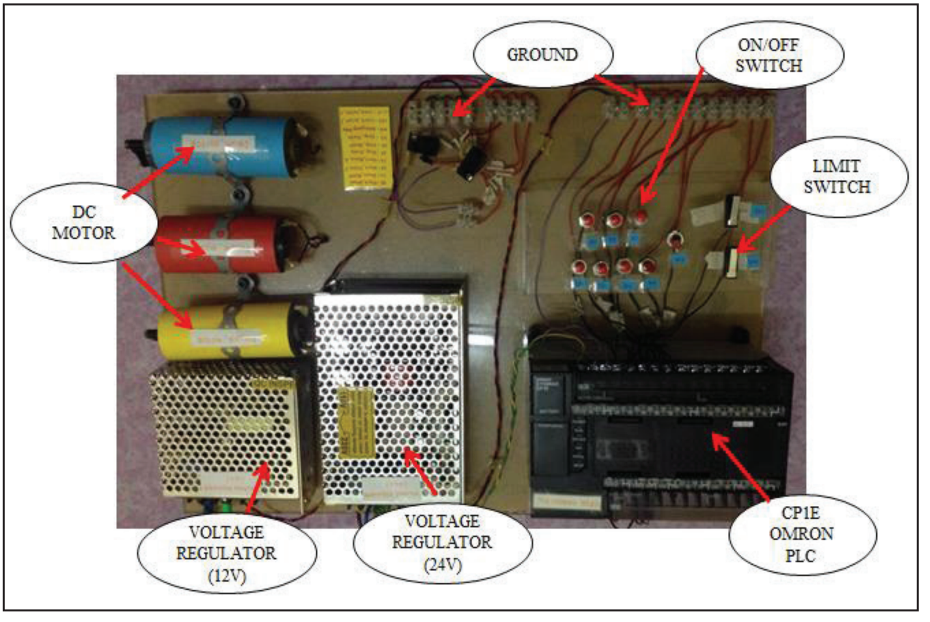

Figure 4: The Electrical Component

There are 6 electrical components that are used to setup the controller which are as follows:

i) PLC OMRON CP1E
ii) Voltage regulator for 24V DC
iii) Voltage regulator for 12V DC
iv) ON/OFF switch
v) Limit switch
vi) 12V DC motor

Firstly, from the power source 240 Watt, it is connected to the Life (L), Neutral (N) and Earth (E) connection in the power regulator 24V DC to. The function of the power regulator is to convert and lowered the main power source to 24 Volt (V). This is because the input power for the PLC OMRON is 24 Volt (V). The positive wire and negative wire is connected to the ground. Secondly, from the positive ground, ON/OF switch is connected. The red wire is connected to the positive ground and another one wire is connected to the PLC. The input communication (COM) from the PLC is connected to the ground. Third step is the DC motor is connected from the PLC to the ground. The voltage regulator 12V DC is used in order to lower the voltage power supply that enter into the motor. This is because the motor can be easily damage if the voltage that enters the motor is higher than the capacity voltage that it has. The output COM from the PLC is connected to the negative 12V ground. The limit switch is used to interlock the motor of the pinion in order to stop the all the motor after the limit switch is turn ON. This limit switch is also as the safety switch for this machine. Figure 5 shows the wiring diagram for lab-scale pre-pregger machine.

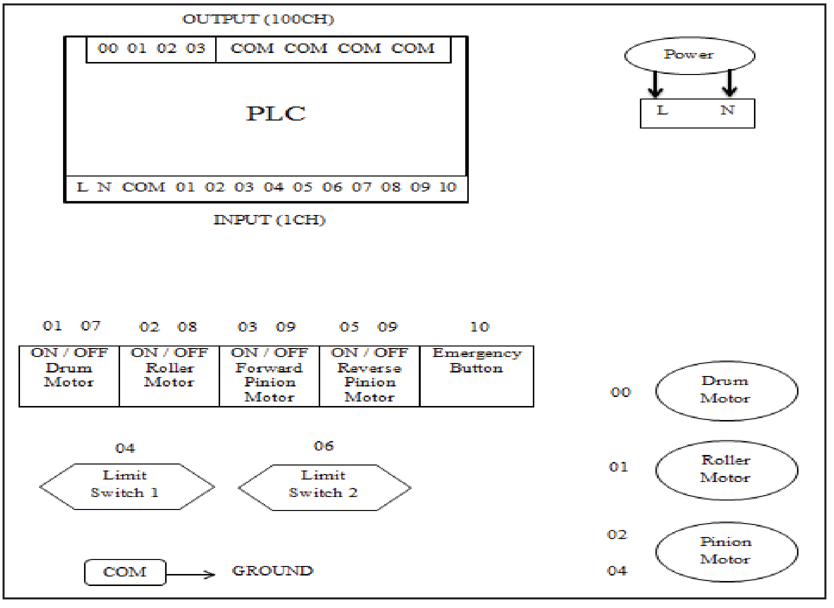

Figure 5: Wiring Diagram for Lab-Scale Pre-pregger Machine

Based on the figure, the direct current (DC) is powered into Life (L) and Neutral (N) connection. Then, the 24 volt from the power supply is entered the CP1E OMRON PLC to give a power to PLC. The ON/OFF switch is used as a main switch to all of the circuit. There are eight of switch is used as the input in the circuit. Limit switch is used to stop the motor. There are three DC motor that is used as the output of the circuit, which are drum motor, roller motor and pinion motor. The communication (COM) from the PLC is connected to the ground. All the connections are numbered to make it is easy to understand.

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3.0 RESULTS

3.1 Motor Power Consumption

Based on the existing pre-pregger machine, the force of the drum is about 260 N. The speed range is 6 rpm and the distance is 0.7367 meter. The calculation are as follows:

$$\text{Power, } P = T \text{ (Torque) x } w \text{ (Angular Velocity)} \quad (1)$$

The torque of the motor is

$$\begin{aligned} T &= \text{Force x distance} \quad (2) \\ &= 260 \text{ N x } 0.7367 \text{ m} \\ &= 191.54 \text{ N} \end{aligned}$$

The angular velocity that need to convert to rad/s:

$$\begin{aligned} w &= (100 \text{ rev/min}) \text{ x } (2\pi \text{ rad /1 rev}) \text{ x } (1 \text{ min/60 sec}) \quad (3) \\ &= 0.6283 \text{ rad/s} \end{aligned}$$

Then, the power of motor is

$$\begin{aligned} &= (191.54) \text{ N x } (0.6283) \text{ rad/s} \\ &= 120.34 \text{ Nm/s or Watt} \end{aligned}$$

Therefore the needed power to rotate the drum is 120.34 Watt. The voltage of the motor is 24 Volt since the output of the CP1E OMRON is 24 Volt.

3.2 The Programming Controller

The programming part of the lab-scale pre-pregger machine consist of limit switch, direct current (DC) motor, push button and emergency button. The ladder diagram of the control strategies is as in Figure 6. From Figure 6, the system is started when the start button for drum is pushed; the motor for drum will rotate in counter clockwise direction. After that, the start button for roller is started and the motor for roller will be moving in counter clockwise direction. Then the start button for pinion rack is pushed, the motor 3 is started rotate in counter clockwise until the gear of the motor is touched the limit switch 1 at the end of the rack and pinion railway. When the limit switch is touched, all the motor is stopped automatically. After that, the start button for drum, roller and pinion are pushed again to start the motor. The motor drum and roller are rotated in counter clockwise direction but the pinion motor is rotate in clockwise direction. The pinion motor is rotated until it touched the limit switch 2 at the end of the rack and pinion railway

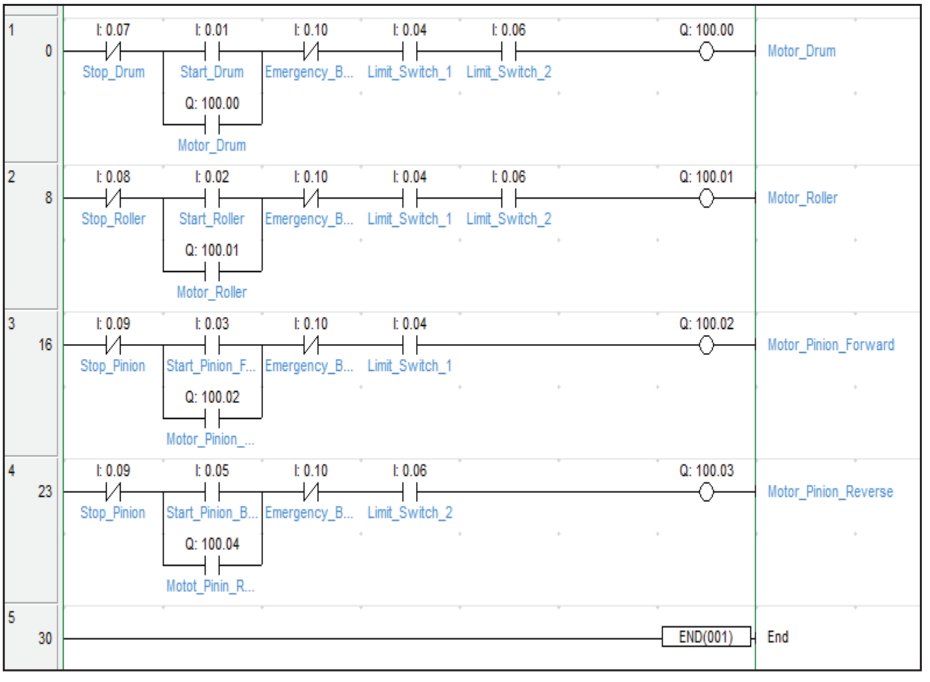

Figure 6: The Ladder Diagram of Lab-Scale Pre-Pregger Machine

In the future, several work need to be done to further study the speed motor controlled and the flexibility of the machine. The speed of the two motor needs to support and work concurrently between each other, therefore, the final machine can work better. Besides that, the design of the machine needs some improvement in the other parts such as the resin bath and fiber spindle. The drum part also can be made more flexible. The drum may be made to change automatically into the desired size without taking it off from the machine manually. It will be much easier and efficient and also can avoid from risk while taking the drum off from the machine.

3.3 Material Selection

For material selection, it is divided into two categories; the drum and other parts (Pressure roller, body part and roller). For drum, a material selection calculation was made to find out the best material used to manufacture drum. This is because the drum needs a material that has a high maximum surface temperature and has a high corrosion resistance to ensure the drum can be used for a longer time. There are four processes to calculate the best material for drum which are translation process, screening process, ranking process and documentation. The documentation is not the main part of the process. It is based on the final score whether it need for documentation or not. CESEDUPACK software was used to find the possible material used to manufacture the drum. Table 1 shows how the most suitable material for drum is calculated and its ranking score.

Based on the ranking process, Low Alloy Steel gain the highest score compare to others. It indicates that the best material used to manufacture drum is Low Alloy Steel. The surface of the drum is covered with a layer of copper because the drum is usually tends to the liquid coating. This is to make sure the drum cannot be rust easily and can be used in a longer time period. For the frame, the aluminium profile is the best material among the other because it is lightweight, cheap, and easy to assembly with other part and the design is look simple. Besides that, it has a good thermal conductivity. Aluminium can retain under load at a low temperature. It is also one of the economic recycling of the material. For the stainless steel, it has high resistance corrosion. This factor is the most important thing because the pre-pregger machine is almost involve with the wet operation, therefore the material that is used to manufacture the machine must have high resistance corrosion to avoid it rust easily and can be used in a long time. Besides that, stainless steel is also a lightweight material and the price is reasonable.

Table 1: Score of material properties for few materials

Design Requirement	Material			
	Cast iron, gray	Cast iron, ductile (nodular)	High Carbon Steel	Low Alloy Steel
Fracture toughness(MPa.m^1/2)	(17/112)*10= 1.52	(38/112)*10= 3.39	(59.5/112)*10= 5.31	(112/112)*10= 10
Young Modulus(GPa)	(115/209)*10=5.50	(172.5/209)*10=8.25	(207.5/209)*10= 9.93	(209/209)*10= 10
Tensile strength (MPa)	(275/1452.5)*10 = 1.89	(675/1452.5)*10= 4.65	(1095/1452.5)*10= 7.54	(1452.5/1452.5)*10= 10
Density (kg/m^3)	(7125/7125)*10= 10	(7125/7150)*10= 9.97	(7125/7850)*10= 9.08	(7125/7850)*10= 9.08
Price (MYR/kg)	(1.650/1.650)*10= 10	(1.650/2.511)*10= 6.57	(1.650/3.228)*10= 5.11	(1.650/3.228)*10= 5.11
Maximum service temperature (C)	**(400/415)*10= 9.64**	**(400/415)*10= 9.64**	**(252.5/415)*10= 6.08**	**(415/415)*10= 10**
Resistance of corrosion	**Average= 10**	**Average= 10**	**Average= 10**	**Average= 10**
Total score	**48.55**	**52.47**	**53.05**	**64.19**

4.0 CONCLUSION

The work has achieved it initial objective to conceptually design a lab-scale pre-pregger machine for in house production of pre-preg material. This work was divided into two categories in term of conceptual design which are mechanical design and electrical design. For the mechanical part, the final conceptual of the pre-pregger machine depends on the size of the drum that was used. The length of the machine has been made that it will change when the diameter of the drum increases. The machine is designed with flexible concept. The design focuses on the drum part which is the main controller for the lab-scale pre-pregger machine. The drum can be change into two different sizes which is 600 mm and 300 mm in diameter.

A test has been conducted through a simulation in Solidwork software and the result is positively encouraging.

For the electrical and control strategies, the controller was controlled successfully through the simple wiring that has been created to show the concept of the electrical part. The testing has been successful through simulating the programming using a real wiring. The motor connected through the simulation is functioning very well. The control is simple and easy to understand.

In short, the study has fulfilled the objectives of this project. This preliminary work will be used for further development of the lab-scale pre-pregger machine in the near future.

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