CONTROL OF THE PRETENSION IN FILAMENT WINDING PROCESS

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Abstract: A tension control system which simulates the effect of tension force in the filament winding machines has been designed and implemented in the present study. Filament Winding (FW) machines are widely used in Fiber Reinforced Plastic (FRP) composite production systems in which they have a pretensioning system to optimize the tension of the fiber during winding process. The precise control of the winding path needs highly mechatronic systems. The designed control system consists of magnetic break, servo motor, a PID control unit, a load cell and a data converter. The tension of the carbon fiber was measured by a load cell and compared to the preset value to keep the tension of the carbon fiber in predefined certain range.

1. INTRODUCTION

Composite systems which consist of fibers and resins have high usage in industrial areas as new structural materials. Composites are strong and light, thus they are mostly used where the mobility is important. There are many types of manufacturing process such as Sheet Molding, Compression Molding, Pultrusion, Resin Transfer Molding, Prepreg forming to create structural parts. Most of the manufactured One of the important composite forming processes is the Filament Winding (FW) process, which needs high path control of the continuous fiber. The winding pattern in the FW process should be precisely controlled to have better wound product with high quality. Thus the FW machines which are used to produce mostly axisymetric and symmetrical parts are mostly accepted as a type of mechatronics machines. The main parts of the FW machines are;

- Winding machine body, similar to that of lathe machine,
- Control unit (mostly by NC, CNC or DNC unit),
- Heat controlled resin impregnation system,
- Roving storage and pretensioning unit.

The FW machine is an integrated system of the above sub systems and needs to be run by control and coordination of the sub systems.

The brittle structure of the fiber especially that of carbon fiber affected very much from the pretensioning pro-cess. Optimizations of the above parameters are very important to lessen the damage caused on the fiber roving. Thus a servo motor controlled PID control system was designed and manufactured to carry out the necessary experiment. The task of the PID control was to keep the pretensioning force in a certain range under various tension forces.

Mainly, pre tension control for filament winding is the interest of researchers. In the literature some studies exist on the influence of winding tension on composite part quality, even if they are referred to symmetric part shapes that may be obtained by traditional filament winding (Cogen, 1997; Lauke and Friedrich, 1993; Mertiny and Ellyin, 2002). All studies stated that once the tension value has been set, it is necessary to assure that the tension acting on the roving during winding is as near as possible to the set nominal value for best strength of the final product.

Chan et al. (1996) described the evaluation of a robot based filament winding cell consisting of an industrial robot. They studied accuracy vs. speed relationships of the robotic winding cell for more prices winding of the fiber bundles. Sharon and Lin (2001) suggested the development of a fully automated fiber optic winding machine capable of accurately winding several different coil patterns, incorporates active tension control during winding, and includes a vision-based, automated error detection and correction system for improved reliability. Choi and et al. (1997) proposed that, a feedback controller for a moving tape tensioning system which uses an ER (electro-rheological) brake actuator. Yeung and et al. (1995) suggested a new drive system with fuzzy control and a synchronized compensator has been incorporated in the system to achieve these results. A low-displacement, high-bandwidth filament tension sensor has been developed as an integral part of the system.

Kudo and et al. (2000) proposed a new automated sewing system is described, consisting of two robots handling the fabric on the table in a similar manner as does a human operator during sewing. To enable user-friendly operation of the system operation, particularly in the phase of preparing new tasks, the original Multi-arm Robot Control (MRC) system has been developed. The control of hand coordination and the fabric tension has also been developed and implemented. To control seam path and its deviation from the desired trajectory, visual feedback was adopted. Sauter and et al. (2005) proposed a method for fault-tolerant control in dynamic systems. The proposed approach is composed of two stages. The first stage is the detection and isolation of the failed component using a directional filter designed under a particular eigenstructure assignment. The second stage is represented by the reconfiguration mechanism which makes possible the compensation of the fault effects. Polini and Sorrentino (2005) studied a new type of robotized winding cell in which the winding tension tried to be kept constant. They equipped the cell with a dynamometer that has been mounted under the winding die. Components of the force along three orthogonal directions (Fx, Fy and Fz) were aimed to be measured in the system and the data of tension were managed by Labview software of National Instrument. Polini and Sorrentino (2006) suggested system to keep the winding tension on roving near to the nominal value and to avoid collision occurrence. Carrino and et al. (2003) studied a modular structure of a new feed-deposition head for a robotized cell able to manufacture complex shape parts in composite material by means of the filament winding technology. Imamura and et al. (1999) purpose two kinds of winding tension control methods, and implement them using PID or I-PD control and they proposed tension control methods, which make use of the rotational velocity diffe-rence between the mandrel and nip-roll parts, performed well in trials. Carrino and et al. (2004) suggested an original method to optimize and to compare alternative winding trajectories for robotized filament winding.

Another fiber tensioning system with a conventional load cell (Kyowa Instruments) was used to check the correctness of the developed servo-mechanic pretensioning system Carbon fibers were wound under various pretension forces using the developed system [Fig. 1 and 2]. Tension tests were carried out to understand several tensioning parameters on the carbon fiber strength using Instron tension machines.

2. DESIGN OF SERVO CONTROLLED TENSION SYSTEM

A pretension control system for filament winding process was designed and manufactured to understand the effect of the pretension system parameters in the present this study. The diameter of the single fiber is around 10 micrometer. The fibers are not used as single fiber but they are used generally as bundle whose fiber numbers are changed from 1000 (1K) to 48000 (48K). They are brittle and can be easily damaged if any friction or bending forces are in present during winding process. To simulate the friction and bending of the fibers, an experimental set up was designed and manufactured as it is in real situations.

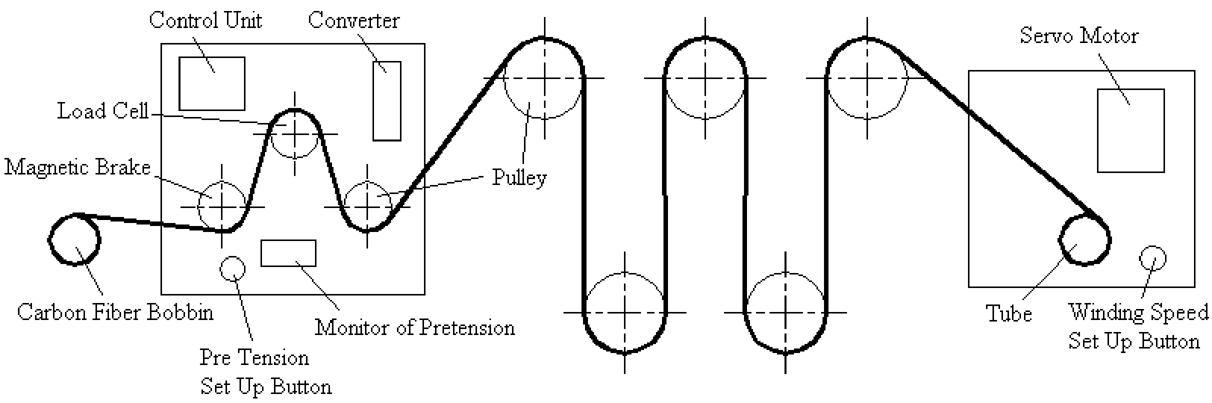

Fig. 1. Servo System Controlled Filament Winding System (a – Magnetic Brake Unit, b – Pre Tension Unit, c – Servo Motor Unit)

Tensioners which are the main object in the present study are used to pull the fiber so that the fiber could follow precisely the winding pattern path which it is supposed to go. The parameters which affect the winding are;

- The pretensioning force,
- The diameter of the pulleys which the fibers goes trough,
- The angle of the fiber between pulleys.

To control of the some of the above parameters are important to prevent strength loss in fibers caused by breakage. To do this, the strength loss measurement of the fiber bundle is important task. Bending strength in the fibers is mostly caused by vertical distance between pulleys and angle which defined by pulley diameter. A pulley system in which the above parameters can be changed was manufactured. The tension force on the fiber body was measured by a torque controlled servo motor which was located at one end of the tension system. At the end of the system, there was a winding roll to pull the fiber. The tension force on the fiber was measured by a load cell which is located juts prior to last roll. The first unit is tension setup of carbon fiber by magnetic brake with indicator of tension value.

Servo system controlled filament winding tension system which is seen in Fig. 1. consist of mainly from 3 units.

1. Magnetic brake unit which adjusted the speed of the fiber. This is also resulted the increase or decrease on the tension force in the fiber body (Fig. 2.).
2. The second unit is consisted of pulleys. The unit has two kind pulleys which are different in diameter. The

pulleys task was to transfer the fibers to the FW machine in a proper manner and create a room for tensioning adjustment (Fig. 1.b). The other task of the pulley was to change the travel angle of the fiber by changing the a and b distance between pulleys.

3. the third unit is fiber roll out unit. The task of the unit was to pull out of the fiber according to the predefined speed and wound it on a roll.

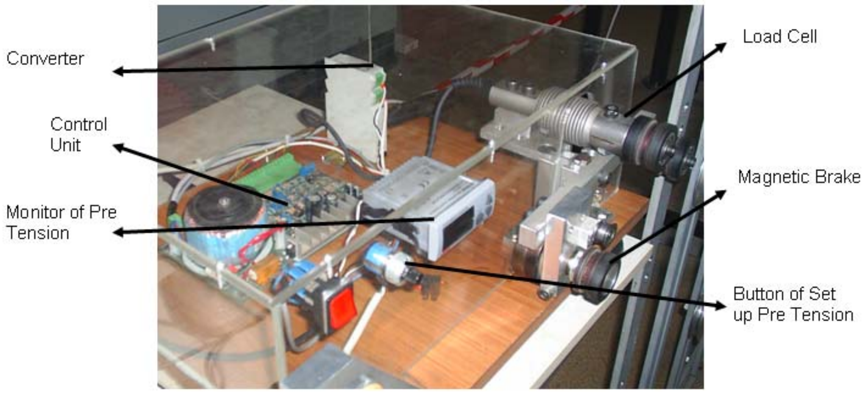

Fig. 2. Magnetic Brake Unit

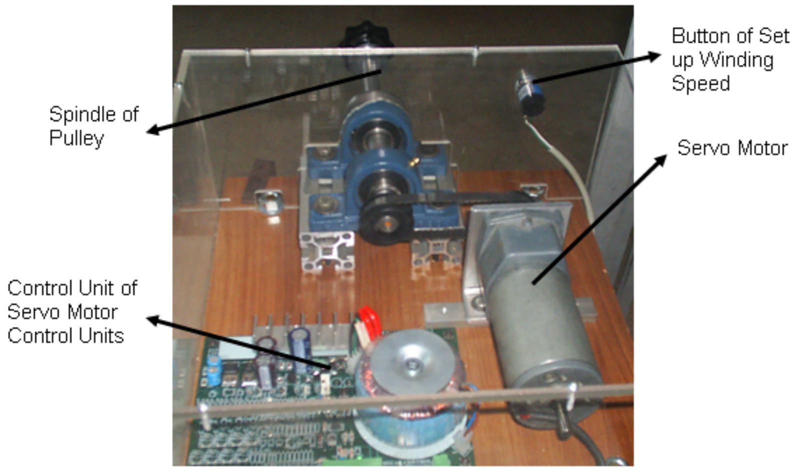

Fig. 3. Servo Motor Unit

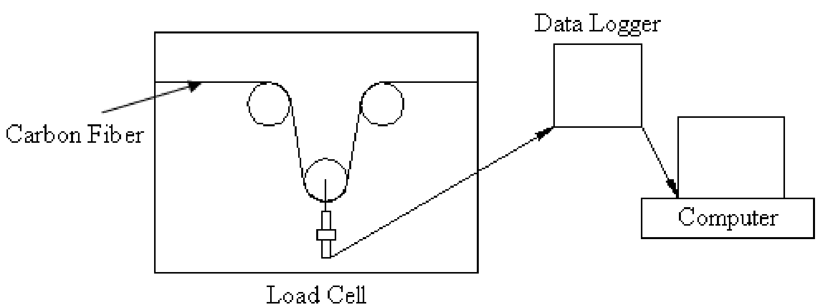

Fig. 4. Schematic Load Cell System

Pre tension unit which has pulleys – that can change positions is the second unit (Fig. 1b.). The third unit which can be change winding speed during filament winding. However this unit has bobbin for winding (Fig. 3).

During winding, converter takes the measured load signal and converts it to signal between 0 – 10 V and transmits the parameter to the control unit. A proportional–integral–derivative controller (PID controller) was used as control loop feedback mechanism. As it is well known, the PID controller calculation involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the brake movement. The PID controller attempted to correct the error between a measured tension force and a desired set point of tension force by calculating and then outputting a corrective action that can adjust the process accordingly.

The tuning of the PID controller was performed manually. According to the manual tuning, if the system must remain online, one tuning method is to first set the I and D values to zero. Increase the P until the output of the loop oscillates, and then the P should be left set to be approximately half of that value for a "quarter amplitude decay" type response. Then increase D until any offset is correct in sufficient time for the process. However, too much D will cause instability. Finally, increase I, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much I will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an "over-damped" closed-loop system is required, which will require a P setting significantly less than half that of the P setting causing oscillation. The contributors of the PID control scheme is correcting terms, whose sum constitutes the manipulated variable (MV). That is:

$$MV(t) = Pout + Iout + Dout \quad (1)$$

Where Pout, Iout, and Dout are the contributions to the output from the PID controller from each of the three terms.

The effectiveness of the PID control system was also checked by a conventional measurement system which was consisted of a load cell, high speed data logger and a computer. A three pulley system with a load cell (Kyowa Instruments), originally proposed by Horide et al.(1999) was employed. The schematic of the load cell system is given in Fig. 4.

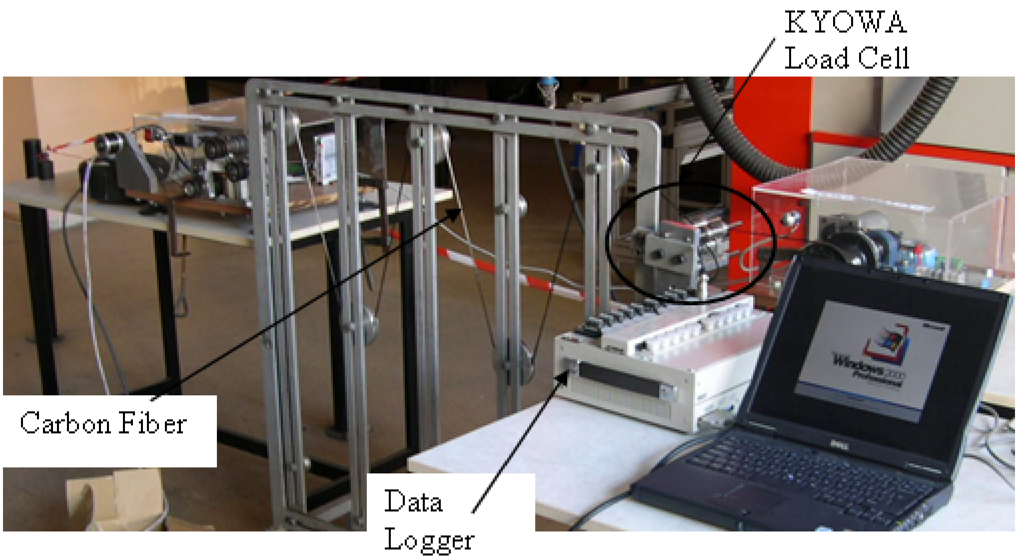

Fig. 5. Calibration System with KYOWA-UCAM 21 Measure System

The pre tension load on the fiber during winding process must be constant on acceptable value. Pre tension load, which is set up during filament winding process, compare with is measured value by system which had accepted the correctness. Fiber tensioning system with a conventional load cell (Kyowa Instruments) was used to check the correctness of the developed servo-mechanic pretensioning system Carbon fibers were wound under various pretension forces using the developed system [Fig. 5]. The loads, which are measured by KYOWA-UCAM 21, are saved to computer as shown in Fig. 5.

3. RESULT AND DISCUSSION

In this study, the effect of the primary manufacturing parameter 'winding tension' on filament winding process which widely uses on composite manufactured. It was designed to handle carbon fibers at high speeds while maintaining exact and very uniform tension. But it can be used with any type of fiber in composite manufacturing of continuous fiber. In composite winding, exact tension of each fiber is critical in order to achieve a finished product which has a high quality and good strength-to-weight ratio. Thus, an advanced tension control system with real-time control of the winding tension for filament-winding machine has been designed, manufactured and tested. Two kinds of winding tension control methods namely PID control and direct load cell control were used in the experiments. Imamura et al. has proposed a tension control methods, which make use of the rotational velocity difference between the mandrel and nip-roll parts. Rotational velocity is undirected parameters in case of fiber tensioning. Any sliding between pulley and fiber may cause an incorrect data. Thus, in the present study, the tension force on the fibers body was directly measured by a load cell and the value was evaluated by a PID controller to keep the tensioning constant. A conventional load cell system with a very high sampling rate (80 microsecond-1) was also used to check the effectiveness of the PID controlled load cell system. Fig. 5. shows the comparison of the tension force measurements data obtained from PID controller tensioning system with the conventional load cell system. This figure indicates that the tensioning can be kept within 10 % variation of the set value which is generally acceptable.

With the implementation of the better tensioning system such as one proposed in the present study, it may be possible to have advantage in the FW machines. Those advantages may be:

– Production cost reduction may be possible,
– Less row material loss during winding may occurs,
– Production speed can be increased,
– Better product quality may be available.

To have better winding pattern with optimized fiber waviness more winding parameters should be included in the control system, especially in the wet winding process. The fibers are always tending to slide on the mandrel during the placement in the machine.

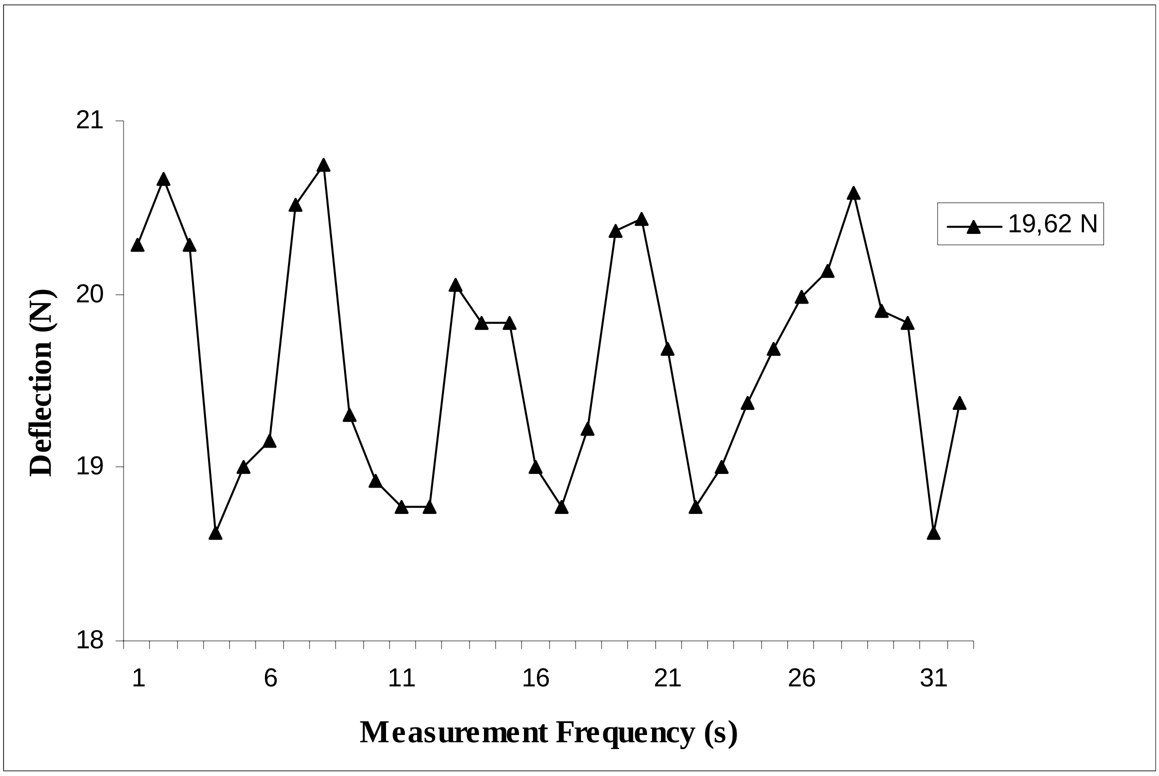

Fig. 6. Variation of the Tension Force in the Fiber during Winding

Fig. 6. shows deflections of the pre tension and measurement frequency per second. Like 19,62 N load which are set up during winding process. This value are taken approximately ± 1 N deflections values as shown in Fig. 6. As the pretension load are taken on the acceptable constant value breaking of the fiber are handicapped and the pre tension value are set up during winding process on the desirable values.

4. CONCLUDING REMARKS

A pretension control system with PID control for filament winding process was designed and manufactured to understand the effect of the pretension system parameters in the present this study. Tension controls of this process are important factors in beter winding paterns which is the main reson of high strength. A proportional–integral–derivative controller (PID controller) was used as control loop feedback mechanism. Proportional, integral, and derivative (PID) control requires real-time system feedback. PID is a sophisticated control technique which monitors the error between a desired variable value and the actual value, and adjusts the control accordingly (proportional).The aim of the fiber control was to keep fiber tension force constant in a pre-defined value. The tested pre-tension control system for filament winding led to the following conclusions:

– Pretension was controlled in variable value successfully during filament winding.
– The primary test of the system showed that the fiber tension may be kept constant within the 10% of aimed tension value.

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