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Nylon Tension PID Control During Raw Tire Assembly

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NYLON TENSION PID CONTROL DURING RAW TIRE ASSEMBLY

by

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(Under the Direction of Fernando Rios-Gutierrez)

ABSTRACT

The purpose of this study is to evaluate several control methods to see which one has the best control of nylon tension during raw tire assembly. After nylon application step of the tire building process, the shape of the tire will undergo inflation that causes the nylon layers to expand and produces tension gradient. To overcome such a problem, the process needs to pre-apply a nylon trip with a gradient of tension so the tension can be balanced after the inflation step. The study evaluated several PID controllers and gathered data to see which controller results in the best nylon tension gradient. The study also discusses the cost and simplicity of implementation as well as its overall performance.

INDEX WORDS: Force Control, Nylon Tension Control, PID Controller, Tire Assembly, Raw Tire, LabView

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DEDICATION

This paper is dedicated to my grandma, Ms. Luo, who passed away during my graduate academic year. She had been supporting the growth of my family and family business in every moments of her life.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my parents, my grandparents, my friends, Cheng-Shin Tire Company and Georgia Southern faculties who continue to support me both academically and socially during the past 3 years when I faced several life-changing challenges. Without them I may not able to complete this paper.

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CHAPTER 1:

INTRODUCTION

Today, manufacturing is a process that combines sophisticated technology advancements and complex procedures executed in high precision. The demand for speed, precision, stability and low cost in the manufacturing process are the driving forces for the evolvement of the new generation of machinery. Subsequently, the combination between the demand for cost savings and the incorporation of highly complex interactive components, like sensors, into the already complex machinery has gradually taking over the direct involvement of human body parts. This improves consistency and greatly reduces the danger of direct contact with the machinery as well as the cost for human labor. However, to achieve such a goal, the machinery needs to perform complex procedures on its own, have sensors to sense any abnormality, and to have error correction mechanisms to correct any sensible errors and/or send a warning signal to the appropriate terminals. The machinery also needs to cooperate with other machinery upstream and downstream, and it needs to control its transport of materials from itself to machines, even if there are errors occurring during the transferring process.

Such complex machinery, which is only part of the whole automatic assembly line within a factory, is the core for modern and future manufacturing. Successful companies continue to improve both the individual machines and the communication between them. The resulting complex system is fully automatic and requires only a few staff members to monitor vital signals. Such a system can consists of tens or hundreds of machines, and each machine consists of hundreds or thousands of components. Individual components within each machine can involve several physical and chemical properties across the whole science field. Any small improvements on an individual component adds up to become significant improvements on individual machines, and even greater improvements to the whole assembly line; the tiny improvements on a component end up reducing large amounts of manufacturing costs. This is the reason why altering a small component of a complex system can affect the speed, precision and stability of the entire assembly line as a whole. This paper will focus on the design of a controlling mechanism for a tire building machines -in particular the control of the tension or the nylon ply.

Motivation and Justification

Roller systems are widely use in today's manufacturing industry. Their main application is to transfer material and at the same time, process the material to improve its physical properties. One of the most important physical properties for sheet materials over roller systems is the tension. By controlling the tension one can reduce manufacturing defects and improve physical properties of the material because many sheet materials works better if they are under a limited range of tension. For this research, the main processing material is the tension control of rubber coated nylon ply.

The composite sheet material consists of highly woven nylon sheets coated with a layer of thin un-cured rubber on its surface. Due to the un-cured nature of rubber (called green rubber) the composite material is best if run under a controlled tension to prevent under-tension, which causes rubber thickness of the tire to build up, or over-tension, which stresses the nylon ply and produces thinning in the rubber coatings making the tire unsafe. The Green rubber, or un-cured rubber, has fluid-like properties; it also could act like a liquid with very high viscosity. Any variations in the tension of a green rubber material can greatly affect the final cured product. For example an over-tension rubber coated nylon ply during nylon ply assembly can result in early separation between nylon and its rubber coated surface before final assembly. During final assembly the uneven rubber surface caused by over-tension can result in separation between such layer and all other layers required for a complete tire. Once the tire is cured (vulcanized) by applying a sulfur cross-linking process, the problem area can cause the tire to lose its structure and cause tread separation during high-speed operations, resulting in tire blow-up and potentially passenger injury or death. Here we see that tension control not only improves the quality of the product, it also prevents serious failures that could cause property damage or even human lives.

The implementation of this project was on a green-rubber tire building machine (HP - high performance shaping machine) owned by the Cheng-Shin Tire manufacturing company in Taiwan (Republic of China). The HP machine is a complex equipment that brings multiple sheets of raw rubber materials together. The function of the entire tire building machine is out of the scope of this paper; the focus of the research was on the tension control mechanism of the rubber coated nylon ply delivery system, shown in *Figure 1* below.

Figure 1. Rubber coated nylon ply tension control mechanism.

The HP machine's predecessor did not include tension control for the rubber coated nylon ply; to improve the overall quality of the tire, the current generation (3rd) was developed to deliver the nylon material to the building machine with a controllable and stable tension control. The important reason for tension control is that once the nylon ply is applied on a raw tire (green tire), the assembled green tire will need to inflate so that other type of layers can be applied. Such inflation changes the tire shape, hence changing the tension distribution of the nylon ply across the width of the tire. To maintain even distribution of tension across the width of the tire after inflation, the nylon ply feeding process before inflation needs to have higher tension at the edge and lower tension at the middle; this is because the center of the tire after inflation will have a greater diameter than the two edges. According to the description giving by the Cheng-Shin machine control engineer, the controlling mechanism of the whole tire building machine is controlled by a Programmable Logic Controller (PLC). Due to the massive information that the PLC controller needed to process in a given unit time, the nylon tension controller mechanism built within the new generation of the tire building machine was unable to deliver real time feedback back to the tension controlling servo motors, hence the old PLC controller couldn't handle the newer tension control hardware. In summary, the original PLC controller for the new HP machine was already saturated with existing controlling requirements; the extra tension control commands were unable to catch up with the speed of the machine, and the slow PLC feedback hindered the overall tension controlling mechanisms. The scope of this research was therefore to find an economical solution to improve the tension controlling mechanism of the new tire building machine. With a better tension control, the optimum physical quality of the material could be maintained and would lead to improve the overall quality of the final product.

Tension Controller Description

The experimental version of the tension controller of this research consists of a PC-based LabView virtual controller interface implementing a close-looped Proportional, Integral, Derivative (PID) controller. The software based controller obtains the input data from the existing PLC controller of the tire assembly machine, which are generated by the outputs of the load-cell sensor and servo motors of the actual tension controlling mechanism. The benefits of this initial approach were to obtain a detailed and graphical representation of the tension for the nylon ply over time that could also be used to deduce the rise time to reach certain goal (*Tr* from

10% to 90%) and the Steady State Error E_{ss}. This experimental set up helped to find the performance of the PID controller on the nylon tension system before the physical implementation of the actual circuit board. The graphical interface also helped to compare the theoretical performance of the LabView controller to the actual performance of the final PID circuit. Overall the new implementation could by-pass the slow PLC internal controlling mechanism and allowed direct process of the input signal as well as corrected signals back to the servo motor.

The final implementation of the PID controlling scheme was done on a single-chip microprocessor PIC-16F877 that has both speed and economical advantage over the PC-based controller. The input and output signals from/ to the PLC of the HP were exactly the same than the PC-based implementation. The overall implementation of the microprocessor and PLC controller resulted in the following workflow: The PLC provided target signals and load-cell sensor feedback, the microprocessor with written PID code provided the necessary compensation and finally the compensated output was put back to the servo motor. The overall assembly solved the problem of the original over-saturated PLC controller that was unable to provide real-time processing of the tension signal by giving the actual tension control to the independent microcontroller.

CHAPTER 2: BACKGROUND

BACKGROUND

Rolling System

In recent years, technology advancements have become the major trend within the manufacturing sector. The combination of high labor costs, demand for uniformity of quality and reduction in hazards from human-machine direct contact have all pushed modern industries in search for better automatic processes, which solve all the problems together. The key driving force beyond automation is the advancement of technology. Manufacturing speed pushes to fulfill the gap caused by intense competition in the world market. Manufacturing machinery needs to be designed with greater precision, higher stability and lower cost to meet the same goals by manufacturers.

Today's automatic machinery important elements like sensors and micro controllers; these combined with required power for the process is what makes automatic processes free of intensive labor. One of the common processes that exist in the manufacturing industry today is the rolling component process. Rolling components are used mostly for transportation of materials; they may or may not include processes for changing the chemical or physical properties of the materials that they transport. We can find various examples of rolling systems in the studies by Su (2005) with his web winding example, Liau (2011) with rolling of elastic plastic film and Ren, Lu, Wang & Fu (2007) with their control of fiber tension; in terms of advanced materials, Imamura, Kuroiwa, Terashima & Takemoto's (1999) work on rolling carbon fiber material and Park & Hwang's (2007) work on hot strip finishing mills all demonstrate industrial examples of rolling components. The works by the above authors demonstrate that the rolling system is not only one of the most important parts of controlling the quality of the material, but the most important system where advanced controllers need to be in place due to the complexity of the system.

Examples like paper making, gift wrapping, printing, coloring, cabling and raw material processing involving rubber and fibers all require rolling components to process and transfer materials from one step to the next. Some industries even involve multiple continuous material transports by rolling systems, or the whole process is done on a one step continuous rolling system from beginning to the end. The required control properties involved in controlling materials on the roller can be very complex; one such property is the tension, which is one of the most important physical properties in continuous rolling systems that affect the quality of the end product.

Tension Control

Tension control is a very important parameter for maintaining quality of rolling materials during the assembly process. Many materials require tight tension tolerances and may be delicate enough that any abnormality can cause catastrophic failure and render the materials unusable. From the several industrial applications examples mentioned in the previous section, extremely fine tension control is needed during raw material mixing, property changing and transportation; hence, the stability of the tension during manufacturing can greatly improve the quality of the material and reduce manufacturing cost as well as to increase manufacturing efficiency.

There are many existing studies on the topic of tension control, for example the rolling device mentioned by Su (2005) is a very stable rolling machine for web material. In such an example, the web material required constant tension to maintain material stability; however, the rolling speed and tension changes due to the change in both the diameter of the input roller and the output roller when sheet material moves from one roller to another. Such changes can cause both under-tension, which can cause waves and ribbons on the surface of the finish product, and over-tension, which can cause ripening due to excessive deformation. Extremely under-tension rolling can even cause the sheet material to drop and drag on the bottom floor, and sabotage the whole continuous process. Here the solution is to control the speed of the roller. Due to the non-linear change in diameter of both the input and the output rollers, one needs a higher end controller like the combination of a PLC, a microprocessor and a PC-based controller to program and control tension.

In 1993, Ebler, Arnason, Michaelis and D'sa developed a computer simulation model of a modern paper manufacturing machine for load-cell versus dancer cell (position control) study; this study was to find which of the tension controlling methods was more efficient and had less response time. In this study they found that computer modeling and simulation is a really efficient tool for studying tension control of a rather complicated machine. In later years more and more studies on tension control's controller had been published. Another study by Janabi-Sharifi (2003) using looper tension control system, which is very common in tension control, to control the tension of a rolling mill. In the Janabi-Sharifi's study, he found that common controlling schemes based on rolling model cannot account for unaccounted variations and dynamics, so he use a neurologic approach to design a controller that can turn several controlling elements on or off and resulting in different controlling scheme for different situations. The conclusions of this study showed that neurologic controllers are much better than PID controllers for handling looper tension system.

In many of the tension control systems, the transport of material was also done on the same rolling device, so in 2005 Kang and Lee designed another controlling scheme not based on the looper tension control mentioned before. The challenges that Kang and Lee faced were to maintain stable tension on a continuous roll to roll gravure printing machine; due to the sensitivity of paper to tension, any slight over or under tension can ruin the material, causing deformation, gearing, surface damaging and register errors (Kang & Lee, 2005). To overcome tension stability problem, Kang and Lee designed a tension control system that vary the speed between adjacent rollers, as shown in Figure 2 below.

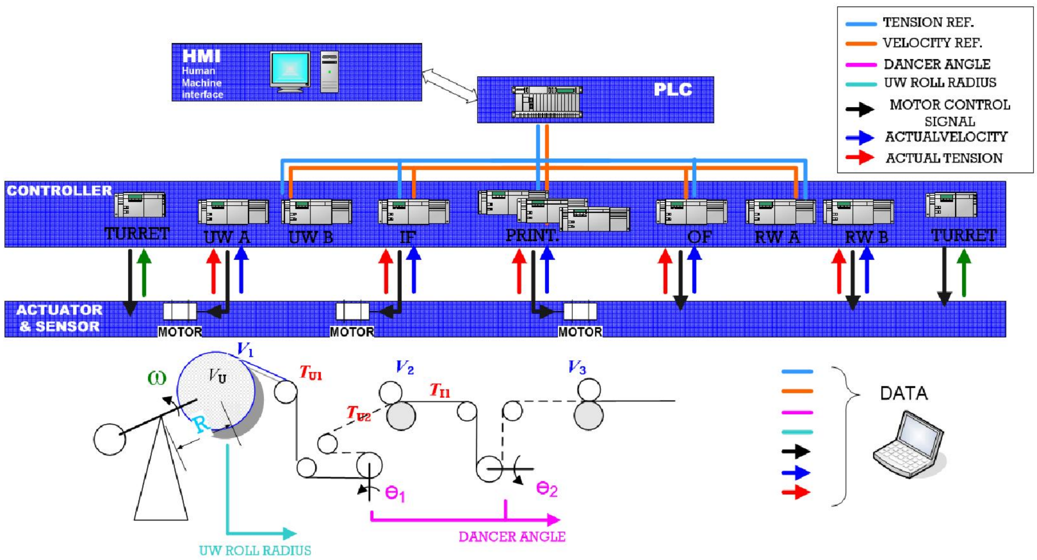

Figure 2. Experimental setup of the study by Kang and Lee, 2005.

In this study by Kang and Lee (2005), three of the rollers can adjust their speed to form three discreet tensions, labeled in red *T* in *Figure 2* above. The study also derived a nonlinear

MIMO (multi-input, multi-output) model and tested it using Simulink to check its effectiveness before input into an industrial PLC controller shown in *Figure 2* above. In this study we can see that varying the speed can be as effective as looper tension control.

The PLC controller in Kang and Lee's study has been used in the manufacturing industry for a long time. The PLC controller can implement PID algorithms; together with an AD/DA modules it is widely used for adjusting tension by altering a motor's torque and speed, as shown in studies by Liau (2011), and Ren et al. (2007). The flexibility of a PLC controller can also be seen in the study by Imamura et al. (1999) where a PLC enabled the control of Mandrel through compressing air more efficient. The PLC allows the comparison between the controlling torque of the Mandrel and the controlling speed between the Mandrel and Nip-roll winder to be done and to assess which has the better tension control (Imamura et al. 1999). From these examples we see that different tension control techniques fit different machinery, environments and purposes; there is not one universal tension control that fits all purposes.

However, the PLC has its own disadvantages - as the required data processing speed keeps getting faster and faster through time and reaches the limit of the PLC controller response time, the microprocessor within the PLC may be too slow to send out effective feedback signals, causing inefficient controlling results. This happened to the original HP machine prior to this study and the Cheng-Shin Tire Company has been searching for an improvement to overcome the PLC's native response time and slow feedback. The main goal of this study was to find an economical solution to improve manufacturing efficiency and quality of the original HP machine; to achieve this goal; the PC- Based controller was used initially for testing purposes only followed by the microprocessor based controller.

PID Controller Implementation

The improvements of the nylon tension control in this research were done on both a microprocessor-based controller and a PC-Based controller. The controlling algorithm of choice was the PID controller. Compared to the neural-network based controller or other more complicated control methods implemented in the studies presented in the previous sections, the PID controller is relatively simple and easier to implement; also, the PID control scheme has been used for a long time and is well-studied. Thus, it was much safer to implement on an actual manufacturing machine without the need to build a complicated model to test it out first. Such simpler and robust implementation is a more direct method as well as being cost efficient for the HP tire building machine used in this study.

The PID controller includes proportional, integral and derivative terms. The proportional term in the PID controller normally refer as proportional gain, is the primary compensator for errors between the feedback and the input signal. The proportional terms correlate to the magnitude of the error that deviates from the goal; however, if this compensation gets too large, it could produce excessive over-shoot and steady state errors. Another problem when proportional terms gets too large is that the actual circuit may require excessive energy, because gain compensation also correlates to the required input energy for the controller. To overcome the overshoot, the integral term is added to reduce the steady state errors and to increase the response time. Now the whole system reflects better to the set goal in the steady state, with the exception of having amplified over-shoot that has not been compensated for. The final derivative term was added to control the overshoot but remained limited due to its time-slowing property that reduced response time and led to instability over time. Any combination of the P (proportional), I (integral) and D (derivative) terms result in a corresponding controller type, for example P only control (proportional only), PI control (proportional & Integral only) or PD control (proportional & derivative only), etc. The overall summary of a PID controller is summarized in chapter 9 of the textbook written by Nise (2007).

Over the development of manufacturing technology, PID has been used to directly control analog signals like for hydraulic, compressed air, electro-mechanical and analog circuits; in recent years in manufacturing, the PID controller has become microprocessor based, and new tuning methods have continued to be found. The general diagram of a PID controller related to the overall controlling mechanism is shown in the block diagram of *Figure 3* below.

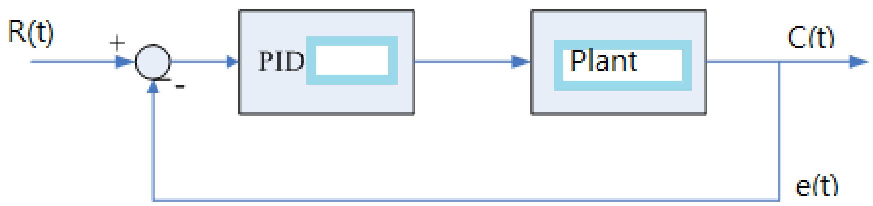

Figure 3. PID block diagram; the plant is the control target.

The overall equation of the PID control scheme is shown in equation (1) below:

$$u(t) = K_p e(t) + K_I \int_0^t e(\tau) d\tau + K_D \frac{de(t)}{dt} \qquad (1)$$

Where

- $u(t)$: control value
- $e(t)$: error
- K_P: Proportional gain
- K_I: Integral gain
- K_D: Derivative gain

It can also be re-written using the Laplace Transform form as:

$$G_C(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right) \quad \text{--- (2)}$$

Here each of the terms adds up to the complete PID controller. The Proportional control handles most of the control signal but it cannot by itself maintain a stable steady state error. PI control overcomes steady state errors but sacrifices reaction time, and decreases stability. PD can greatly help in response time but is sensitive to noise and errors. The combination of PI and PD controllers result in a much better steady state as well as optimum response; this is the reason why PID controller remains very popular for control applications.

CHAPTER 3:

PROJECT IMPLEMENTATION DESCRIPTION

Nylon Tension Control Apparatus Description and Setup

HP machine introduction

The main apparatus is the HP (high performance shaping machine) provided by Cheng-Shin Tire Inc. The layout of the whole tire building machine is shown in *Figure 4* below. Due to proprietary technology most of the functions of the HP tire building machine are not discussed in this paper; the main focus is the nylon ply feeding apparatus circled in red.

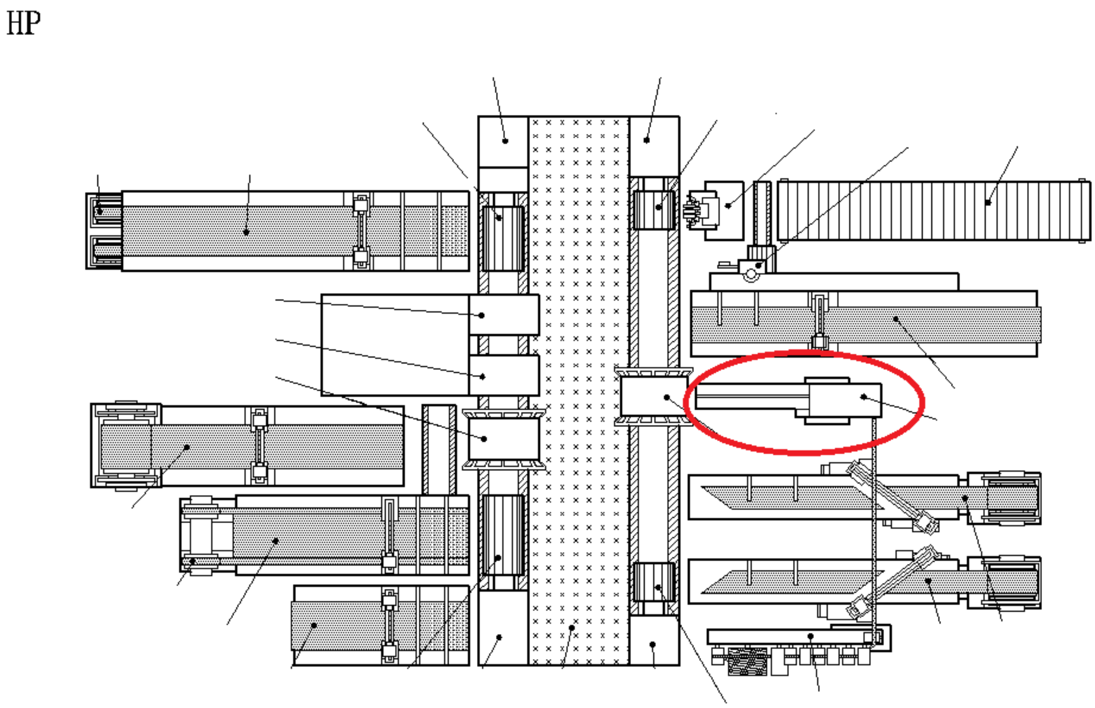

Figure 4. Overall layout of HP tire building machine and nylon feeder circle in red; property of Cheng-Shin Tire company.

The nylon feeding apparatus took the pre-built rubber coated nylon tape, maintained its tension and folded on a multi-stage roller system to maintain sufficient supply of material for one tire assembly process-this can double as a buffer during the raw material replacement process when a roll of nylon ply runs out. The whole nylon wrapping assembly is shown in *Figure 5* below, which belongs to the second-generation HP tire building machine.

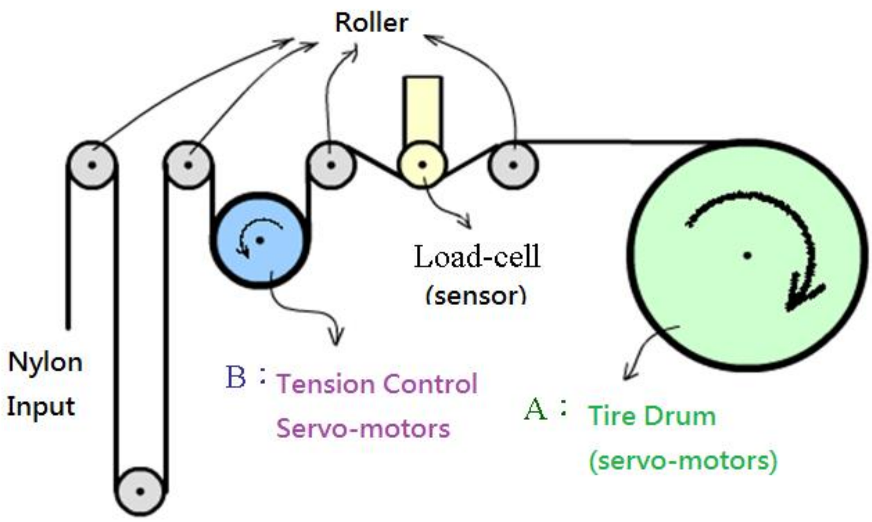

Figure 5. Assembly of the nylon ply feeder of this study

During nylon ply assembly, both the A and B servo motors rotate while the load-cell sensor provides to the controller the force (tension) feedback. The load-cell sensor continues to send tension signals to the controller and the controller adjusts the power and the speed of the B tension control servo motors so that the ply tension can reach the control target. All input and output signals are processed using the existing PLC controller, which maintaining the whole workflow of the HP machine, and sends it to the PID controllers built for tension control. The terminals of the PLC controller are shown in *Figure 6* below.

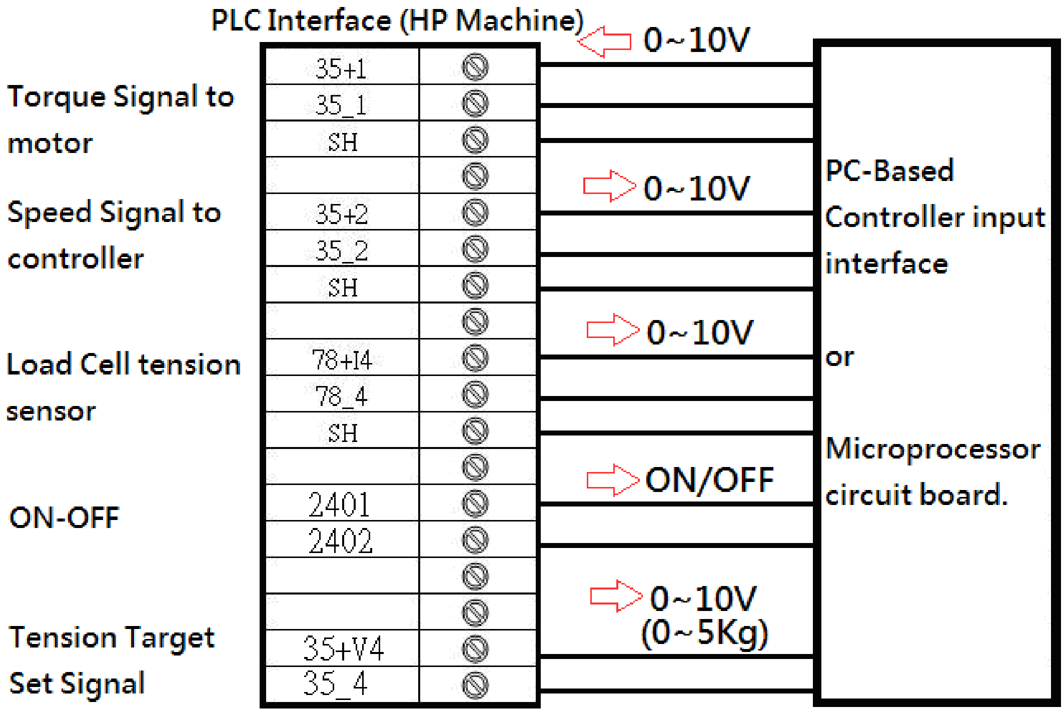

Figure 6. Terminals of the PLC interface that controls the whole HP machine

Major terminals from the PLC interface are as follows:

1. Input (also A/D-2 Channel for PC-Based data acquisition card): "Tension Target" signals to control tension (0~10V) and "Load Cell" tension sensor (0~10V)
2. Output (also D/A-1 Channel for PC-Based data acquisition card): "Torque Signal" that controls the torque power of the tension-control servo motor (0~10V)
3. Digital Input (DI-1 Channel for PC-Based data acquisition card): Simple ON-OFF switch to switch on the PLC controller.

The primary hardware components of the nylon ply feeder are as follows:

A Tension control servo motor, and its corresponding driving interface (B in *Figure 5*) The servo motor is made by Mitsubishi Electric and the model number is HC-SFS102(B), with interface MR-J3-100A to drive and control all motor functions; both components are built for high speed and high accuracy specifications. The motor has a maximum rotation speed of 2000 rpm and maximum torque of 14.3 N-m while the interface handle analog input from PLC interface. The analog speed control input ranges from 0 to 10 volt and the torque control input ranges from 0 to 8 volt. A photo of the servo motor and its interface is shown in *Figure 7* below.

Figure 7. Servo-motor and interface

- Load-cell sensors:

  The *MAXCESS* load-cell sensor is manufactured by *MAGPWR* and consists of a *CL1-15* suspension arm vertical force sensor and a *TSA 9A22-1 SC-15* signal magnifier. The maximum detection force is 15 lb. Combined with the signal magnifier the relative output ranges from 0 to 10 volts (or 4~20 mA) and can be calibrated to suit specific needs.

The ways in which the nylon wrapping machine works are shown in *Figure 8* below. When an unfinished tire layer is on the drum been prepared to apply the nylon ply later, the tip of the nylon feeder first reaches the initial position shown in (a) below. Once the drum begins to rotate the nylon feeder applies a continuous strip to the tire layer; when the tip moves slowly to the right side, an equal thickness of nylon strip begins to cover up the designation area, shown in (b) below. Once a layer of nylon ply has formed, the tip wraps to an end position shown in (c) and finally both the nylon feeding tip and the drum stop while the nylon strip is cut, shown in (d) of *Figure 8* below. The whole process uses narrow width of nylon ply instead of just one sheet of nylon ply because the resulting layer is more controllable, more uniform, and has no obvious overlap area.

As mentioned in the Introduction of this paper, a nylon ply applied tire will later go through inflation; hence changing the tension across the width of the tire. During the primary application process (b) in *Figure 8* below, the ply tension should increase when it approaches the middle and decrease once it reaches the other edge (right edge). With good tension control the completed raw tire should have greater tension on the edges and lower tension on the middle. Once such a raw tire is transferred to another layer building process with air inflation, the increase in the central diameter will eventually bring up the tension; this will result in equal ply tension across the final stage of raw tire building, and increase the quality of the final tire.

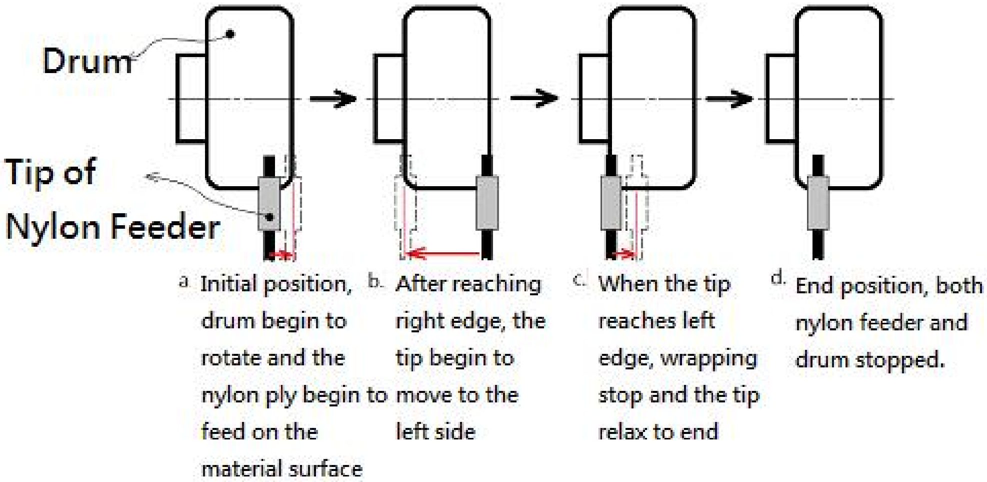

Figure 8. Actual nylon ply wrapping process on an unfinished tire layer.

In this research, we designed two PID control methods and compared the results; one is a PC-Based controller and the other one is a microprocessor-based controller. The PC-based controller takes the input analog voltage signals from the PLC controller and converts them to digital signals and process' them through a National Instrument LabView application. The resulting PID adjusted signal is then returned back to the tension control servo motor through the PLC interface and the load-cell sensor continuously provides signal feedback for the PID controller. The microprocessor controller is similar to the PC-Based controller except that the whole PC assembly with LabView is replaced by a microprocessor circuit that provides a similar PID functions. The PC-based controller will act as the reference PID controller to test out the PID performance on the actual HP nylon tension control machine while the microprocessor based controller is the actual cost-saving solution that will be permanently implemented on the

Nylon Tension Control apparatus once the PC-Based PID controller results turn out to be positive.

PC-Based Nylon Ply Tension Control

In the PC-based nylon control, we took signals from the PLC interface shown in *Figure 6* in the previous section, and connected them to a National Instrument data acquisition card NI USB-6009 shown in *Figure 9* below. A brief introduction of the USB-6009 data acquisition card shows that it has 8 discreet A/D inputs, two 0~5V D/A outputs and 12 digital DI/DO inputs/outputs; the maximum data capture speed with LabView is 1ms and the data resolution is 14-bit. The signals from the data acquisition card are then feed to a laptop computer with LabView software installed.

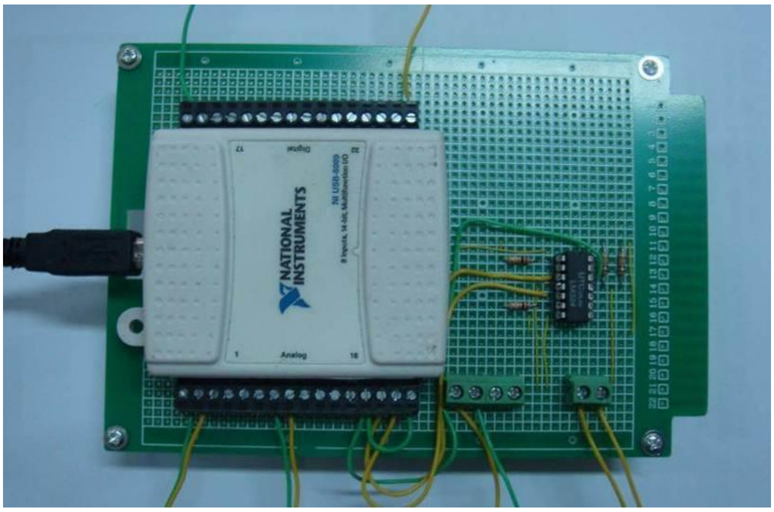

Figure 9. National Instrument USB-6009 data acquisition card

The primary controller was designed using the LabView (Laboratory Virtual Instrument Engineering Workbench) software that is capable of simulating a software-based controller using an ordinary PC. The LabView software is similar to C or BASIC programming language, with the exception of its ability to program in a graphical base environment, especially block-diagram type architecture design. The LabView software and hardware together bring programming closer to the thinking of engineers and many of its terminologies correspond to engineer design terminologies.

In summary, for this project a LabView program was designed that takes the inputs/outputs terminals from a the PLC interface as shown in *Figure 6* and creates a close-loop controller that controls the torque of the servo-motor; later the program is capable of accepting control signals and to adjusts the torque of the servo motors accordingly. In more detail, when the PLC interface sends out both the tension set point and the load-cell sensor signal to their corresponding terminals, the PC-based PID controller acquires and feeds both signals to its close loop controls within its program and adjusts the output servo-motor torque accordingly. The overall layout and the close loop block diagram of the PID controller are shown in *Figure 10* below.

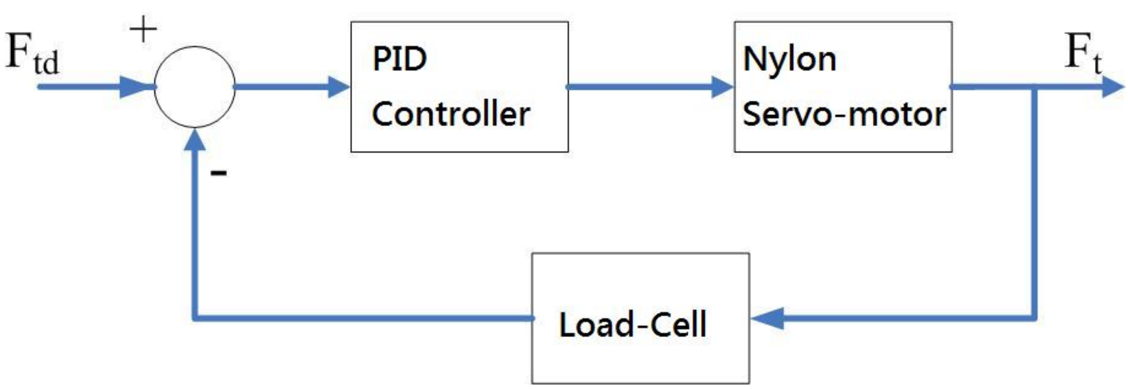

Figure 10. Block diagram of the LabView PID controller

The LabView program has 5 major parts. The first part is the graphical interface shown in *Figure 11* below and it serves as the control panel of the whole process, which control the start/stop function and monitors the tension of the nylon ply in real time. The graphical interface also allows manual entering of the PID controller's P/I/D gains values and to program running time. The interface is capable of showing tension values (Kg) over time (ms) and it can be used to find out the rise time *Tr* (10%~90% target) and steady state errors (E_{SS}). Before running the PLC of the machine, it accepts the speed control signal, tension set point, start command and load-cell sensor data. The PC-Based LabView controller took most signals except the speed control signal, which is calculated within the complex machinery. The output of the PC-Based LabView controller is the voltage signal that will adjust the torque of the tension control servo motor.

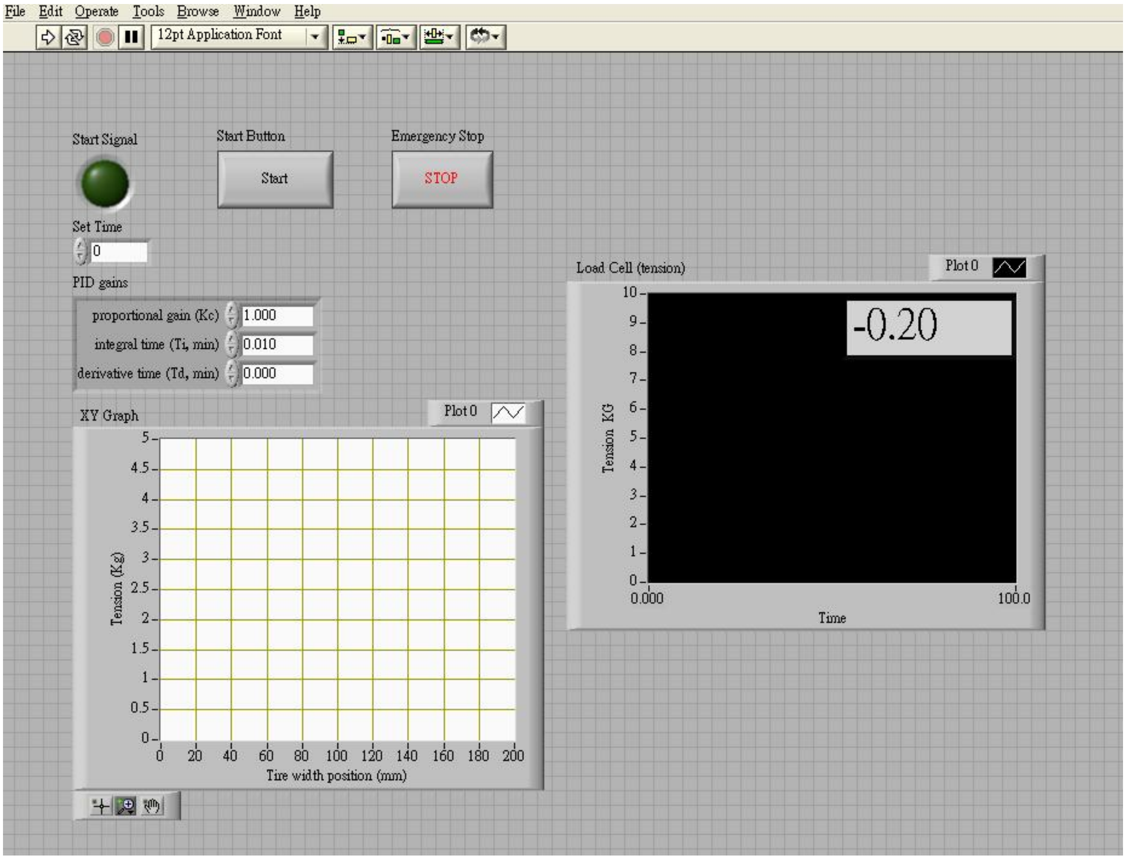

Figure 11. Graphical interface of the LabView PID controller

The other four parts are the actual code itself and are shown in Appendices A through D with comments. It is built on a sequencing structure, where completion of commands in one sequence leads to another set of commands within the adjacent sequence and so on. The summary of each sequence structure is described below.

1. Appendix A consists of a data acquisition signal from the stop command of the PLC controller of the rolling machine. The LabView program takes the STOP signal to stop the function of the sequence; in addition, there is also an OR gate with an additional STOP signal for the control panel as shown in *Figure 11*. The whole structure is within a

WHILE-LOOP to ensure that the sequence will stop when any of the Stop commands are given.

2. Appendix B consists of a data acquisition block used to take an initial reading of the load-cell sensor and the set data (set tension) from the PLC controller. The 1V load-cell voltage corresponds to 0.5 kg while the 1V set tension voltage corresponds to 200 kg. A time delay function is used to delay the data acquisition frequency from approximately 1 ms (LabView default) to 250 ms, in order to prevent data overflow in this short period of time.
3. Appendix C shows the primary structure of the PID controller. Within the sequence it consists of three parts.
    a. The first two parts are within the central flat sequence structure that consist of a left and a right block:
        i. The left block includes the data acquisition block within a FOR-LOOP that collects both the load-cell sensor and set data for 10 times, averages and de-noises them, and compares them to the initial data from the previous sequence shown in Appendix B.
        ii. The right block takes the compared data and feeds it into the PID controller block; the PID controller block uses the P/I/D gain values from the graphic interface in *Figure 11* and outputs the corresponding voltage to the nylon-tension servo motor.
        iii. The simulated signal is a square wave that simulates a sequence of inputs for the experiment in Chapter 4.

b. The third part of the overall PID code is the entire flat sequence structure (sequence structure with two ordered side) within the WHILE-LOOP. The difference in the timer is a value that serves two purposes: first it calculates the time to run the WHILE-LOOP once and uses it to set the run time for the PID controller; second it uses the value to stop the process.
c. There are both a continuous load-cell tension monitor and a recorded output X-Y graph to show the tune process over time as is shown in *Figure 11*.
d. The mean load-cell sensor value and the set value from the FOR-LOOP of (b) above are needed to reduce the noise of the X-Y graph.

4. Appendix D is the final signal to the nylon tension servo-motor, meaning that the building process cycle is stopped.

Microprocessor Based Nylon Ply Tension Control

In the microprocessor based nylon tension control, a PIC-16F887 microprocessor was used to implement the PID controller. The microprocessor software was prepared by the teams of Cheng-Shin Tire engineers and students from the National Yunlin University of Science and Technology (abbreviated as Yun Tech University), using factory default templates; both teams used MPLAB V8.3 developed by Microchip to write the microprocessor code for the PIC-16F887. The actual code itself is listed in Appendix E at the back of this paper with the permission from Cheng-Shin Tire engineers and Yun Tech University. Note that due to the digital nature of the microprocessor, the output voltage is limited to 0~5V and it is accomplished using a Pulse Width Modulated (PWM) signals instead of a constant analog voltage.

To test out the code written by the Cheng-Shin Tire engineers and Yun Tech University team, the project used Proteus to simulate and to test out the microprocessor with PID code built in. Proteus is a circuit building and simulating software similar to Multisim. Multisim was not used because only Proteus was available at Yun Tech University. The commands in Multisim and Proteus are slightly different but the actual simulation part is very similar. The actual layout of the circuit simulated in Proteus is shown in *Figure 12* below.

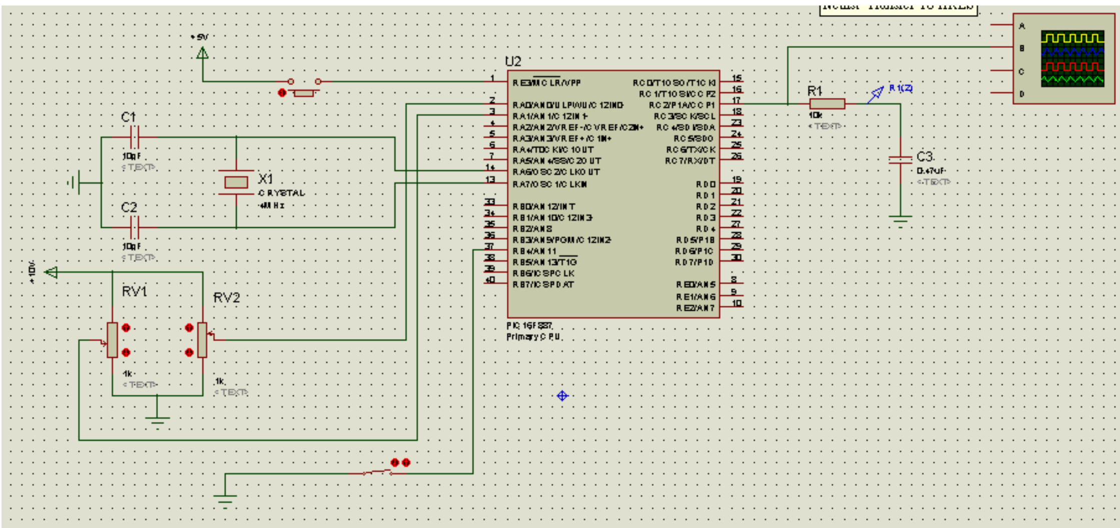

Figure 12. Software layout of the circuit simulation in Proteus

The layout in *Figure 12* above consists of a PIC-16F887 microprocessor, loaded with the software in a *.c* or *.hex* file format. The switch and the crystal oscillator/twin capacitor group at the top left corner of the microprocessor are the factory default circuit components needed to run the microprocessor. The two variable resistors R_{V1} and R_{V2} just below the crystal oscillator are the primary tension-set and load-cell sensor inputs, and both connect to a 10 V source. At the right side of the microprocessor, an output is sent directly to an oscilloscope, while the output is stabilized by an RC filter.

The primary controls are the two variable resistors R_{V1} and R_{V2}. First, the program sets a constant value for the variable resistor R_{V2} on the right side, which simulates the set tension given by the machine. Second, the software begins to simulate the whole circuit; while the simulation is running we adjusted the variable resistor R_{V1} on the left side to see the change in PWM output on the oscilloscope. If the PID is working correctly, the voltage on the output should increase as the difference between the two variable resistors R_{V1} and R_{V2} increases. The reason is that the PID is trying to adjust the servo-motor output when there is a difference existing in the set tension voltage and the load-cell sensor voltage, and it is trying to make both values equal. If the resistors are set to the same value, there is no voltage output from the microprocessor. The whole circuit is simulated using a 4MHz crystal.

Once the simulation was done and showed promising results, the next step was to build the actual circuit and load the control software into the microprocessor using the MPLAB REAL ICE formatter. The actual circuit was built with the help of a Yun Tech University team and it is shown in *Figure 13* below. The actual circuit mirrors the simulated circuit in *Figure 12* above with an additional start signal LED and an RS232 interface for outputting signals to a computer. The inputs are the target tension signal, the load-cell sensor signal and the startup signal from the PLC. The output is the voltage PWM signal to the servo-motor through the PLC. The first two parts of the experiment are explained in detail in Chapter 4 next, the actual PLC signals, which include tension set values and load-cell sensor values, were replaced with adjustable resistors as shown below.

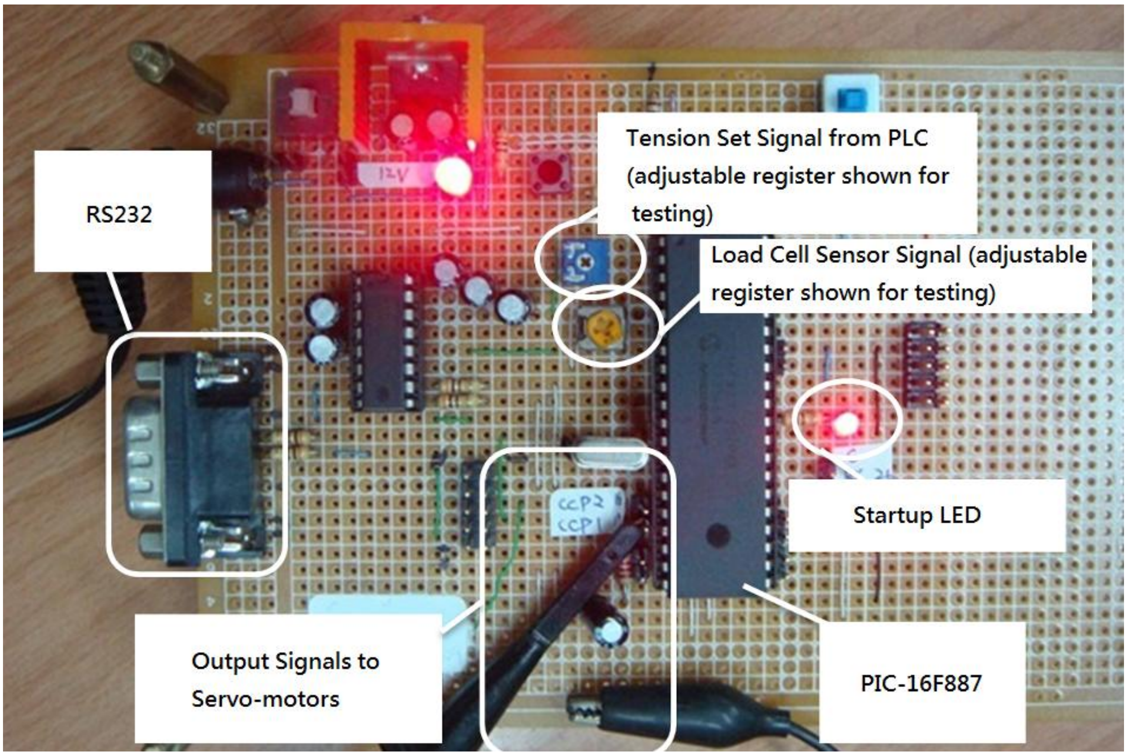

Figure 13. Actual circuit board of the microprocessor based PID controller

CHAPTER 4:

RESULTS

Results from PC-Based PID Controller - LabView

Initial Trial - Constant Tension:

The first goal was to test out the actual tension parameter from 1kg to 4kg in the tire feeding process without altering tension during each complete cycle. To begin, the Cheng-Shin Tire engineers disabled all parameters of the whole tire building machine, and allowed only the nylon ply feeding process to run; in addition, a green tire was loaded to the machine for the nylon ply to apply. Because every trial would results in a length of nylon ply to be wasted, then the experiment required careful preparation in each trial. The set tension data was entered by the machine engineers at Cheng-Shin Tire through the PLC interface, and the PLC system automatically converted it to the speed parameter for the servo-motor. The default tension setting of the nylon feeder apparatus was set at 1 kg and it was converted to 630 rpm (700 degrees per second) by the PLC system. The mean average time for the nylon feeding process was 10.5s and the width of the green tire was 190.0mm, given by the machine engineer.

Initial test results are shown in *Figure 14* below. To change the tension of each cycle from 1 kg to 4 kg takes about a 2 seconds rise time *Tr* (10%~90%) and has about +/- 0.2 kg steady state error in the tension parameter. We noticed that the higher the set tension was set, the further the tension set point from the machine default was and the more the steady state error was. We also tested for a 0.5 kg tension but this tension couldn't be reached by the target, possibly because the PLC controller servo-motor has a 1 kg as its upper limit. To overcome this limit one must increase the default drum speed and change the whole speed/torque control process of the PLC controller.

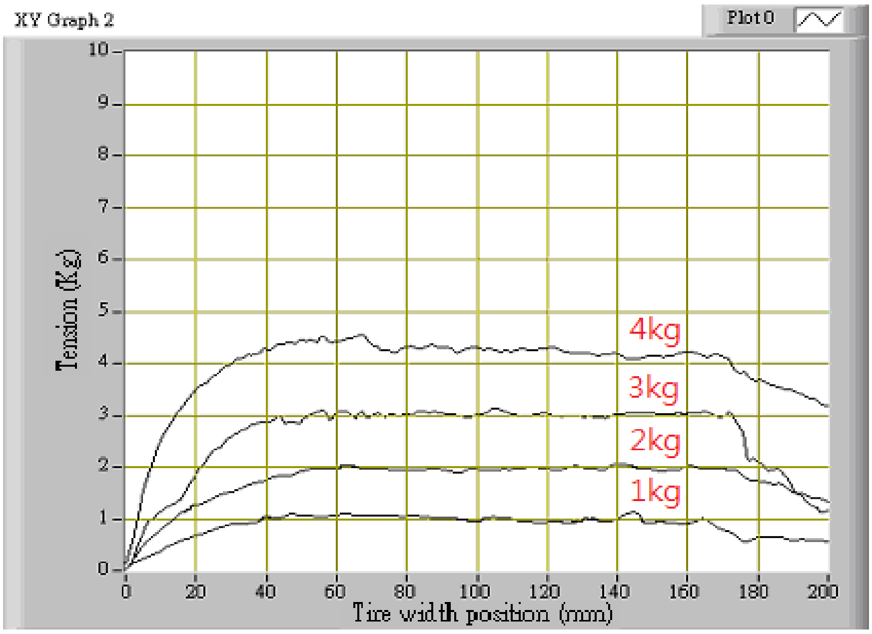

Figure 14. Initial trial of the PC-Based controller without altering tension

Variable Tensions - Step Response:

Once the initial results showed that the tension was relatively stable from 1kg to 4kg, the next experiment was to test the system for various tensions. To begin, we created a simulation block in the LabView program that simulates two sequences of target inputs, as shown in Appendix C. Each sequence was created using the "Simulate Signal" block built into the LabView program; the sequence was created by a square wave that changes between low and high voltage values, which simulated the actual target tension signals. The two sequences of choice were (1) A: 3 kg, B: 1 kg, C: 3 kg and (2) A: 1 kg, B: 3 kg, C: 1 kg. The reason for the two different sets of sequences is to test how well the PID controller responds when dealing with different tension sequences. Each sequence was based on a 190 mm tire width and a drum speed of 700 degrees per second. The results are shown in *Figure 15* and *Figure 16* below.

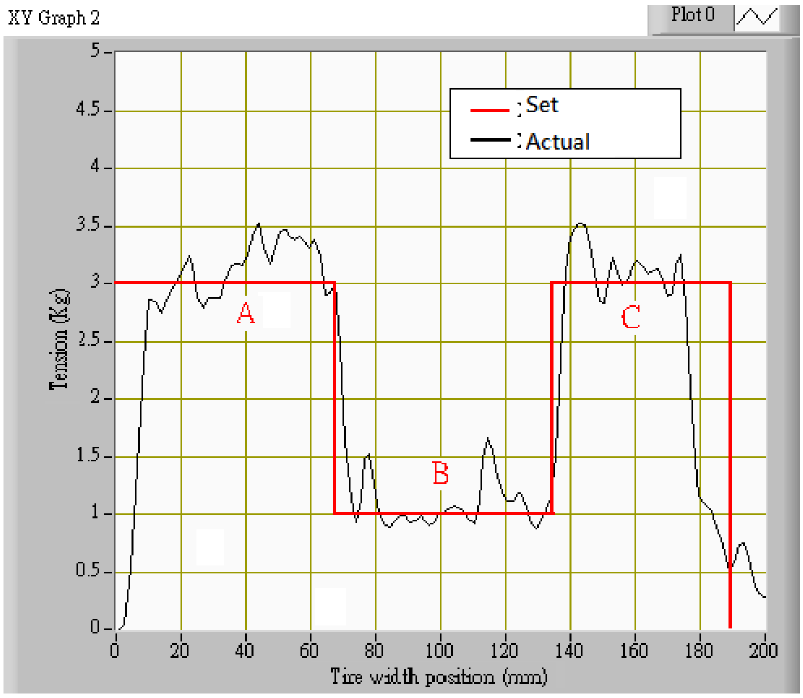

Figure 15. Simulated tension result from sequence 3kg-1kg-3kg

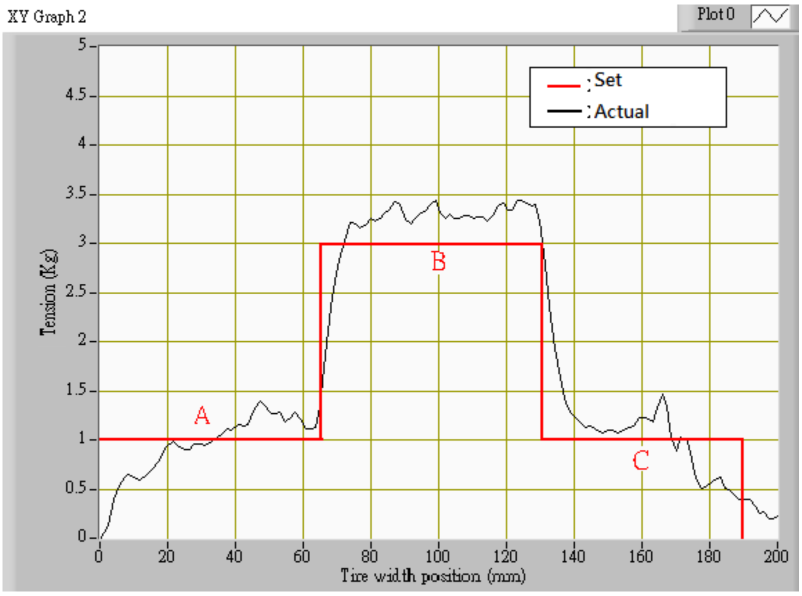

Figure 16. Simulated tension result from sequence 1kg-3kg-1kg

The above results were done using the PID gains listed in Table 1 below, that were found by a trial-and-error procedure. The rough visually inspected data values are summarized in Tables 2 and 3 below. From Table 1, the results show that only a small increase in the proportional gain and a slight increase in the integral gain are sufficient to produce the well-controlled results shown in *Figure 15* and *Figure 16* above. The resulting time delay and the steady-state-error are small enough to maintain good quality of the nylon ply application.

Table 1

Trial and error PID gain values for the simulated results

Gains	Target A：3.0 Kg, B：1.0 Kg, C：3.0 Kg	Target A：1.0 Kg, B：3.0 Kg, C：1.0 Kg
K_P (V/kg)	0.112	0.095
K_I (V/kg)	0.005	0.010
K_D (V/kg)	0.001	0.001

Table 2

Data collected from the 3kg-1kg-3kg sequence in the simulated result

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	3.0Kg	64mm	11.0mm	< 0.1 Kg
B	1.0Kg	128mm	5.0mm	< 0.25 Kg
C	3.0Kg	189.7mm	8.0mm	< 0.2 Kg

Table 3

Data collected from the 1kg-3kg-1kg sequence in the simulated result

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	1.0Kg	64mm	15.0mm	< 0.15 Kg
B	3.0Kg	128mm	9.0mm	< 0.2 Kg
C	1.0Kg	189.7mm	12.0mm	< 0.3 Kg

Variable Tensions - HP Machine:

The variable tension results obtained using a step response to demonstrated that the LabView program is sufficient to produce good results; the next experiment was to test the various tensions on the actual HP machine, which was the primary goal of this study. To achieve a greater quality of the nylon ply tension, the raw tire completed from this HP machine needs to have a larger initial tension, a lower tension at the center and a larger tension towards the other edge. The tension set signal is again controlled by the engineer of the HP machine and it is set with three varying tensions across the tire width, labeled A, B and C (E in *Figure 17.1* and *17.2* due to C and D intentionally left blank) and the layouts are shown in *Figure 17.1* and *17.2* below (shown in Chinese language). The tire width segments are defaulted by the HP machine and the tensions changing points are set at A: 64.0 mm, B: 64.0 mm and C: 61.7 mm and the total precise length is 189.7 mm or approximately 190 mm. The same two sets of tension alternating sequences were tested: (1) First from A: 3 kg to B: 1 kg to C: 3 kg; and (2) another set from A: 1 kg to B: 3 kg to C: 1 kg. Both results are shown in *Figure 18* and *Figure 19* below with the trial-and-error generated PID gains as shown in Table 4 below.

Figure 17.1. PLC interface for sequence 3kg - 1kg - 3kg **(**Display in Chinese**)**

Figure 17.2. PLC interface for sequence 1kg - 3kg - 1kg (Display in Chinese)

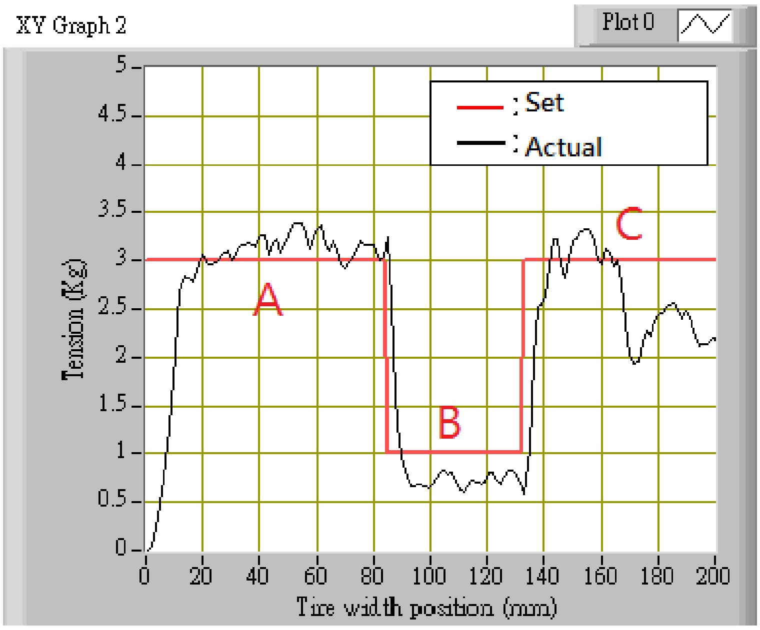

Figure 18. Machine tension resulting from sequence 3kg - 1kg - 3kg

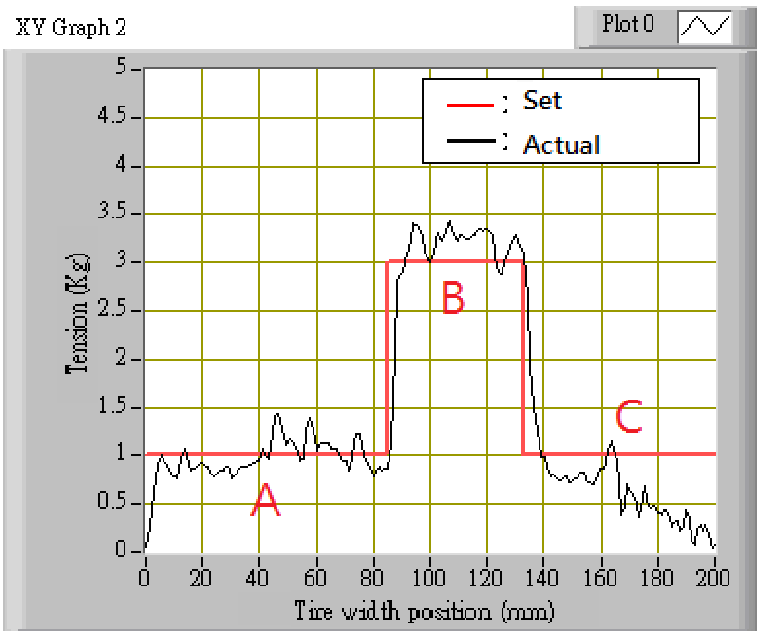

Figure 19. Machine tension resulting from sequence 1kg - 3kg - 1kg

Table 4

Trial and error PID gain values for the HP machine

Gains	Target A：3.0 Kg, B：1.0 Kg, C：3.0 Kg	Target A：1.0 Kg, B：3.0 Kg, C：1.0 Kg
K_P (V/kg)	0.130	0.125
K_I (V/kg)	0.002	0.003
K_D (V/kg)	0.001	0.001

Overall we can see that the tensions results fit the target goals really well. However, the actual PC reading of the tensions changing points are A: 82 mm B: 46 mm and C: 61.7 mm respectively, and this is due to the extra overlap during the initial and the ending of the nylon ply application process, mentioned in *Figure 8* of Chapter 3 above. Towards the end of each sequence C we see that the tension is gradually lower than the set tension, around 170mm; during this time the drum that holds the green tire begins to slow down, as well as the servo motor for the tension control. The possible reason for such gradual drops in tension is because the PC-Based controller can only provide feedback torque data, and the speed converter of the PLC code does not compensate for the lowering speed of the process near the end so the tension drops gradually. In the PID gains of Table 1 above, sufficient proportional gains and small increases in integral gain is all it needs to decrease the steady state errors under higher tension settings. The approximations of the data obtained from the two sequences are summarized in Table 5 and Table 6 below.

Table 5

Data collected from the 3kg-1kg-3kg sequence in HP machine run

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	3.0 Kg	82 mm (82.0 mm)	11.0 mm	< 0.1 Kg
B	1.0 Kg	128 mm (46.0 mm)	8.0 mm	< 0.25 Kg
C	3.0 Kg	189.7 mm (61.7 mm)	13.0 mm	< 0.25 Kg

Table 6

Data collected from the 1kg-3kg-1kg sequence in HP machine run

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	3.0 Kg	82 mm (82.0 mm)	5.0 mm	< 0.15 Kg
B	1.0 Kg	128 mm (46.0 mm)	8.0 mm	< 0.2 Kg
C	3.0 Kg	189.7 mm (61.7 mm)	13.0 mm	< 0.3 Kg

Note that if we remove both the initial (0~30mm) and final (160~190mm) overlapping stages of the nylon ply feeding process, which correspond to the (a) and (c) stages listed in *Figure 8* of Chapter 3.1, we obtain a better width that corresponding to the actual PLC settings from both experiments; the modified graph is shown in *Figure 20* below.

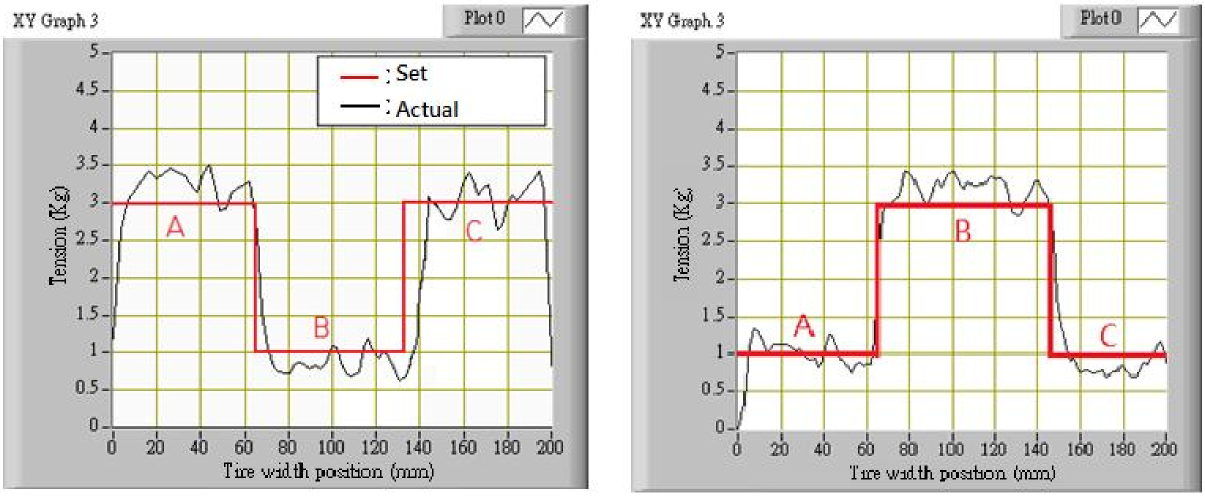

Figure 20. Left: sequence 3kg-1kg-3kg; Right: sequence 1kg-3kg-1kg; both with initial and end segments removed

Both, the simulated response using a square wave and the actual HP machine data produced very similar results with almost equal delays and steady-state-errors. The required trial-and-error gains of the actual machine tuning were slightly higher, possibly due to the more inherent variations produced by the actual machinery compared to the nearly ideal sensor input simulated by the square wave of the LabView simulator.

Results from the Microprocessor-Based PID Controller

Initial Trial - Simulation through Proteus

The simulation results of the circuit shown in *Figure 12* were obtained using the Proteus software. The results show that the PWM signal adjusts itself according to the difference between the two variable resistors. In an ideal situation the greater the difference between the two variable resistors, the larger the output signals that is fed to the servo-motor would be. The built in software oscilloscope shows that the PWM signal strength does adjust itself according to the difference between the two variable resistors. However, the simulation results and the range of change of the resistors are very coarse; a change in resistor values using its pre-set interval can trigger a massive change in the PWM waveform, and eventually lead to saturation - constant 5V value. The pre-set intervals of the variable resistors are fixed and are part of the built-in simulation modules that cannot be changed. *Figure* 21 and *Figure* 22 below show that an increase in the resistor values changes the PWM waveform, and increases the mean voltage output to the servo-motor.

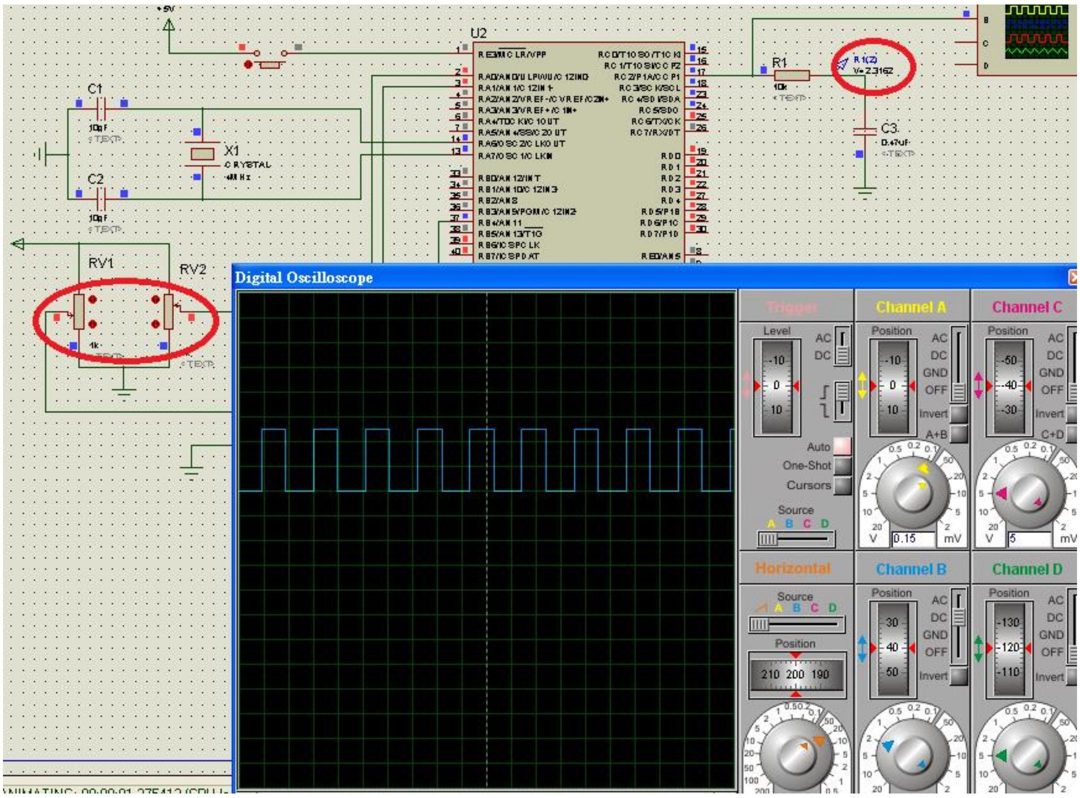

Figure 21. PWM signal with mean voltage output of 2.316V

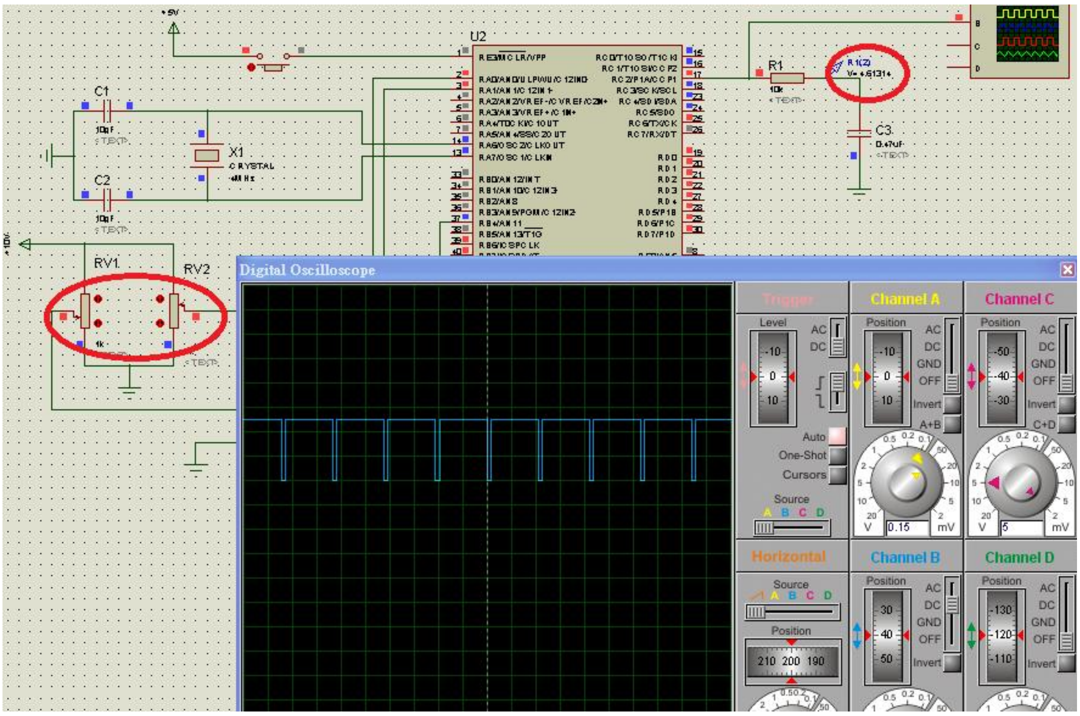

Figure 22. PWM signal with mean voltage of 4.613 when resistor R_{V1} drops one pre-set resistance (compared to *Figure 21*), results with greater differences between R_{V1} and R_{V2} resistors.

Testing Microprocessor Output Using Variable Resistors

Once the simulations in Proteus showed promising results, the next step was to upload the software to the physical microprocessor, and to test the whole circuit (*Figure 13*) to check the PWM output. To simulate the tension set signal and the load-cell sensor signal, the circuit board has two adjustable resistors that mirror the functions of the variable resistors in Proteus. Once the circuit power is on, an actual oscilloscope connects to the servo-motor output while the two adjustable resistors are adjusted using Philip screws. The PWM signal decreases as the two adjustable resistor values come closer together; the actual PWM signal readout with mean values of 3.41, 2.22 and 1.34 volts are shown in *Figure 23* below. Here we see that an increase in tension set values (assume load-cell sensor values remain constant) that increases the output to the servo-motors. This shows that the circuit behaves correctly and that it was ready to be tested on the actual HP machine.

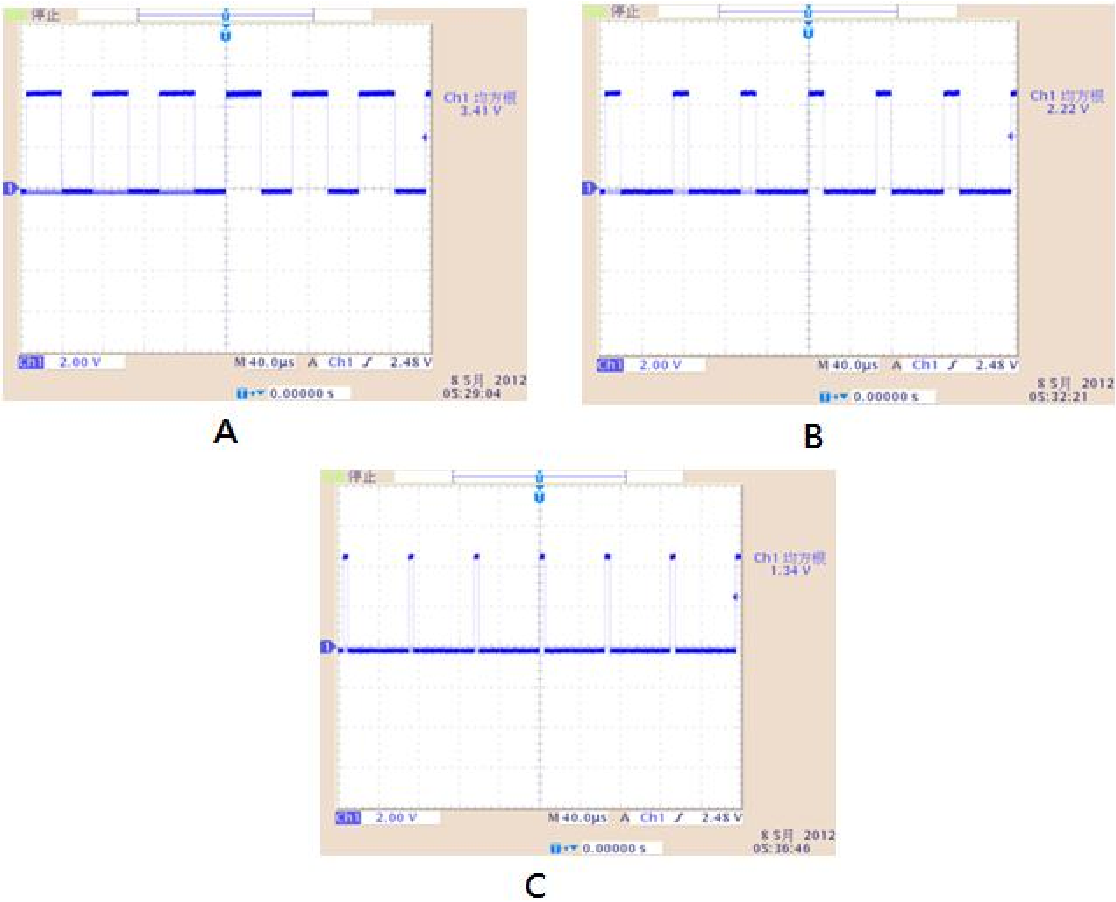

Figure 23. PWM signals results when the two variable resistors are turned close together (A to B to C).

Testing Microprocessor Output Performance on the HP Machine

In the above two experiments, we see that the microprocessor-based controller behaved correctly to deliver the required tension control function of this project; hence, the circuit board was ready to be tested on the actual tension control apparatus of the HP machine. The circuits again was tested and verified that it could successfully use the signals from the PLC interface of the HP machine. Similarly to the testing criteria of the PC-Based PID controller discussed in previous sections, the circuit tested out two possible sequences (A: 3 kg, B: 1 kg, C: 3 kg & A: 1 kg, B: 3 kg, C: 1 kg) and checked their PID tuning performance. The tension changing points were again set around A: 64 mm, B: 64 mm and C: 61.7 mm with total length of 189.7 mm and a rotation speed of 700 degrees per second.

The results of both sequences are shown in *Figure 24* and *Figure 25* below, with rough error estimations summarized in Tables 7 and 8 and their corresponding resulting graphs. Comparing these results to the PC-Based results we can see that the steady state errors are approximately the same, ranging from 0.1~0.3 kg over the set tension. The rise time, or the position when the PLC switches tension set points, is larger; this is due to the microprocessor takes longer to tune the tension to the desired target. From both *Figure 24* and *Figure 25* the tension rises steadily but a bit slower to the desire set point after the target command is given as compared to *Figure 20* where the tuned load-cell signals rise much faster to the target tension. The inherently simpler microprocessor tuning process and the slower processing speed compared to the PC-Based CPU may be the reason why the tension took more time to reach the target.

Also, we see a similar trend with the PC-Based controller results - the actual nylon ply application process mentioned in *Figure 8* of Chapter 3 had both overlaps during the initial and the ending processes. The actual set points were set again at A: 82 mm, B: 46 mm and C: 61.7 mm. We then ignore the left and right overlaps (0~30mm and 160~190mm) of *Figure 24* and *25,* the graph will mirror the performance of the theoretical simulations by LabView. Towards the end, around 160mm, the tension again faces a decreasing rolling speed of the default process so the tension can no longer keep up with the target set points. This was again due to the fact that the PID tuning path cannot efficiently compensate for the lowering speed of the process near the end.

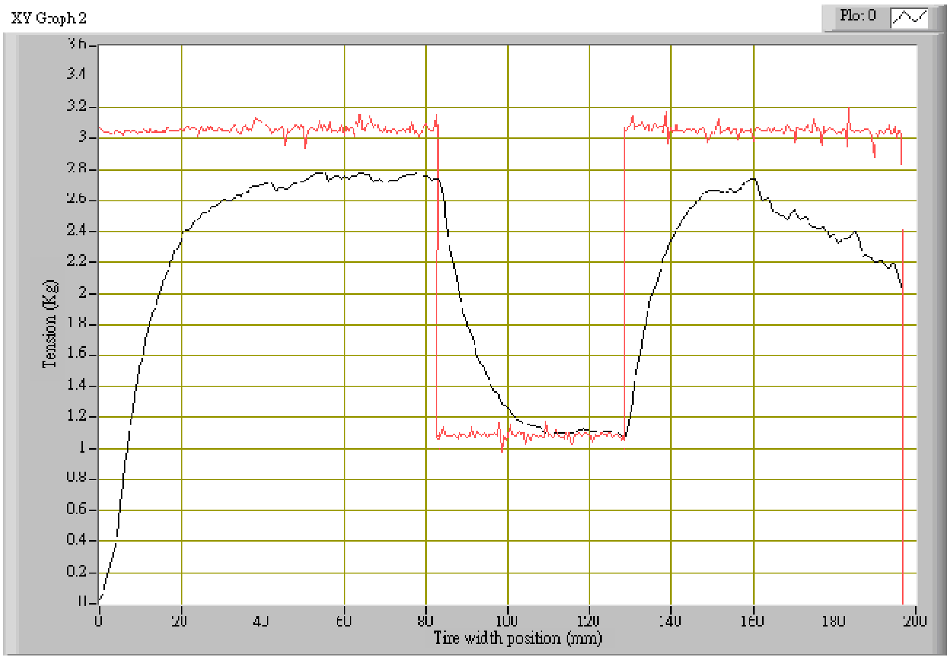

Figure 24. Tension results for the sequence 3kg-1kg-3kg using the microprocessor-based controller

Table 7

Data collected from 3kg-1kg-3kg sequence in HP machine run

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	3.0 Kg	82 mm (82.0 mm)	40.0 mm	< 0.22 Kg
B	1.0 Kg	128 mm (46.0 mm)	20.0 mm	< 0.05 Kg
C	3.0 Kg	189.7 mm (61.7 mm)	20.0 mm	< 0.24 Kg

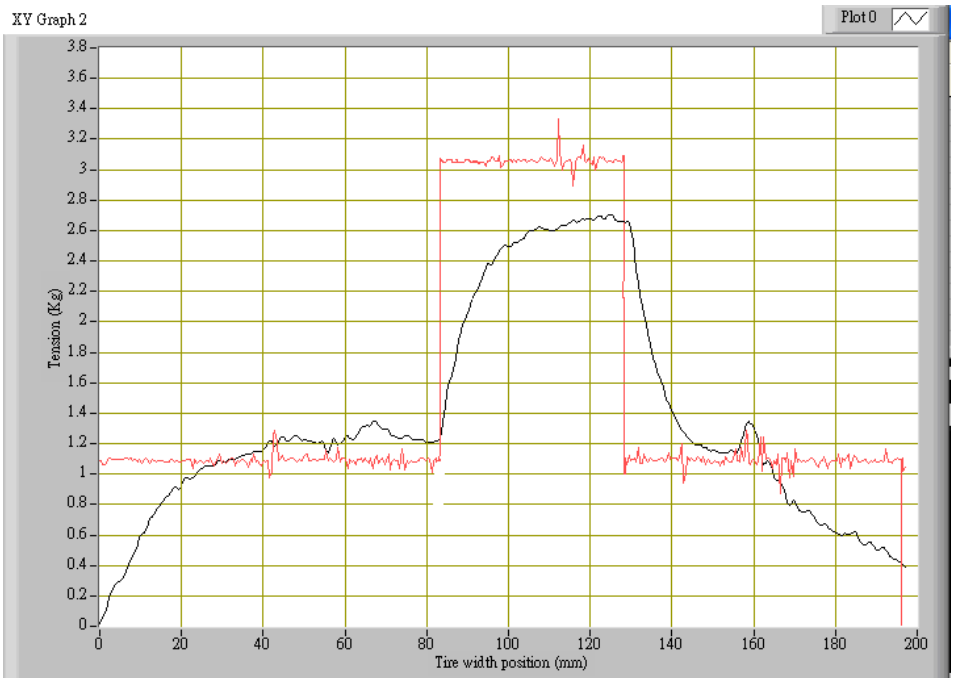

Figure 25. Tension results for the sequence 1kg-3kg-1kg using the microprocessor-based controller

Table 8

Summary of results from 1kg-3kg-1kg sequence using microprocessor

Sequence	Set Tension	Tension changing points	Rise distance (mm) (*10%~90%)	SSE (Kg)
A	1.0 Kg	82 mm (82.0 mm)	30.0 mm	< 0.2 Kg
B	3.0 Kg	128 mm (46.0 mm)	30.0 mm	< 0.3 Kg
C	1.0 Kg	189.7 mm (61.7 mm)	20.0 mm	< 0.15 Kg

CHAPTER 5:

CONCLUSION AND DISCUSSION

Tension control is widely used on roller systems in paper, fabric and other sheet processing industries. However, there have not been many studies of tension control in the tire industry. From the results we see that both the PC-Based PID controller and a microprocessor-based PID controller can efficiently provide a good tension profile for the nylon rolling process; the green tires produced with both controllers can far exceed the quality of the green tires made without a proper tension control. Even though the tension profile results shown in *Figure 18* and *Figure 24* have some steady-state errors and rise times, both are much better than the ones without any tension control. As stated in Chapter 1 of this paper, once the nylon ply layer is applied on the green tire, the green tire will go through inflation before application of the rest of the tire material layers. With both tension profiles showing approximately greater tension at the center, the quality of the finished tire will have a better tension distribution when done. Both tension controllers proved to be efficient to create the sufficient tension profile to the desired requirements.

Comparing the PC-Based results to the microprocessor-based controller results, we can see that the steady-state errors are about the same, but the rise times of the microprocessor-based controller are higher as can be demonstrated by comparing Tables 5 and 6 to Tables 7 and 8 respectively. The slower processing power and software efficiency of the microprocessor compared to the processing power of a modern computer CPU is the primary reason for the rise time and it can result in more deviations from the ideal tension set points. The PC-Based controller gave much better overall tension profiles at the cost of having to rely on PC computers;

the microprocessor-based controller has greater variations but the cost of the whole controller is much cheaper and robust. So far, both controllers satisfy the quality requirements by Cheng-Shin Tire Company, but a faster and more complex microprocessor system is needed to decrease the rise-time of the resulting tension profiles.

In addition to the similarities above, the results in *Figures* 20, 24 and 25 show obvious oscillatory tension signals throughout the whole process. The oscillation is more frequent and the magnitude is too large to be caused by general noise. The oscillation is more likely produce from the actual tension fluctuation of the nylon ply. The reason is that nylon ply is a hybrid sheet material made by layers of nylon and a thick rubber coating. Even though the rubber is not vulcanized and still remains in semi-viscous phase, the molecule interaction within the rubber matrix can provide sufficient elasticity to cause various vibrations during the nylon application process.

For further improvement possibilities, many improvements can be made on other components of the HP machine. One example is the servo-motor used in this study which already has a sophisticated positioning and speed control. In the future, the combination of a PID controller with a lower cost DC-motors and an Automatic Brake System (ABS) can reduce the overall complexity of the HP machine, allowing a much better maintenance costs without sacrificing many of the tension control properties. Another possible improvement is to use much faster PLC controller like the PLC-Q03 that already exists in the market. This may seem like the best solution to this study and can replace both the complex PC-Based controller and the microprocessor-based controller, which has a re-write limit to its program memory. However, with the results obtained in this study both Cheng-Shin engineers and Yun Tech University can have a better understanding of the whole tension control mechanism, which would assist any newer PLC controllers to be implemented more smoothly. The knowledge obtained from this project can benefit technicians and engineers who want to further improve the overall process of the HP machine.

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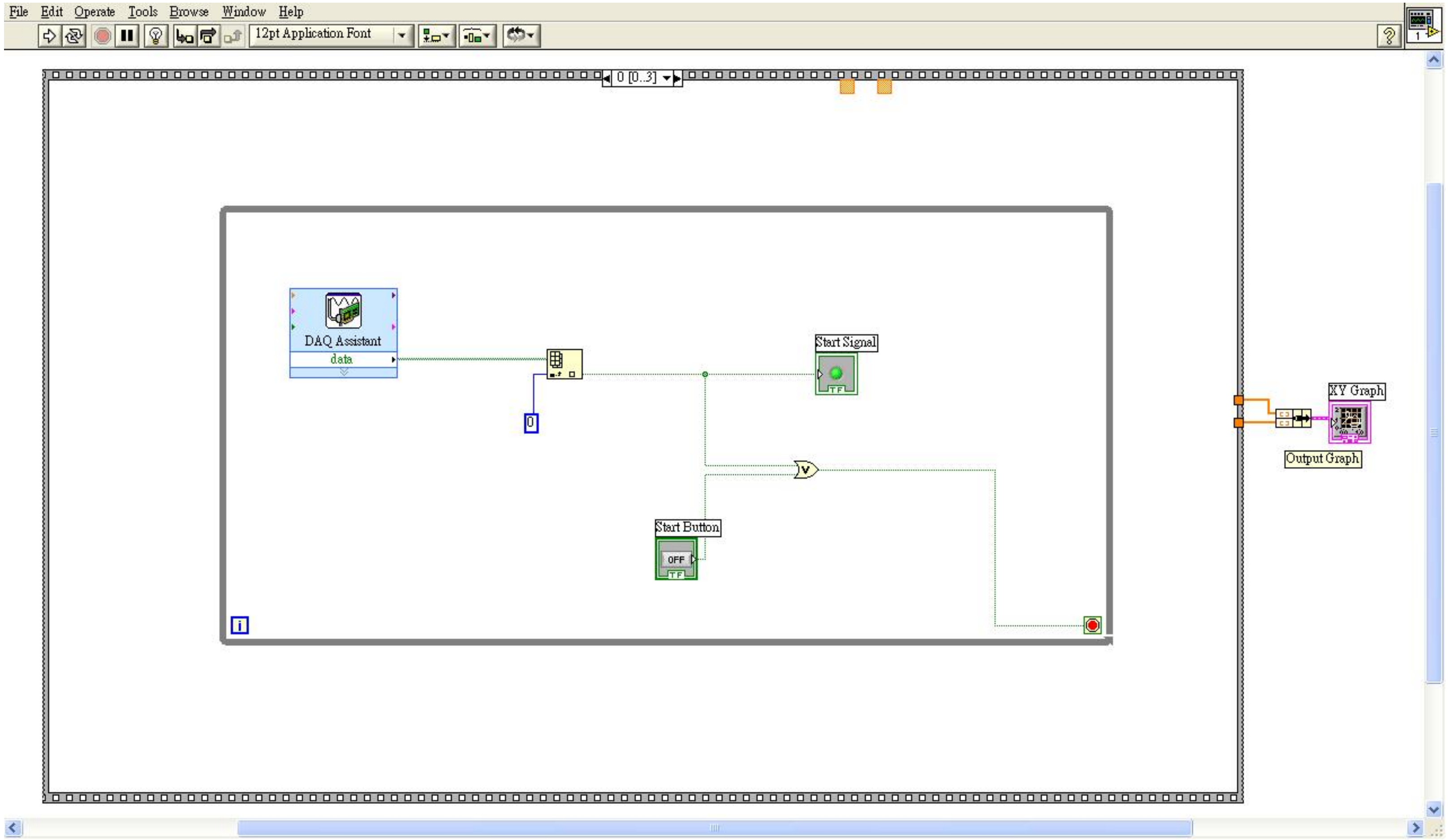
APPENDIX A

LABVIEW PID PROGRAM PART 1 OF 4

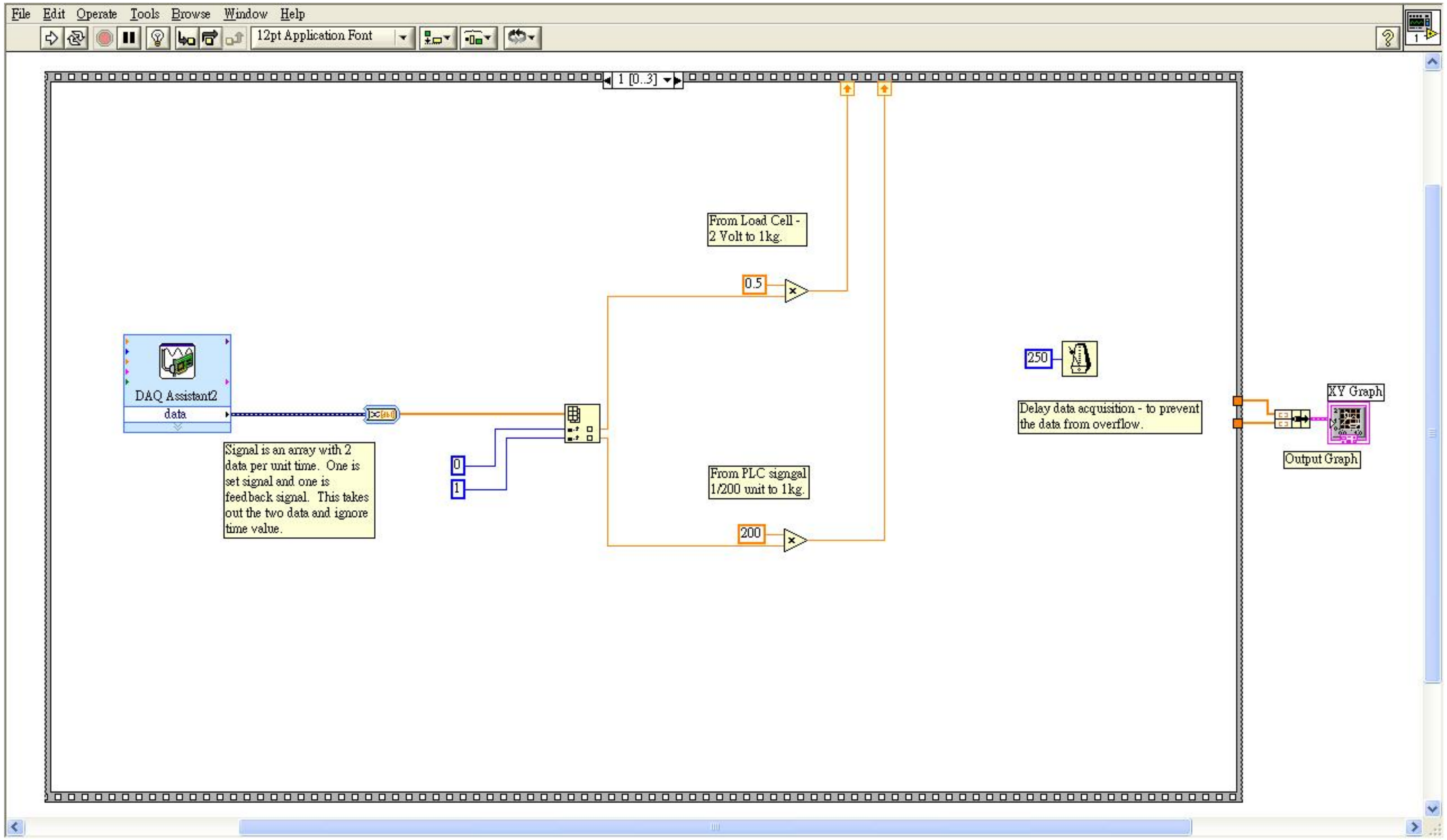
Sequence structure 1: acquire stop signals with an additional stop command.



APPENDIX B

LABVIEW PID PROGRAM PART 2 OF 4

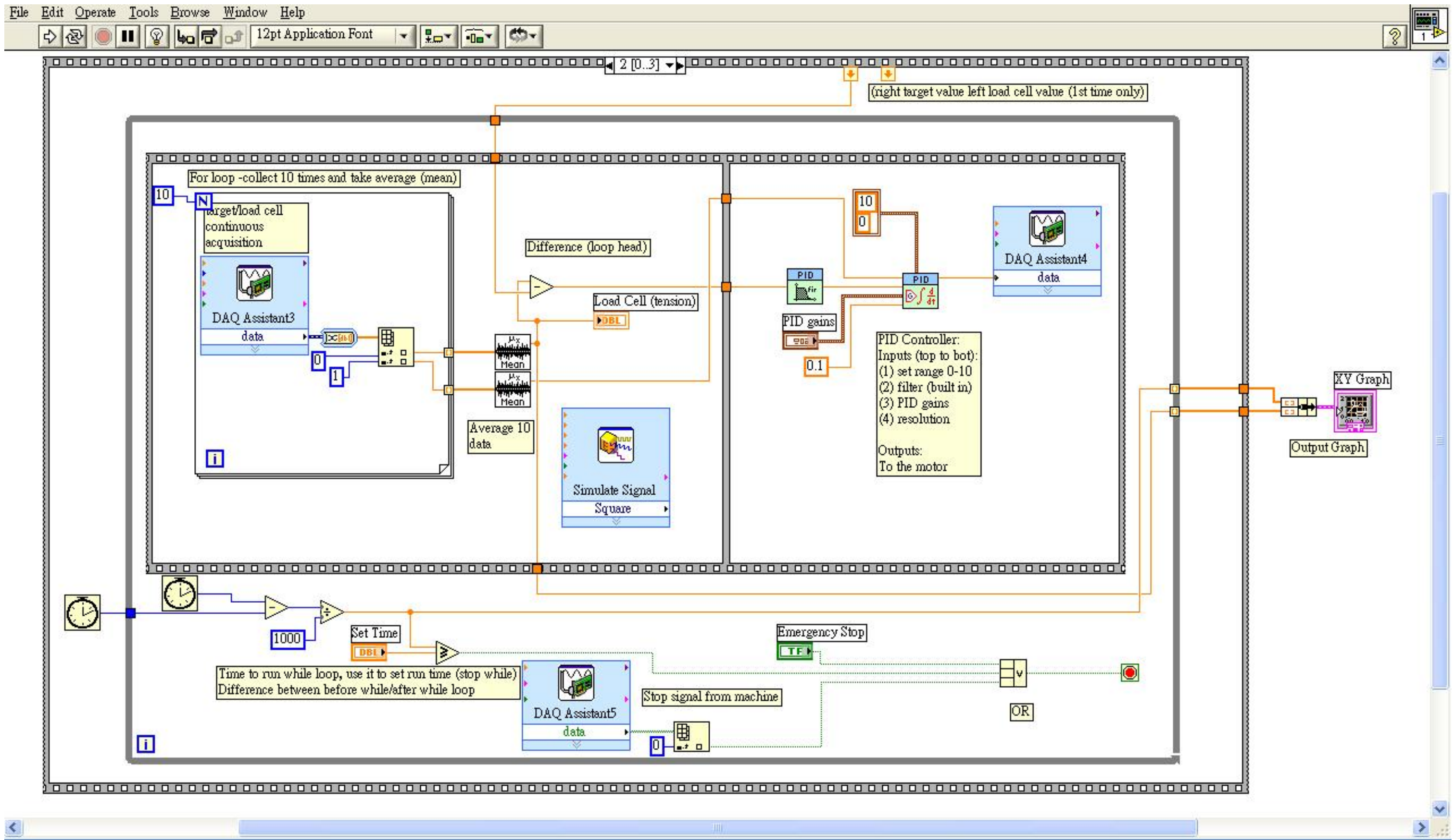
Sequence structure 2: acquire initial load-cell sensor and control signal; also delay acquisition to prevent data overflow.



APPENDIX C

LABVIEW PID PROGRAM PART 3 OF 4

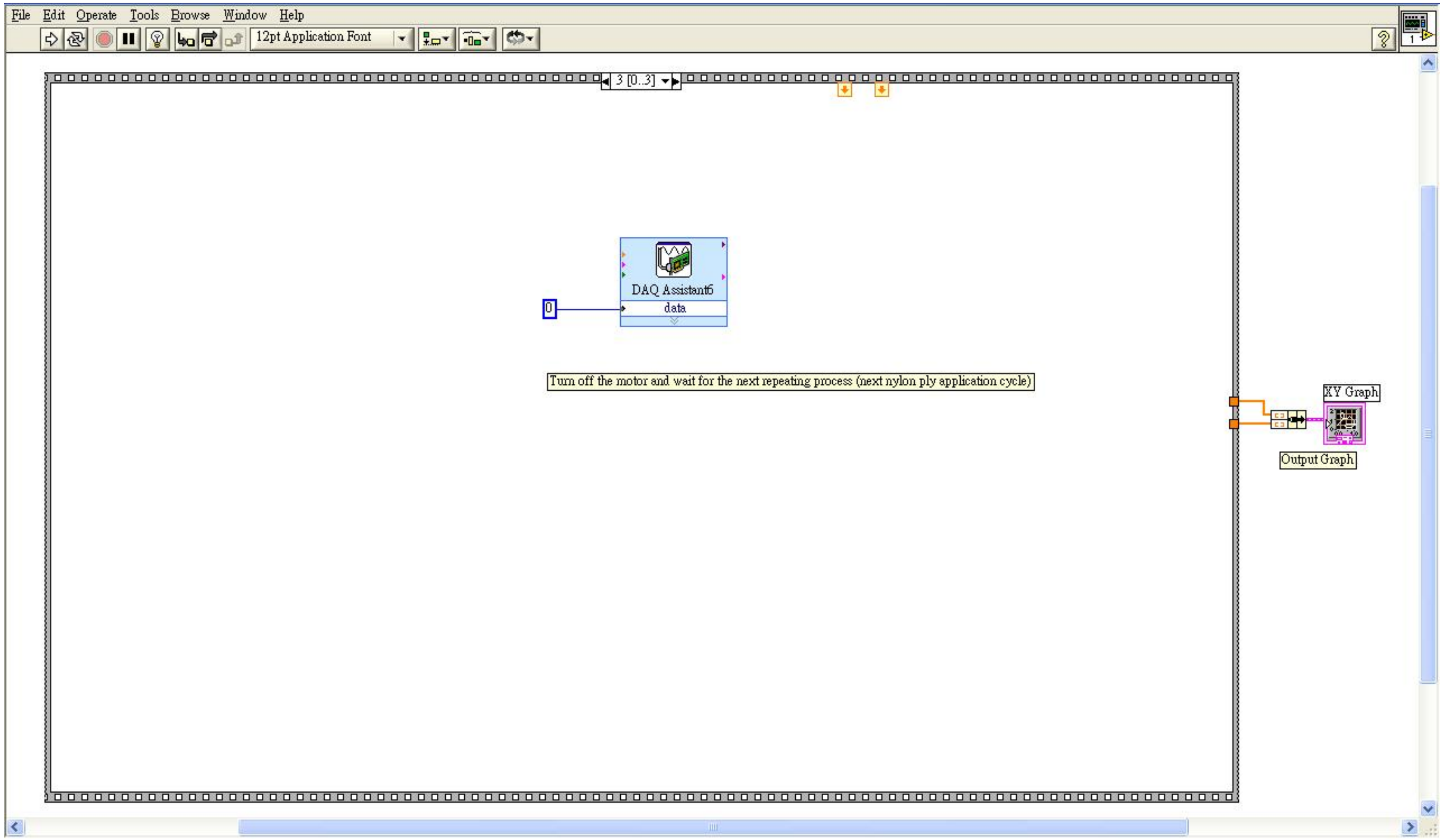
Sequence structure 3: close loop PID controller that continue to take both the load-cell sensor data and the tension set data; the tuned result then feed back to servo-motor.



APPENDIX D

LABVIEW PID PROGRAM PART 4 OF 4

Sequence structure 4: end of the sequence structure; send out a stop signal to the servo-motor.



APPENDIX E

MICROPROCESSOR PROGRAM: PERMISSION FROM CHEN-SHIN ENGINEER AND YUNTECH UNIVERSITY

```
#INCLUDE<MATH16.H>
#PRAGMA CHIP PIC16F877
#DEFINE KONFIG_PORTA 0X0F        /*DEFINE VARIABLE*/
#DEFINE INIT_PORTA 0X00
#DEFINE KONFIG_PORTB 0X0F
#DEFINE INIT_PORTB   0X0F
#DEFINE KONFIG_PORTC 0X80
#DEFINE INIT_PORTC   0X00
#DEFINE KONFIG_PORTD 0X00
#DEFINE INIT_PORTD   0X00
#DEFINE P_N_LED       PORTD.1
CONST STATIC LIGHT[]={0X01,0X67,0X12,0X42,0X64,0X48,0X08,0X61,0X00,0X40,0X20,0X0C,0X19,0X06,0X18,0X38};
#DEFINE KP 3
#DEFINE KI 3
#DEFINE KD 1

#DEFINE CHANNEL_FOURCE 2   // FOURCE CHANNEL
#DEFINE CHANNEL_TARGET 1  // COMMAND CHANNEL
#DEFINE CONTROL_LAW_MAX 1000
#DEFINE CONTROL_LAW_MIN 0
#DEFINE PER 3                              //4=除 16 3=除 8 ...PWM 段數
#DEFINE PWM_MAX 9
INT16 TARGET;
INT16 VALDISPOLD,VALPROP,VALINT,VALDERI,VALDISPNEW;
CHAR OLDDUTY;
CHAR OLDCHANNEL;
VOID WAITMUSEC(CHAR N)  //AD TRANSFER DELAY TIME
{ /* DELAY N*4? MU SEC */
        WHILE(N>0)
        N--;
}
```

```
INT16 GETAD(CHAR CHANNEL)  //AD CONVERSION
{
        INT16 ADHIGH;
        CHANNEL=CHANNEL<<3;
        ADCON0 = ADCON0 & BIN(11000111); /* SELECT CHANNEL */
        ADCON0 = ADCON0 | CHANNEL; /* SECLECT CHANNEL */
        IF(CHANNEL!=OLDCHANNEL)
        WAITMUSEC(5);   //<----- WHY DELETED?

        GO = 1; /*START A/D CONVERSION*/

        WHILE(!ADIF)
        ; /* WAIT FOR CONVERSION TO COMPLETE */
        ADIF = 0;
        ADHIGH = ADRESH*256;
        OLDCHANNEL=CHANNEL;

        RETURN(ADHIGH + ADRESL);
}

INT16 GETFOURCE()
{
        UNS16 AD, AVE_AD, SUM_AD;
        SUM_AD = 0;
        CHAR I=0;

        FOR (I=0;I<4;I++)
        {
                AD = GETAD(CHANNEL_FOURCE);
                SUM_AD = SUM_AD + AD;                    //TOTAL AD CONVERT VALUE
        }
   AVE_AD = SUM_AD>>2; //AVERAGE AD VALUE
        RETURN AVE_AD;
}

INT16 GETTARGET()       // GET INPUT COMMAND
{
        UNS16 AD;
```

```
            AD = GETAD(CHANNEL_TARGET);
            RETURN AD;
}

VOID PWM(UNS16 X)
{
            UNS16 U1;


            U1=X>>2;  // REDUCE THE OUTPUT VALUE
            CCPR1L = U1.LOW8;
            CCP1CON.5 = X.1; //PLACE BIT-0 OF THE DUTY IN THE LSB REGISTER(BIT-5)
   CCP1CON.4 = X.0; //PLACE BIT-1 OF THE DUTY IN THE LSB REGISTER(BIT-4)
   //CCP1CON.2 = 1;
   //CCP1CON.3 = 1;
}

INT16 CONTROL(INT16 POS)
{  TRISB=0XFF;
  TRISD=0;
   INT16  U;     //  IMPORTANT! (DO NOT USE GLOBAL VARIABLE UNLESS NECESSARY)

   VALDISPNEW=POS;
   VALPROP=TARGET-VALDISPNEW; //POSITION ERROR
   VALPROP=KP*VALPROP; //P CONTROL  E1
   VALPROP=VALPROP>>1;
   VALINT=VALDISPOLD+VALDISPNEW;  //I CONTROL  I+E1
   VALINT=KI*VALINT;
   VALINT=VALINT>>2;
   VALDERI=VALDISPOLD-VALDISPNEW; //VELOCITY ERROR E0-E1
   VALDERI=KD*VALDERI; //D CONTROL
   //VALDERI=VALDERI>>8;

   U=VALPROP+VALDERI; //PID CONTROLLER
   VALDISPOLD=VALDISPNEW; //UPDATE POSITION AD
   IF(U<CONTROL_LAW_MIN)
     U=CONTROL_LAW_MIN;
   ELSE IF(U>CONTROL_LAW_MAX)     // <--- USE "ELSE IF" INSTEAD OF "IF"
```

```
    U=CONTROL_LAW_MAX;
  RETURN U;        // <----  'U' SHOULD BE A LOCAL VARIABLE!!
}

VOID MAIN ( VOID)
{
          INT16 U;   // <---- LOCAL VARIABLES
          UNS16 TOTAL_AD , POSITION, TOTAL_TARGET,PWM_VALUE;
          CHAR I=0;
          /* INITIALIZE */


          OPTION = 2;  /* PRESCALER DIVIDE BY 8 */
          ADCON1 = BIN(10000000);
          ADCON0 = BIN(01000001);
          PORTA = INIT_PORTA;
          TRISA = KONFIG_PORTA;
          PORTB = INIT_PORTB;
          TRISB = KONFIG_PORTB;
          PORTC = INIT_PORTC;
          TRISC = KONFIG_PORTC;
          PORTD = INIT_PORTD;
          TRISD = KONFIG_PORTD;


/*****************PWM******************/
          CCP1CON=0X0C;
          T2CON=0X04;  //SET THE PRESCALER FOR 1:1, AND TURN ON TMR2
          PR2=249;     //SEE ABOVE CALCULATION IN NOTES FOR THE OUTPUT PERIOD
/*****************PWM******************/

/*****************RS232******************/
          SPEN = 1; /*SERIAL PORT ENABLED*/
          CREN = 1;
          SPBRG = 0X19; //4MHZ BAUD RATE 9600
          TXSTA = 0XA4;
/*****************RS232******************/
          TRISD=0;
```

```
            PWM(0);
            T1CON=0X00;
            WHILE (1)
            {    IF (PORTB.7==1)
                        {           TARGET=0;
                                    U=0;
           PORTC.2=0;
           PORTD=0X00; }

        ELSE IF (PORTB.7==0)
                PORTD=0XFF;
                        TMR1H=0XEC;
                        TMR1L=0X77;
                        TMR1ON=1;
                        FOR(I=0;I<10;I++)
                        {
                                    TOTAL_AD=TOTAL_AD+GETFOURCE();
                        TOTAL_TARGET=TOTAL_TARGET+GETTARGET();
                        }
                        POSITION = TOTAL_AD>>3;
                        TARGET=TOTAL_TARGET>>3;
            U=CONTROL(POSITION);
                        PWM_VALUE=U+500;
                        PWM(PWM_VALUE);



                        WHILE(!TMR1IF)
                        TMR1IF=0;
                        TOTAL_AD=0;
                        TOTAL_TARGET=0;


            }
}
```