

Final Report

by Bruno Forkuoh

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UNIVERSITY OF WALES
Trinity Saint David



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B.Sc. Electrical & Electronic

Engineering



PSDE 6019: Major Project

Final Report

Airway Height Control System

Work Supervisors: Neil Godden / Bryan Anderson

College Supervisors: Bill McIntyre / Robert Davies

Bruno Forkuoh

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ABSTRACT

Airway height is a critical characteristic when considering the build process of heat exchange components such as radiators and condensers. Understanding and controlling the strip tension of airway machines will help in reducing the scrapped cores caused by dimensional drift of airway height.

The scope of this project is to examine the issue of tension control on an airway machine and the effects of tension upon airway height.

There are several factors that affect the stability of airway height (i.e. machine speed, material, lubrication, form roll settings, pack up and pull out roll speed and material tension). Material tension is the backward acting force that keeps the strip at an optimum tension when presented to the forming rolls. Too little tension will cause 'pile-ups' with the potential of damaging the machine and too much tension will tear the material because of the forming process. Strip tension is a delicate but very important factor in the airway manufacturing process.

The proposed method of tension control will involve the design and installation of a closed loop system that can be interfaced to the PLC.

The implementation of the tension measurement system will involve understanding the principle of operation of the Wheatstone bridge in relation to Load Cells, calibration, interfacing and scaling of signals in order to obtain an accurate and reliable measurement of strip tension. This will then lead to the design and software implementation of a control system that will control the tension by regulating an electro-pneumatic proportional valve that operates on friction pads in order to alter the strip tension.

The implementation of the airway height measurement system will involve the use of an LVDT (Linear Variable Differential Transformer) that will act as the contact transducer of the measurement. This will also involve the design of a supporting mechanical system that will present the LVDT to the airway.

The overall effect of tension monitoring and control, along with that of airway height measurement with the LVDT is the focus within the project. This report sets out to demonstrate PID / Feedback systems that will maintain a stable airway height. This will not only ease the airway machine operator from procedures such as performing spot checks of airway height and the adjustment of strip tension, but will also allow scrap reduction.

Very detailed abstract given which clearly shows the scope of the project

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1 INTRODUCTION AND BACKGROUND RESEARCH

1.1 Introduction

1.1.1 Company information

This project is based at the Llanelli site of Calsonic Kansei, which is a worldwide supplier of automotive components such as heat exchange, air conditioning, exhaust, interior and electronic components. Calsonic Kansei has almost 50 manufacturing centres between Europe, America and Asia.

The Llanelli site is one of the main manufacturing plant for heat exchange components such as radiator and condensers as shown in Figure 1.1. Also shown below are some of the customers of Calsonic Kansei.

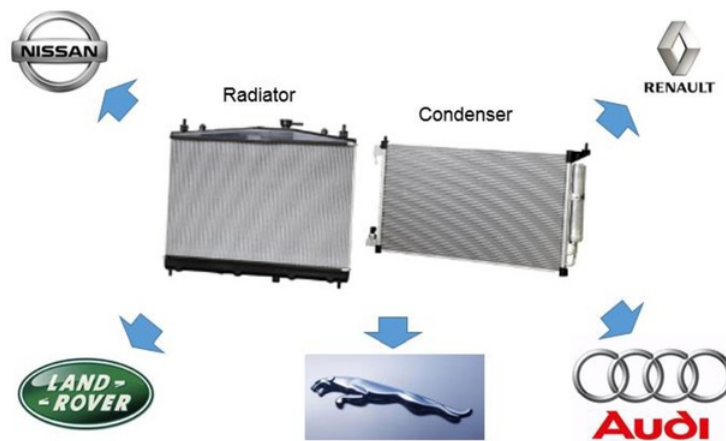


Figure 1.1 - Products and customers (Calsonic Kansei Europe, 2018)

1.1.2 Aims and objectives

The objective of this project is to look at the airway production process with the focus on reducing rejects, scrap volume and setting downtime.

In order to achieve the aim of the project an automated control system for airway height is to be developed implemented. This system is to produce a stable airway production process that will satisfy the above criteria.

This project could have a significant impact on the business since it would not only allow reducing production downtime by eliminating the need for operators to periodically measure the airway height and manually adjust the strip tension, but it would also significantly reduce the number of production rejects and scrap items, which contributes to the business loss.

As a working practice, airway height is manually measured at the start of every shift and after every change of coil. Despite these periodic checks, there is no guarantee that the airways produced are always within the specified tolerance. This is due to many factors – as mentioned in the abstract, but the main causal factor is strip tension.

Figure 1.2 shows the manual measurement method for airway height, which is performed using a Dial Test Indicator (DTI).



Figure 1.2 - Dial test indicator (DTI)

Figure 1.3 shows the variation in airway height measurement due to operator interaction. Ten samples were measured by three different operators and the results obtained were different from one operator to the other confirming that there is a variation caused by the operator interaction with the measurement of airway height.

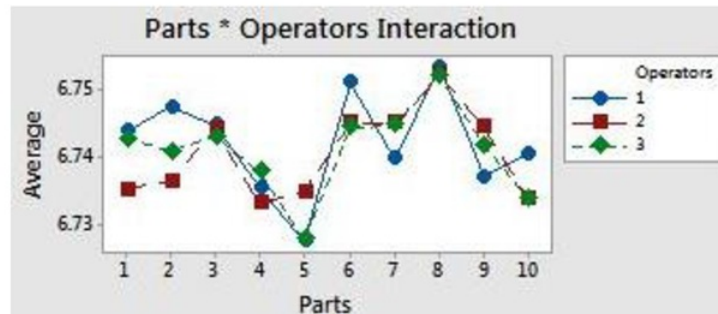


Figure 1.3 - Operator interaction

Experienced operators usually detect products with airways that are not to specification by handling the product and visually inspecting it, however, these unwanted changes are usually undetected and cause rejects and scrap.

When airways are deemed to be outside specifications, the operator adjusts the pressure regulator, which then changes the tension of the aluminium strip and therefore changes the height of the airway.

After the adjustment, the operator measures the height of one airway by using the DTI. If the height is still not within the specification limits, the pneumatic pressure is adjusted again. This process is repeated until the measured airway height is within the provided specification. This adjustment method can often last several minutes causing significant production downtime.

Very good detail on how the airway height is adjusted manually at present and what the problems are with operator interfacing

1.2 Background Research

1.2.1 Airway machine

Airways are produced from a fin mill or airway machine, shown in Figure 1.4.



Figure 1.4 - Airway machine

Figure 1.5 shows a process diagram of the airway machine, which is further explained in the following pages.

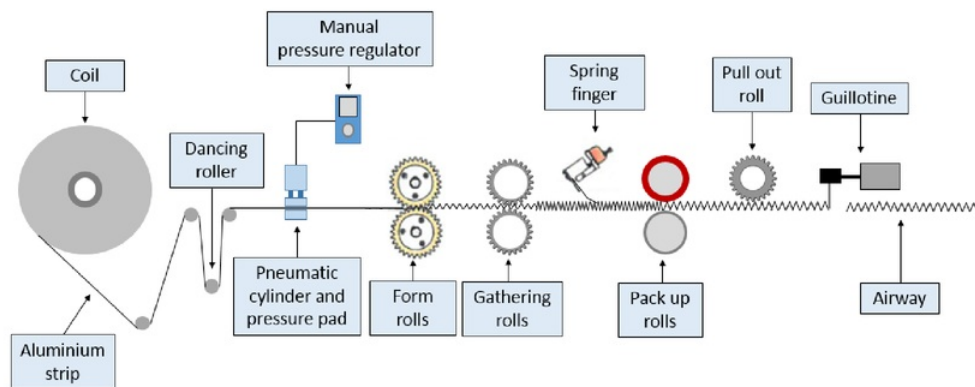


Figure 1.5 - Airway machine existing process diagram

Excellent detail showing the existing system

The first stage of the airway production process involves an unwinding mechanism of the aluminium coil, the speed of which is controlled by the “dancing arm”. This system gives a constant feed of aluminium strip to the machine and will not be investigated further as it is outside the scope of this project.

A pneumatic cylinder and pressure pads are then used to apply force on the strip in order to produce tension. Figure 1.6 shows the pneumatic cylinder and pressure pads.

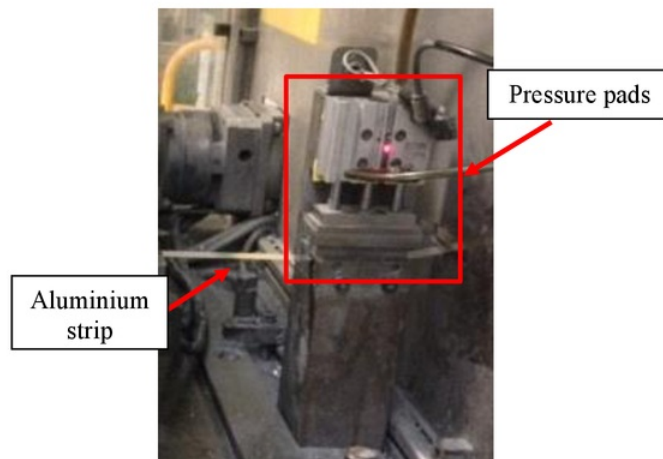


Figure 1.6 - Pressure pad

The pneumatic pressure, and therefore the tension, can be adjusted manually via the pneumatic pressure regulator shown in Figure 1.7. Typical pressure levels for best machine performance vary between 25 and 35 psi.

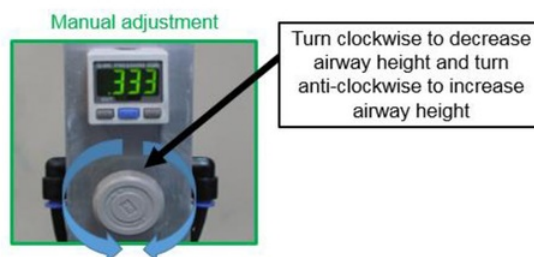


Figure 1.7 - Pressure regulator

The strip tension is critical for the forming process of the airway as it affects the airway height.

Figure 1.8 and Figure 1.9 show the three key characteristics of an airway, which are height, length and fin pitch. The fin pitch is the distance between a top peak and the next bottom peak, while the height is the distance between the highest and lowest point.

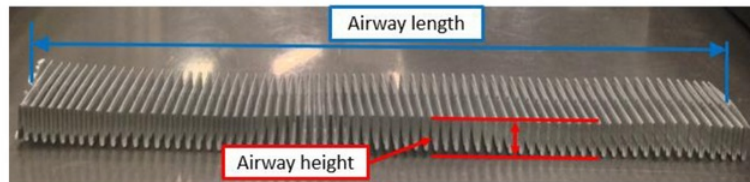


Figure 1.8 – Airway height and length

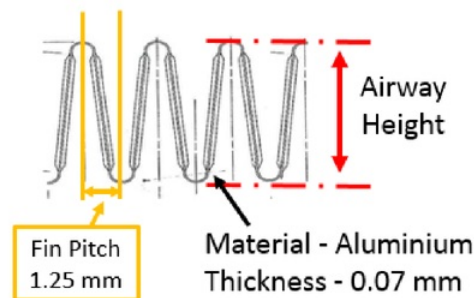


Figure 1.9 - Airway height and fin pitch

The next stage of the airway manufacturing process involves a series of rolls and a spring finger that allow adjusting the fin pitch.

Once the airway is formed and both airway height and fin pitch have been adjusted, the airway is cut to length by the guillotine. This guillotine is a blade coupled to a motor that cuts the airway during a single cycle motion.

Very good explanation of how the system functions before the project implementation

Figure 1.10 shows a diagram of the airway machine, which is used to explain the process that will be developed in this project.

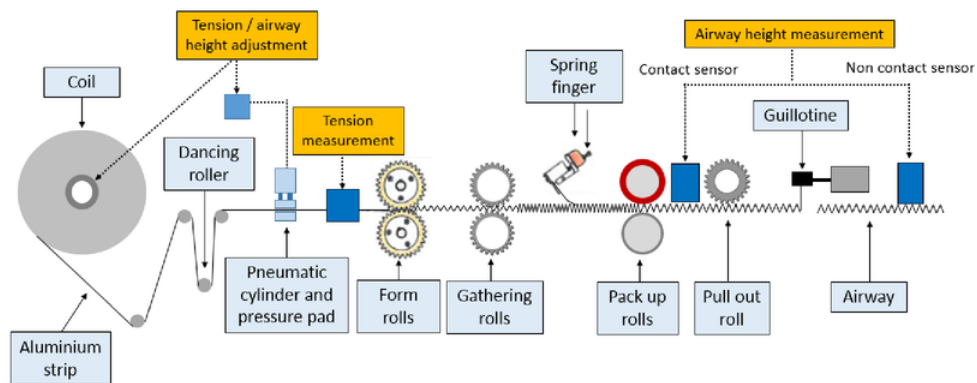


Figure 1.10 - Airway machine new process diagram

Strip tension will be measured between the pneumatic cylinder and the form rolls. The tension in the material is critical at this point since it determines the airway height based on forming speed and tensile strength.

Strip tension adjustment can be achieved by controlling the unwinding speed and torque of the unwinding mechanism or by automatically adjusting the pneumatic pressure of a friction system. Controlling strip tension will influence airway height.

Airway height measurement can be achieved via a contact or non-contact sensor. If a contact sensor is chosen, it will be located between the pack up rolls and the pull out rolls. At this point the airway is formed and is relatively strong and therefore, it will not be subject to damage due to contact with other parts. If a non-contact sensor is chosen, it could be located as above but also further forward in the process because of its non-intrusive nature.

Clear indication of how the project will automatically alleviate the operator interface for strip tension and measure airway height

1.2.2 Process capability

Figure 1.11 shows the process capability report for airway height, which quantifies how well the process meets the specification. It compares the output of the process to the specification limits (NIST/SEMATECH, 2013).

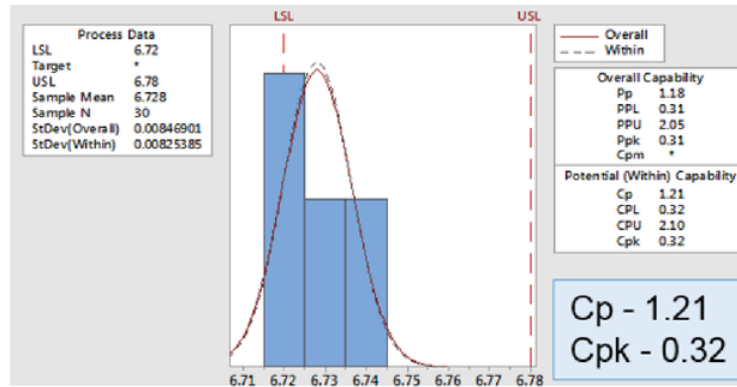


Figure 1.11 - Airway height capability report

The specification limits are represented by the Lower Specification Limit (LSL) and the Upper Specification Limit (USL). These are identified by the vertical dashed lines in red on the histogram (NIST/SEMATECH, 2013).

The capability (Cp) and capability index (Cpk) values highlighted in Figure 1.5 are two statistical values used to determine how well a process meets the specification.

Cp is the ratio between the spread of the specification ($USL - LSL$) and the process spread (Minitab Inc., 2017).

Figure 1.12 and Figure 1.13 show respectively a process with low and high Cp. The spread of the specification is represented by the blue line, while the spread of the process is represented by the red line. A process with a Cp value greater or equal to 1.33 is considered capable, which means that improvements are not necessary (Minitab Inc., 2017).

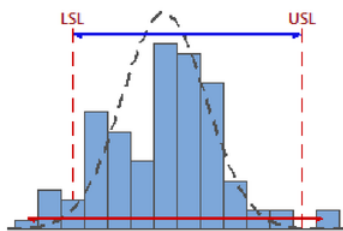


Figure 1.12 - Low Cp (Minitab Inc., 2017)

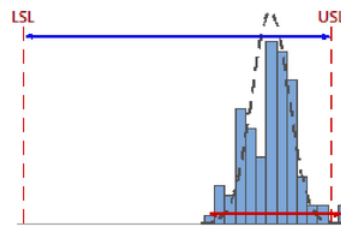


Figure 1.13 - High Cp (Minitab Inc., 2017)

Cpk is also used to indicate how capable a process is, but it takes into consideration the distance from the process mean, which is the average value of all measured samples, closest to the specification limit (USL or LSL) and the one sided spread of the process (Minitab Inc., 2017).

Figure 1.14 and Figure 1.15 show respectively a process with low and high Cpk where the process mean is represented by the black line, the distance from the process mean to the closest specification limit is represented by the blue line and the one sided spread of the process is represented by the red line. A process is considered capable when the Cpk value is greater or equal to 1.33 (Minitab Inc., 2017).

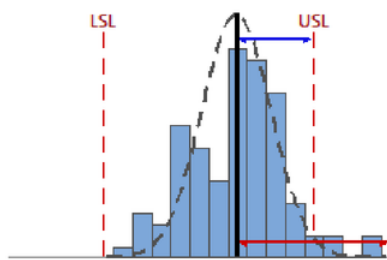


Figure 1.14 - Low Cpk (Minitab Inc., 2017)

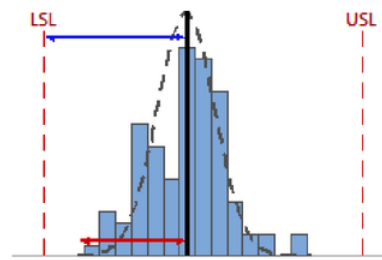


Figure 1.15 - High Cpk (Minitab Inc., 2017)

If Cp and/or Cpk is lower than the benchmark of 1.33, as shown in Figure 1.11, then the process is not capable and therefore needs to be improved in order to reduce its variation and/or the shift of the mean towards one of the two specification limits (Minitab Inc., 2017).

2 SPECIFICATION

The project will focus on the following areas:

1. Strip tension measurement
2. Strip tension control
3. Airway height measurement
4. Airway height control

2.1 Strip tension measurement

Strip tension will be measured and displayed to the user as a kilogram force (KgF) value. The measurement instrument will have a minimum resolution of 0.01KgF and must be capable of measuring strip tension up to 10 KgF. The accuracy of the instrument must be at least 0.2KgF.

2.2 Strip tension control

Strip tension control will be automated, meaning that operator interaction with the control system must be completely removed. The control system will be developed using the PLC of the fin mill and a suitable device that will enable adjusting the tension in the aluminium strip. The system must be able to maintain the tension within $\pm 0.2\text{KgF}$ of the set point value.

2.3 Airway height measurement

Airway height will be measured via an in-line automated measurement system. The accuracy of the instrument must be at least 6 μm .

The resolution of the measurement instrument must be 6 μm or less. This is determined according to “The Rule of Tens” mentioned in the AIAG guideline, which states that gauge resolution should divide process tolerance, in this case 60 μm , into at least 10 parts (Minitab, 2017).

The measurement system must have an output signal that can be fed back to the controller.

The measured airway height will be displayed to the user using the machine HMI, which is a machine operator interface.

2.4 Airway height control

Airway height control must be automated and able to maintain the height within its process control limits of $\pm 30\mu\text{m}$. The control system will be developed using the machine PLC.

General specification for height control & measurement and tension control & measurement clearly stated

2.5 Time constraints

The system must be fully implemented and tested by April 2018.

2.6 Budgetary constraints

The budget allocated for this project is £6,000. This was determined through an assessment of the benefits. The benefits include material scrap and assembly rejects savings. This system will also increase productivity due to decreased setting downtime.

2.7 Maintenance

Attention must be paid to the maintenance aspect when introducing the new systems. They must be relatively easy to set, maintain and modify to suit generation of machines.

Principles must be clear and understood so that fault finding procedures can be followed by the maintenance personnel.

2.8 Reliability

Although maintenance personnel will be trained to support this new system the system must be reliable. This will allow high productivity and low downtime.

System reliability will be quantified by calculating the “mean time between maintenance” (MTBM). It is obtained by dividing the number of uptime hours, or the number of hours the system has functioned correctly, by the number of maintenance events, both planned and unplanned (Weibull, 2013). MTBM must be greater than 40 hours.

Maintenance & reliability issues noted within the specification

3 TEST PLANNING

The table in Figure 3.1 shows the criteria that will determine whether the project is successful or not. In order for the project to be successful, the answer to all criteria questions must be positive.

CRITERIA		YES	NO
Strip tension measurement	Is the resolution 0.01 KgF or better?		
	Is the measurement range at least 0-10KgF?		
	Is the accuracy 0.2 KgF or better?		
	Is strip tension displayed to the user?		
Strip tension control	Is strip tension control automated?		
	Is strip tension maintained within ± 0.2 KgF of the set point value?		
Airway height measurement	Is the accuracy of the measurement instrument less than 6 μ m?		
	Is the resolution 6 μ m or less?		
	Is airway height displayed to the user?		
Airway height control	Is airway height control automated?		
	Is airway height maintained at the set point value?		
Timing	Has the project been completed within the time constraints?		
Budget	Has the project been completed within the budgetary constraints?		
Maintenance	Has fault finding procedure been provided?		
	Has maintenance personnel been trained?		
Reliability	Is mean time between maintenance greater than 40 hours?		

Figure 3.1- Successful / failure criteria

Test table noted on how the system is to perform with realistic criteria set

4 LITERATURE REVIEW

The force applied on the strip is proportional to the pneumatic pressure due to the area of contact between the pads and the strip being a constant.

Figure 4.1 shows the relationship between pressure, force and area. When the area is constant, the pressure is directly proportional to the force, which explains how pneumatic pressure can be used for adjusting the strip tension.

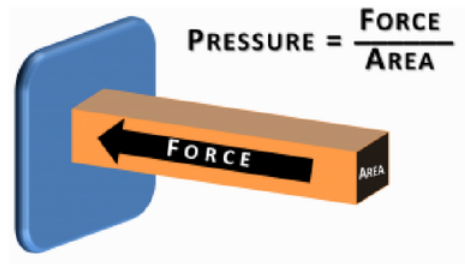


Figure 4.1 - Pressure, force and area (Swanson, 2011)

The strip tension is a result of kinetic friction force, which occurs when the strip is moving between the pressure pads (Jane & Joe, n.d.).

Figure 4.2 shows the equation for the kinetic friction, which is the product of the coefficient of friction, μ_k , which depends upon the material, and F_N , which is the force applied by the pressure pads.

Since the force applied is the product of mass and gravitational force ($mg = N$) the kinetic friction force is expressed in Newton (Jane & Joe, n.d.).

$$f_k = \mu_k F_N \text{ (Newton)}$$

Figure 4.2 - Equation of kinetic friction force (N) (Jane & Joe, n.d.)

Tension force, F_T , is the product of mass and gravitational force 'g', as stated by Jane in the sample report for the Kinetic friction experiment (Jane & Joe, n.d.).

Figure 4.3 shows the tension force equation, which in this case, is the same as the kinetic friction force. This means that the pneumatic pressure, and therefore the force applied by the pads, is proportional to the tension.

$$F_T = mg = f_k$$

Figure 4.3 - Equation for tension force (Jane & Joe, n.d.)

The graph in Figure 4.4 shows the results of three trials where both force and tension were measured. This proves that increasing the force applied on the body increases the tension force.

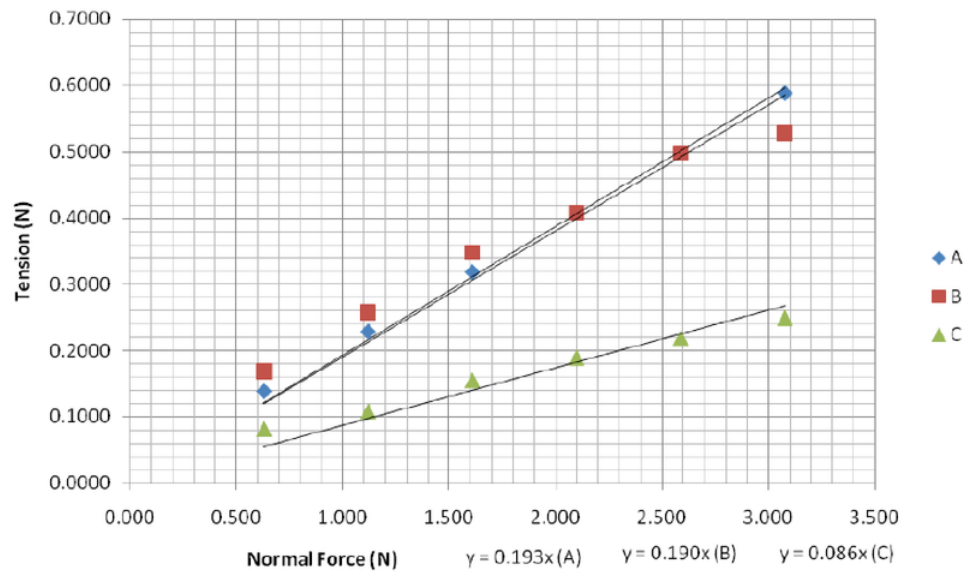


Figure 4.4 - Tension / force relationship (Jane & Joe, n.d.)

This proportionality means that increasing the pneumatic pressure will increase the strip tension and decreasing the pressure will decrease the strip tension.

Airway height is inversely proportional to the tension. Increasing the tension decreases airway height, while decreasing tension increases airway height.

4.1 Strip tension measurement

Strip tension measurement can be achieved by using a load cell, which is a very accurate device that allows measuring weight or force. It consists of four strain gauges that are connected electrically in a Wheatstone bridge configuration in order to obtain maximum sensitivity and temperature compensation. Each strain gauge is a length of wire subject to a force, or tension, within its elastic limit. The length of the wire increases when the tension increases causing its diameter to increase. The increase in diameter causes the resistance to increase (Omega, 2017).

Figure 4.5 shows the Wheatstone bridge configuration in a strain gauge load cell.

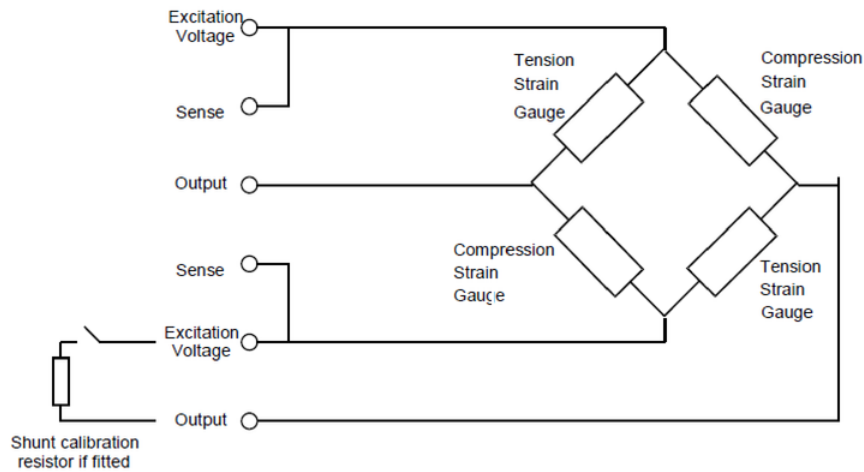


Figure 4.5 - Wheatstone bridge configuration (Hunt, et al., 1998)

4.1.1 Load cell

A single point load cell could be used as it allows highly accurate force measurements even when loads are applied off centre (flintec, 2017). Figure 4.6 shows an example of single point load cell. When using this type of load cell the force can be applied anywhere on the top plate.

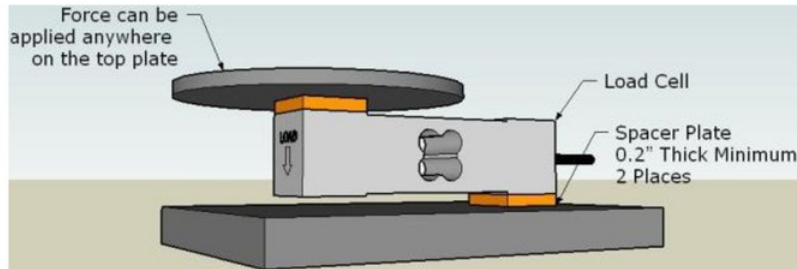


Figure 4.6 - Single point load cell (flintec, 2017)

Figure 4.7 shows how the tension of a strip can be measured using a roller. The strip passes over the roller 'C' in such a way that the strip tension produces a force on the roller.

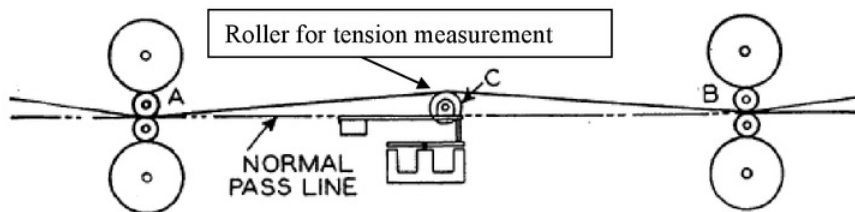


Figure 4.7 - Tension measurement (Hathaway & Mohler, n.d.)

The strip tension can be determined as a function of the force applied on the roller, which can be mounted on a load cell in order to obtain an accurate measurement (Hathaway & Mohler, n.d.).

4.1.2 Tension sensor

A tension sensor is a tension measurement device that uses an LVDT (linear variable differential transformer) in order to measure the displacement produced by the web, which is proportional to the tension. The LVDT sensor converts the measured force into an electrical signal that provides a very accurate tension measurement (Nexen, n.d.). Figure 4.8 shows the diagram of a tension sensor.

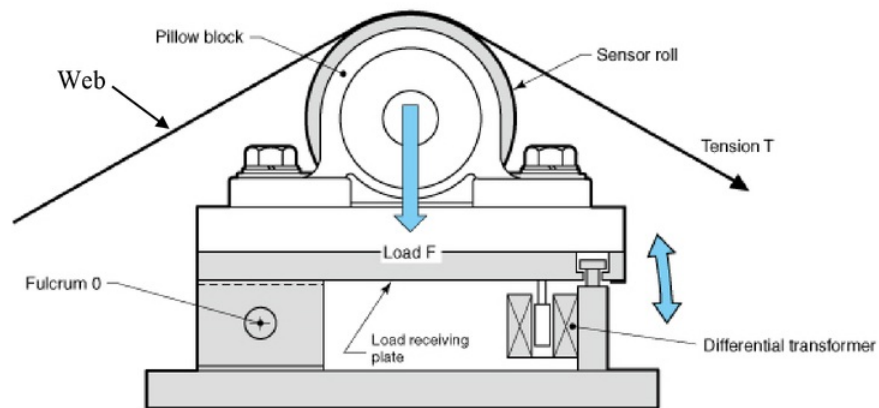


Figure 4.8 - LVDT tension sensor (Nireco, 2016)

4.1.3 Decision

Figure 4.9 shows the multiple criteria decision analysis matrix used in order to establish the appropriate solutions for the tension measurement.

CRITERIA	Weighting (1 to 5)	Tension load cell				Tension sensor			
		Value	Score	Total	Comment	Value	Score	Total	Comment
Load range	5	10 Kg / 22 LB	3	15	Load range meets specification	10 Kg / 22 LB	3	15	Load range meets specification
Resolution	4	0.3g	5	20	Very high resolution	0.3g	5	20	Very high resolution
Accuracy	4	± 1% (100g)	4	16	High accuracy	± 1% (100g)	4	16	High accuracy
Amplifier input	1	240 VAC 24 VDC	5	5	Both AC and DC power can be used meaning that low DC voltage can be used if a power supply is already available	240 VAC 100 VAC 24 VDC	5	5	Both AC and DC power can be used meaning that low DC voltage can be used if a power supply is already available
Amplifier output	4	0-10 V 4-20 mA	4	16	Both voltage and current output is available	0-10 V 0-5 V 4-20 mA	4	16	Both voltage and current output is available
Ease of installation	3	N/A	4	12	Only requires a mounting frame and a shaft roll assembly	N/A	3	9	Can be installed at any angle
Ease of calibration	3	N/A	3	9	Tension reference output require calibration	N/A	5	15	Calibration is not required
Cost	3	£1,189	4	12	Very cost effective	£2,010	3	9	Nearly twice as expensive
Availability	3	N/A	5	15	Device currently available and therefore does not require to be purchased	N/A	3	9	Device currently not available and therefore require to be purchased
Additional items required	2	Yes	3	6	Shaft/roll assembly	Yes	4	8	Pillow block
IP Protection Classification	4	IP67	4	16	Total protection against dust and liquids	IP30	3	12	Protection against tools and wires. No protection against liquids
				142					134

Figure 4.9 - Criteria decision analysis for strip tension measurement

The tension load cell was chosen due to the highest overall score.

4.2 Strip tension control

Strip tension control can be achieved via a controller and an actuation device that can produce strip tension adjustment (Becker, n.d.).

A PLC will be used as the controller. The control algorithm will be either the standard proportional–integral–derivative (PID) or a ‘Predictive’ control element, which combines time-delay capabilities and disturbance rejection to the PID control system (Giovannini, 2009).

The actuation device for adjustment of the strip tension could be one of the following:

- Speed regulation of a motor (Whiteside, 2007)
- Torque regulation of a motor (Whiteside, 2007)
- Electro-pneumatic regulator

4.2.1 Speed control

One of the methods used for the adjustment of strip tension is that mentioned in “A survey of the looper-tension control technology in hot rolling mills” (Choi, et al., n.d.), where it is stated that the rotating speed of a mill motor is used for tension control.

Figure 4.10 shows how a clutch can be used to adjust the speed and therefore control the tension in the strip.

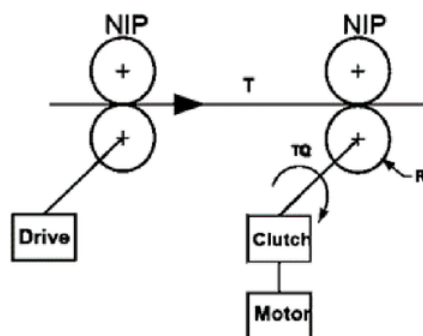


Figure 4.10 - Tension control via speed adjustment (Whiteside, 2007)

The resultant tension (T) is the ratio between the torque (TQ) and the radius (R) of the nip roll, as shown in the below equation. To be noted is the fact that the tension can be expressed in KgF or N.

$$T = \frac{TQ}{R} = (KgF \text{ or } N) \quad (\text{Whiteside, 2007})$$

4.2.2 Torque control

Tension adjustment through torque control can be achieved by using a brake.

Figure 4.11 shows how a brake can be used to adjust the torque and therefore the tension on the strip. As in the previous case, the tension is a result of the ratio between the torque and the radius of the nip roll.

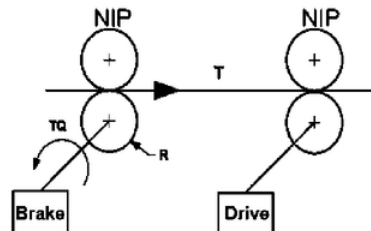


Figure 4.11 - Tension control via torque adjustment (Whiteside, 2007)

4.2.3 Electro-pneumatic regulator with pressure pad

The third alternative would be to use an electro-pneumatic regulator connected to the pneumatic cylinder. This would control the pneumatic pressure, and therefore the strip tension, via a voltage or current signal, which would automate the adjustment process by removing any operator interaction.

Electronic pressure regulators provide a regulated output pressure that is proportional to the electrical input signal. Figure 4.12 shows a diagram of an electronic pressure regulator that uses a push valve, shown as air supply, and a vent valve to maintain the outlet pressure at the required set point (Equilibar, n.d.).

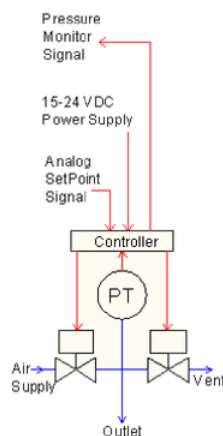


Figure 4.12 - Electronic pressure regulator diagram (Equilibar, n.d.)

4.2.4 Decision

Figure 4.13 shows the multiple criteria decision analysis matrix used in order to establish the appropriate solutions for the strip tension control system.

CRITERIA	Weighting (1 to 5)	Motor torque control			Motor speed control			Electro pneumatic regulator		
		Score	Total	Comment	Score	Total	Comment	Score	Total	Comment
Reliability	4	4	16	Motor is reliable	4	16	Motor is reliable	3	12	Pressure required depends upon quality of pressure pad
Availability	3	3	9	Motor available on site. AC/DC drive must be purchased	3	9	Motor available on site. AC/DC drive must be purchased	5	15	Electronic pressure regulator is available on site
Ease of installation	3	2	6	Looper angle (contact land on shaft) is critical	2	6	Looper angle (contact land on shaft) is critical	5	15	Easy to install (replace manual pressure regulator)
Cost	4	2	8	Exact cost to be confirmed	2	8	Exact cost to be confirmed	4	16	Relatively cheap £219,49
Maintenance	3	5	15	Does not require maintenance	5	15	Does not require maintenance	3	9	Pressure pad requires periodic maintenance / replacement
Additional items required	3	3	9	AC / DC drive	3	9	AC / DC drive	5	15	None
Energy consumption	3	3	9	Higher energy consumption although energy efficient	3	9	Higher energy consumption although energy efficient	5	15	Lower energy consumption
		72			72			97		

Figure 4.13 - Criteria decision analysis matrix for strip tension control

The electro-pneumatic regulator was chosen for controlling the strip tension mainly due its ease of implementation and its relatively cheap cost.

The control system will be developed within the machine PLC. The signal from the load cell will be the process variable of the tension control system.

Programming will be carried out using the Rockwell Automation software 'Logix500' with the view of using an analogue signal from the PLC to control an electro-pneumatic regulator.

The electro-pneumatic regulator will increase or decrease the pneumatic pressure applied to a tension cylinder, which will impact on friction pads. These pads provide the friction to motion on the strip to give tension ($T = uF$ where u = coefficient of friction of pads relative to strip and F = force produced by the cylinder).

Strip tension measurement & control research carried out to a very good standard with a reasoned choice made as to which system to take forward

4.3 Airway height measurement

As previously mentioned this project will require the introduction of an airway height measurement system, which will use one of the following devices:

- Laser displacement sensor
- Image sensor
- Laser micrometre
- Linear Variable Differential Transformer (LVDT)

4.3.1 Laser displacement sensor

There are two types of laser displacement sensors. One operates upon the basic principle of triangulation. Figure 4.14 shows the triangulation principle used in laser displacement sensors that involve a semiconductor laser that emits a laser beam, which is reflected from the surface of the target. The reflected light is then collected by the light-receiving element. Due to the known position of the semiconductor laser and the light-receiving element, the position of the target can be calculated by determining the position of the reflected light spot produced on the receiving element (Keyence Corporation, 2008).

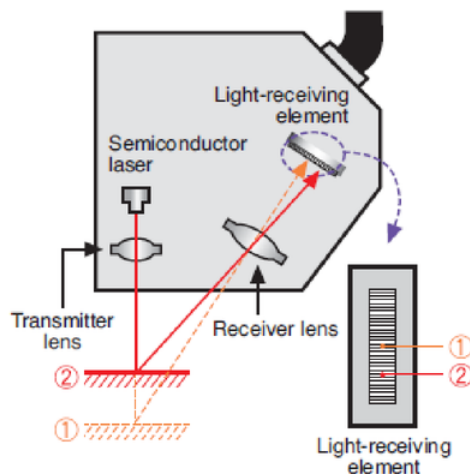


Figure 4.14 - Triangulation principle (Keyence Corporation, 2008)

The second type of laser displacement sensor is based upon the confocal principle of operation, which uses white light instead of a laser beam.

Figure 4.15 shows the confocal measurement principle.

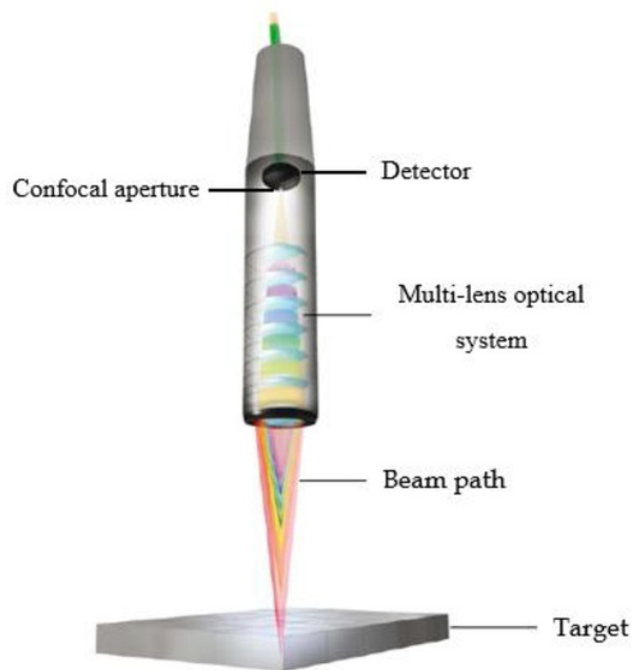


Figure 4.15 - Confocal principle (Micro-epsilon, 2017)

A confocal displacement sensor consists of a multi-lens optical system that allow focusing polychromatic white light onto the target surface.

The lenses disperse the light into monochromatic stages along the measurement axis in order to create different wavelengths. Each wavelength corresponds to a specific distance to the target, which is determined by the deviation assigned in the factory calibration.

The reflected light from the target surface is passed via the confocal aperture to the detector. The optical system oscillates over the whole measurement range changing the intensity of the white light reaching the detector. At the true focal point, which is the instant where all of the reflected light reaches the detector via the pinhole, the profile value is calculated in order to obtain the displacement (Micro-epsilon, 2017).

4.3.2 Image sensor

Image sensors, also known as vision systems, consists of one or more sensors that capture pictures, an inspection software and a processing element that executes the user-defined program created using the inspection software.

The result of the inspection is then sent to a device for controlling or acting upon the inspection result (Teledyne DALSA , 2017).

They can be used for several types of inspections such as counting the number of objects, checking presence, detecting flaws/defects, measurements, positioning and character checks. Figure 4.16 shows some practical examples of the mentioned applications (Keyence Corporation, 2017).

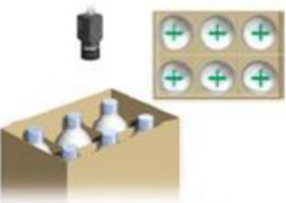
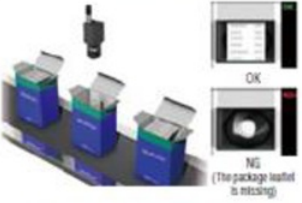
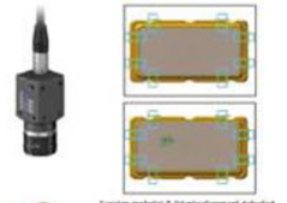
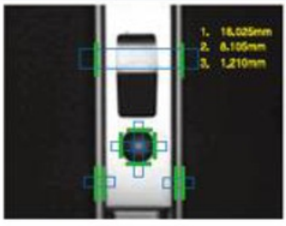
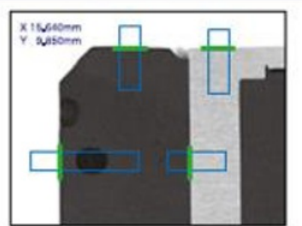
COUNTING	PRESENCE	DEFECT
 Counting the number of bottles	 Presence/absence of package leaflets	 Defect inspection of crystal oscillator
MEASUREMENT	POSITION	CHARACTER CHECK
 Measurement of outer diameter, inner diameter and width	 Detection of end face positions and label positions	 Product number character check

Figure 4.16 - Image sensor applications (Keyence Corporation, 2017)

4.3.3 Laser Micrometer

Laser micrometres, also known as optical micrometers, operate based on the thru-beam principle.

Figure 4.17 shows the measurement principle of a laser micrometer. Laser micrometers involve a transmitter, shown as a rotating mirror, which produces a parallel light curtain that is transmitted via a lens arrangement into a receiving unit. When an object is in the light path, the beam is interrupted. The shadow generated by the object is then detected by the receiving element, which is a photocell that analyses the time at which each laser crosses each part of the photocell. Software is then used to convert the timing data into a meaningful distance measurement.

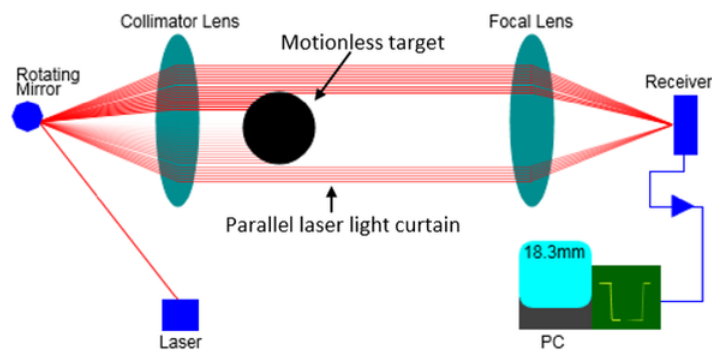


Figure 4.17 - Laser micrometer principle (LaserLinc, 2015)

Laser micrometers are typically used for dimensional measurements such as diameter gap, height and position (Micro-epsilpon, 2017).

Figure 4.18 shows three different measurement modes that can be achieved using an optical micrometer.

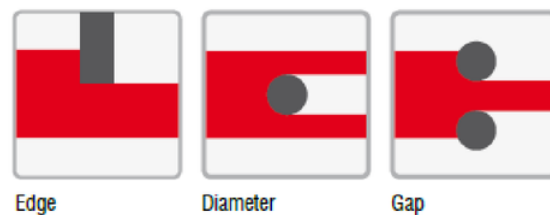


Figure 4.18 - Optical micrometer measurement modes (Micro-epsilpon, 2017)

4.3.4 Linear variable differential transformer (LVDT)

Figure 4.19 shows the basic components that constitute an LVDT.

An LVDT is made of:

- A coil winding assembly, which consists of a primary and two secondary coils spaced from the centre.
- A cylindrical case that encloses and protects the coil windings.
- A magnetic core that moves freely axially within the coil winding assembly,
- A shield used for electromagnetic shielding.

(Collins Technologies, 2003).

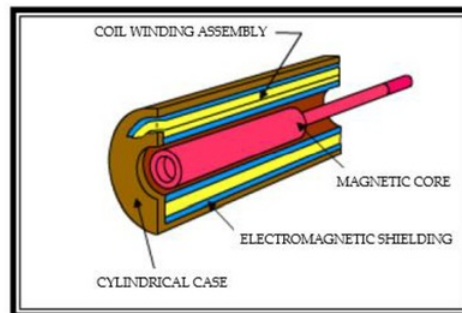


Figure 4.19 - LVDT basic components (Collins Technologies, 2003)

As suggested by their name, LVDTs operate on the principle of a transformer. Figure 4.20 shows an electrical diagram of an LVDT. The movable core can move freely in the cylindrical form, while the primary winding is excited by an AC source. The movement of the core causes the electrical voltage induced in the two secondary coils to change. This electrical voltage is proportional to displacement of the core. (National Instruments, 2016)

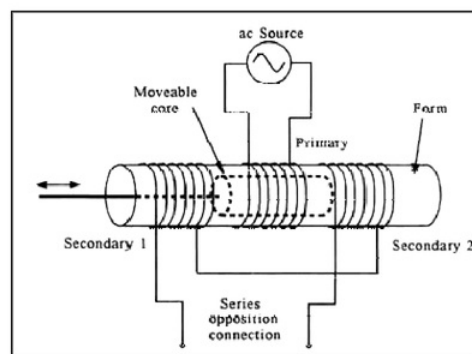


Figure 4.20 - LVDT electrical diagram (National Instruments, 2016)

4.3.5 Decision

Figure 4.21 shows the multiple criteria decision analysis matrix used in order to establish the appropriate solutions for the strip tension control system.

CRITERIA	Weighting (1 to 5)	Laser sensor		Image sensor		Laser micrometer		LVDT	
		Score	Total	Score	Total	Score	Total	Score	Total
Accuracy (must be < 6um)	4	5	20	4	16	4	16	5	20
Suitable for the environment	3	3	9	4	12	4	12	5	15
Suitable for the application	4	4	16	5	20	2	8	3	12
Cost	3	3	9	1	3	4	12	5	15
Distance from the product	4	4	16	3	12	5	20	4	16
Reliability	4	4	16	3	12	3	12	4	16
Effect on component being measured	4	5	20	5	20	5	20	3	12
			106		95		100		106

Figure 4.21 - Decision for airway height measurement

The LVDT measurement device was chosen ahead of the laser sensor due its lower cost and ease of set-up.

The result of the airway height measurement will be displayed on the HMI.

In order to display the result of the airway height measurement to the user the output signal of the measurement device will have to be manipulated by the PLC and scaled accordingly.

As well as displaying the height measurement parameter, the system will also be programmed to alarm the operator of any deviation in the height should it drift outside the control limits.

4.4 Airway height control

Airway height control will be achieved using the machine PLC and an electro-pneumatic regulator.

The PLC will be programmed to process the height measurement and alter the strip tension set point of the tension control system. This set point will control the signal to the electro-pneumatic regulator.

Airway height measurement research carried out to a very good standard with a reasoned choice made as to which system to take forward

4.5 Summary of chosen devices

Below is a summary showing the devices that will be used for achieving airway height control.

1. Strip tension measurement will be achieved using a tension load cell in a roller configuration.
2. Strip tension control will be achieved using the PLC PID instruction. The electro-pneumatic regulator will allow strip tension control based on pneumatic pressure changes.
3. Airway height measurement will be achieved using an LVDT sensor.
4. Airway height control will be achieved via Proportional (P) control using the existing fin mill PLC. The electro-pneumatic regulator will be used once again for adjusting the strip tension and therefore the airway height.

Figure 4.22 shows the chosen devices that will be used for airway height control and their location within the existing process.

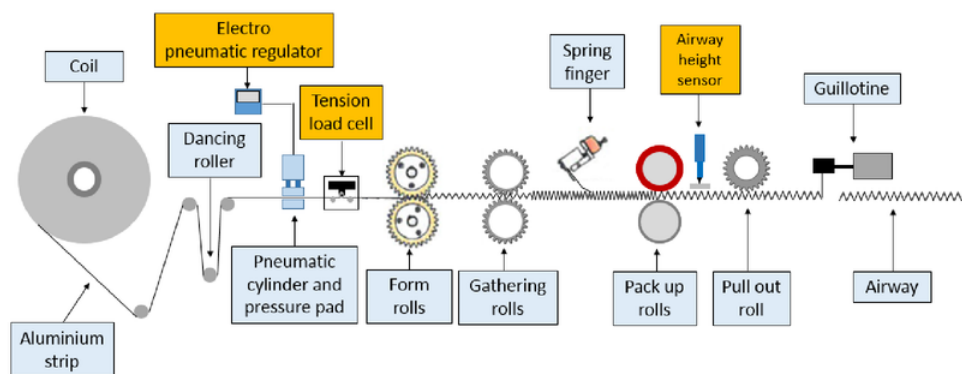


Figure 4.22 - New fin mill process diagram

5 SAFETY, SUSTAINABILITY, ENVIRONMENT, PROFESSIONALISM, MAINTENANCE AND RELIABILITY

5.1 Safety

Health and safety regulations will be followed throughout the project by ensuring that all implemented devices or systems comply with current U.K. and E.U. Health and Safety guidelines, CE compliance, Codes of practice and British Standards that may be relevant.

Electromagnetic Compatibility (EMC) guidelines will also be followed during the design and installation (i.e. using twisted conductors in order to reduce the effect of disturbances, running conductors as close as possible to the ground and using electrostatic screens).

In order to limit electromagnetic disturbances appropriate measures such as power supply filtering, cable shielding, radio frequency (RF) suppression techniques and connection of chassis to earth will be implemented (British Standards Institution (BSI), 2009).

Following the implementation of any changes on the equipment an assessment of all risks associated with the system will be carried out. The user of the equipment will be informed of the identified risks and training on how to deal with those risks will be carried out. Where appropriate suitable arrangements aimed at managing and controlling the health and safety risks will be put in place (HSE, 2013).

The implementation of a control system for airway height reflects business ethics and management philosophy, where human interaction with control system must be reduced to a minimum wherever possible. An automated control system does not only eliminate the potential of human error but also reduce the exposure of production operators to the equipment and therefore reduces the risk of injuries.

Although there are significant financial benefits, this project will result in simpler machine operation as production operators will not be required to interfere with the tension system. Human interaction with key parameters such as tension, pneumatic pressure and airway height will be significantly reduced.

5.2 Environment and Sustainability

The goal of this project is in line with those of the modern industry and of Calsonic Kansei, which aim to achieve sustainable development through sustainable energy and resource efficiency.

As a result of the implementation of the control system outlined in this report, aluminium scrap will be significantly reduced and so the footprint of the manufacturing plant. Reducing aluminium scrap levels will cause an increase in production efficiency, which will result in a reduction of production time required to meet customer volumes. This will mean a reduction of plant energy consumption.

A reduction of scrap will also result in resource efficiency improvement since there will be a reduction in materials, such as aluminium, required by the manufacturing plant in order to produce heat exchangers.

5.3 Professionalism

High levels of professionalism will be maintained throughout the design and implementation of this project.

Company standards and procedures will also be followed at all times. This includes PLC programming and supporting documentation i.e. comments/annotations. Comments are the descriptive properties assigned to a PLC program.

The use of comments makes fault finding and support much easier for other programmers and helps identify problematic areas. It also enables the understanding of logic and the qualifying elements for ongoing modifications.

Company procedures involve the storage of any machine software and instruction manuals in pre-determined machine folders. These are stored on the company network.

5.4 Maintenance and Reliability

Maintenance and reliability have been discussed in section 2 of this report.

*Good detail related to safety, sustainability, professionalism
and environment*

6 IMPLEMENTATION

6.1 Strip tension measurement system

6.1.1 Design and calibration

The tension measurement system is a load cell that operates upon the principle of a Wheatstone bridge. Figure 6.1 shows the process diagram of the airway machine including the tension load cell.

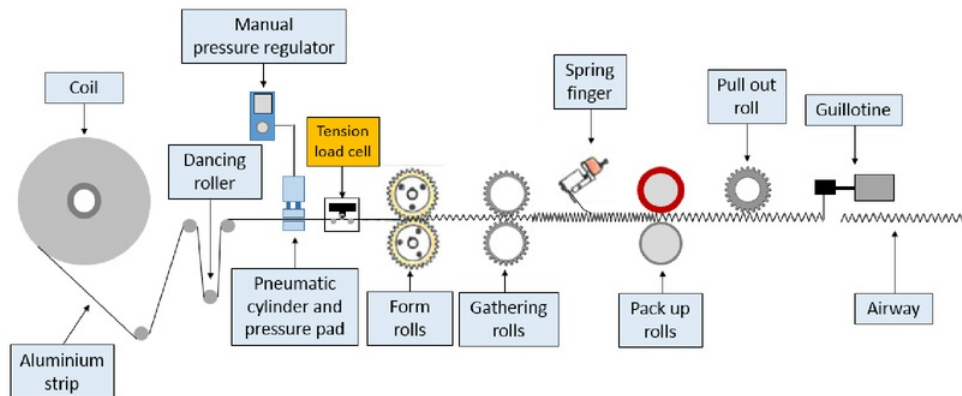


Figure 6.1 - Process diagram (tension load cell)

Figure 6.2 shows the load cell used for strip tension measurement. The aluminium strip passes under the middle roller, which is attached to the load cell. The upward force detected by the load cell corresponds to the tension in the aluminium strip.

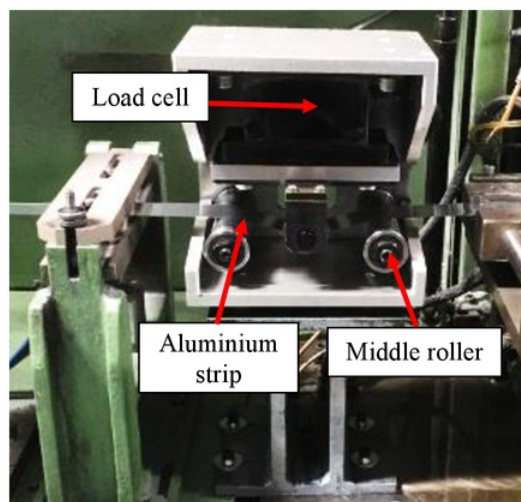


Figure 6.2 - Tension load cell (Roller configuration)

Figure 6.3 shows the tension load cell. Highlighted in the image are the vectors that produce the force detected by the load cell, which is proportional to the tension in the strip.

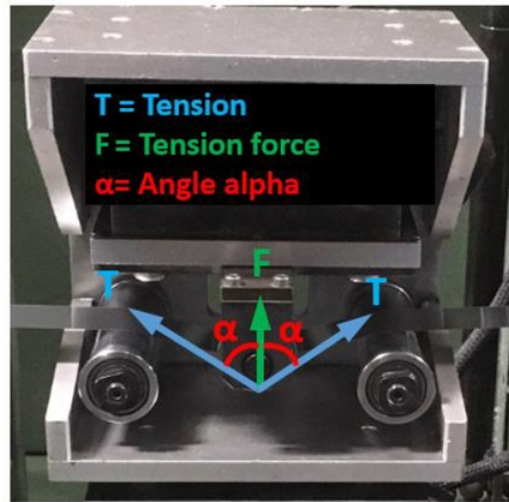


Figure 6.3 - Strip tension measurement principle

The equation that determines the relationship between the tension force measured by the load cell and the strip tension is:

$$F = 2(T \cos \alpha)$$

The force (F) detected by the load cell is the vector sum of the two equal tensions forces (T) in the aluminium strip. Alpha (α) is the angular difference between the vertical component and each tension force.

In order to ensure that the instrument was suitable for tension measurement, it was calibrated by applying no load at first and subsequently three known loads. For each of the three tests the output voltage of the instrument was measured using a digital Multimeter.

Figure 6.4 shows the behaviour of the load cell before and after calibration. The load cell was calibrated in the compression quadrant to produce an output of 0V at no load and 4.41V at know load of 5.9 KgF.

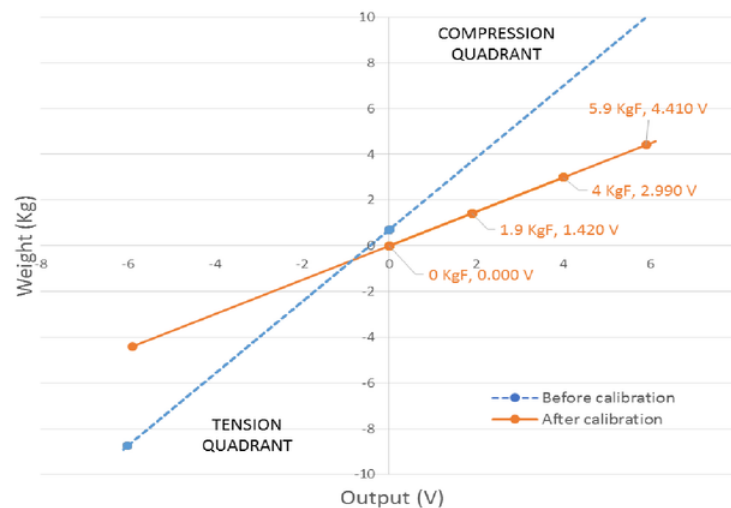


Figure 6.4 - Load cell calibration

In order to obtain a stable measurement signal without any noise a digital low pass filter was deigned. Figure 6.5 shows the digital low pass filter equation used for noise reduction.

$$\frac{\text{Input} + \text{Output}_{\text{last}} * (\text{Weight} - 1)}{\text{Weight}} = \text{Output}$$

Figure 6.5 - Digital low pass filter equation (PLC How To, n.d.)

Figure 6.6 shows the legend of the above equation explaining the meaning of each term.

- Input is the incoming signal value
- Output is the result of the filter
- Weight is how much influence you want past values to hold.
Higher numbers place more importance on past values. Weight must be greater than 1.

Figure 6.6 - Legend - Low pass filter equation (PLC How To, n.d.)

Figure 6.7 shows the instruction used within the PLC for implementing a low pass digital filter. This was implemented by replicating the equation shown in Figure 6.5 using the Allen Bradley PLC software.

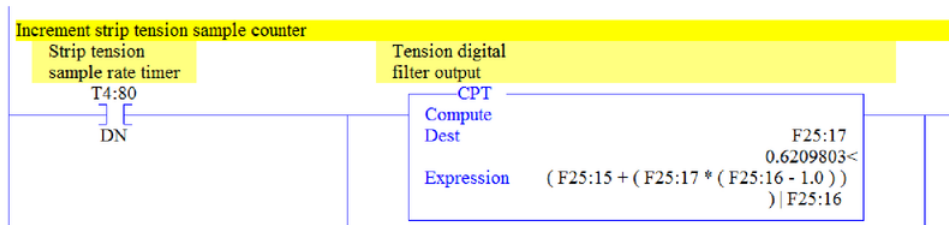


Figure 6.7 - Digital low pass filter (tension measurement signal)

An equation was developed in order to convert the load cell output signal into a KgF value that could be displayed to the user.

Figure 6.8 shows the section within the PLC program where the signal was converted into a KgF value.

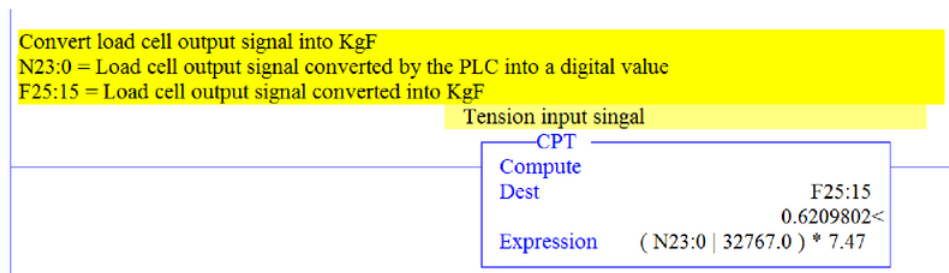


Figure 6.8 - PLC software conversion of load cell output signal

Excellent detail on the use of a low pass filter within a PLC program

6.1.2 Testing

Following the design and installation of the load cell, testing was carried out in order to understand the variation in tension during machine operation. The initial trials showed that the measurement signal was subject to noise and the measurement was not accurate. In order to overcome this issue a low pass digital filter was implemented.

Figure 6.9 shows the output signal from the load cell before and after digital filtering. This was achieved using a low pass digital filter, which produced a significant reduction in noise.

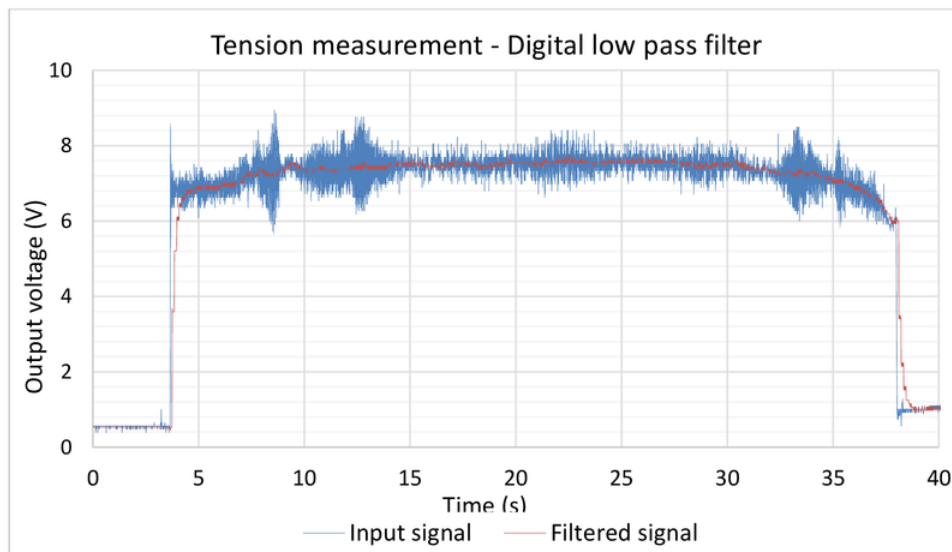


Figure 6.9 – Digital low pass filter – strip tension measurement

Following the implementation of the tension load cell a test was carried out with manual control of the strip tension in order to understand the behaviour of the system.

Figure 6.10 shows the strip tension measured during the operation of the machine, shown in blue, and the constant pneumatic pressure shown in red. The variation in strip tension is caused by disturbances in the system such as form rolls and strip feed variation due to dancing roller movement.

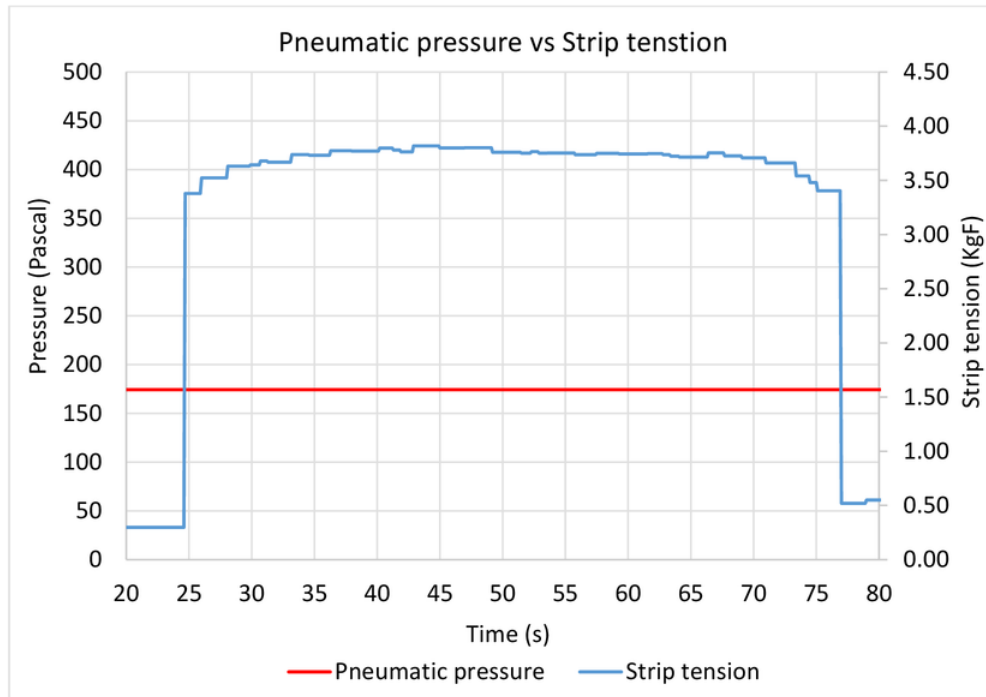


Figure 6.10 - Pneumatic pressure vs Strip tension - Manual tension control (open loop)

Another cause of strip tension fluctuation is machine speed, shown in Figure 6.11 along with the strip tension. *Good*

The strip tension increased with the increase in machine speed and reduced with the reduction of machine speed. This is due to the kinetic friction, which is proportional to the speed as previously explained. As machine speed increases there are additional forces in system, such as dancing arm and rollers, which cause the tension in the strip to increase.

This confirmed that machine speed needed to be taken in consideration when designing the tension control system.

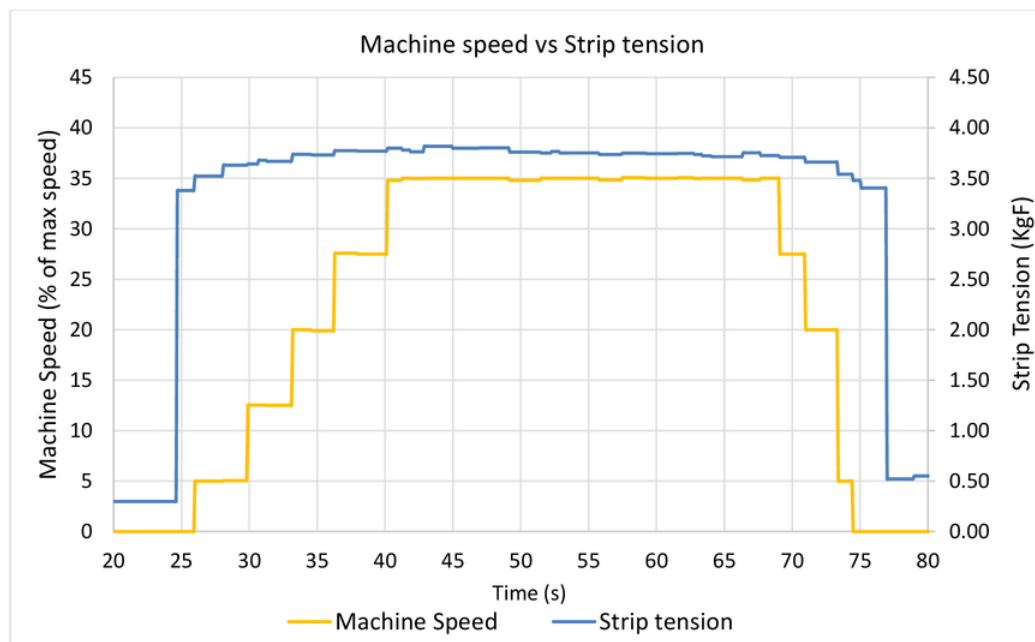


Figure 6.11 - Machine speed vs strip tension - Manual tension control (open loop)

6.1.3 Analysis

6.1.3.1 Resolution

The resolution of the strip tension measurement depends upon the signal-conditioning unit used for receiving the signal from the load cell. In this case, an analogue input card with an analogue to digital converter was used for receiving the analogue signal into the PLC.

The 0 to 10V signal from the load cell was converted into a 15 bits signal, which means that the voltage signal was represented by a digital value that vary between 0 and 32,767.

$$\frac{5.9 \text{ KgF}}{4.41 \text{ V}} = \frac{10 \text{ KgF}}{x} \quad \longrightarrow \quad x = \frac{10 \text{ KgF}}{5.9 \text{ KgF}} 4.41 = 7.47 \text{ V}$$

$$\frac{32,767}{10 \text{ V}} = \frac{x}{7.47 \text{ V}} \quad \longrightarrow \quad x = \frac{32,767}{10 \text{ V}} 7.47 = 24,477$$

$$\text{Resolution} = \frac{10 \text{ KgF}}{24,477} = 0.4 \times 10^{-3} \text{ KgF} = 0.4 \text{ gF}$$

6.1.3.2 Measurement range and accuracy

As stated in the datasheet the measurement range of the load cell was 98.07N, which corresponds to 10 KgF, and the accuracy was $\pm 1\%$, which corresponds to $\pm 0.1 \text{ KgF}$.

形式	PLT-5K	PLT-10K	PLT-50K	PLT-100K
定格張力	49.03N	98.07N	490.3N	980.7N
風袋荷重	定格の50%以内			
精度	$\pm 1\%/R.O.$			
入力電源	DC+24V 55mA以下/定格張力時			
出力	$\pm DC10V$ /定格張力時			
検出口一変位置	MAX.0.3mm/定格張力時			
温度補償範囲	0~40°C			
保護構造	IP52			
過負荷耐量	200%/R.C.			

Figure 6.12 - Load cell specification

6.1.3.3 Strip tension display

Figure 6.13 shows the strip tension measurement, or process variable, displayed on the HMI as required in the specification.



Figure 6.13 - HMI – Tension measurement

6.1.3.4 Comparison to specification

The table in Figure 6.14 shows that all strip tension measurement criteria were successfully met.

CRITERIA	RESULT	PARAMETER
Is the resolution 0.01KgF or better?	YES	0.004 KgF
Is the measurement range at least 0-10KgF?	YES	10 KgF
Is the accuracy 0.1KgF or better?	YES	0.1 KgF
Is strip tension displayed to the user?	YES	n/a

Figure 6.14 - Strip tension measurement summary

*Implementation of strip tension measurement
clearly shown*

6.2 Strip tension control

6.2.1 Design

In order to be able to control strip tension, an electro-pneumatic regulator was installed. The regulator adjusts the pneumatic pressure and therefore the force applied to the strip in order to obtain the required tension.

The output pressure of the regulator is controlled by an input signal that varies between 0V and 10V. This voltage produces an output pressure that varies between 0.005 MP (Mega Pascal) and 0.5 MPa.

Figure 6.15 shows the electro-pneumatic regulator installed on the machine.



Figure 6.15 – Electro-pneumatic regulator (Allied Electronics & Automation, 2018)

Figure 6.16 shows the process diagram after the electro-pneumatic regulator was installed. The electro-pneumatic regulator was connected to the existing pneumatic cylinder. This meant that the existing pressure pads were used for applying force on the strip.

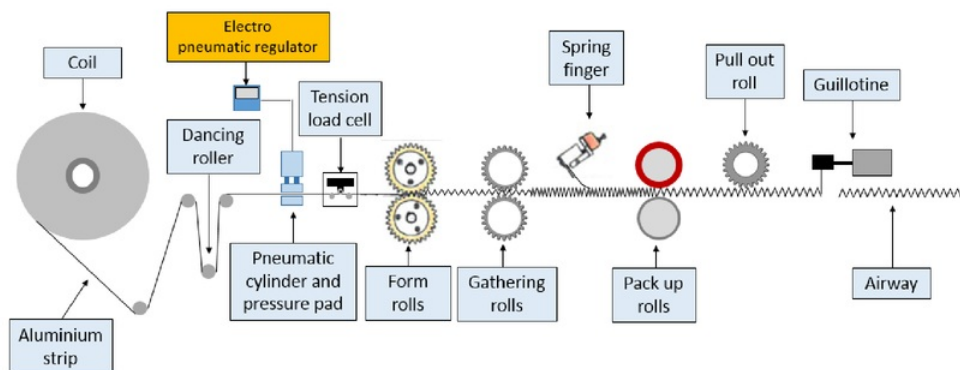


Figure 6.16 - Process diagram (electro-pneumatic regulator)

Figure 6.17 shows the control block diagram of the tension control system. The tension measurement feedback produced by the load cell - process variable (PV), is filtered so that the high frequency components are removed giving a more stable signal. The difference between the tension set point (SP) and the process value (PV) produces an error (e) that is used by the PI controller to condition the output signal to the electro-pneumatic regulator.

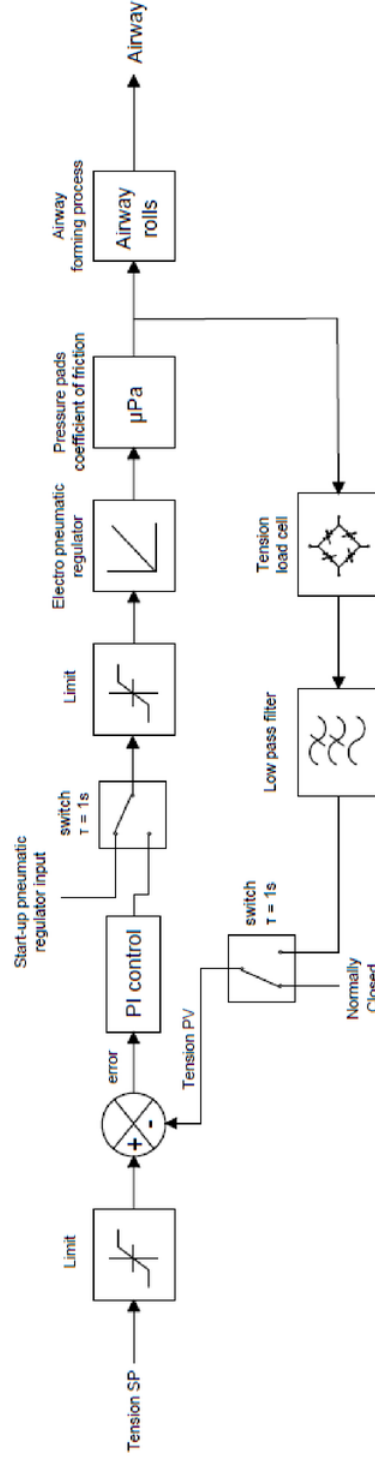


Figure 6.17 – Tension control block diagram

In order to implement the PI control for strip tension, the ‘trial and error’ method advised in the reference manual for “SLC 500 Instruction Set” was followed. The equation in Figure 6.18 shows the PID algorithm used within the PLC PID instruction. There are four terms in the algorithm that can be used as options by the programmer. These are the proportional gain K_c , the integral time constant T_i , the derivative term or rate term T_D , and feed forward/bias term. The feed/forward term is used in applications that require anticipated control.

$$Output = K_c \left[(E) + \frac{1}{T_i} \int (E) dt + T_D \cdot \frac{D(PV)}{df} \right] + \text{Feed Forward/Bias}$$

Figure 6.18 - PID algorithm (Rockwell Automation, 2008)

Figure 6.19 shows the set-up of the proportional-integral controller that was used to control strip tension. The proportional gain K_c was set to 0.3 and the integral time constant T_i was set to 0.2. These values were developed based on previous tests and stability assessments.

The loop update, which represents the update time of the output, was set to 0.10 seconds. This was the same as the sample rate, which meant that before and after every change of the output variable, a sample of the strip tension measurement was taken.

To be noted is the fact that a dead band value of 400 was used, which represents 0.16 KgF. The dead band represents a zone that extends above and below the set point where the process variable can deviate without the controller producing any correction. When in this region the controller holds its output. This feature allow reducing oscillation of the process variable due to the fast response of the system.

In order to prevent damage to the machine caused by overshoot in strip tension the output control variable was limited to a maximum of 40%.

The screenshot shows a 'PID Setup' dialog box with the following settings:

Tuning Parameters	Inputs	Output	Flags
Controller Gain K_c = 0.3	Setpoint SP = 10813	Control Output CV (%) = 40	TM = 0
Reset T_i = 0.2	Setpoint MAX(Smax) = 32767	Output Max CV (%) = 40	AM = 0
Rate T_d = 0.00	Setpoint MIN(Smin) = 0	Output Min CV (%) = 0	CM = 0
Loop Update = 0.10	Process Variable PV = 4700	Scaled Error SE = 6113	OL = 1
Control Mode = E=SP-PV			RG = 0
PID Control = AUTO			SC = 0
Time Mode = STI			TF = 0
Limit Output CV = YES			DA = 0
Deadband = 400			DB = 0
Feed Forward Bias = 0			UL = 1
			LL = 0
			SP = 0
			PV = 0
			DN = 1
			EN = 1

Buttons: OK, Cancel, Help

Figure 6.19 - PI control block

Due to the implementation of the digital filter, the response of the system was exponential at machine start-up. This means that the processed response compared to the actual value was delayed. This delay was a trade-off for signal smoothing and stability.

The sampling rate of the digital low pass filter was 100ms meaning that changes in strip tension were only detected every 100ms.

Figure 6.20 shows the ramp up delay.

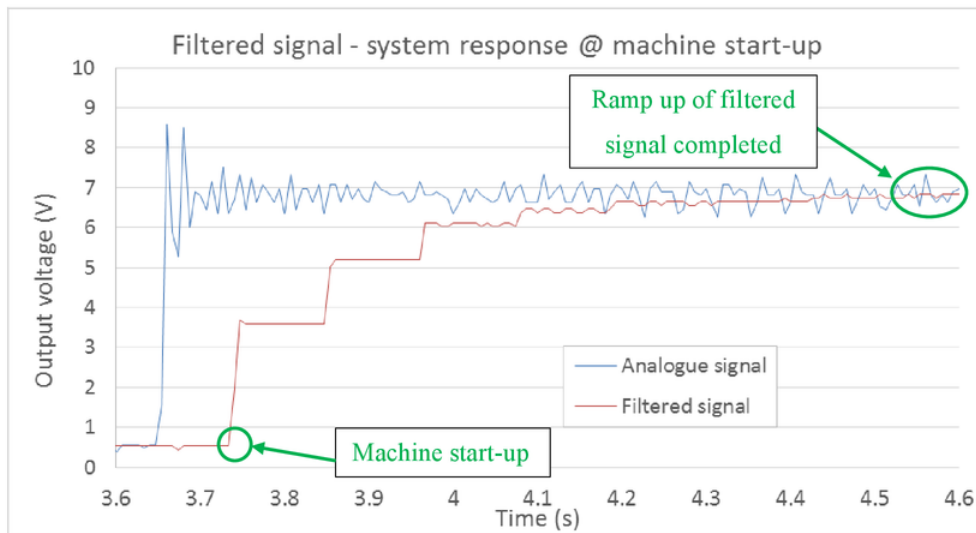


Figure 6.20 - System response at machine start up

Because of this delay, the PI controller was enabled one second after the start-up of the machine. This allowed the system to stabilise before engaging the PID instruction and as a result removing any previously experienced overshoot.

6.2.2 Testing

In order to prove that the strip tension control system was functioning as required a test was carried out by monitoring the tension process variable and the set point.

Figure 6.21 shows the strip tension process variable, in blue, and the pneumatic pressure, in red. The strip tension reduced to the set point value of 2.0 KgF after machine start-up and it was then controlled as expected. After changing the set point to 4 KgF the system responded by increasing the strip tension to the new set point as expected.

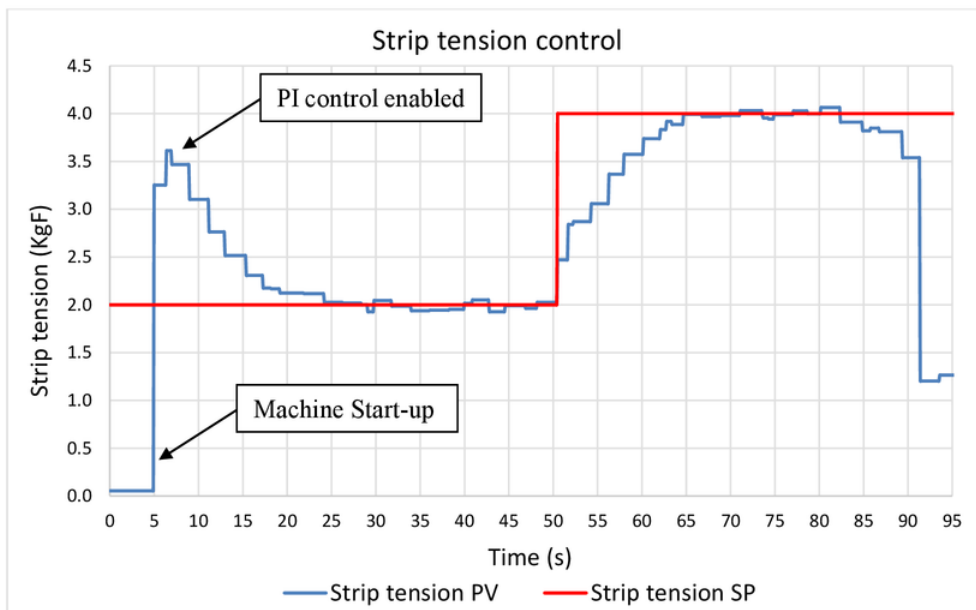


Figure 6.21 - Strip tension control (Closed loop)

In order to understand how the pneumatic pressure varies the strip tension, several tests were carried out while monitoring both the electro-pneumatic regulator input signal and the strip tension output signal produced by the load cell.

Figure 6.22 shows the strip tension, in blue, and the pneumatic pressure in red. The strip tension reduces as the pneumatic pressure reduces and increases as the pressure increases, and therefore, as predicted, strip tension is proportional to pneumatic pressure.

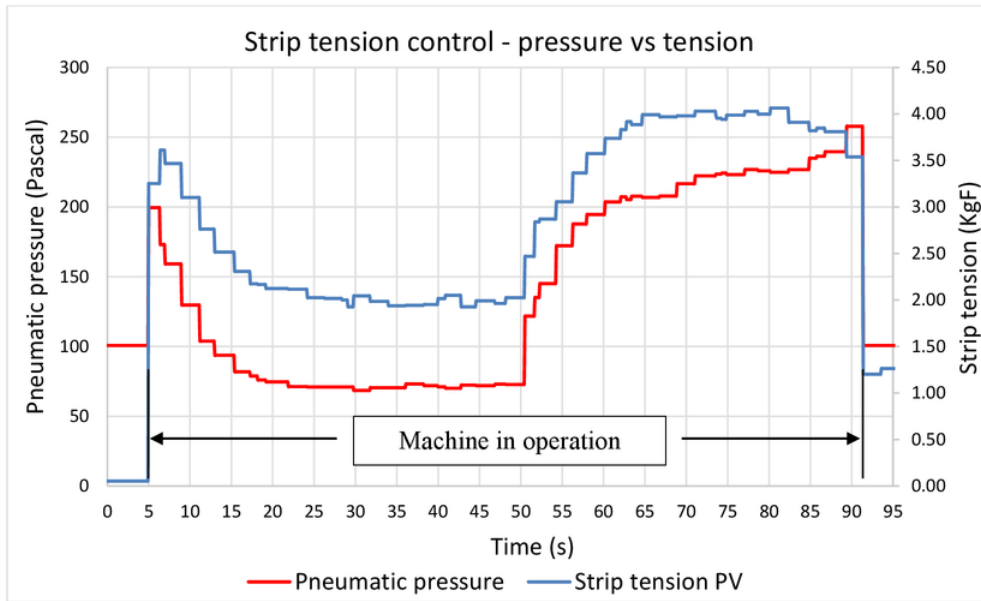


Figure 6.22 - Strip tension vs pneumatic pressure (Closed loop)

In order to understand the effect of machine speed upon strip tension a series of open loop tests were carried out. During these tests, both strip tension and pneumatic pressure were monitored and recorded.

Figure 6.23 shows the predicted strip tension at different levels of machine speed. This is based on the assumption that strip tension is a result of kinetic friction and therefore is proportional to the machine speed.

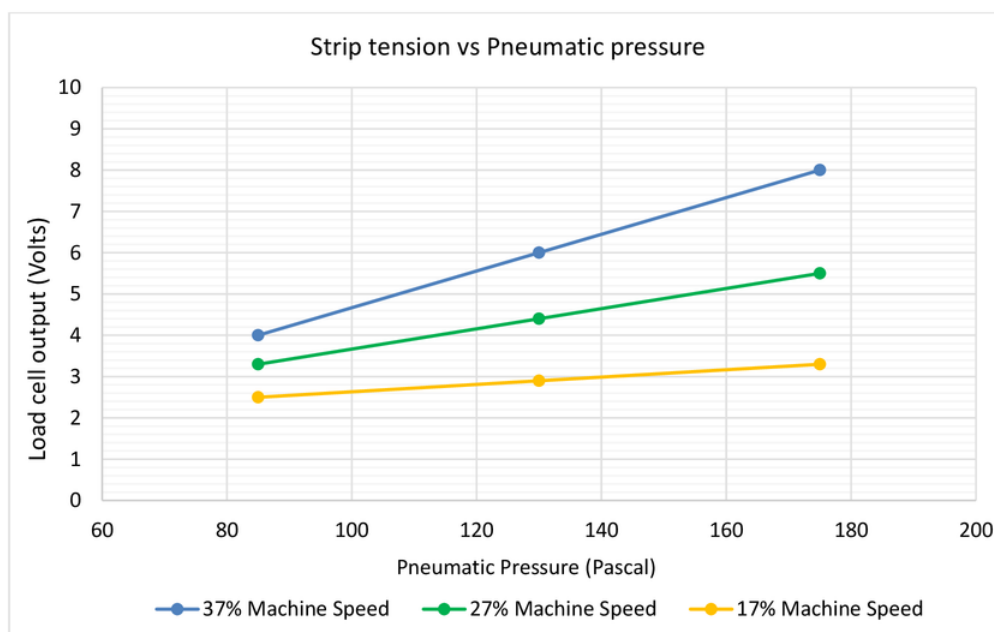


Figure 6.23 - Predicted results - Strip tension vs pneumatic pressure (Open loop)

Figure 6.24 shows the results obtained from the practical tests. The difference between strip tension at different machine speeds is negligible. This is due to the small changes in kinetic friction at the three chosen speeds.

The results proved that machine speed could be ignored due to the limited effect on strip tension.

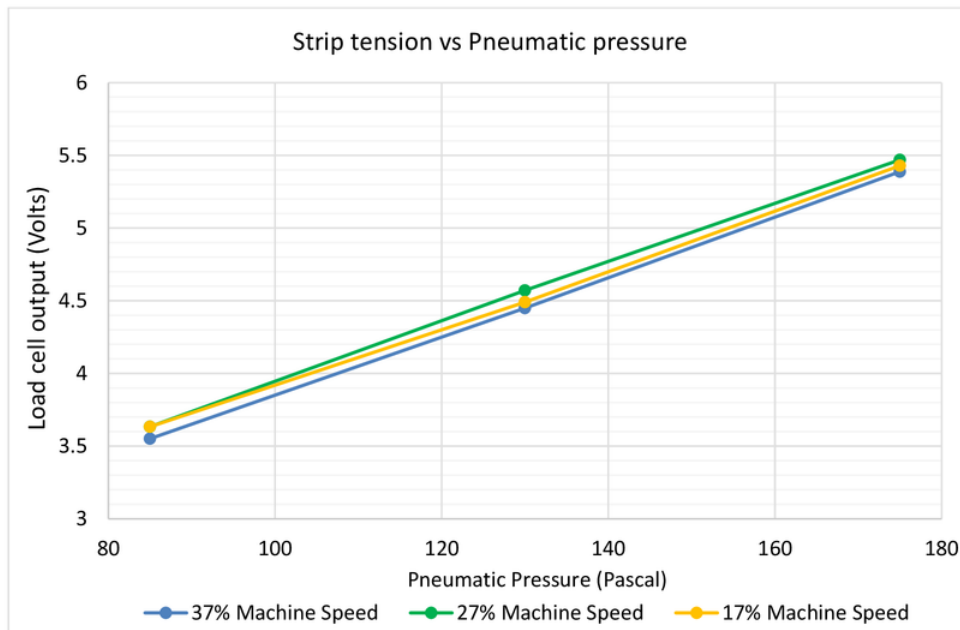


Figure 6.24 - Practical results - Strip tension vs pneumatic pressure (Open loop)

Figure 6.25 shows the test results of the automated strip tension control system. Following the start-up of the machine, the strip tension decreased until the set point was reached.

The dotted green lines, representing the upper and lower control limits, show that the control system was able to maintain the strip tension within ± 0.2 KgF of the set point value, as stated in the specification.

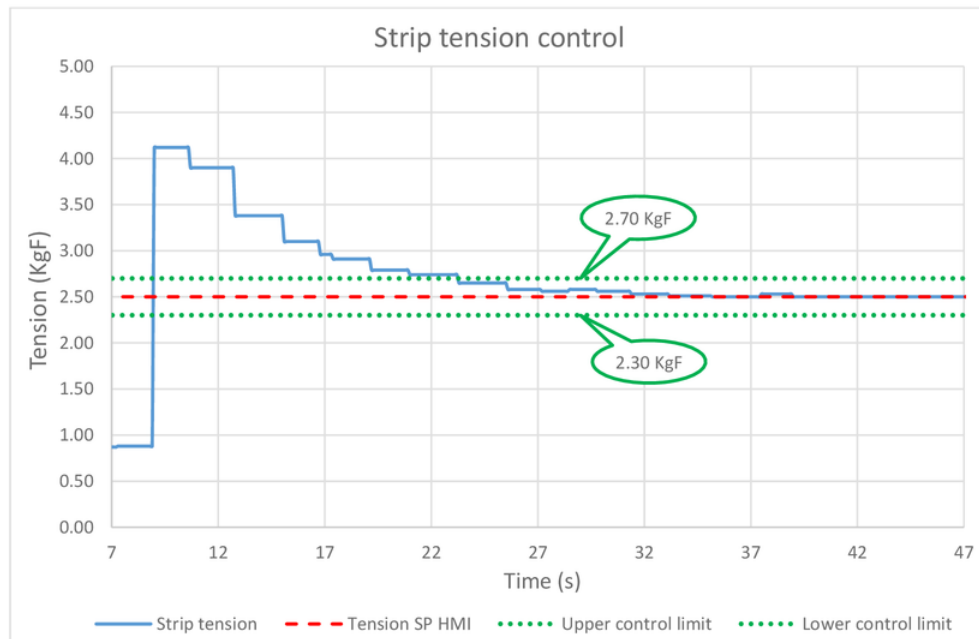


Figure 6.25 - Strip tension control - test results

6.2.3 Analysis

Figure 6.26 shows the strip tension control screen on the HMI. Strip tension control can be switched between auto and manual mode.

When in manual mode the manual pressure regulator is adjusted by the machine operator in order to achieve the required tension.

When in auto mode the tension set point is entered by the user and the tension control system adjusts the pneumatic pressure in order to achieve the set point.

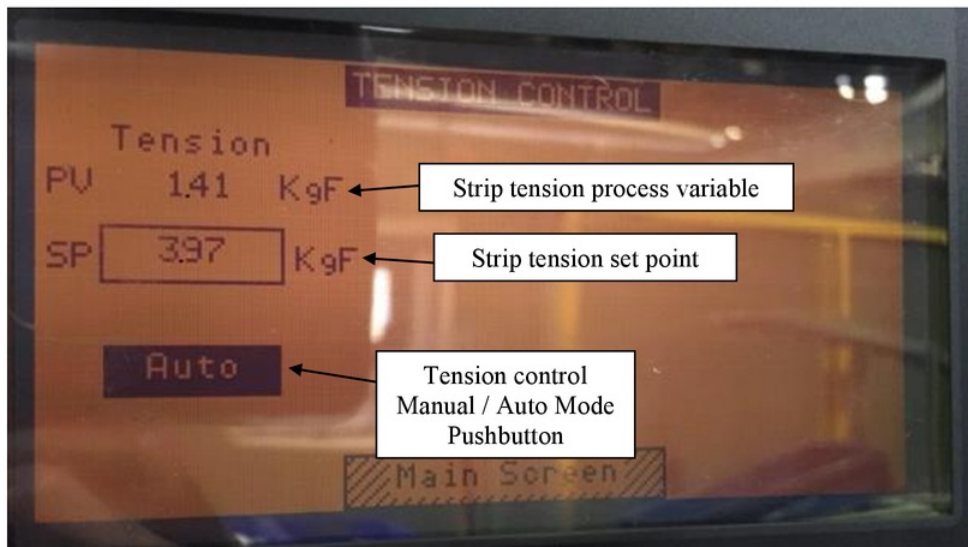


Figure 6.26 – HMI - Strip tension control

6.2.3.1 Comparison to specification

Figure 6.27 shows that the objective of the project in terms of tension control were satisfied.

CRITERIA	RESULT
Is strip tension control automated?	YES
Is strip tension maintained within $\pm 0.2\text{KgF}$ of the set point value?	YES

Figure 6.27 - Specification criteria - Strip tension control

Excellent, very detailed testing carried out on automated tension control which showed great understanding on how PID looping can be used successfully in PLC programming

6.3 Airway height measurement

6.3.1 Design and calibration

In order to prevent contact damage to the product during the initial measurement, a flat block of steel was placed between the contact probe of the LVDT and the airway. This was chosen based on three criteria - width, length and weight.

These are as follows:

- Not too heavy to cause contact damage and airway deformation (the LVDT downward spring force was considered).
- Not too light to prevent erratic movements and to filter out disturbances.
- The length for mechanical filtering.
- The width for surface contact area.

Figure 6.28 shows the installed LVDT sensor for airway height measurement and the mechanical support designed to allow this measurement.

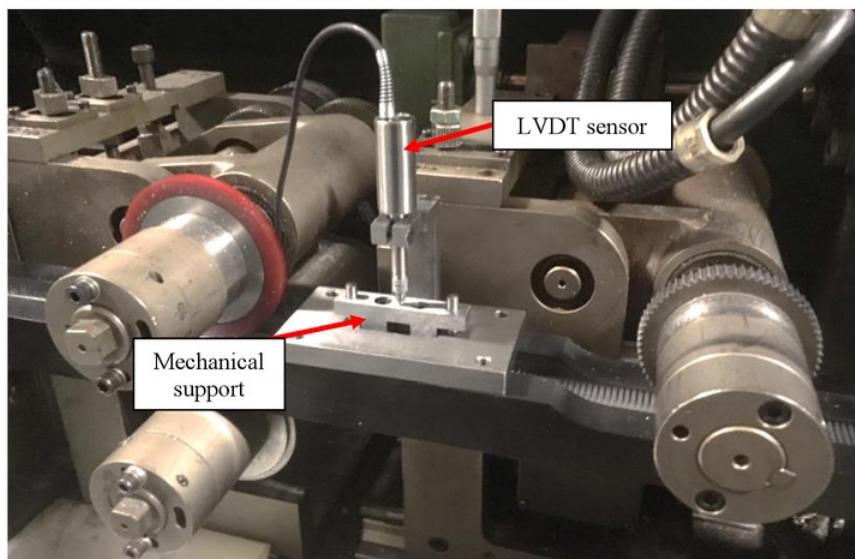


Figure 6.28 - LVDT sensor

Prior to the use of the LVDT to measure airway height, slip gauges were used within the support assembly as a mean to determine the accuracy and repeatability of the measurements.

Figure 6.29 shows the actual linearity of the device.

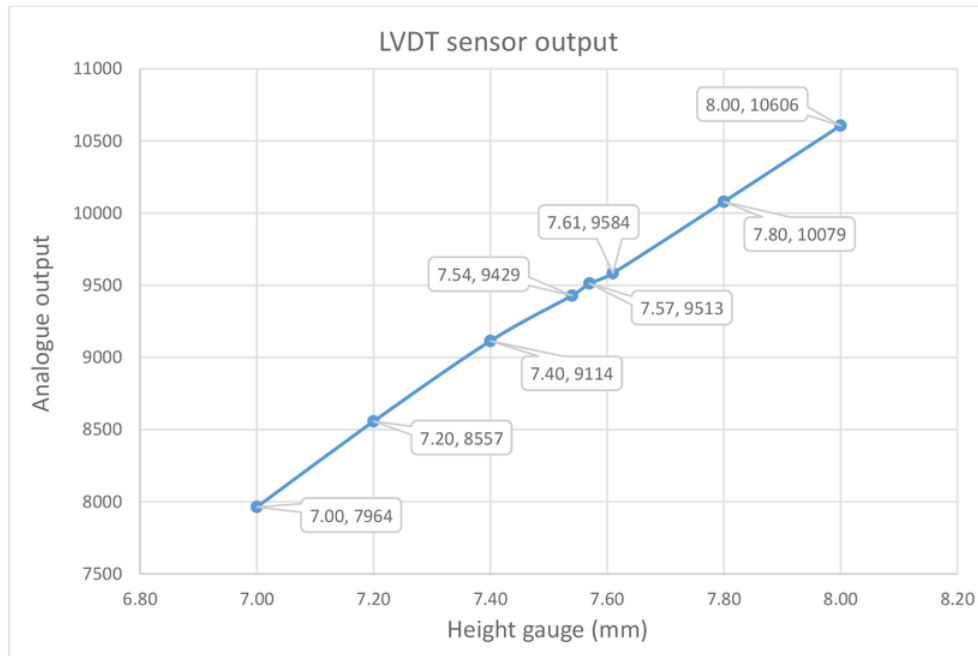


Figure 6.29 - LVDT calibration results

Because of the linear relationship between the height gauge and the output signal, an equation was developed in order to convert the signal into a millimetre value. The constant 0.000797 was determined by calculating the ratio between the height gauge and the digital value shown in the PLC software.

Figure 6.30 shows the instruction used in the PLC program in order to convert the LVDT analogue output signal into a meaningful millimetre value to be displayed to the user of the machine.

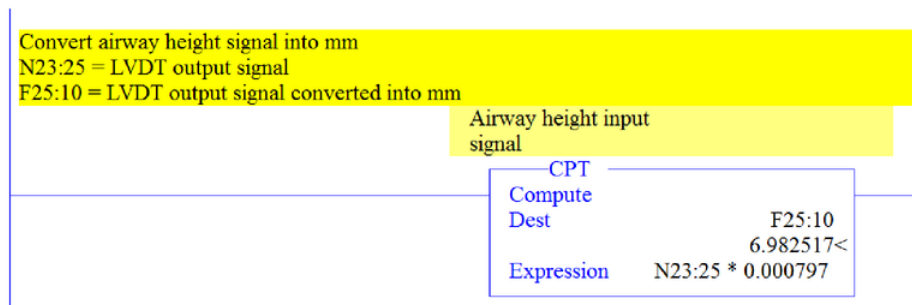


Figure 6.30 – PLC conversion of LVDT output signal

Figure 6.31 shows the instruction used within the PLC software for implementing a low pass digital filter for noise reduction. The 'compute' or mathematical instruction was implemented by replicating the equation used for filtering the tension measurement signal.

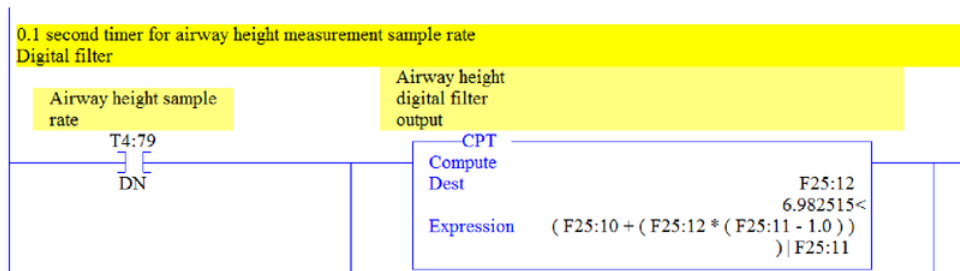


Figure 6.31 - Digital low pass filter (airway height measurement signal)

Good detail on how the PLC filters the airway height measurement from the LVDT

6.3.2 Testing

In order to reduce the noise in the output signal and obtain a stable airway height measurement that could be used for the airway height control system, a digital low pass filter was implemented. The principle of operation of the digital filter designed for noise reduction in the airway height measurement signal was the same as that adopted for the tension measurement signal.

Figure 6.32 shows the output signal of the LVDT subject to noise, in blue, and that of the digital filter, in red. The filtered signal was stable and suitable to be used within the airway height control system.

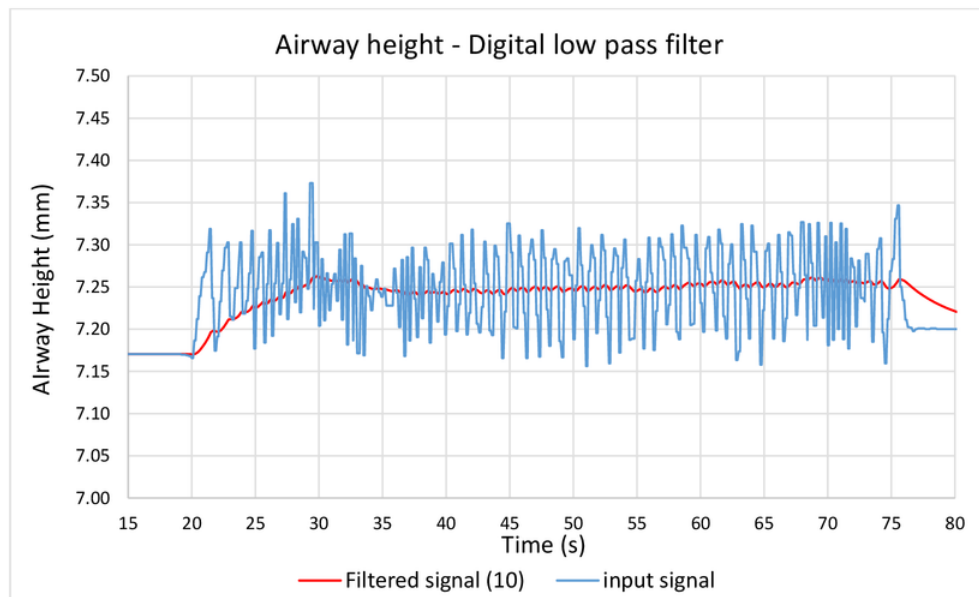


Figure 6.32 – Digital low pass filter - airway height measurement

As it can be seen above, the measured airway height was roughly 7.25mm while the expected measurement was roughly 7.57mm. This discrepancy was due to the LVDT sensor location relative to the position of the final formed airway. It may be worthwhile noting that although this discrepancy was anticipated, this was attributed to the airway strength between the pack-up and pull-out rolls.

Excellent detail

Figure 6.33 shows the difference between airway height measurements performed using LVDT and DTI as function of increased tension. As it can be seen in the graph below, the difference between the two measurements was consistent.

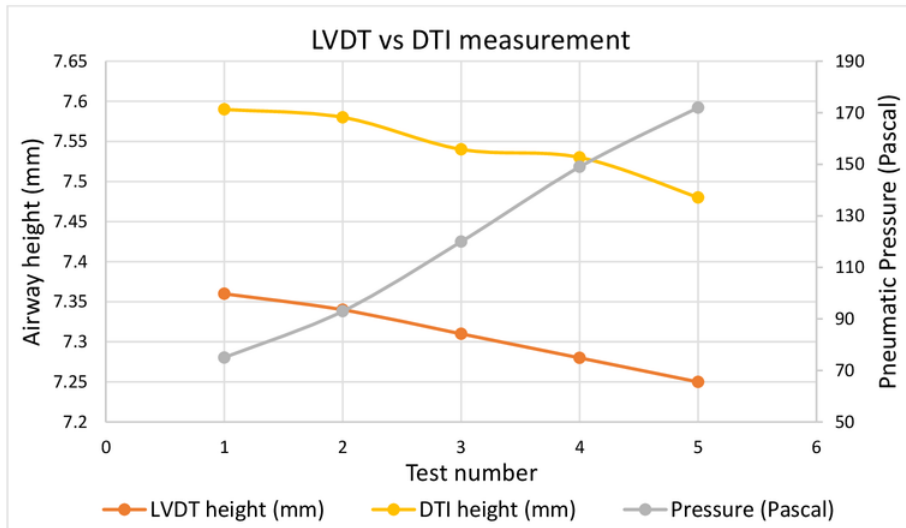


Figure 6.33 - Comparison of LVDT and DTI measurement

The correlation factor obtained by calculating the average of the five ratios, as shown in Figure 6.34, was multiplied by the LVDT measurement, in order to obtain the airway height.

LVDT height (mm)	DTI height (mm)	Ratio = $\frac{DTI\ height}{LVDT\ height}$
7.36	7.59	1.031
7.34	7.58	1.033
7.31	7.54	1.031
7.28	7.53	1.034
7.25	7.48	1.032
Average = constant of proportionality		1.032

Figure 6.34 - Constant of proportionality

6.3.3 Analysis

6.3.3.1 Accuracy

The accuracy of the airway height measurement is 4.35µm as shown below. The full-scale deviation of the LVDT is 5mm and the maximum full-scale error is 0.087%.

$$\text{Accuracy } 0.063\% \text{ of FS} = \pm (5\text{mm} / 100 * 0.087) = \pm 0.00435\text{mm or } \pm 4.35\mu\text{m}$$

6.3.3.2 Resolution

The resolution of the airway height measurement is also dependent on the resolution of the analogue to digital converter, in this case the resolution of the PLC analogue input card.

The 5mm measurement range is represented by a 4-20mA signal. This is converted into a value ranging from 3,277 to 16,384. The resolution of the measurement was calculated as shown below.

$$\text{resolution} = \frac{\text{measurement range}}{\text{decimal representation range}} = \frac{5\text{mm}}{16,384 - 3,277} = \frac{5\text{mm}}{13,107} = 0.38\mu\text{m}$$

The resolution of the measurement system is less than that specified of 6µm and therefore meets the requirements in the specification.

Figure 6.35 shows the HMI where the airway height measurement was displayed to the user of the machine.

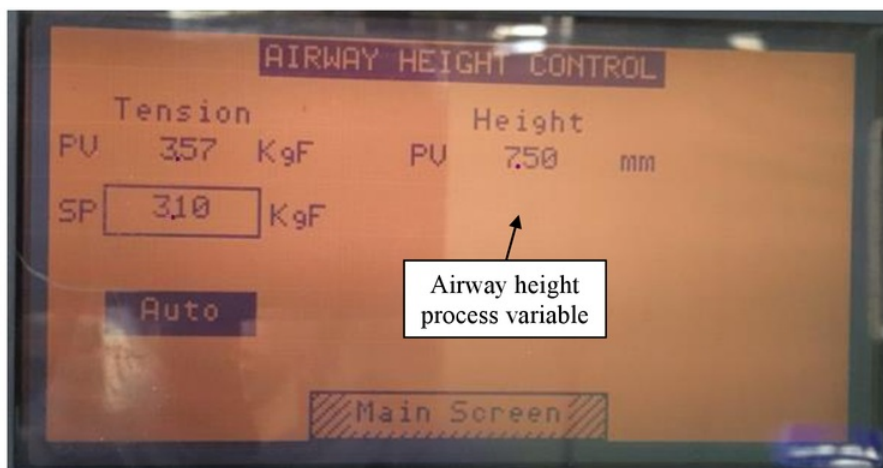


Figure 6.35 – HMI - Airway height measurement

Excellent detail

6.3.3.3 Comparison to specification

Figure 6.36 shows the specified criteria for the airway height control system. Accuracy and resolution of the instrument were less than 6um and therefore met the specification criteria. Airway height is also displayed to the use via the HMI.

CRITERIA		RESULT
Airway height measurement	Is the accuracy of the measurement instrument less than 6um?	YES
	Is the resolution 6um or less?	YES
	Is airway height displayed to the user?	YES

Figure 6.36 - Specification criteria - airway height measurement

Comparison made to specification shows the airway height measurement meets criteria set.

6.4 Airway height control

6.4.1 Design

Figure 6.37 shows the control block diagram of the airway height control system. In order to control airway height the set point of the strip tension control 'Tension SP (Tension control)' will be adjusted. It will be increased if airway height is above the airway height set point and it will reduced if it is below the set point. The airway height control system will be enabled 20 seconds after the airway machine has been started. This allows the machine to settle at the set speed so that any changes in airway height or tension will not be subject to machine speed changes.

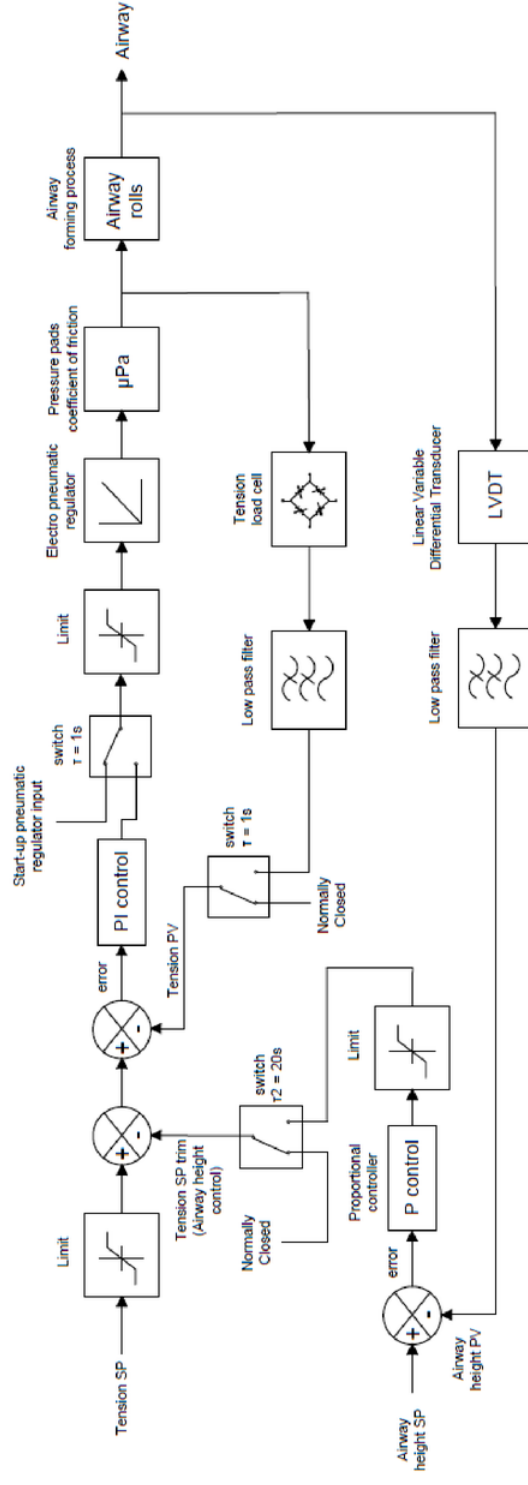


Figure 6.37 - Airway height control block diagram

6.4.2 Testing

Figure 6.38 shows the test carried out in order to determine the loop update time of the airway height measurement. The delay was determined by creating a step change of strip tension and measuring the time delay, shown in green, required for the LVDT to detect a change in airway height.

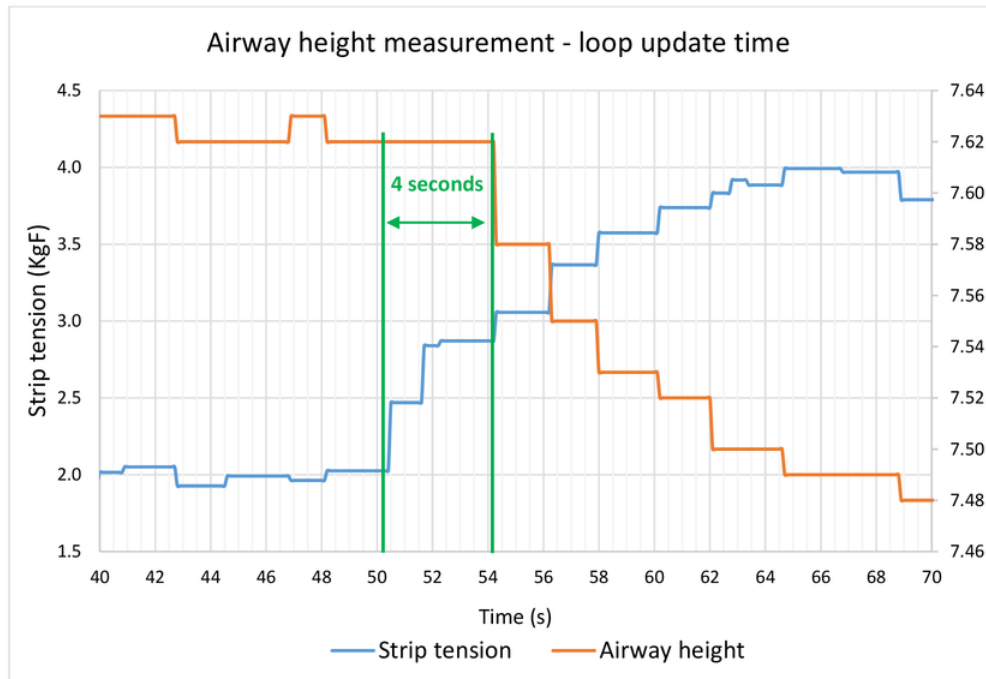


Figure 6.38 - Airway height measurement loop update time

The loop update time obtained from the above trial was considered when establishing delay between strip tension set point adjustments. This meant that strip tension set point was changed every 5 seconds.

Figure 6.39 shows the results obtained from testing the airway height control system. As anticipated from the control loops developed within this project, the strip tension was automatically adjusted so that the airway height PV matched that of the airway height SP.

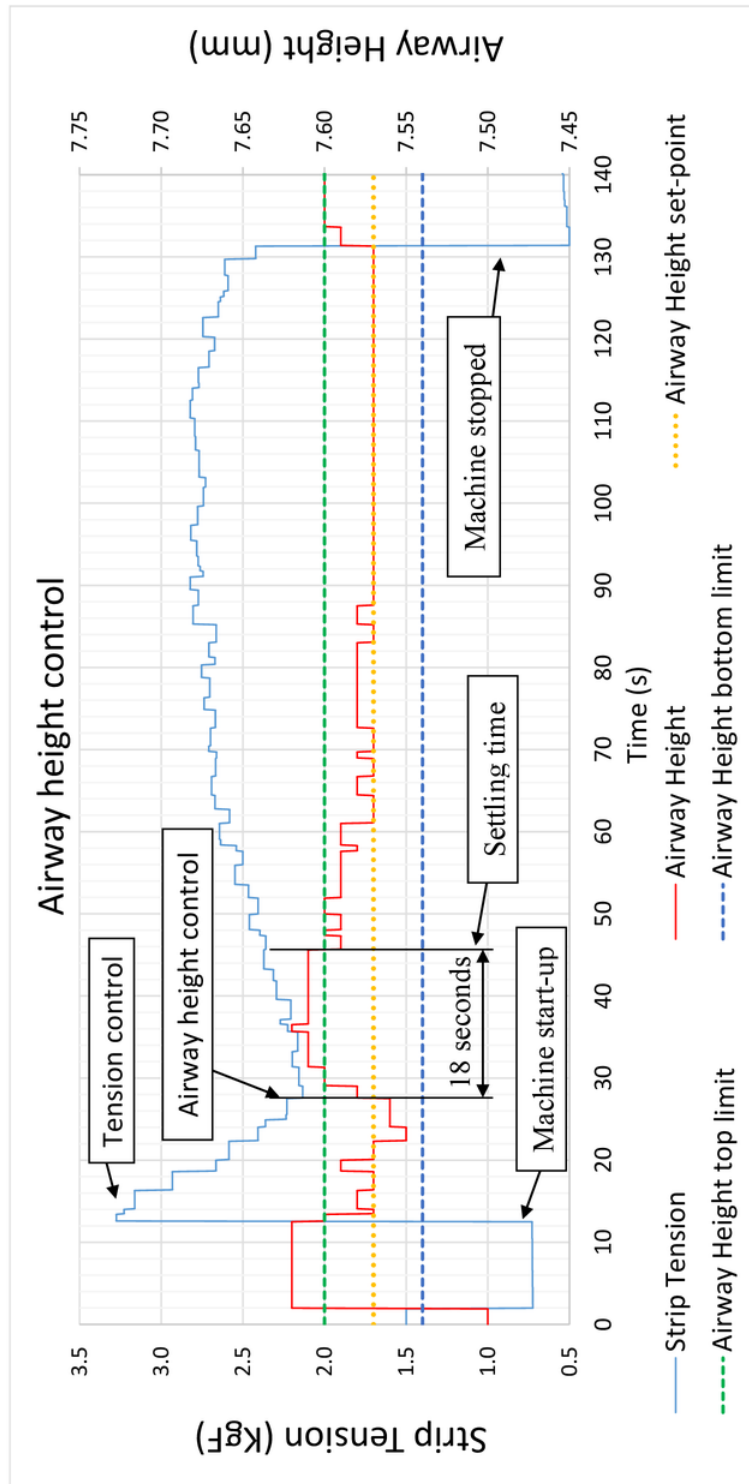


Figure 6.39 - Airway height control system test results

Excellent graphical analysis shown that clearly shows airway height being controlled via strip tension

The graph in Figure 6.39 shows three events that summarise the airway height control system.

The first event involves the start-up of the machine where the input signal of the electro-pneumatic regulator causes a sharp increase in strip tension. The start-up input signal is set to a pre-set value in order to prevent material pile-up at start. These pile-ups can cause serious and costly damage to forming rolls.

The second event, which occurs one second after the start-up of the machine, represents the start of the strip tension control system, which reduces the strip tension until the set point is achieved.

The third event, which occurs twenty seconds after the machine start-up, represents the start of the airway height control system. The airway height control system influences the tension control system so that the airway height SP is achieved.

Highlighted in the graph is the settling time of 18 seconds, which is the time required for the airway height to be within the upper and lower control limits.

6.4.3 Analysis

Figure 6.40 shows the airway height set point entered by the user and the control button for manual/auto airway height control.

When the control is in manual mode, the strip tension set point must be adjusted in order to alter the airway height.

When the control is in auto mode, the airway height is automatically controlled. If the airway height process value is less than the set point, the tension is decreased in order to increase airway height and vice versa.

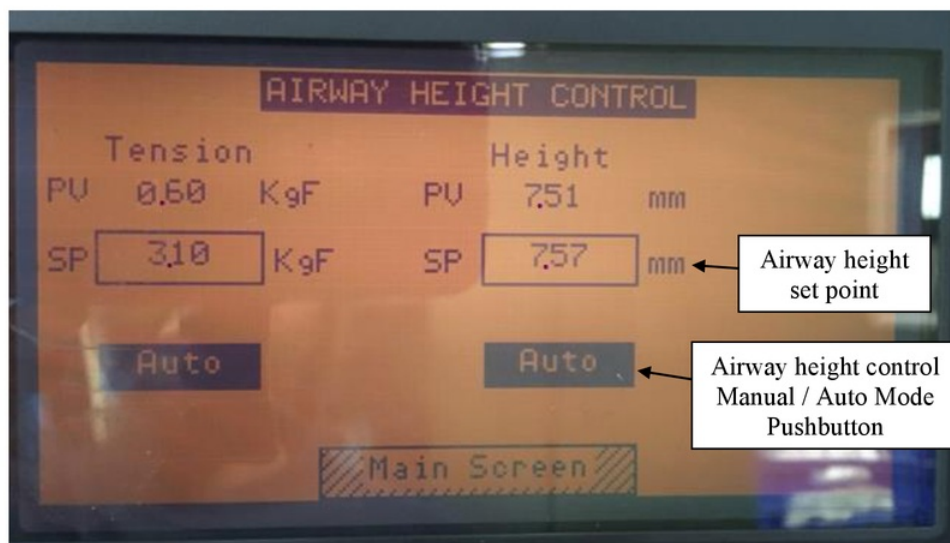


Figure 6.40 - HMI - Airway height control

6.4.3.1 Comparison to specification

Figure 6.41 shows that both specification criteria for the airway height control system were met.

CRITERIA		RESULT
Airway height control	Is airway height control automated?	YES
	Is airway height maintained at the set point value?	YES

Figure 6.41 - Specification criteria - Airway height control

Again, good comparison back to specification

7 CONCLUSION, EVALUATION, RECOMMENDATIONS AND REFLECTIONS

7.1 Conclusion

This report has its main focus of attention on the concept of airway height control and serious issue of process drift. Many factors influence airway height, but the main factor is tension control. Other factors are machine speed, material, lubrication, form roll settings, pack-up and pull-out roll settings.

Material forming at speed requires tension to maintain the forming height as well as the heat exchange properties of the airway. The tension variable is therefore a critical setting on the machine and its control, monitoring and stability have been investigated in this report.

As an extension to the effects of tension, the airway height is also looked at within another control loop, which will also influence the tension control loop. The practical application, research and software aspects of this project will apply to the long-term issue of tension control.

To control the tension it must be measured. In order to compensate for tension fluctuations, the measured value has to be processed and presented to the controlling device.

The tension control system involves the design and implementation of a load cell for tension measurement with a proportional-integral (PI) algorithm and electro pneumatic regulator for tension adjustment.

The load cell was calibrated using a series of known loads and an equation was developed in order to convert the output signal of the load cell into a tension force value to be displayed to the user of the machine. The measurement instrument was subsequently interfaced to the machine's PLC via an analogue input card and the PLC software was used for scaling the signal. A low pass digital filter was also designed using the PLC software in order to reduce signal noise. The output signal of the low pass digital filter was then converted into a KgF force value to be displayed on the HMI.

A PI tension control system was designed within the PLC program using the PID control instruction. Proportional and integral time constant were determined via a 'trial and error' method. The output of the PI control instruction was used to adjust the tension using an electro pneumatic regulator. This regulator outputs a pneumatic pressure proportional to its input signal.

As well as tension measurement and control, this projects covers airway height measurement and control. This second section was designed to work in conjunction with the tension loop to allow incremental changes.

The implementation of the airway height measurement system involved the installation, calibration and scaling of an LVDT.

In order to prevent damages to the product during the measurement process a support structure was designed, manufactured and installed. This support structure produces uniform contact on the product and prevents damage to the airways.

The calibration of the LVDT was carried out using slip gauges in order to simulate the output characteristics of the sensor when subject to different airway heights. A noise reduction method was implemented using a digital low pass filter in order to obtain a stable signal.

The airway height control system involved the design of a proportional controller with the purpose of trimming the set point of the tension control system at constant intervals. The polarity of the trim signal was same as that of the airway height error ($e = SP - PV$), which is the different between the airway height set point (SP) and the process value (PV).

Figure 7.1 shows detailed cost of each purchased device and the total cost, which is below that of £6,000 stated in the specification.

Device	Cost
Tension Load Cell	£1,189.00
Electro pneumatic regulator	£219.49
LVDT	£364.00
TOTAL	£1,772.49

Figure 7.1 - Purchased devices

Following the installation of the airway height control system the airway machine has run for a total of 145 hours. During this period three events of unplanned maintenance relating to the implemented system have occurred. Below is the calculation showing how mean time between maintenance is calculated, which quantifies the reliability of the implemented system.

$$\text{Mean time between maintenance (MTBM)} = 145 / 3 = 48.3 \text{ hours}$$

Maintenance personnel and machine operators were trained by explaining and demonstrating the operation of the control system. The fault finding procedure was provided to the maintenance personnel. See section 9.5 for fault finding procedure.

Very detailed conclusion given which summarises the design and implementation of the project

7.2 Evaluation

Figure 7.2 shows a summary of the criteria set out in the test planning procedure. As demonstrated in the analysis and evaluation section of each implemented system, all criteria relating to the airway height control system were met.

CRITERIA		YES	NO
Strip tension measurement	Is the resolution 0.01 KgF or better?	✓	
	Is the measurement range at least 0-10KgF?	✓	
	Is the accuracy 0.2 KgF or better?	✓	
	Is strip tension displayed to the user?	✓	
Strip tension control	Is strip tension control automated?	✓	
	Is strip tension maintained within ± 0.2 KgF of the set point value?	✓	
Airway height measurement	Is the accuracy of the measurement instrument less than 6 μ m?	✓	
	Is the resolution 6 μ m or less?	✓	
	Is airway height displayed to the user?	✓	
Airway height control	Is airway height control automated?	✓	
	Is airway height maintained at the set point value?	✓	
Timing	Has the project been completed within the time constraints?	✓	
Budget	Has the project been completed within the budgetary constraints?	✓	
Maintenance	Has fault finding procedure been provided?	✓	
	Has maintenance personnel been trained?	✓	
Reliability	Is mean time between maintenance greater than 40 hours?	✓	

Figure 7.2 - Test planning criteria

Although all criteria were satisfied and the project was completed within the timing constraints, the project completion was delayed by one week due to the necessity of the design and implementation of signal filtering, which was not considered during planning.

Good evaluation of project which compares all tests carried out to specification

7.3 Recommendations

7.3.1 Improve system response

As shown in Figure 6.39 the settling time of the airway height control system is 18 seconds. The response of the system could be further improved by increasing the proportional constant. This would allow both reducing the settling time and reduce the amount of scrap.

7.3.2 Worn pressure pads

Although the pressure pads used for applying force on the aluminium strip are subject to wear, the system does not detect excessively worn pressure pads that require replacement. This means that the existing system requires periodic unplanned maintenance. Introducing and monitoring the pneumatic pressure feedback from the electro-pneumatic regulator would enable the detection of excessively worn pressure pads. This could be achieved by displaying an alarm message to the user in order to prompt for the replacement of pressure pads. The alarming function could be mapped into the PID output in terms a limit of compensation.

7.3.3 Electro-pneumatic regulator fault

Monitoring the output signal of the pressure regulator, would make possible the detection of a faulty electro-pneumatic regulator. The output signal corresponds to the valve commanded pressure. When there is a deviation from the actual output pressure, an alarm could be activated to indicate electro-pneumatic regulator problems.

7.3.4 Tension control system not subject to wear

The pressure pads used for strip tension adjustment are subject to wear (section 7.3.2) and therefore require periodic maintenance. The need for periodic maintenance could be eliminated if an alternative strip tension system was used (i.e. speed or torque control). These were indicated in section 4.2.1 and section 4.2.2 of this report.

7.3.5 Energy saving

In order to reduce energy consumption an automatic shutdown feature could be added to the machine. In the event of the Machine not being run for a period of more than 15 minutes the pneumatic systems could be shut down and reactivated by pressing the control on or start button.

Very good recommendations noted showing understanding on what still could be improved within the system

7.4 Reflection

The work encompassed within this project has been a significant big learning curve from both a project management and application engineering point of view.

Research, planning and progress monitoring proved crucial for the completion of the project within the time constraints.

A good understanding in the approach to the practical application of a control system was experienced. These include instrument calibration, scaling of analogue signals and software considerations.

The issue of filtering was introduced later in the project and it was a good opportunity to examine and correct the effects of noisy signals.

Analogue and digital low pass filters were designed and tested in order to draw comparisons and understand the advantages and disadvantage of each type and therefore determine what applications each type is best suited.

Good reflection noted

8 CITATION LIST

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9 APPENDIX

9.1 Planning and Procedures

Figure 9.1 and Figure 9.2 show the project plan. Microsoft Project was used due its progress monitoring capability. The Gantt chart shows how each task was monitored. The planned tasks are shown with blue bards while the actual timing is shown by the red bars.

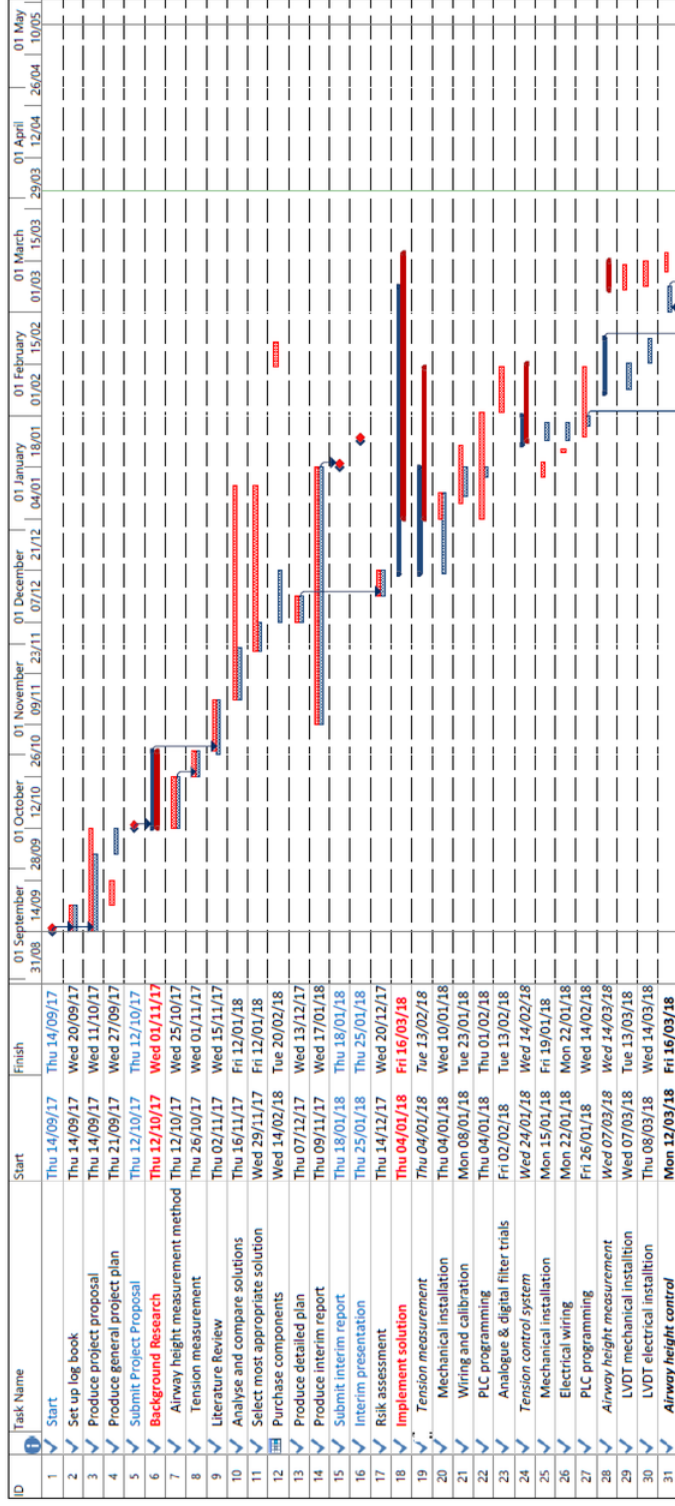


Figure 9.1 - Project plan (part 1)

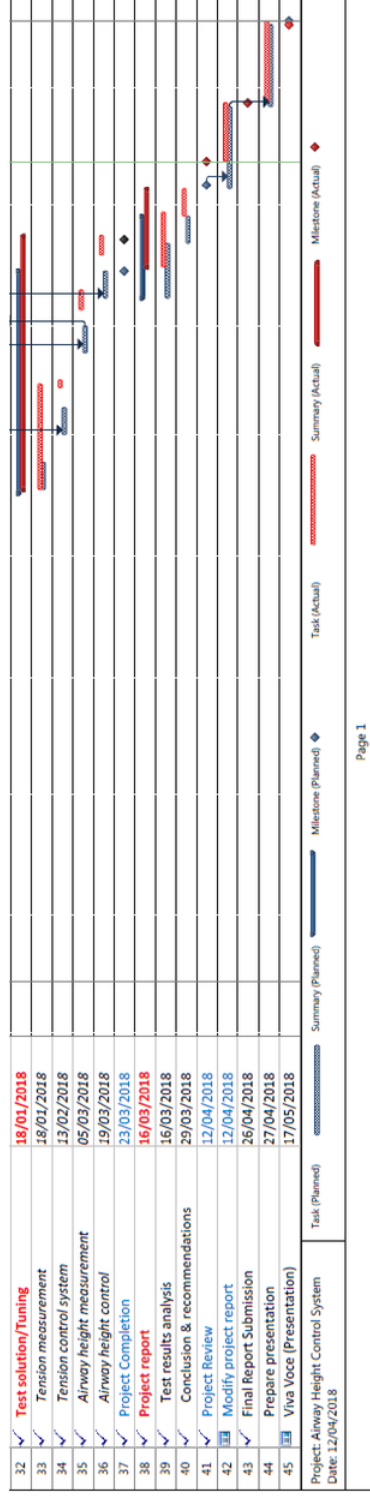


Figure 9.2 - Project plan (part 2)

Although the project was completed within the time constraints, the duration of some tasks, such as the literature review and the selection of the final solution, were underestimated. Time was recuperated by beginning the implementation of the solution ahead of plan since some components were available ahead of schedule.

The need of signal filtering was not considered during the planning stage of the project. During the implementation of both tension and airway height measurement systems, signal filtering was necessary in order to be able to implement the control systems. This caused the completion of the project to be delayed by one week. However, the project was still completed by April as stated in the specification.

Good explanations given as to why the actual Gantt chart did not fully follow that which was predicted

9.1.1 Work breakdown structure

Following is the work breakdown structure for the project that identifies all tasks that must be carried out in order to complete the project.

- 1 Set up log book**
- 2 Produce project proposal**
- 3 Produce general project plan**
- 4 Submit Project Proposal**
- 5 Background Research**
 - 5.1 Airway machine
- 6 Literature Review**
 - 6.1 Strip tension measurement
 - 6.2 Strip tension control
 - 6.3 Airway height measurement
 - 6.4 Airway height control
- 7 Analyse and compare solutions**
- 8 Select most appropriate solution**
- 9 Purchase components**
- 10 Produce detailed plan**
- 11 Produce interim report**
- 12 Submit interim report**
- 13 Interim presentation**
- 14 Risk assessment**
- 15 Implement solution**
 - 15.1 Tension measurement
 - 15.1.1 Mechanical installation*
 - 15.1.2 Wiring and calibration*
 - 15.1.3 PLC programming*
 - 15.1.4 Analogue & digital filter trials*
 - 15.2 Tension control system
 - 15.2.1 Mechanical installation*
 - 15.2.2 Electrical wiring*
 - 15.2.3 PLC programming*

- 15.3 Airway height measurement
 - 15.3.1 *Mechanical installation*
 - 15.3.2 *Electrical installation*
 - 15.3.3 *Calibration*
- 15.4 Airway height control
- 16 **Test solution/Tuning**
 - 16.1 Tension measurement
 - 16.2 Tension control system
 - 16.3 Airway height measurement
 - 16.4 Airway height control system
- 17 **Project Completion**
- 18 **Project report**
 - 18.1 Design
 - 18.2 Implementation
 - 18.3 Testing
 - 18.4 Results analysis
 - 18.5 Conclusion & recommendations
- 19 **Project Review**
- 20 **Amend project report**
- 21 **Final Report Submission**
- 22 **Prepare presentation**
- 23 **Viva Voce (Presentation)**

9.1.2 Contingency plans

Two contingency plans were drawn up following an analysis of the risks associated with the implementation of this project.

The purpose of the first plan was to guarantee continuity in the implementation of the project in the event where the equipment was not available due to production requirements. This plan enabled project completion within the time constraints.

The purpose of the second plan was to ensure that there was no disruption to the production process due to faults caused by software or hardware changes related to the implementation of the airway height control system.

9.1.2.1 Contingency plan 1

In the event of the equipment not being available due to production requirements, software changes will be implemented with the machine in operation.

9.1.2.2 Contingency plan 2

In order to minimise downtime caused by machine modifications and maintain production continuity both software and hardware changes will need recovery aspects.

A back up of the PLC software will be stored in a predefined location on the company network. The location will be communicated to the maintenance personnel so that in the event of issues caused by software previous revisions can be restored. Every back up revision of the software will also contain a brief description of the changes carried out.

In order to prevent disruption to production caused by hardware installation, where applicable - all devices fitted to the machine will included quick-change consideration.

9.2 Risk assessment

Figure 9.3 shows the core build risk assessment amended to include the airway height control system. All items were low risk and therefore no further action were required.

Assessors		Frequency				Likelihood				Severity				Low Risk 1-10	Med Risk 11-20	High Risk 21-30	This Risk level is the desired standard required by Calsonic																
		Occurs once or twice a year	Rare	1	Impact very unlikely to occur	Rare	1	Trivial	1	Occurs Monthly	Occasional	2	Impact possible but unlikely to occur					Low	2	Minor injury / First Aid given	Minor	3	Occurs Weekly / Daily / Part Shift	Frequent	3	Impact not certain but likely to occur	Medium	3	Significant injury, loss of 3 days work	Severe	4	Occurs Continually / Full Shift	Continual
Bruno Forkuoh Ian Williams Neil Jones		At this Risk level the process can carry on but action must be taken within four weeks to reduce the risk of injury.																															
		At this Risk level the process must stop and action must be taken to IMMEDIATELY reduce the risk of injury.																															
Cell / Area:		C6 Airway machine																				10/11/2017		Review Date:									
Item No.	Activity	Hazard	Who Might be Harmed	Existing control measures				Frequency (F)	Likelihood (L)	Severity (S)	Risk Rating Fx L x S = R		Supporting Information		Further actions required																		
1	Airway Coil Change	Potential cuts from sharp edges of aluminium strip	Operator	Operator to wear relevant PPE (i.e. safety gloves)				3	2	2	12																						
2	During the replacement of the coil the operator manually feed the strip under the tension roller.	Risk of finger trap between aluminium strip and tension load cell roller	Operator	Pneumatic regulator output is disabled once the guard is open to feed the strip under the tension roller. No tension in the strip and therefore the operator cannot be hurt				3	1	1	3																						
3	During the replacement of the coil the operator manually feed the strip under the tension roller.	Risk of finger trap between pressure pads.	Operator	Pneumatic regulator output is disabled once the guard is open to feed the strip under the tension roller. No tension in the strip and therefore the operator cannot be hurt				3	1	1	3																						
4	General Environment	Potential of injuries from trip or slip hazards, poor lighting levels, extremes of temperature, excessive noise levels or vibration.	All	The area isn clear of trip hazards. Lighting levels are good with local lighting on the machine build area and overhead lighting. There is a fan sited at the build area and general ventilation in the area is good. Overhead heating is provided during cold weather. There is no significant vibration generated. Noise levels are moderate but will require checking during normal production conditions in the surrounding vicinity.				4	2	2	16																						

Figure 9.3 - Risk assessment

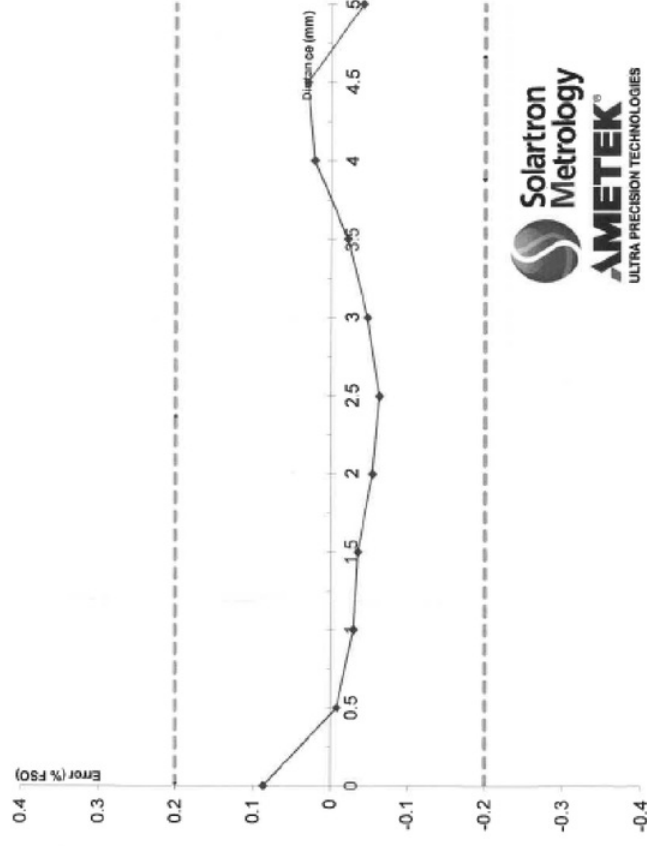
9.3 LVDT Calibration Certificate

Calibration Certificate

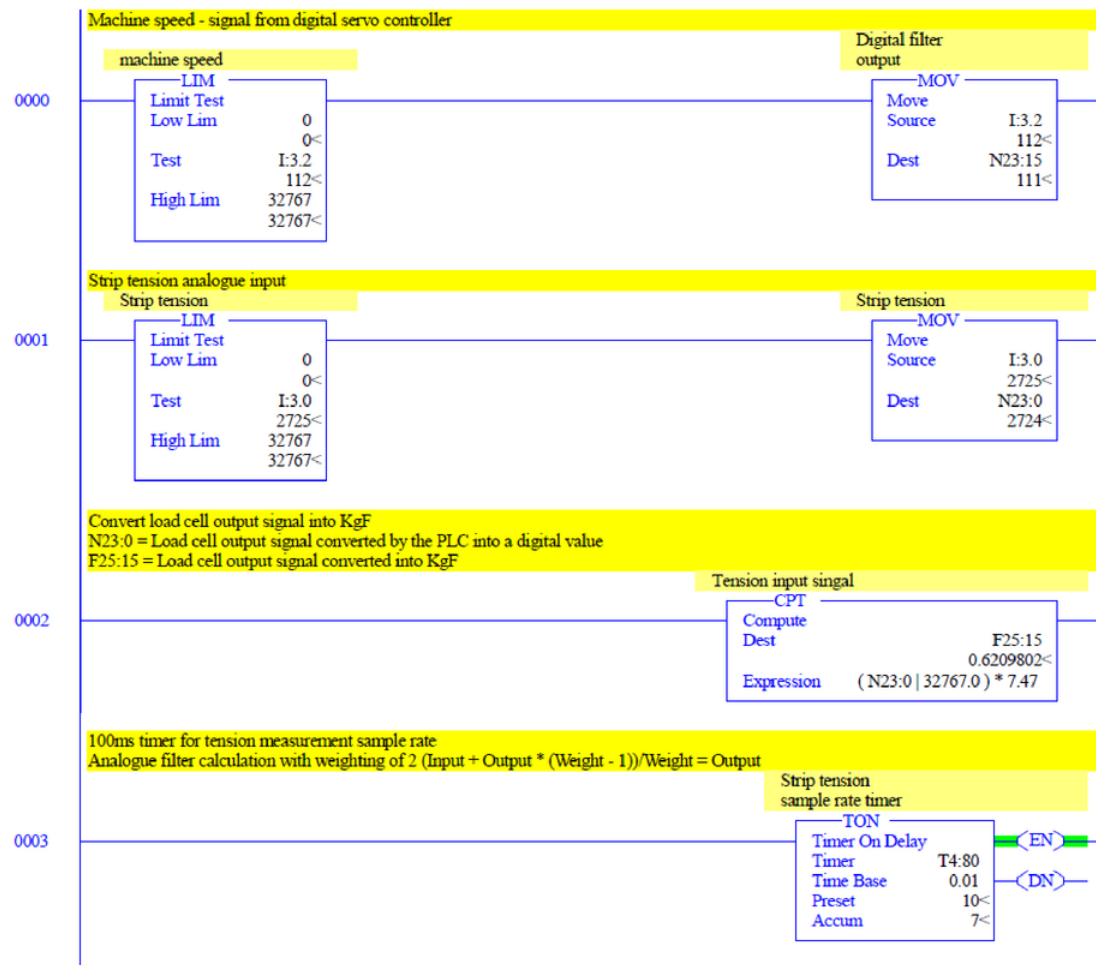
Probe SNo: M931140BK24-02
 Probe Part No: 931140
 Probe Type No: G/S/S
 Date: 20/06/17,08:25
 Operator: R.FAKE

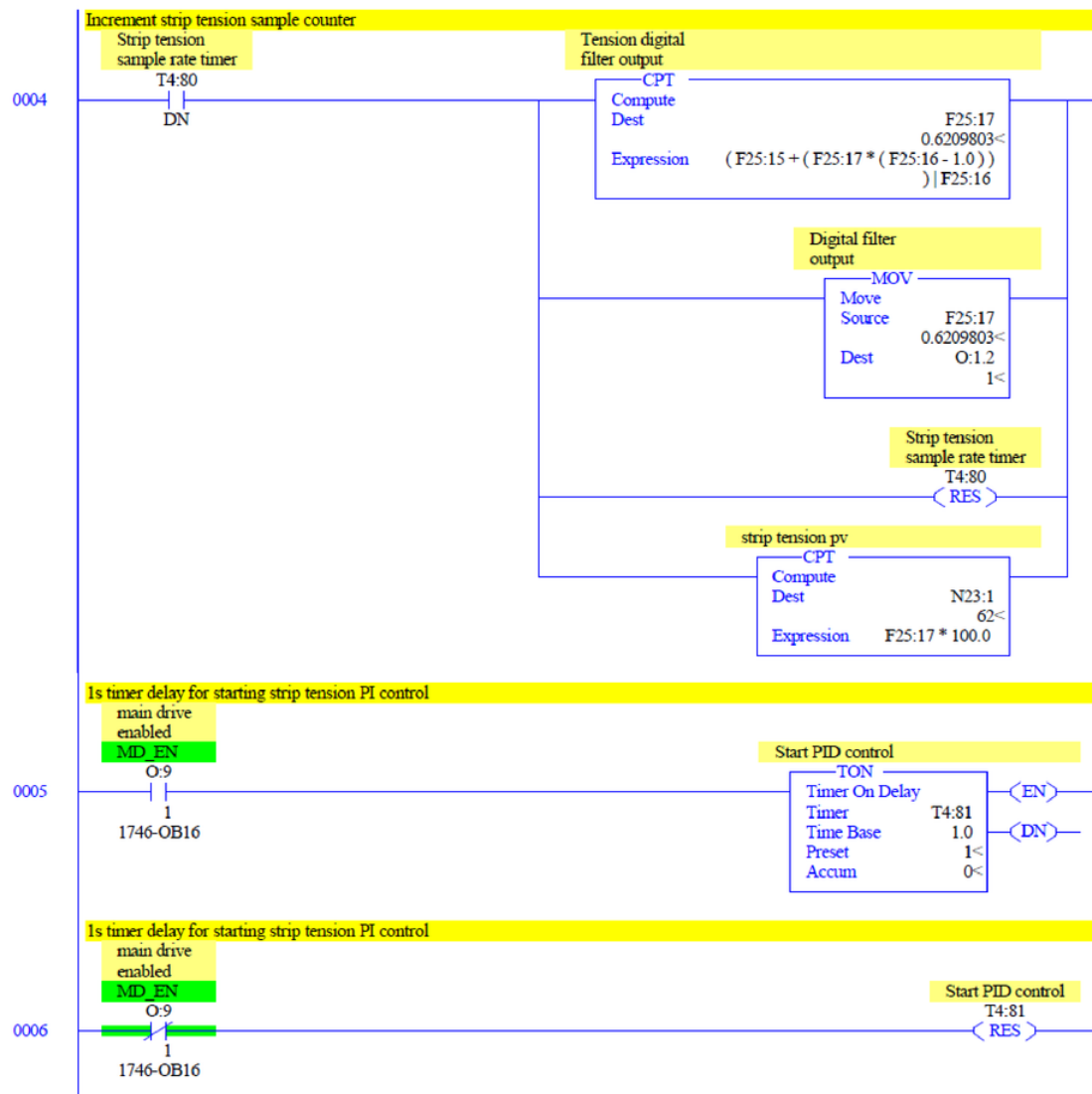
Fixture: CAL01-DT3_V4.4
 Position Reference: 3687
 DIMM Ser No: 2732
 Test Equipment: 2368
 Max Error: 0.087 % Full Scale

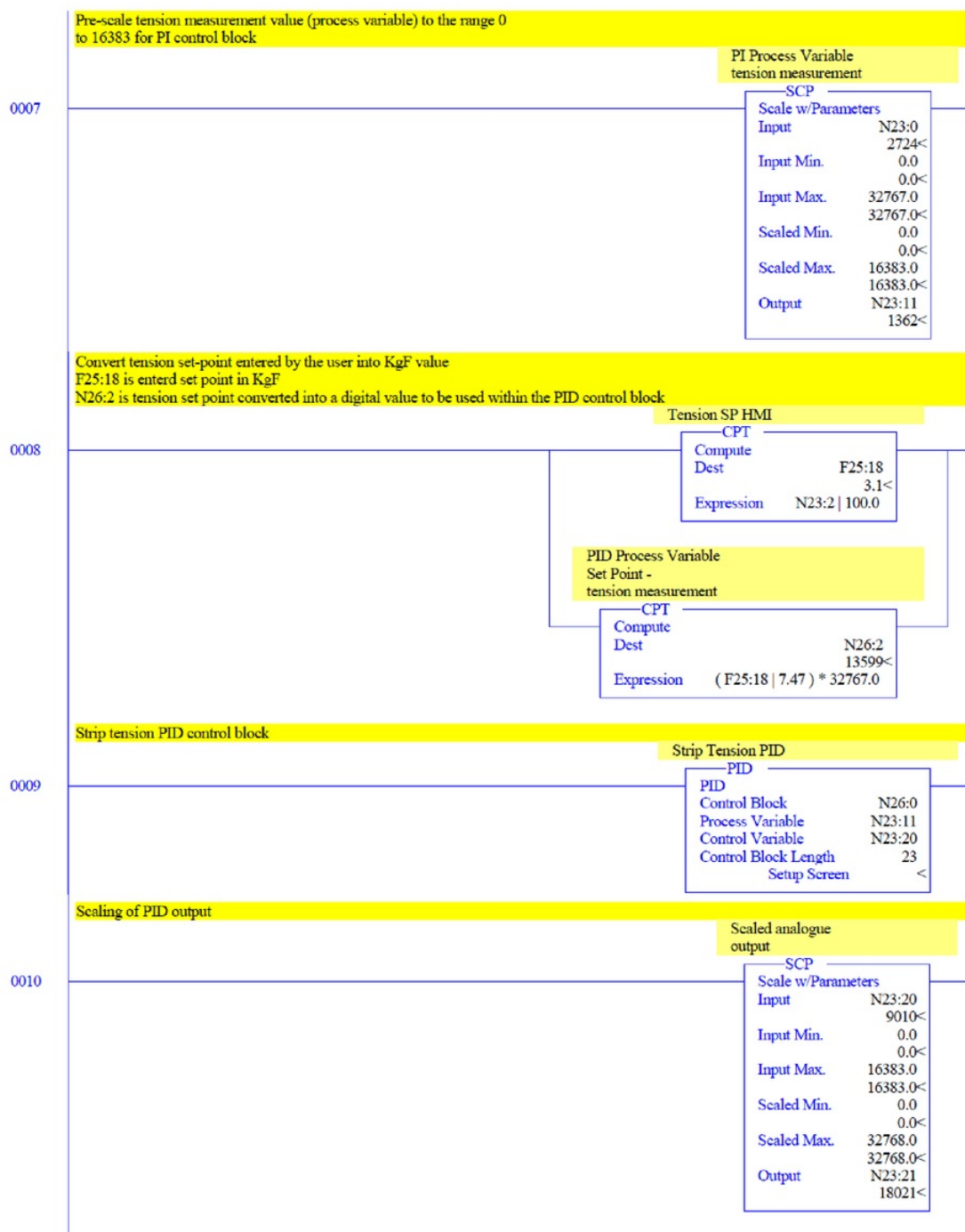
Position (mm)	Output (mV)	Error (% FSO)
0.000	4.0139	0.087
0.500	5.5987	-0.008
1.000	7.1952	-0.030
1.500	8.7943	-0.036
2.000	10.3913	-0.055
2.500	11.9899	-0.063
3.000	13.5923	-0.048
3.500	15.1964	-0.023
4.000	16.8033	0.021
4.500	18.4048	0.030
5.000	19.9932	-0.042

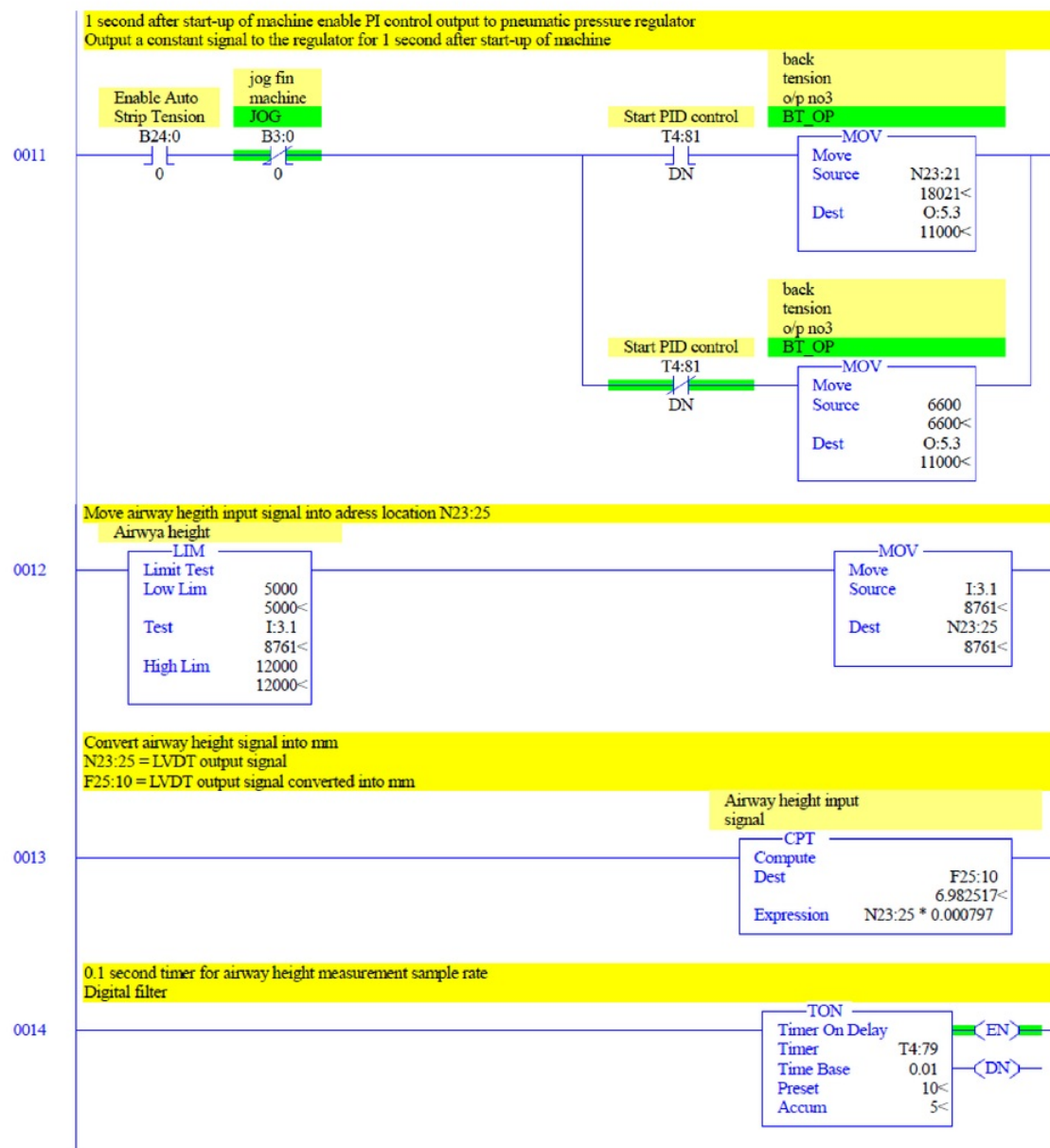


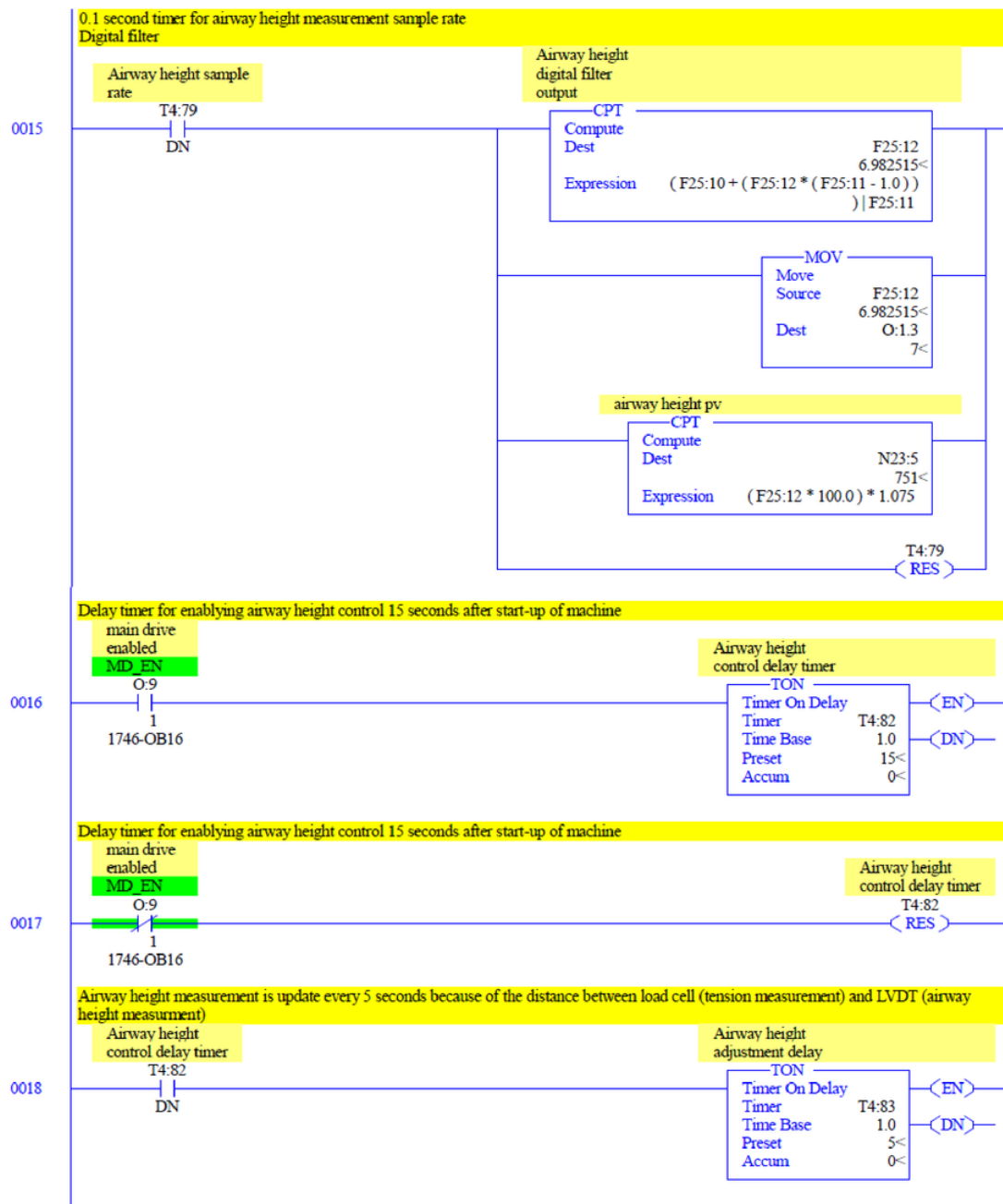
9.4 PLC Program

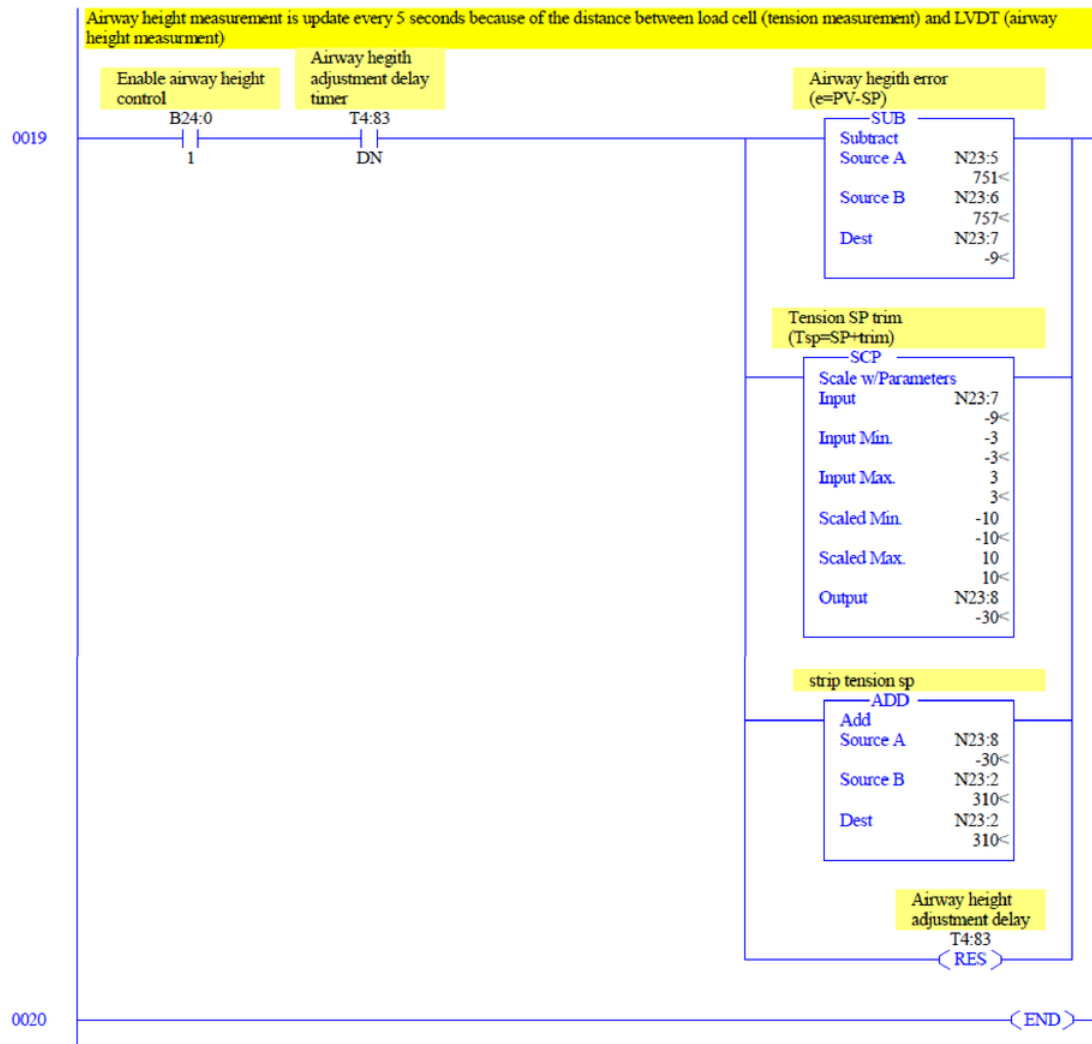












Full PLC program shown and documented which shows understanding on how the PLC controlled and indicated strip tension and airway height

9.5 Fault finding procedure

Problem	Possible Cause(s)	Remedy
Pneumatic pressure too high	Worn pressure pads	Replace pressure pads
Tension cannot reach set point	Worn pressure pads	Replace pressure pads
Airway height outside control limits	LVDT not set-up correctly	Set up LVDT using slip gauges
Unable to set up LVDT	Worn mechanical support structure / probe	switch airway height control to manual mode / replace mechanical support structure
	LVDT failure	Replace LVDT
Tension control system not functioning correctly	Faulty pneumatic regulator	Replace pneumatic regulator
No tension feedback	Faulty load cell	Replace load cell
	Loose cable	Check cables in junction box and control panel
	Strip fed incorrectly	Feed aluminium strip under tension roller

Very helpfull in terms of operator fault finding

Final Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

77/100

PAGE 1

PAGE 2

Text Comment. Very detailed abstract given which clearly shows the scope of the project

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

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PAGE 9

PAGE 10

PAGE 11

PAGE 12

Text Comment. Very good detail on how the airway height is adjusted manually at present and what the problems are with operator interfacing

PAGE 13

Text Comment. Excellent detail showing the existing system

PAGE 14

PAGE 15

Text Comment. Very good explanation of how the system functions before the project implementation

Text Comment. Clear indication of how the project will automatically alleviate the operator interface for strip tension and measure airway height

Text Comment. General specification for height control & measurement and tension control & measurement clearly stated

Text Comment. Maintenance & reliability issues noted within the specification

Text Comment. Test table noted on how the system is to perform with realistic criteria set

Text Comment. Strip tension measurement & control research carried out to a very good standard with a reasoned choice made as to which system to take forward

PAGE 36

PAGE 37

PAGE 38

Text Comment. Airway height measurement research carried out to a very good standard with a reasoned choice made as to which system to take forward

PAGE 39

PAGE 40

PAGE 41

Text Comment. Good detail related to safety, sustainability, professionalism and environment

PAGE 42

PAGE 43

PAGE 44

PAGE 45

Text Comment. Excellent detail on the use of a low pass filter within a PLC program

PAGE 46

PAGE 47

PAGE 48

Text Comment. Good

PAGE 49

PAGE 50

Text Comment. Implementation of strip tension measurement clearly shown

PAGE 51

PAGE 52

PAGE 53

PAGE 54

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PAGE 58

PAGE 59

PAGE 60

Text Comment. Excellent, very detailed testing carried out on automated tension control which showed great understanding on how PID looping can be used successfully in PLC programming

PAGE 61

PAGE 62

PAGE 63

Text Comment. Good detail on how the PLC filters the airway height measurement from the LVDT

PAGE 64

Text Comment. Excellent detail

PAGE 65

PAGE 66

Text Comment. Excellent detail

PAGE 67

Text Comment. Comparison made to specification shows the airway height measurement meets criteria set.

PAGE 68

PAGE 69

PAGE 70

Text Comment. Excellent graphical analysis shown that clearly shows airway height being controlled via strip tension

PAGE 71

PAGE 72

Text Comment. Again, good comparison back to specification

Text Comment. Very detailed conclusion given which summarises the design and implementation of the project

Text Comment. Good evaluation of project which compares all tests carried out to specification

Text Comment. Very good recommendations noted showing understanding on what still could be improved within the system

Text Comment. Good reflection noted

Text Comment. Extensive list of citations noted

Text Comment. Good explanations given as to why the actual Gantt chart did not fully follow that which was predicted

Text Comment. Full PLC program shown and documented which shows understanding on how the PLC controlled and indicated strip tension and airway height

Text Comment. Very helpfull in terms of operator fault finding

GRADING FORM: MAJOR PROJECT 2017_18

BRUNO FORKUOH

77

RESEARCH (20%)

Research Informed Literature: 1. Abstract, acknowledgements, introduction and setting out of aims and objectives. (/20) 2. Background research, setting the context of the project, statement of user or customer needs. (/30) 3. Literature review, solutions considered and choice made. (/40) 4. Use of Harvard Referencing for citing and listing sources. (/10)



1. Very detailed abstract given which clearly shows the scope of the project. Very good detail on how the airway height is adjusted manually at present and what the problems are with operator interfacing. (15) 2. Very good explanation of how the system functions before the project implementation. Clear

16

indication of how the project will automatically alleviate the operator interface for strip tension and measure airway height. (24) 3. Strip tension measurement and control and airway height research carried out to a very good standard with a reasoned choice made as to which systems to take forward. (33) 4. Extensive research noted in literature review and throughout the report with citations correctly referenced. (8)

KNOWLEDGE (20%)

Knowledge & Understanding of Subject: 1. Specification, design requirements and project outcomes, time and financial constraints. (/30) 2. Test planning and procedures. (/20) 3. Formal project planning and identification of milestones. (/25) 4. Consideration of maintenance and reliability. (/25)



1. General specification for height control & measurement and tension control & measurement clearly stated. Time & Budgetary constraints are realistic. The design shown for each system is extensive and well developed. (23) 2. Test table noted on how the system is to perform with realistic criteria set. (14) 3. Good explanations given as to why the actual Gantt chart did not fully follow that which was predicted. Good WBS noted. Contingencies shown which were realistic (20) 4. Maintenance & reliability issues noted within the specification. (16)

14.6

ANALYSIS (20%)

Analysis: 1. Evaluation of Implementation stage, monitoring of progress and milestone activities. (/20) 2. Testing & test results. (/30) 3. Comparison of project outcomes to specification. (/20) 4. Conclusions, recommendations and reflections. (/30)



1. The implementation stage has been shown in great detail for tension and airway height control and measurement. Excellent graphical analysis clearly shows airway height being controlled via strip tension. (16) 2. Excellent, very detailed testing carried out throughout the report which showed great understanding on how PID looping and digital filtering can be used successfully in PLC programming. (25) 3. Comparison made to specification shows the airway height control / measurement and strip tension control / measurement meet the criteria set. (17) 4. Very detailed conclusion given which summarises the design and implementation of the project. Good evaluation of project. Very good recommendations noted showing understanding on what still could be improved within the system. Some reflection noted on what has been learned. (25)

16.6

PRACTICAL APPLICATION (20%)

Practical Application & Deployment: 1. Quality, innovation and creativity of design solution. (/20) 2. Implementation stage, working independently with limited supervision. (/30) 3. Meeting customer or user needs, fitness of solution to purpose, working within time and financial constraints. (/20) 4. Log book. (/30)



1. Design of systems for airway height / control and strip tension measurement / control shows excellent creativity and innovation. Program not fully explained. (15) 2. The implementation stage shows the students understanding of all aspects of design and all tests carried out with limited supervision. (25) 3. The specification clearly showed the requirements of the system to be implemented and the evaluation showed the criteria had been fully met. Budgetary and time constraints were kept within limits. (17) 4. Log book shows clearly how the

15.8

project was developed over the time allocation given. Very good detail throughout.(22)

PROFESSIONAL PRACTICE (20%)

Skills for Professional Practice: 1. Professionalism and ethical conduct. (/25) 2. Health and safety, assessment of risk. (/25) 3. Sustainability and environmental protection.. (/25) 4. Presentation and organisational quality of report. (/25)



1. Good detail related to professionalism shown in Section 5. (16) 2. Good detail related to safety shown in Section 5. Full risk assessment shown in appendix. (16) 3. Good detail related to sustainability and environment protection shown in Section 5. (16) 4. The structure of the report was good and flowed well. Use of pictorial evidence and screen dumps of tests carried out were very clear and enhanced the reader's ability to understand the project concepts. (22)

14