final report

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Prototype automated beef shackling tool

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Contents

Scope

This report details the conclusion of all milestone two and milestone three outcomes for the Beef Shackling Tool project, including the details of the prototype constructed, results of the trial and the way forward for this area of research and development.

1.1 Design Objective

As part of the slaughtering process at many meat processing plants the beast is hoisted up onto a bleed roller for processing. In order to do this a shackle, as shown in **Figure 1**, is applied to the beast's rear leg by an operator. This takes place shortly after the beast has been stunned and the legs are still flailing. As discussed in the document MLA-ABST-M1 manual shackling can have many drawbacks; from slow cycle times due to the operator waiting for the leg to stop kicking, to OH&S issues arising from operators working within the kicking range of the beast. The design of the Automated Beef Shackling Tool aims to improve upon this method of manual shackling by removing the operator from the danger zone and increasing the consistency and reliability of the shackle application.

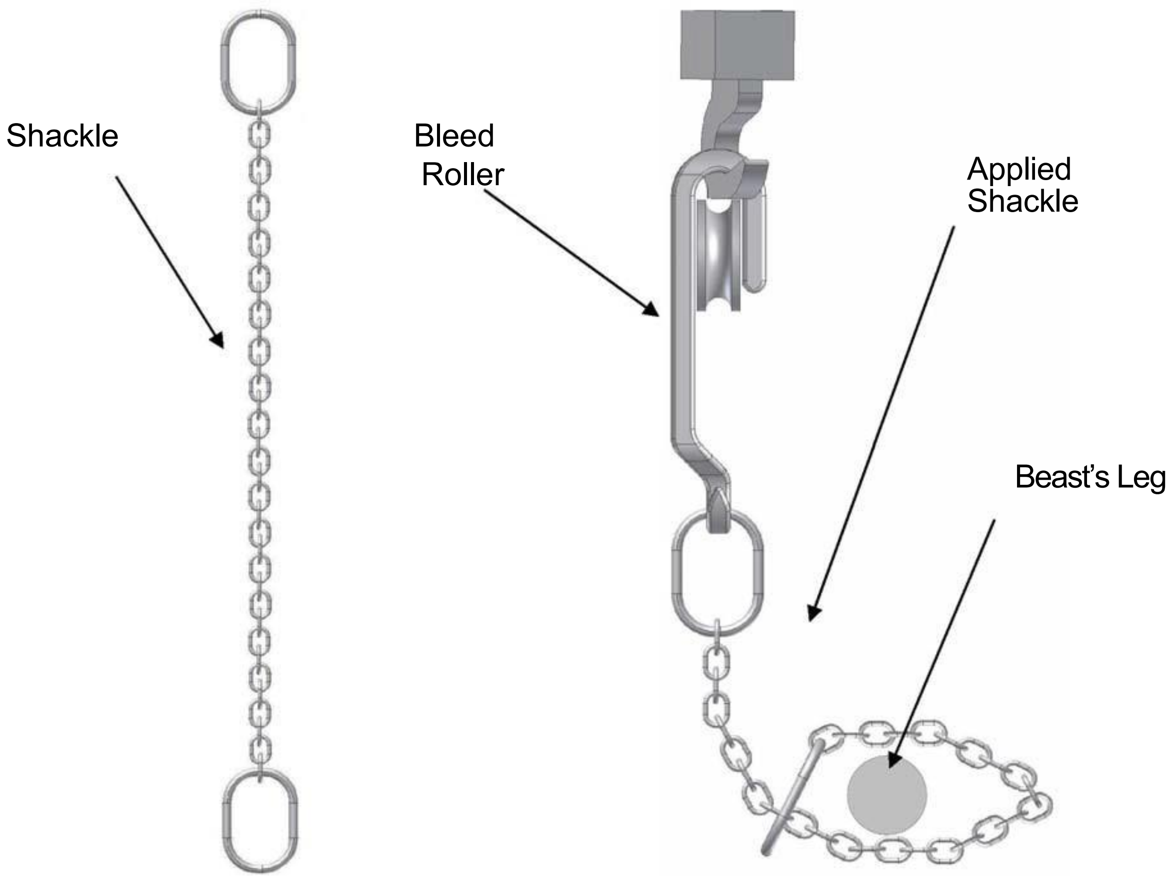

Figure 1: Loose Shackle (Left), Shackle applied to beast's leg & hooked onto Bleed Roller (Right)

1.2 Design Overview

A simple top level design overview for the Automated Beef Shackling Tool is shown in **Figure 2**. Further detail is given following the figure. These design blocks will also be discussed in further depth in the following sections of this report.

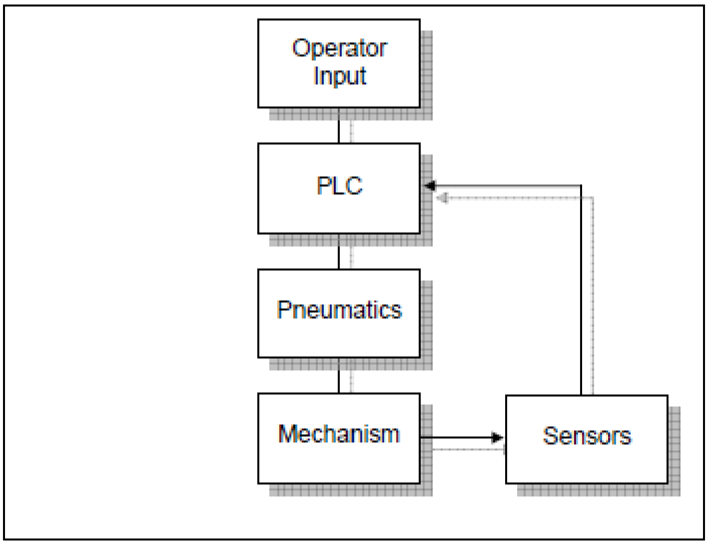

Figure 2: Top level design overview

The operator controls the device via two buttons on the grips. This then sends signals to the PLC (Programmable Logic Controller) which controls the pneumatics of the system. The pneumatics in turn moves the mechanism to complete the task.

2 Mechanism

Illustrated below is a simplified view of the Automated Beef Shackling Tool (**Figure 3**) subtracting the components not directly related to the mechanical operation of the device.
The components indicated in the figure and their relationships will be discussed in more detail in the sections that follow:

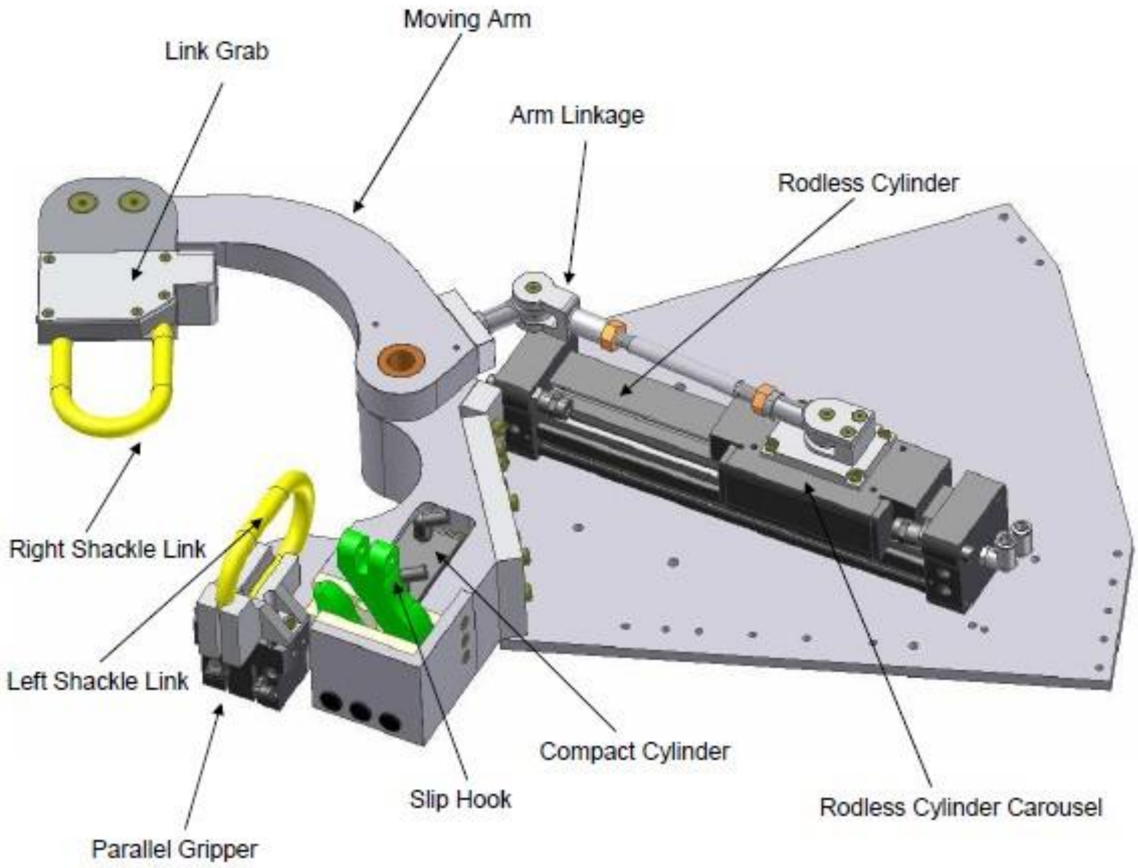

Figure 3: Automated Beef Shackling Tool; Simplified View

2.1 Slip Hook

As seen in **Figure 4** the Slip Hook nests in a nylon recess and is held in place by the shaft of the Compact Cylinder. When the shackling process has been completed, the Compact Cylinder Shaft retracts to release the Slip Hook.

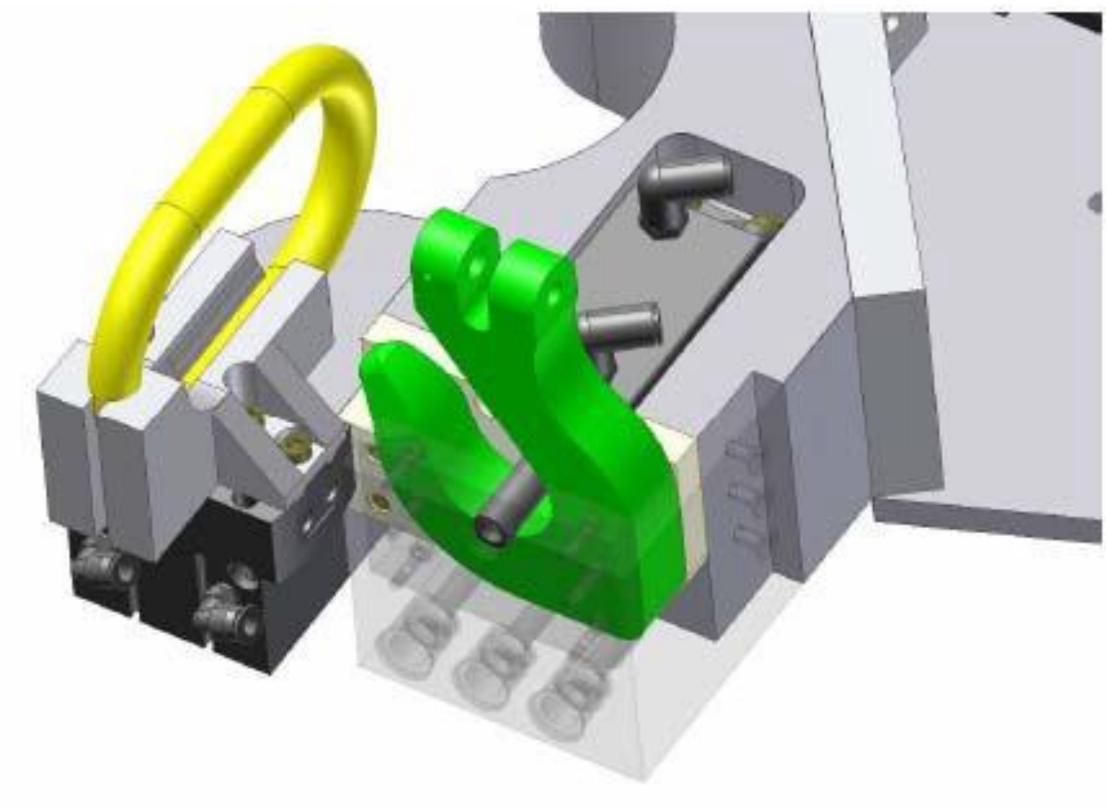

Figure 4: Slip Hook & Compact Cylinder and Left Shackle Link & Parallel Gripper (some detail hidden for clarity)

The Slip Hook itself is part of a Modified Bleed Roller Assembly as shown in **Figure 5**. This Modified Bleed Roller incorporates a chain to allow the slip hook enough freedom to move with the tool while sitting snugly in the nest. The spring is used to tension the chain when the slip hook is secured by the compact cylinder. When the beast’s leg has been shackled and the slip hook is released this spring helps hold the shackle tight around the leg.

Figure 5: Modified Bleed Roller Assembly

2.2 Left Shackle Link

Figure 4 also demonstrates how the Left Shackle Link is held in place by the Parallel Gripper. Once again when the shackling operation has finished the Parallel Gripper will release the Shackle Link.

2.3 Right Shackle Link

The Right Shackle Link is held in place by a spring loaded Link Grab as illustrated in **Figure 6**. The Link Grab is sprung with enough force to hold the Right Shackle Link in place but is weak enough so that when the shackle has been run around the leg it is wrenched free by the action of hoisting the slip hook

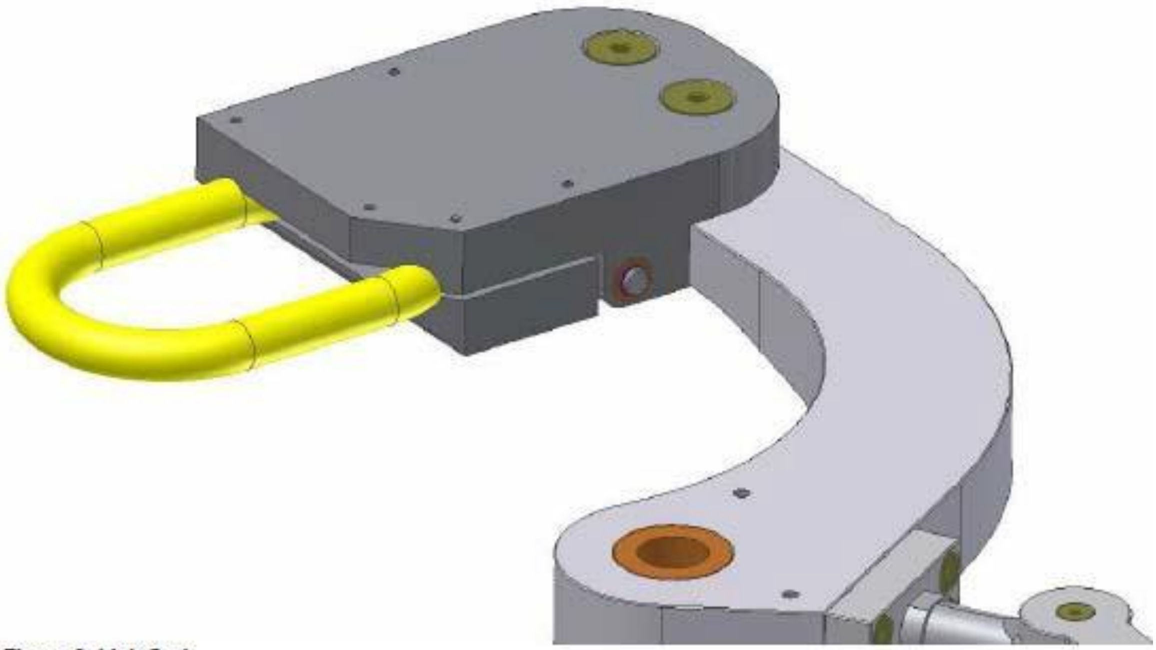

Figure 6: Link Grab

2.4 Moving Arm

The motion of the Moving Arm is controlled by the Rodless Cylinder via a jointed Arm Linkage. As the Rodless Cylinder Guide Moves up and down the length of the Rodless Cylinder the Arm Linkage rotates the Moving Arm about its pivot point. This is illustrated in **Figure 7** and **Figure 8**.

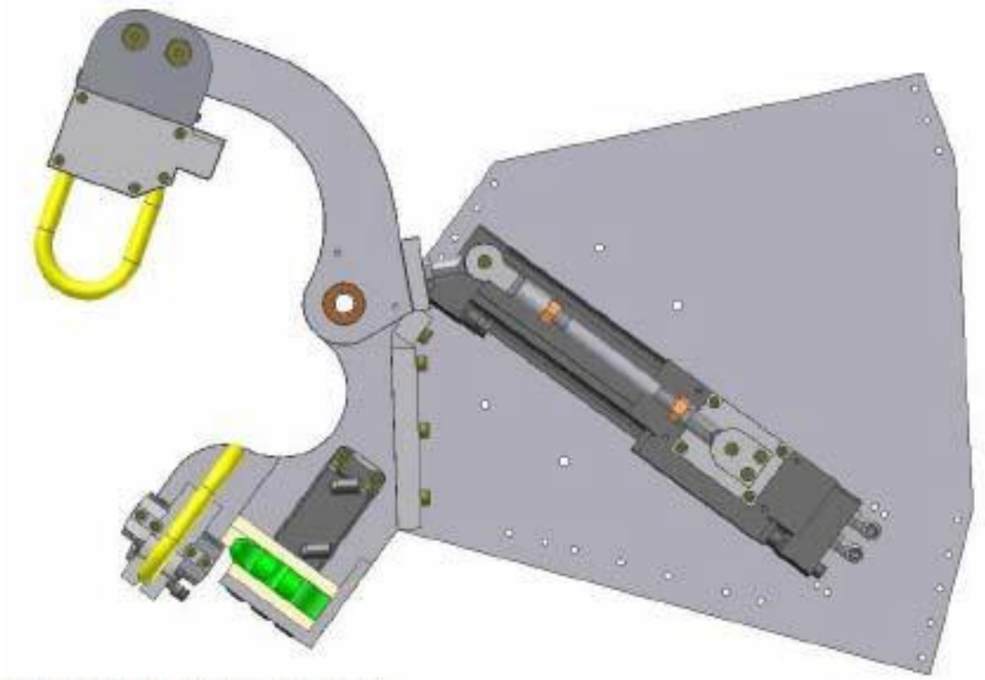

Figure 7: Moving Arm in open position

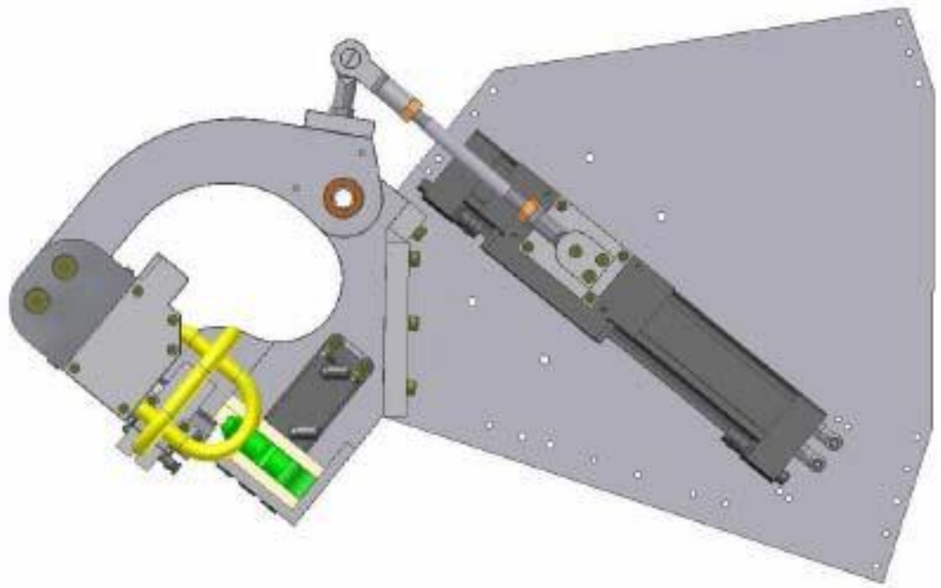

Figure 8: Moving Arm in closed position

3 Pneumatics

The pneumatic system provides the actuation for the mechanical parts of the tool. It includes regulation of the air pressure, flow control, the actuators that move the various mechanical parts of the device and the tubing & connectors that link them all together. It should be noted that a source of compressed air is required for any application of the Beef Shackling Tool.

Figure 9, together with the detailed descriptions that follow, outlines the functionality of the pneumatic system.

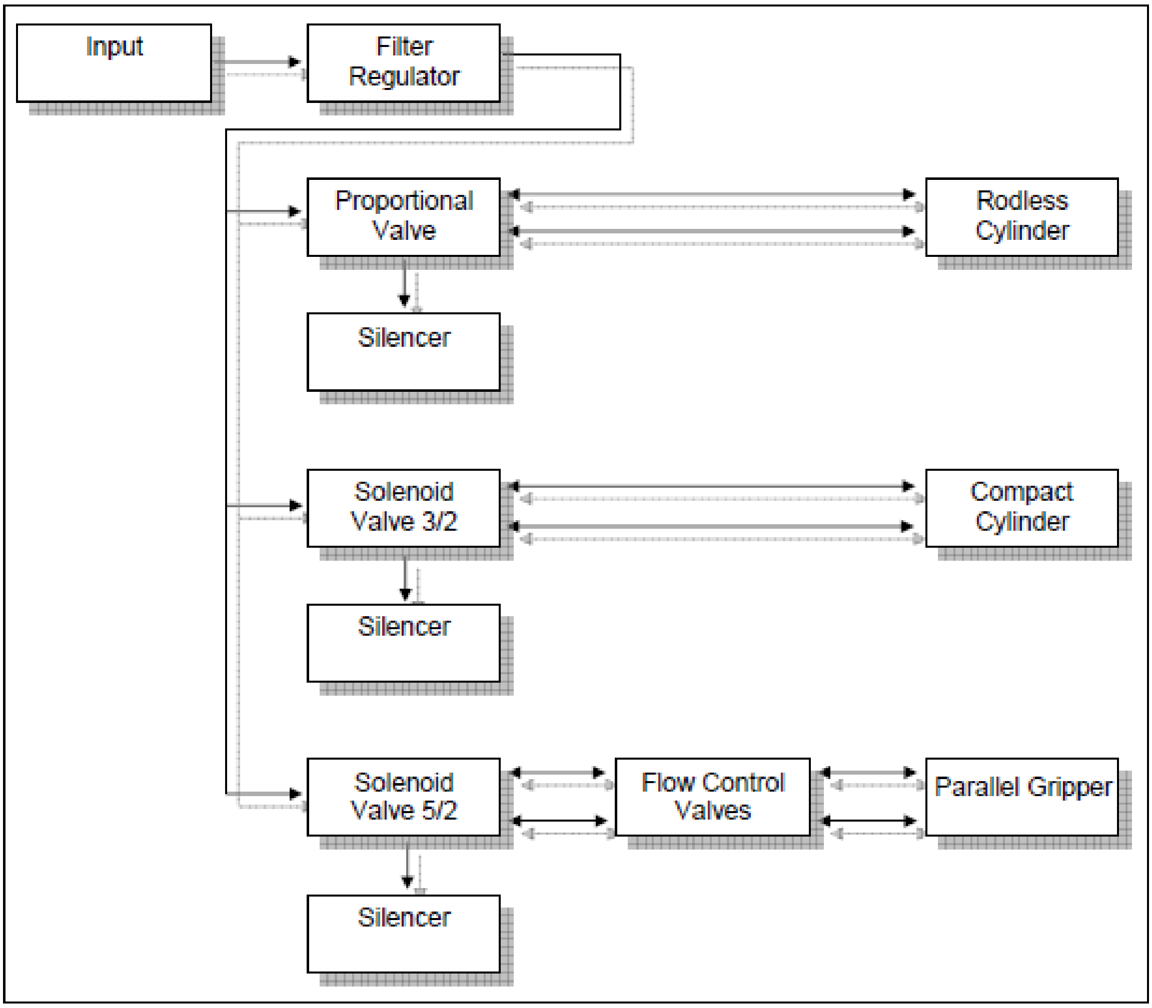

Figure 9: Pneumatic System. NB: arrows represent direction of air flow

3.1 Input

This is simply any air supply compressed to at least 6 Bar and supplied to the Isolation Valve (**Figure 10**) via an 8mm hose. It is preferable that the supplied air is clean and dry. The Isolation Valve allows the air supply to be shut off independently of the Filter Regulator so the working pressure does not need to be reset every time the unit is turned off or disconnected from the air supply.

3.2 Regulation

The Filter Regulator (**Figure 11**) reduces the pressure of the air supply to the desired working pressure which the components in the system can use. It also has the job of removing any contaminants such as water, dust or oil from the air supply so as not to damage or increase wear or corrosion on any of the other components.

Figure 10: Isolation Valve

Figure 11: Filter Regulator

3.3 Proportional Valve

The Proportional Valve (**Figure 12**) takes an input of compressed air and directs it to two ports based on an analogue electrical signal from the Control System. The returned air is expelled via the exhaust port.
The analogue signal from the Control System ranges between zero and ten volts. When a voltage of five volts is applied to the Proportional Valve air is not allowed to flow in either direction from either Port A or Port B. If the voltage applied is between zero and five volts air is allowed to flow out of Port A and in to Port B, as seen in **Figure 13**. The closer the applied voltage is to zero, the more air is allowed to flow. If the voltage is between 5 and 10 volts the direction of flow on the two ports is reversed as in **Figure 14**. In this case the closer the voltage is to ten volts the more air is allowed to flow.

Figure 12: Proportional Valve

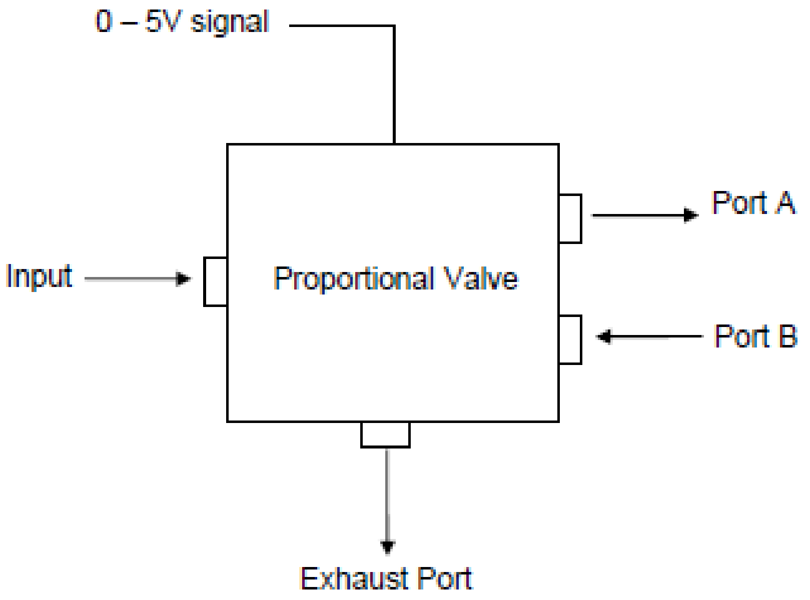

Figure 13: Proportional Valve with 0 – 5V signal applied

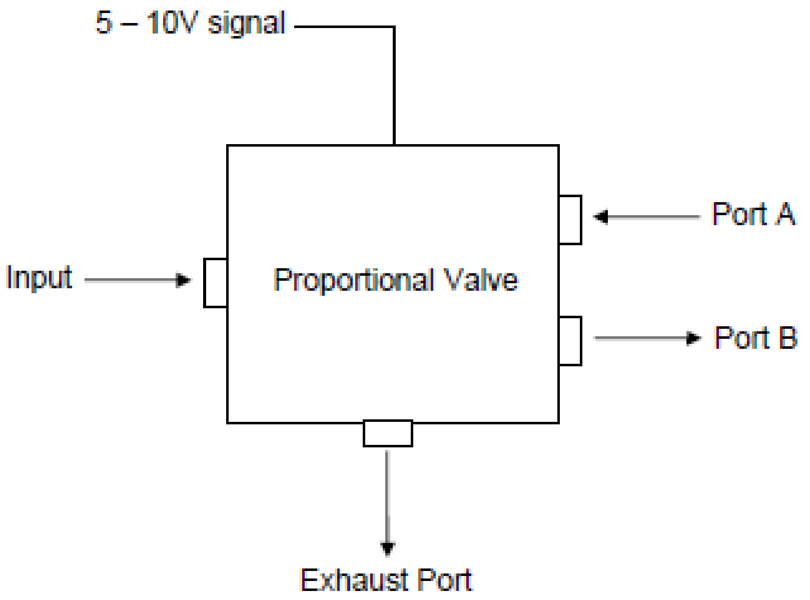

Figure 14: Proportional Valve with 5 – 10V signal applied

3.4 Rodless Cylinder

The Rodless Cylinder's (Figure 15) two chambers are connected to the two input/output ports of the proportional valve. The Rodless Cylinder moves a carousel up and down a slide. The direction of travel depends on which of its two input/output ports are intake or exhaust and the speed at which it operates is due to the amount of flow across the two ports.

Figure 15: Rodless Cylinder

3.5 Solenoid Valve

The Solenoid Valves (Figure 16) take an input of compressed air and direct it to two ports based on digital electrical signals from the Control System. The returned air is then exhausted via the exhaust port. In this regard the Solenoid Valve acts similar to the Proportional Valve only without the added feature of electrical flow control.

Figure 16: Solenoid Valve

Of the two Solenoid Valves used one is of the type 5/2 and the other 3/2. These two different types behave very similarly with the only difference being that the 5/2 variety, in addition to directing flow to it's two ports, can also seal off both ports so as to not allow flow in either direction through either port.
The signals from the PLC are digital values with zero volts representing a digital low (0) and twenty four volts representing a digital high (1). The following truth tables (**Figure 17**) detail all possible digital inputs and the corresponding action of the valve.

5/2 Solenoid Valve		
Input 1	**Input 2**	**Action**
0	0	No Flow
0	1	Flow Through Port 1
1	0	Flow Through Port 2
1	1	Undefined (No Change)

3/2 Solenoid Valve		
Input 1	**Input 2**	**Action**
0	0	Undefined (No Change)
0	1	Flow Through Port 1
1	0	Flow Through Port 2
1	1	Undefined (No Change)

Figure 17: Solenoid Valve truth tables

3.6 Flow Control Valves

The Flow Control Valves (Figure 18) are used to control flow manually where the amount of flow to the actuator needs to be set only once to calibrate the speed of the actuator.

Figure 18: Flow Control Valve

3.7 Compact Cylinder

The Compact Cylinder (Figure 19) is an actuator that takes an input from a solenoid valve, extending or retracting a shaft depending on the direction of flow across its two input/output ports. As the design requires this actuator to be fast acting no flow control is used.

Figure 19: Compact Cylinder

3.8 Parallel Gripper

The Parallel Gripper (**Figure 20**) is an actuator that takes an input from a solenoid valve via flow control valves. Depending on the flow across its two input/output ports the Parallel Gripper will close or open two parallel mounting plates.

Figure 20: Parallel Grippe

3.9 Silencers

Silencers (**Figure 21**) are placed wherever air is exhausted to atmosphere to help reduce the operating noise of the device.

Figure 21: Silence

4 Electrical

All electrical components used in the Automated Beef Shackling Tool require 24Volt DC power. As the supplied power is 240Volt AC a 24Volt DC output, 48W transformer (Figure 22) has been used to supply power to the tool.

Figure 22: 24Volt DC Power Supply

The electrical components that the transformer supplies 24VDC to are as follows:

- PLC
- Incremental Encoder
- Ultrasonic sensor
- Solenoid valves
- Proportional valve

4.1 Incremental Rotary Encoder

As shown in (Figure 23), an Incremental Encoder has been used to determine the position of the stationary arm at all times. This ensures that the Moving Arm is fully closed before the Slip Hook is released as well as providing feedback on the position of the arm to the control system for controlled closing. The chosen encoder is of a robust design with an IP66 environment rating, making it suitable to the intended operating environment.

Figure 23: Incremental Encoder

As detailed below in Figure 24 the encoder is mounted on the axis of the Moving Arm and the Stationary Arm allowing it to read the rotational position of the Moving Arm.

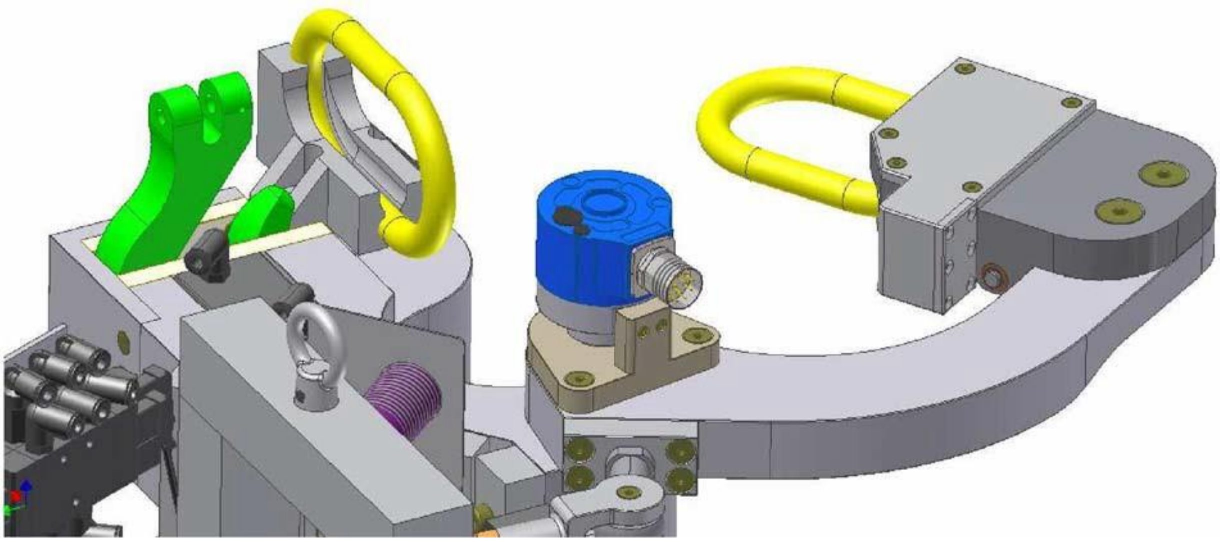

Figure 24: Encoder mounting on Automated Beef Shackling Tool

4.2 Ultrasonic Sensor

The presence of the beast's leg as it enters the tool is detected by an Ultrasonic Sensor (Figure 25) mounted on the body of the tool as shown in Figure 26.

The principle of ultrasonic measurement using sound waves means that the sensor can detect virtually all materials regardless of colour or texture, without being affected by dust laden air or liquid mists.

The Ultrasonic Sensor chosen was designed for operation in harsh environments and hence carries an IP67 rating.

Figure 25: Ultrasonic sensor

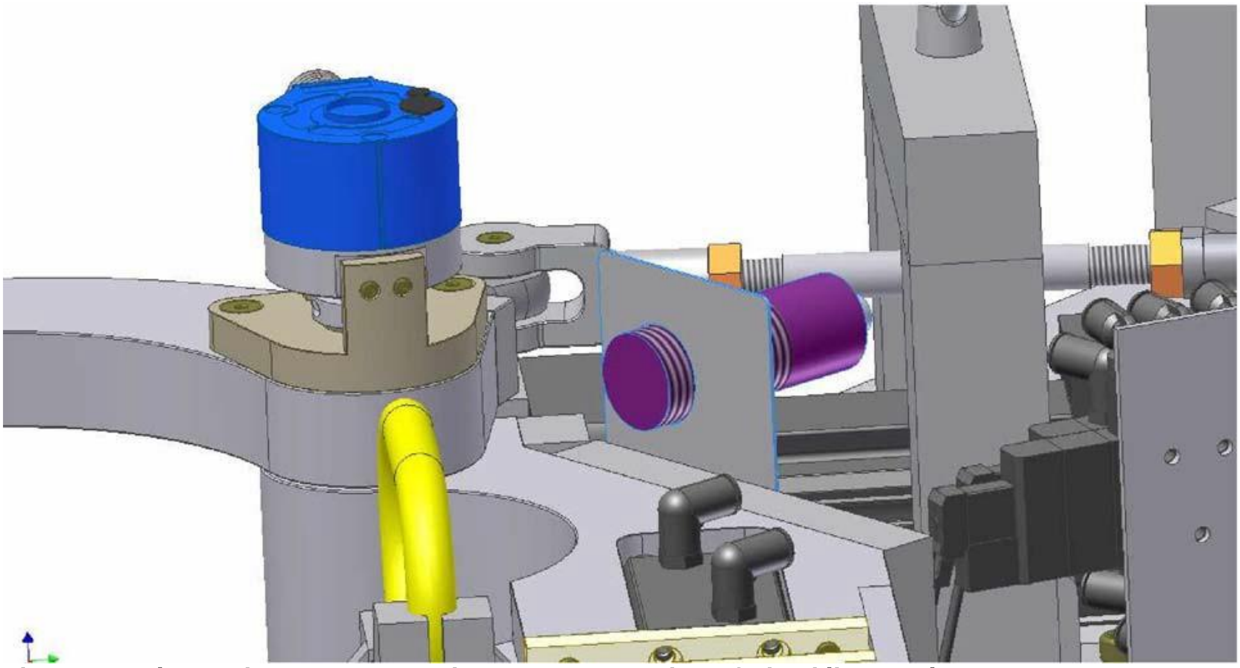

Figure 26: Ultrasonic Sensor mounting on Automated Beef Shackling Tool

5 Control System

The Control System is facilitated by a PLC (Programmable Logic Controller) (Figure 27) which interfaces between the mechanical and electrical parts of the tool. It controls the flow of air in the Proportional Valve & Solenoid Valves and receives the sensing information from the Incremental Encoder & Ultrasonic Sensor.

The PLC chosen has the following required functions:

- analogue output
- analogue input
- digital input
- digital output
- LCD Display

Figure 27: Unitronics PLC

The diagram below (Figure 28) shows all the input/output interactions of the PLC

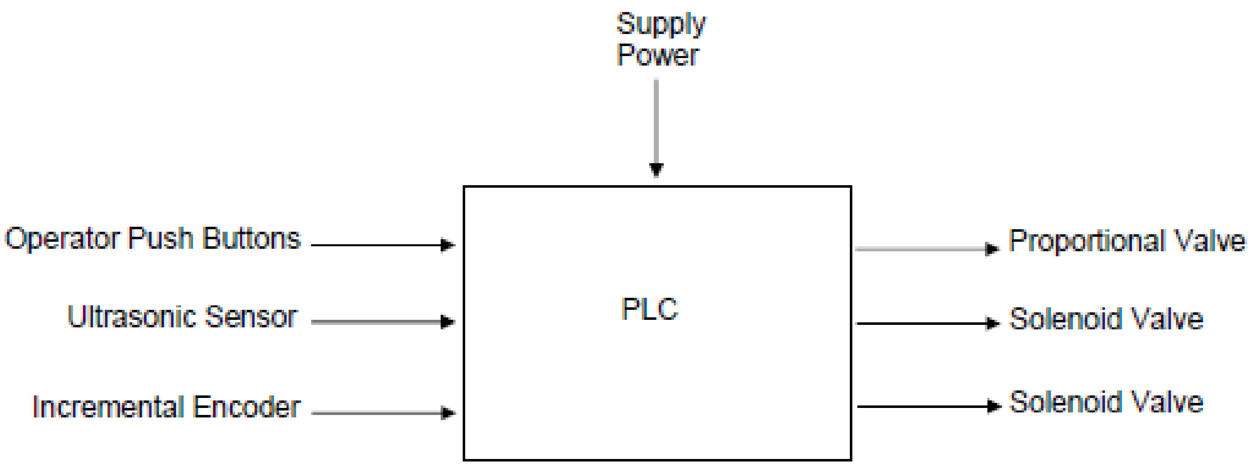

Figure 28: Input/Output Unitronics PLC

5.1 Program Flowchart

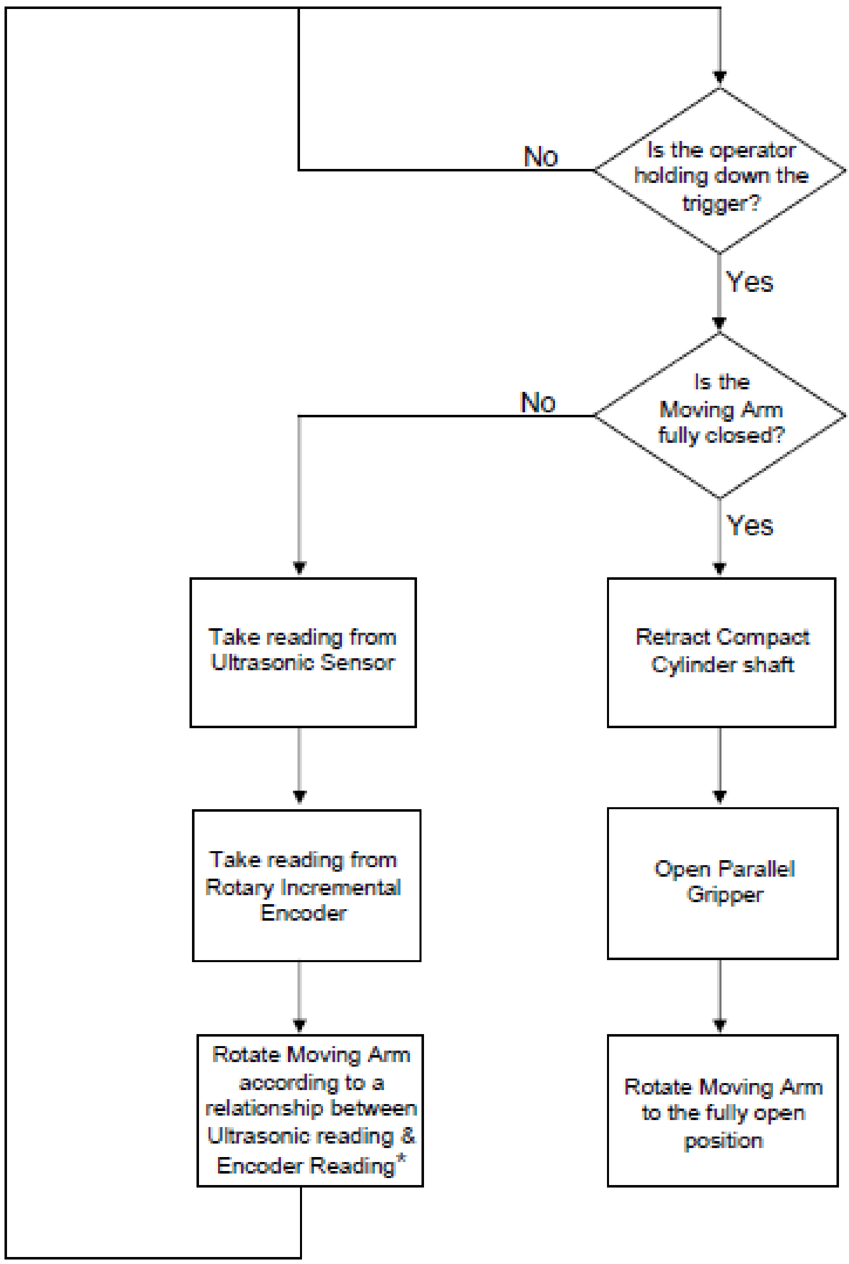

Figure 29: Flowchart diagram PLC program

***For details on the relationship see Section 5.2**

5.2 Movement Relationship

The movement of the Moving Arm is governed by the position of the beast's leg in relation to the tool via the following steps.

- The position of the leg is measured by the Ultrasonic Sensor.
- From this the desired position of the Moving Arm can be attained.
- The current position of the Moving Arm is then determined by the Rotary Incremental Encoder.
- With the current and desired values of the Moving Arm a desired velocity for the Moving Arm is found in the form of an analogue value to send to the Proportional Valve.
- From the difference between this value and the current value being sent to the Proportional Valve the amount to increase the current value by (the acceleration) can be determined and applied.
- The process is repeated continuously to stay in sync with the movement of the leg.

The effect of this relationship is that as the beast's leg approaches the tool the Moving Arm will close at a rate that is proportional to the speed of the leg in a smooth and consistent motion

6 Construction

When choosing construction materials the intended work environment had to be considered, and for this reason the Automated Beef Shackling Tool is constructed primarily out of stainless steel and aluminium.

The exceptions to this are mostly bushings and pneumatic fittings/tubing which are all made out of inert plastics.

Stainless steel was selected for its high corrosion resistance as well as high strength. Aluminium was used where ever it was impractical to use stainless steel due to weight considerations or where such high strength was not required. Aluminium, once anodised, also exhibits excellent corrosion resistance.

As discussed in Section 9 the next phase of the project will involve further refinements to the tool which will include an IP65 Rated cabinet as part of the body of the tool to fully enclose all the electrical and pneumatic components. As well as general increased protection of these components this will also allow for wash down at the end of a shift, end of day etc

7 Operation

The steps that follow outline in detail the procedure for operation of the Beef Shackling Tool:

- Turn on the air by turning the Isolation Valve counter-clockwise (**Figure 30**).

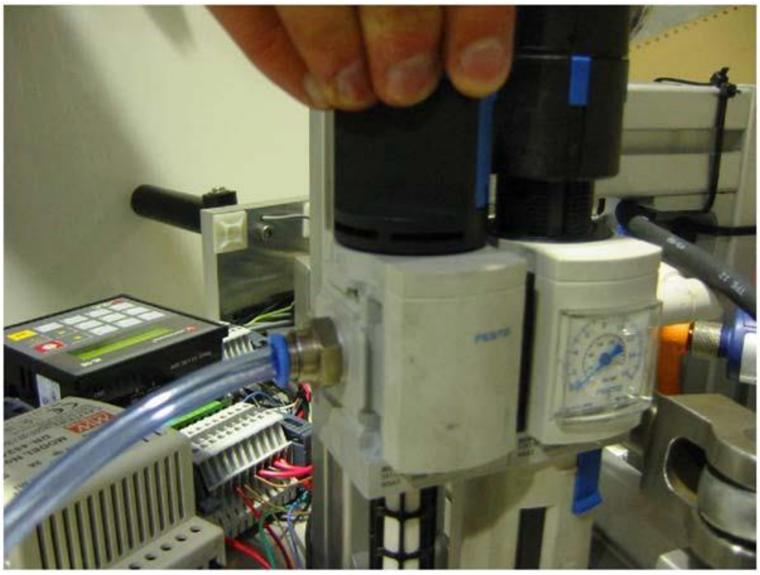

Figure 30: Turning the air on

Inspect the Filter Regulator and ensure that the working pressure is at between 6 and 8 bar. If the pressure needs to be adjusted do so by turning the knob on the Filter Regulator (**Figure 31**)

Figure 31: Adjusting air pressure

- For safety reasons the operator should approach the tool from the rear to avoid proximity to the moving parts. The Operator then places both hands firmly on the grips (Figure 32).

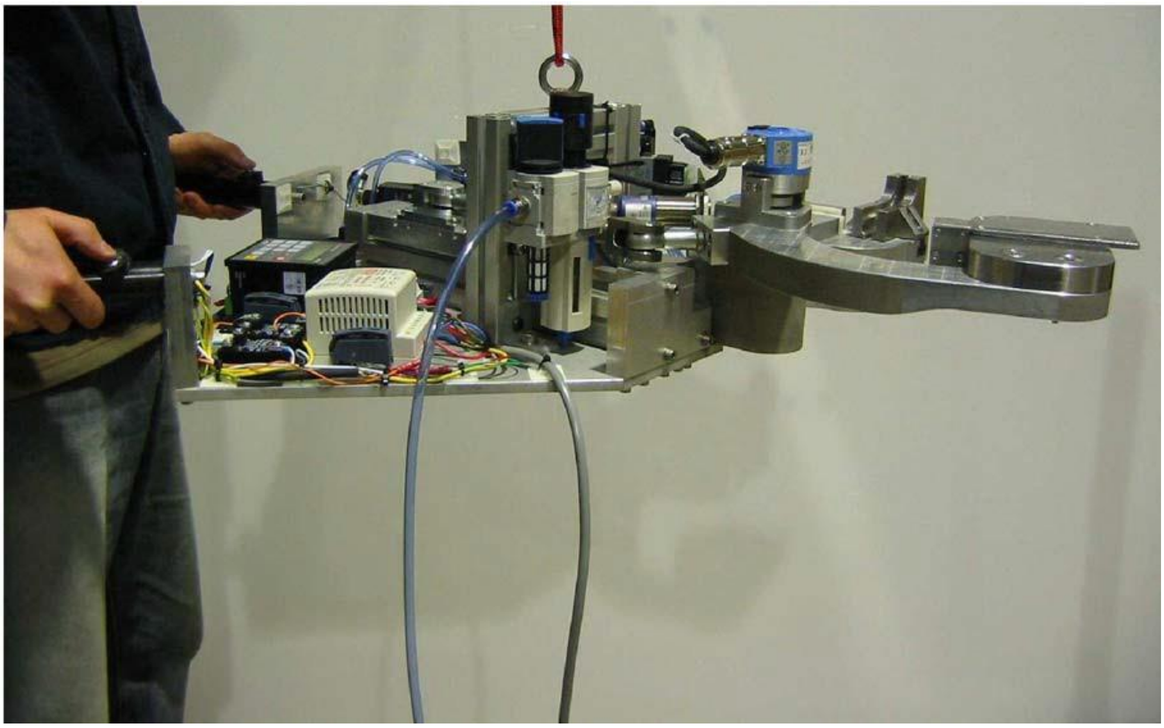

Figure 32: Operator holding Automated Beef Shackling Tool

- When the tool first has power applied the LCD screen on the PLC should read “1. Load Procedure” (Figure 33).

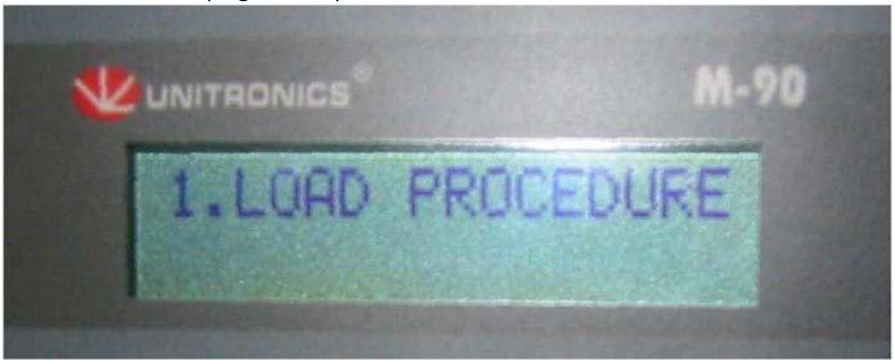

Figure 33: Loading screen of the PLC

Figure 34 shows the menu structure for the tool as displayed on the LCD screen of the PLC. To navigate across the menu branches the operator single clicks the triggers on the grips, left trigger to navigate left and right trigger to navigate right. To navigate along the branches vertically the operator double clicks the triggers, left trigger to navigate up and right trigger to navigate down

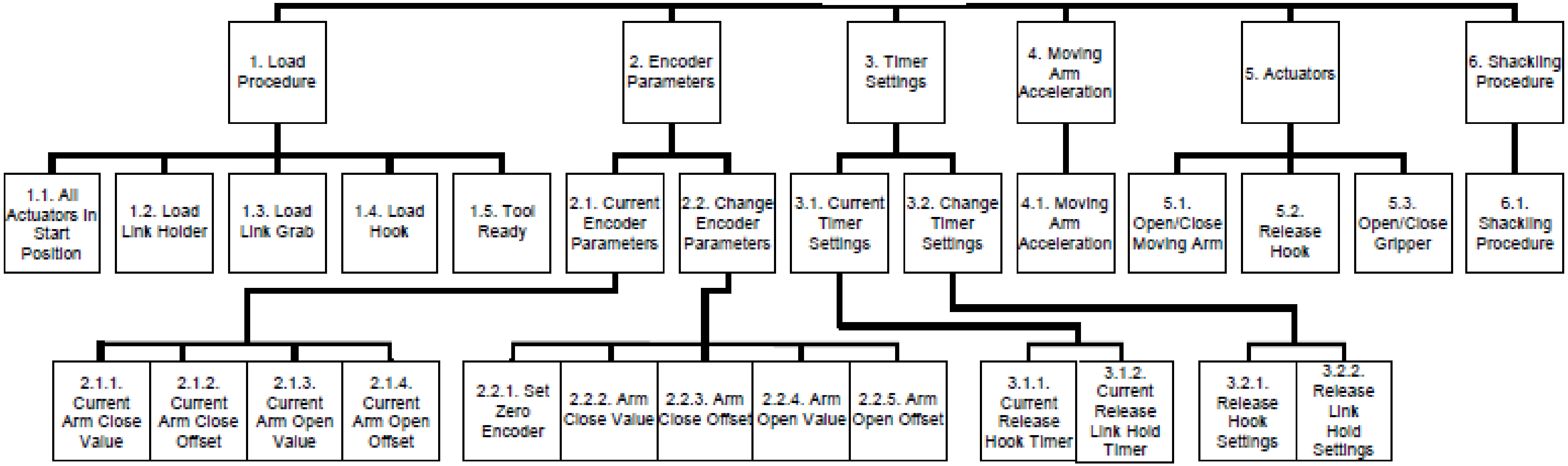

Figure 34: PLC Menu Structure

The top level menus provide the following functions:

- 1. Load Procedure – This walks the operator through the steps necessary to load the tool and ready it for shackling. Once the load procedure is completed the “6. Shackling Procedure” menu is automatically loaded. This menu can be entered either by cycling through the top row of menus or by completing the shackling operation in the “6. Shackling Procedure” menu. The load procedure menu should be used when first beginning shackling after power up.
- 2. Encoder Parameters – This menu contains offset & rest values for the Rotary Incremental Encoder as well as values to change when the moving arm will completely close and complete the shackling process.
- 3. Timer Settings – The timer settings menu allows the operator to fine tune the timers that operate between the Moving Arm closing, the Compact Cylinder retracting to release the Slip Hook and the Parallel Gripper opening to release the Link Grab.
- 4. Moving Arm Acceleration – This menu allows the operator to fine tune the accelerations of the moving arm, allowing it to close faster or more smoothly.
- 5. Actuators – This menu is used to control each of the actuators individually.
- 6. Shackling Procedure – The Shackling Procedure menu is used when the operator is ready to shackle the beast’s leg. It can be entered either by cycling through the top row of menus or by completing the loading of shackles through the “1. Load Procedure” menu. When the shackling operation is complete the “1. Load Procedure” menu is automatically loaded.

- The operator should then enter the “1. Load Procedure” menu. As the operator cycles through the loading procedure prompts are given to put the Slip Hook into the nest, put one Link into the Parallel Gripper and the other link into the spring loaded Link Grab
- Once loading is finished the “6. Shackling Procedure” menu is automatically loaded and the tool is ready for shackling
- To shackle, the operator holds down the right trigger and swings the tool closer to the beast’s leg. As the leg enters the range of the tool the Moving Arm will begin to close and continue to do so for as long as the leg continues to move towards the tool until the arm is fully closed (**Figure 35**). If the leg is kicking violently and enters the tool only to quickly back away the tool’s control system will realise this and reopen so the operator can attempt shackling again.

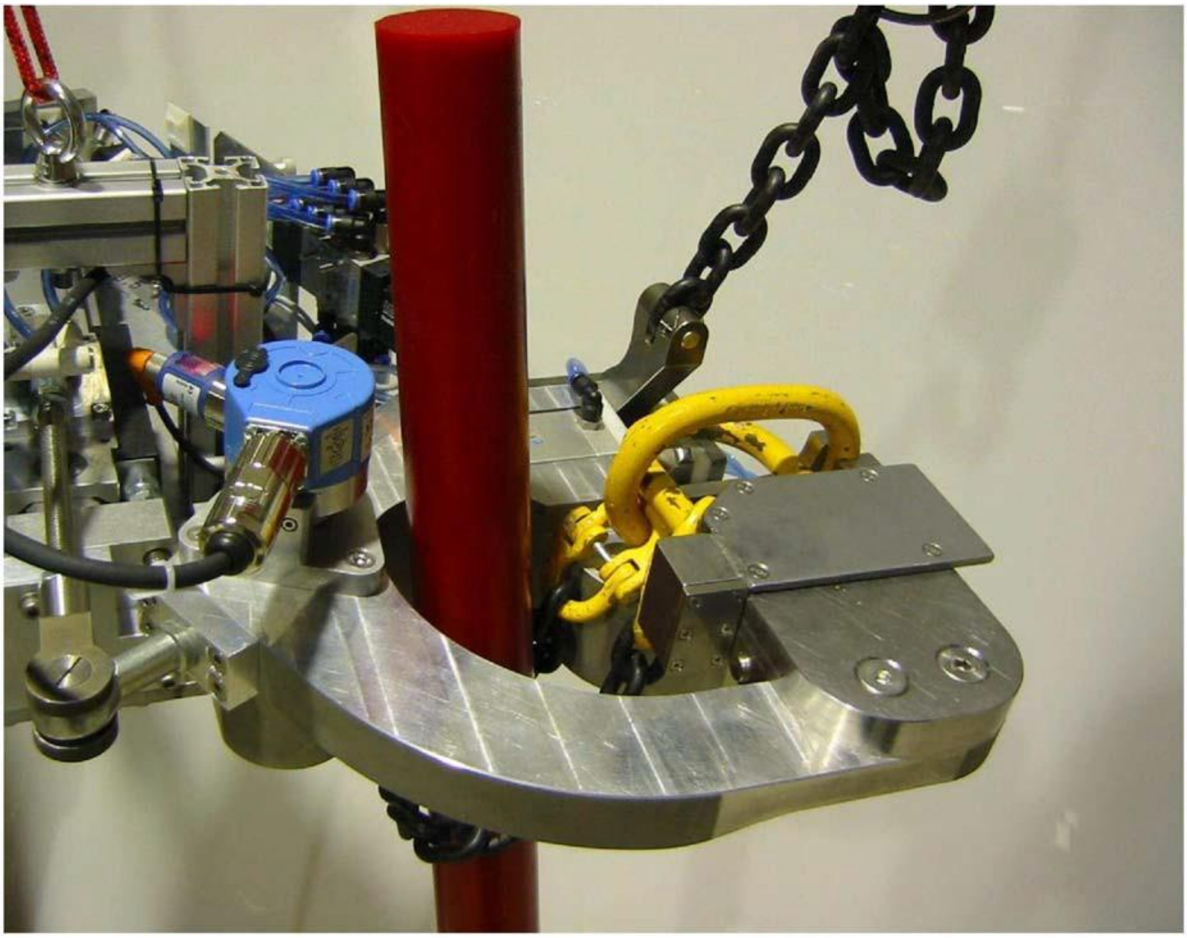

Figure 35: Moving Arm closed around leg

Once the arm is closed and the leg is held in place with the chain wrapped around it, the tool will retract the Compact Cylinder's shaft and open the Parallel Gripper. This releases the Slip Hook to catch the Right Shackle Link as it is passed through the Left Shackle Link therefore shackling the leg (**Figures 36 & 37**)

Figure 36: Hook Released

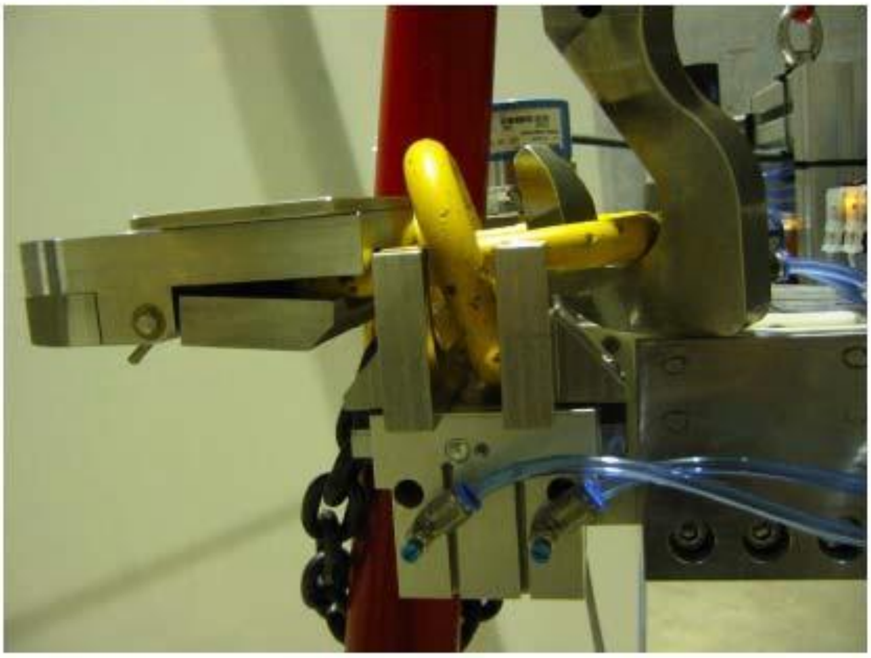

Figure 37: Hook and Link Released

- The Beast is now shackled and ready to be hoisted (**Figure 38**) for processing.

Figure 38: Leg shackled and hoisted

The “1. Load Procedure” menu is automatically loaded so the operator may immediately prepare for the next animal.

8 Results

To test the Automated Beef Shackling Tool a mock cow leg (**Figure 39**) was constructed from a long polyurethane cylinder. The polyurethane cylinder was mounted to a heavy base plate via a large spring. This allowed for the simulation of a kicking cow leg as the polyurethane cylinder was allowed to swing freely.

Figure 39: Mock cow leg

Upon testing, the system performed exactly as intended; applying the shackle in a swift and consistent manner that kept the operator at a safe distance. It was also noted that it was still fairly easy to apply the shackle even when the mock cow leg was swinging wildly.

9 Development Path

As can be seen in the research and development path in Figure 40, this area of research can be broken down into three specific directions; Beef Hock Location Vision System, Automated Shackle Loading System and the Prototype Operator Controlled Beef Shackling System.

9.1 Automated Shackle Loading System

As discussed in Section 7 of this report while the shackling operation itself is automated the loading of the shackles into the tool is done by hand. This branch of research would help to streamline this process by integrating with a meat processing plant's existing shackle return system and picking & placing each end of the shackle into the appropriate grips of the Automated Beef Shackling Tool. This system would reduce the labour content required for Operator-Controlled use of the Automated Beef Shackling Tool and also form an integral part of a greater Robotic Beef Shackling System.

9.2 Operator Controlled Beef Shackling System

This branch of research would involve further developing the Automated Beef Shackling Tool into a working model for use in meat processing plants including design of any peripheral equipment. This would also involve a full trial in a real plant to test the system and assess any unforseen issues that may arise. Development of this in-plant working model would also be of great importance to the development of a greater Robotic Beef Shackling System.

9.3 Beef Hock Location Vision System

A Beef Hock Location Vision System would aid further research into a greater Robotic Beef Shackling System by allowing any robotic system to easily track and locate the beast's leg for shackling.

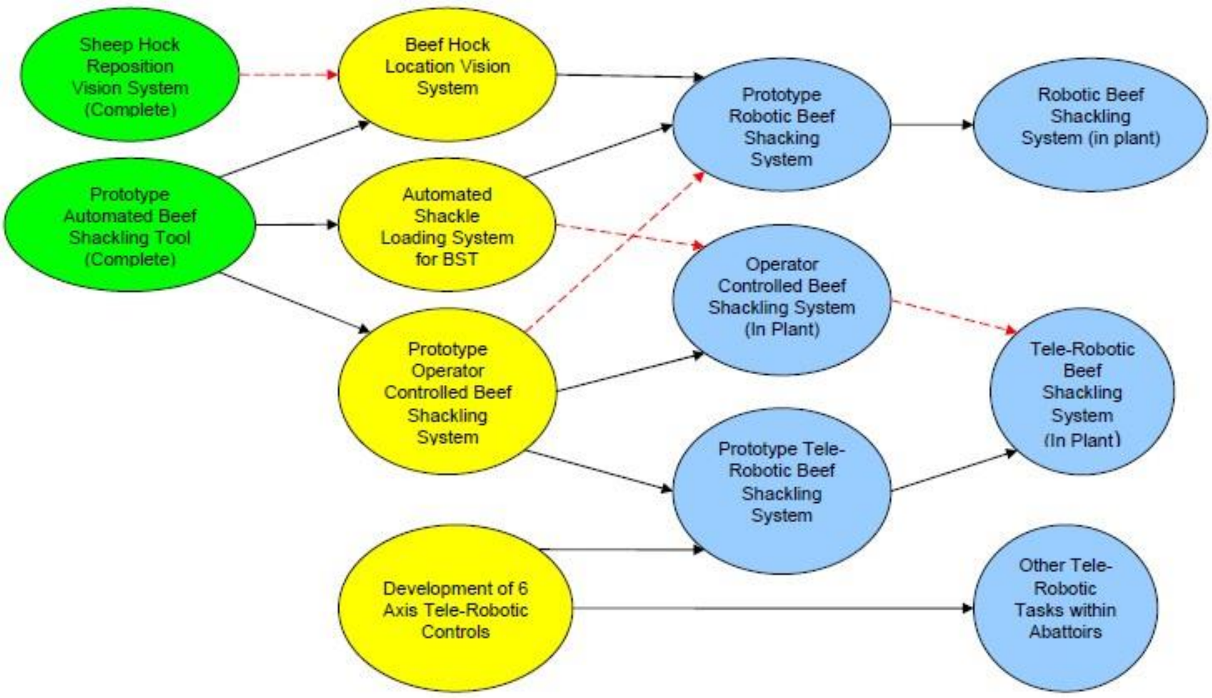

Figure 40: Research and Development Path for Automated Beef Shackling Tool

10 Summary

This report sees the completion of milestone 3 and hence the completion of project no. A.TEC.0061, the Automated Beef Shackling Tool. The prototype tool was designed and constructed, and a trial of the system on a mock leg was carried out successfully. The completion of the tool clearly points the way forward for further research into this area with the ultimate goal of a greater system combining this and other research into a completely automated system which not only reduces labour contact but also reduced OH&S hazards involved in the shackling process.