AUSTRALIAN MEAT PROCESSOR CORPORATION

Pick and Pack – End Effector Gripper Development

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1. Executive Summary

Following findings and recommendations from the AMPC/MLA project "A.TEC.0108 Pick and Pack Materials Handling" a multi head vacuum gripper has been designed and fabricated. This vacuum head has been mounted on an ABB robot and along with the assembled partial product conveyor and vacuum system has been used in Pick and Pack trials conducted at MAR's workshops.
The setup was used to pick Cryovaced primals of beef from a conveyor and place them in appropriate cartons. In particular this report focuses on:

- The setup of the conveyor, robot and primals used to test the vacuum gripper.
- The speed of the robot and how this affected the quality of the pick.
- The orientation required from the 6 axis robot to achieve the correct primal positioning in the carton
- Any damage caused to the Cryovac bags and the methods used to overcome this.
- The cycle time of the pick and pack sequence, which will be required in further development of the pick and pack system
- Imprints and deformation of the meat caused by the vacuum gripper

From the trials it can be concluded that:

- The vacuum gripper is able to pick up both large and small Cryovaced primals.
- The primals can be moved securely at fast speeds and fast acceleration.
- The primals can be accurately placed and stacked, using the six axis capability of the robot, into cartons. It is felt that some redesign would be required if a similar concept was to be used on systems that did not have the 6 axis flexibility.
- Pressure switches on the vacuum gripper allow faster pick and place speeds to be achieved.
- When the primal is held at an angle by the vacuum gripper it is less secure and can possibly fall off, slower speeds and accelerations/decelerations are required for larger primals.
- Repeated pick and place operations on the same pieces of meat can result in the bags being stretched or torn.
- The suction cups can cause deformation of the meat. Shallower suction cups will reduce this deformation.

The project objectives were met for this project.

2. Introduction

Previous work completed by MAR under 'A.TEC.0108 Pick and Pack Materials Handling' proposed a concept for a Primal Pick and Pack Handling system but also identified a number of development areas that need to be addressed prior to full blown development of an automated system. One of these areas is the design, fabrication and testing of an End Effector Gripper, suitable for robotic mounting.

The objectives of this project are to design and fabricate such a gripper and then mount this on a robot and trial its operation in a workshop situation.

3. Project Objectives

This project involves the development, test and trial of a Pick & Pack - End Effector Gripper for use on future automated primal pick & pack system(s). This development is based upon work completed by MAR under "A.TEC.0108 Pick and Pack Materials Handling" study.

The study completed by MAR indicated great potential for automation in the area of "Packing of Primals into Cartons". The concept offered in "A.TEC.0108" for Packing of Primals into Cartons is modular and expandable and able to be adapted to and suit a wide variety of meat processing plants by addressing variable footprints and process requirements.

This development project offers a STEP towards a solution for Packing of Primals into Cartons by focusing on a key development area highlighted in "A.TEC.0108" being a gripper system able to be robot mounted and used for manipulation of meat primals and cuts.

The End Effector Gripper system to be developed and tested is for use and incorporation into the later development of an automated primal pick and pack system(s).

The project will provide the following outcomes:

- Design and manufacture Primal Cut Gripper system for robotic adaption
- Assemble partial product conveyor section for trials and simulation of production
- Project will utilise the following MAR supplied components:
  - Robot System
  - Robot base, and Portable Chiller for cartons
  - Controls systems, sensors and actuators where required
- Procurement of product for trials and to simulate production where practically possible.
- Setup, Program and perform gripper trials at MAR Silverwater
- Trials will be used to confirm the following:
  - Gripper design, functionality and capabilities.
  - Operational speeds and cycle time capabilities
  - Confirm concept design for incorporation into the later development of an automated primal pick and pack system
- Documented report including videos, images and results

4. Methodology

This project aimed to design, manufacture and test a Primal Cut Gripper System suitable for adaption to a robot. This process consisted of a number of steps. Step 1 was to design the gripper and required gathering of data on the dimensions and weights of typical primals, reviewing possible alternative designs, trialing the preferred option then detailing the design. Step 2 was to manufacture the gripper. Step 3 was to test the gripper on a robot with product.

4.1. Gripper design

Based on results found in the previous MLA/AMPC "A.TEC.0108 Pick and Pack Materials Handling" project where it was found that, using JBS Site Beef City as a reference, by automatically Picking and Packing the top 10 products that a significant labor saving was achieved, this project concentrated on designing a gripper that could effectively pick and Pack products from the list below:

Table 1. The Top 10 primal cuts by quantity as determined in project A.TEC.0108

SKU	SKU Number	Product description	Size of Carton used	Number of cuts per carton	Approx Max weight of cut (kg)	Approx min weight of cut (kg)	Approximate Size L x W x H
1	28850	Topside	M	2	12	9.95	400 x 400 x 200
2	28847	Chuck Roll	D	2	12	8.5	600 x 300 x 200
3	28846	Clod	D	2	11.5	8.5	600 x 420 x 150
4	28817	Bolar Blade	M	3	9.3	6.7	600 x 200 x 150
5	28863	Point End Brisket	M	3	6.7	4.67	500 x 400 x 150
6	28874	Striploin	M	3	9	7.33	650 x 300 x 150
7	28852	Rump	D	3	8.67	6.33	400 x 300 x 170
8	28851	Knuckle	M	4	7.5	5.75	350 x 250 x 250
9	28858	Cube Roll	S	5	4	2.2	350 x 180 x 180
10	28857	Tenderloin	S	6	3.3	2.3	650 x 150 x 100

In the A.TEC.0108 project mentioned above it was proposed that a vacuum type gripper would be the gripper with the best chance of success in picking up vacuum sealed cuts of meat in preference to the mechanical/pneumatic style gripper concepts shown below.

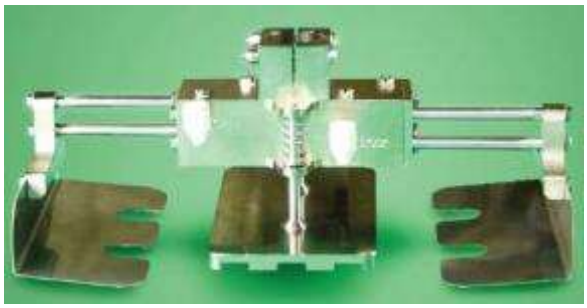
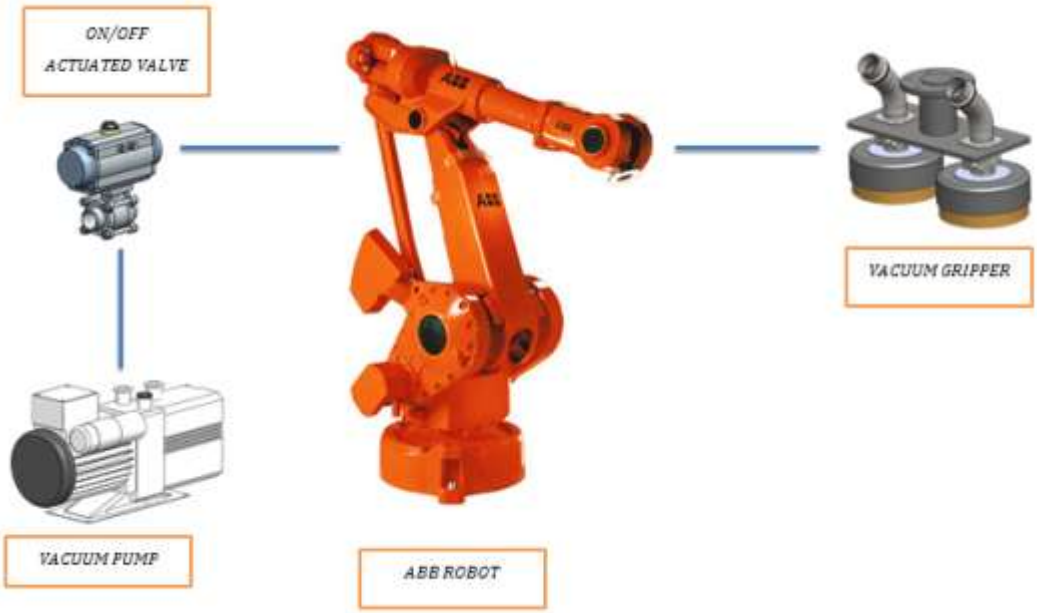
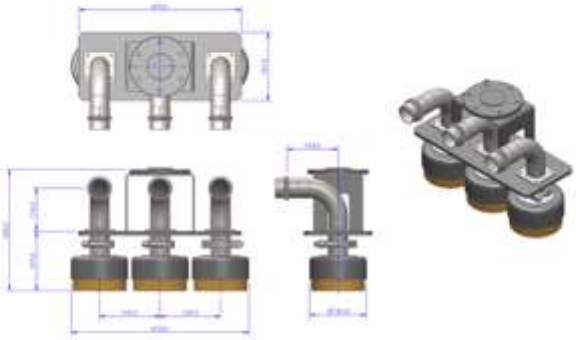


Fig 1. Mechanical and pneumatic grippers reviewed as possible options as part of the design process. The preference was for a pneumatic gripper as it was deemed that this would be the most suitable for picking up primals without causing damage to the vacuum sealed bag.

With this in mind the concept incorporating a vacuum pump and valving, robot and vacuum gripper head was reviewed internally at MAR.


ON/OFF
ACTUATED VALVE
VACUUM GRIPPER
VACUUM PUMP
ABB ROBOT


3 x 150 mm Dia. VACUUM PAD
ON/OFF ACTUATED VALVE
VACUUM PUMP



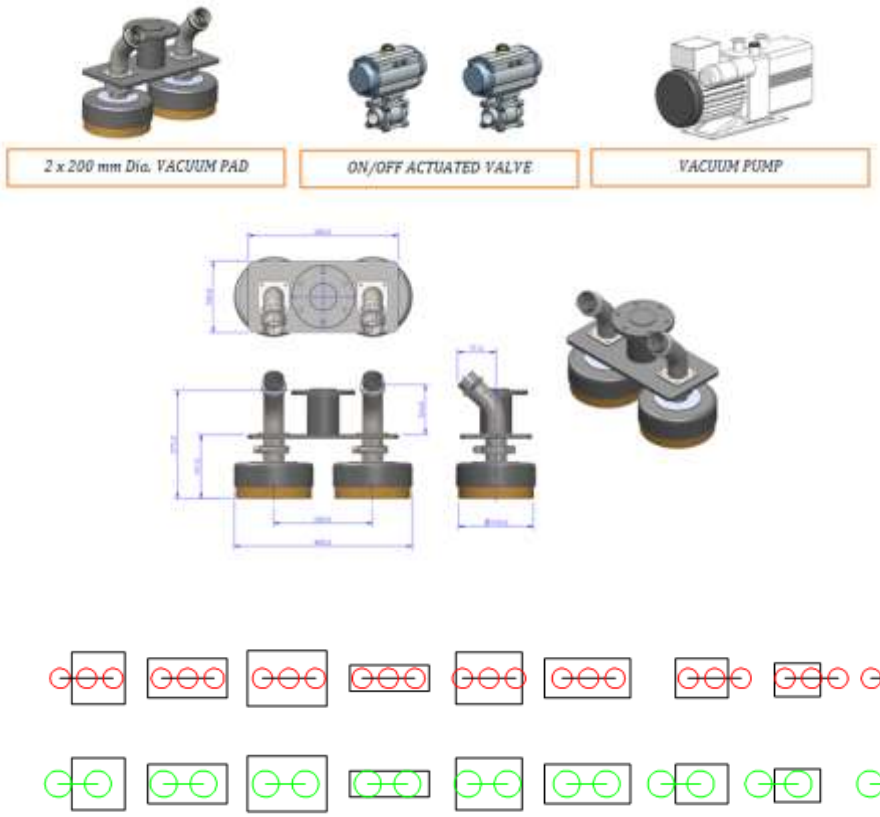


Fig.2 The images above show the various configurations of vacuum heads that were considered and how these configurations would suit the dimensions of the primals listed above.

The review confirmed that the vacuum head gripper was the preferred option, but that a sample head should be procured prior to a full design taking place. The image below shows the head that was procured (compliance foam from the bottom of the gripper has been removed as it has been used in the final fabricated gripper).

Fig.3 A trial Vacuum Gripper head was sourced and fabricated first before detailed design was conducted

This vacuum head required the piping shown attached in the image above to be fabricated so that it could be attached to a vacuum system and trialed as shown in the images below:

Fig.4 Trial gripper head picking up vacuum sealed primals in MAR's workshop - 1

Fig.5 Trial gripper head picking up vacuum sealed primals in MAR's workshop - 2

Fig.6 Trial gripper head picking up vacuum sealed primals in MAR's workshop - 3

The gripper was also trialed picking up a 20kg bag of sand, proving that it can pick up the weights required as listed in the Table 1 above.

Fig.7 Trial gripper head picking up a 20kg sand bag

The following points were noted from these trials

- The diameter of this trial gripper head was 250mm. It was found that this was too large for the smaller or more rounded cuts that were trialed and this would need to be taking into account in the final design.
- This gripper had sharp edges which could pierce the vacuum bags, this would also need to be rectified in the final design.
- The vacuum took a number of seconds to build up enough to pick up the cuts of meat, this can be overcome in the final design by having the valves for the vacuum close to the vacuum head.

With these points in mind and the above trials completed, detailed design of the head proceeded. It was decided that a combined head incorporating one 200mm diameter vacuum head and two 100mm diameter heads was required to cover the range of cuts as shown in the diagrams below.

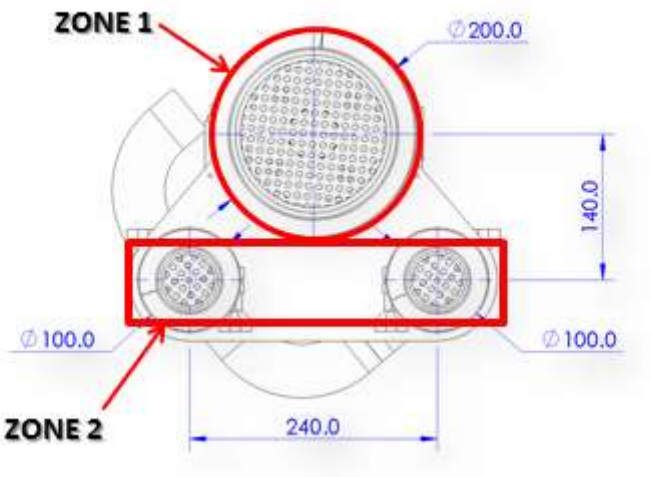


Fig.8 Preferred Gripper configuration with one 200 mm dia and two 100mm dia vacuum heads

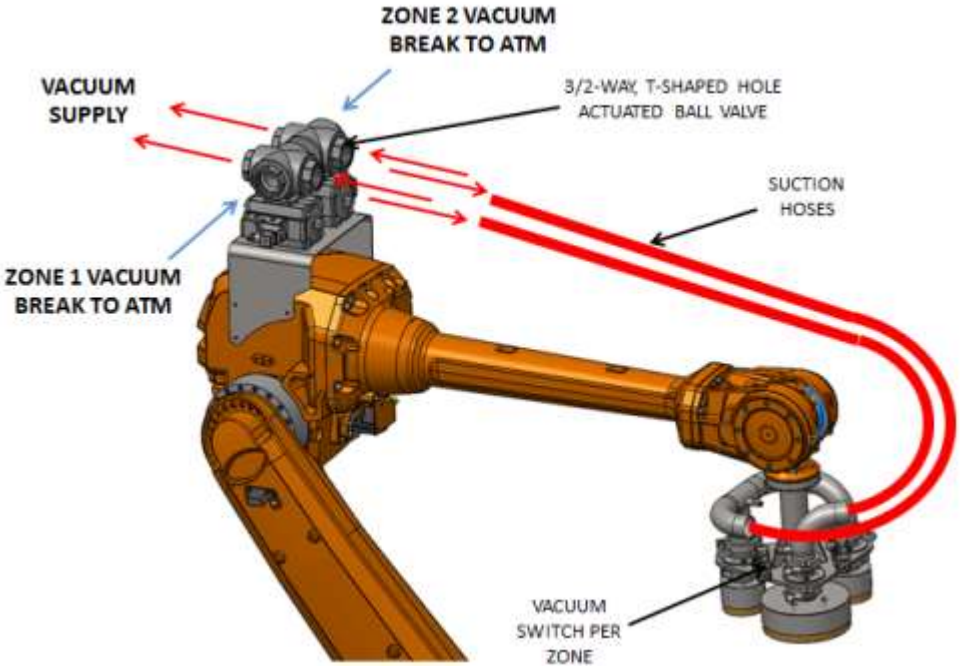


Fig.9 Concept of how the vacuum hoses will connect with the vacuum head when it is mounted on the robot

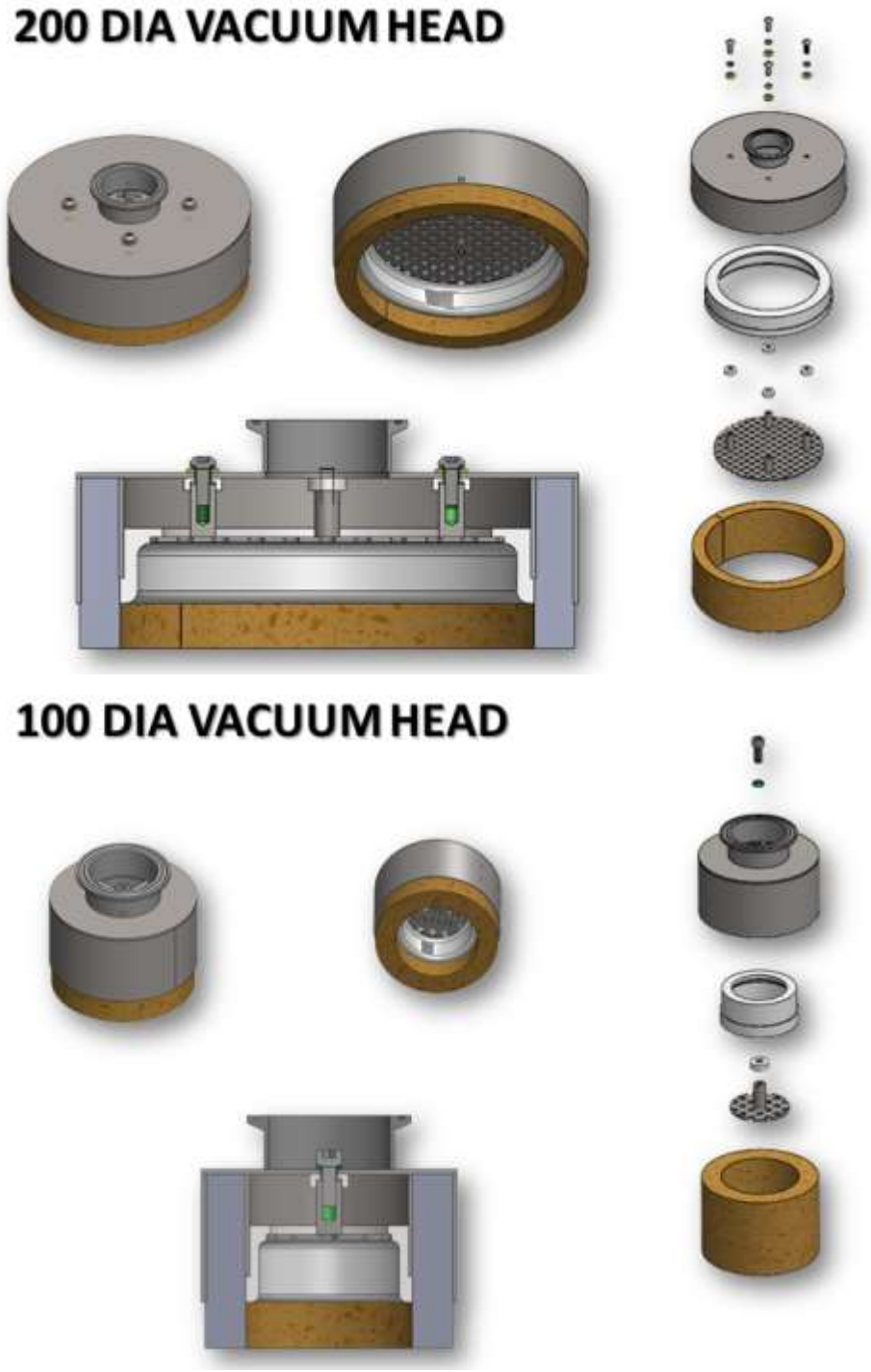


Fig.10 Design of the internals of the 100 and 200mm diameter vacuum heads

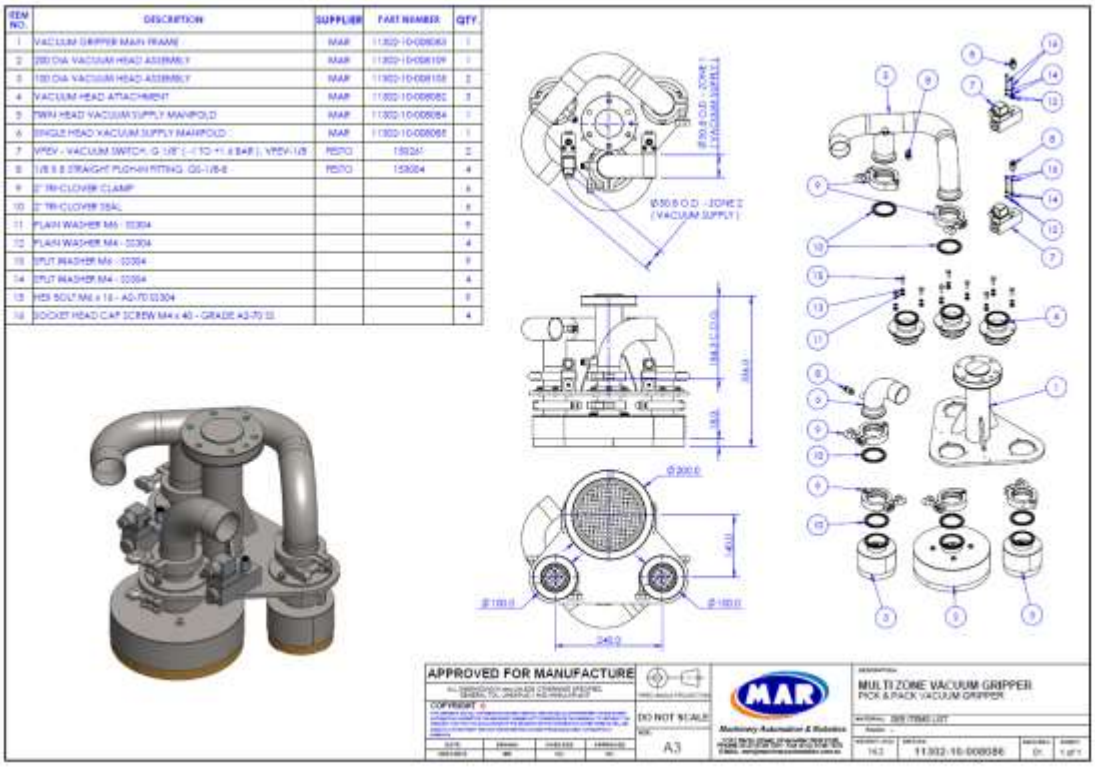


Fig.11 Detailed Assembly diagram for fabrication of the gripper head.

4.2. Gripper Manufacture

Following the detailed design the gripper was fabricated and the delivered product is shown in the images below.

Fig. 12 Fabricated Gripper ready for mounting onto the robot

4.3. System setup at MAR and preparation for testing

The image below shows the setup of the trial system at MAR's workshop:

- The robot is mounted on its base.
- The gripper and vacuum valves, vacuum switches and hosing are shown mounted on the robot, with plumbing and electrical wiring complete.
- The conveyor is shown assembled in a position to allow pick up trials to occur.
- The vacuum system is shown in the back ground with plumbing and electrical wiring complete.

Fig. 13 The system setup for trials in MAR's workshop. The image shows the gripper, vacuum hosing and valving mounted on the robot, the vacuum system in the background with product conveyor in the middle.

The image below shows the product that was sourced from JBS Beef City for trial purposes, MAR thanks JBS Beef City for the supply of this product.

Fig. 14 Cryovaced Primals supplied for trial by JBS Beef City

From the setup shown in **Error! Reference source not found.**3 it can be seen that he conveyor is placed in an appropriate position so that the vacuum gripper on the robot can reach the majority of its surface. The conveyor was left unpowered for the trial. After picking the meat off the conveyor; the robot places the meat in cartons (shown in Figure 155) which are positioned on the black base that the robot is mounted to. The conveyor is positioned higher than the base simulating what would be expected in reality where the pick off conveyor would be higher than the carton conveyor/primal drop off point.

Figure 155: Image of cartons and robot on the robot base with the primals on the conveyor ready for pick up.

The image below shows the system setup and robot positions being taught.

Figure 166 Primal pick up positions being taught

5. Project Outcomes

5.1 Slow Speed Trial

For the trial the robot was first programmed and tested at a slow speed to verify the viability of picking and placing the meat using the vacuum cup, the maximum speed of the robot axes and the ramp and maximum acceleration of the robot were limited. It was observed that at a slow speed the meat was able to be safely picked and placed into the cartons. The attached video *Trial1* shows this slow speed trial. The following observations were made during this trial:

- The vacuum gripper was able to establish a good seal with the primals using. both the small and large suction cups.
- The primals had little to no wobble while moving or when stopping quickly.
- The primals were placed accurately in the cartons.

5.2 High Speed Trial

Once the trial had been completed successfully at a slow speed the robot and vacuum gripper were re-programmed and tested again at a higher speed. In the video *Trial2* the speed of the robot is increased however the acceleration is still limited as in the slow speed trial. In *Trial3* and *Trial4* both the speed of the robot is increased and the acceleration of the robot is increased. From these trials it can be seen that:

- The primals can be picked and placed successfully at high speeds
- There is more wobble in the moving primals compared to the slow speed trials, however it does not affect the quality of the pick and place operation

One cause for concern can be seen in *Trial3*, where the large primal is released too late during the place operation and falls into the carton. Here the vacuum had not been fully released and hence the primal had not been released from the vacuum head before the robot began to move away from the carton. This caused the primal to drop from the head as the robot was moving away from the drop off position. This can be seen in Figure 17.

Figure 177: A large primal being dropped after place operation. This highlighted the need for pressure switches to ensure suitable vacuum had been lost before certain robot moves were initiated.

To address this problem pressure switches were added to the vacuum system to indicate to the robot that vacuum had been lost and hence the primal had been released from the head.

5.3 Optimised Fast Speed Trial using Pressure Switches

As the meat can be picked and placed at high speeds, a trial was conducted to optimise the speed of the pick and place operation. This involved two main procedures:

1. Using the pressure switches on the vacuum gripper to determine when the meat has been picked and when it has been released
2. Measuring the time taken for the small and large suction cups to activate, so that the vacuum can be engaged as soon as the suction cups touch the meat. This minimizes the time spent holding the suction cups on the meat waiting for the vacuum to engage

Two pressure switches were added to the vacuum system; one was connected to the large suction cup and the other to the two smaller suction cups. The pressure switches are set when the vacuum is activated on the relevant suction cup and the suction cup has a good seal against the object it is picking. The pick and place operation using the pressure switches can be seen in the video *Trial5*. Compared to the previous trials, where timers were used to govern the time allowed to achieve vacuum, it can be observed that the gripper can more efficiently pick and place the primals as it can quickly detect when a good seal is achieved between the vacuum gripper and the primal. It can also be seen that when picking the first primal in *Trial5* the robot pauses until a good seal is detected. It is noted that by using the pressure switches there is no longer the problem of releasing the meat too late during the place operation as shown in Figure 17.

As well as using the pressure switches, the timing of the activation of the vacuum on the heads was optimized to improve the speed of the pick and place operation. This is optimization is necessary as there is a small delay between the vacuum being activated and the vacuum actually being effective. This is due to the fact that the vacuum valves are located on axis 3 of the robot and to pull a vacuum at the head means evacuating the hoses between the valves and the head first. For this test the vacuum head was held a set distance away from the primals. The vacuum was engaged at this set distance and the gripper was moved towards the meat at a fast speed. The time taken for the pressure switch to set was measured along with the pressure drop in the vacuum. The optimum distance away from the primal at which to activate the vacuum was found where the pressure switch activated the quickest and there was the smallest drop in vacuum pressure. The full results of these tests are shown in the excel spreadsheet *Vacuum Gripper Test Results* and they are summarized in Figure 18 below. It can be seen that for the optimal picking speed the large suction cup should be activated at a 100 mm from the primal and the small suction cup at a 200 mm. The video *Trial8* shows the robot operating at these optimized offsets. Every pick and place operation takes 2 to 3 seconds to complete.

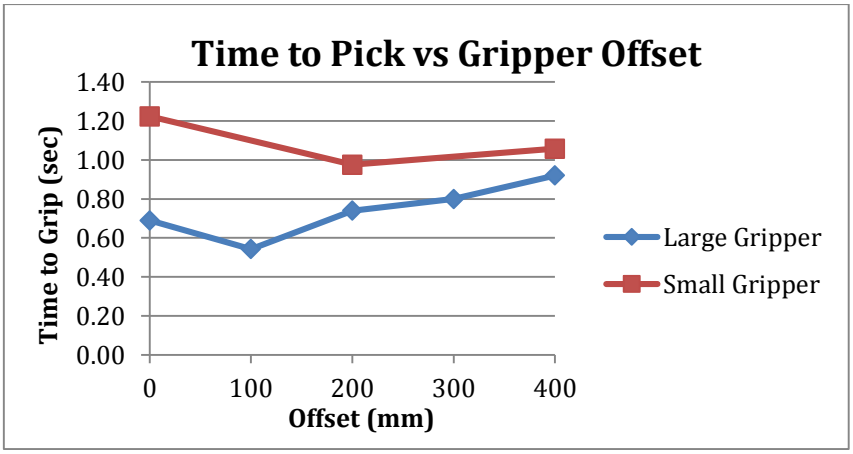


Figure 188: Optimal picking offset for large and small suction cups

5.4 Cycle time

The cycle times for the robot picking and placing the primal for the optimized fast speed trial were recorded using a timer in RobotStudio, the ABB robot software package. The picking time is defined as the time taken for the robot to move from its parked position to above the primal, pick up the primal and lift it above the conveyor. The placing times are the time taken for the gripper to move from its position above the conveyor to the position above the carton , lower the primal into the carton and to then lift the gripper clear of the carton. Table 2 below

shows the picking and placing time for each primal, along with the average. As can be seen from the table the average time for an entire pick and pack cycle is approximately 4.9 seconds.

Piece of Meat (In order of picking)	Picking Time (sec)	Placing Time (sec)
1	1.934	2.382
2	2.487	2.596
3	2.589	2.45
4	2.383	2.382
5	2.618	2.603
Average	2.4022	2.4826

Table 2: Picking and placing times for primals of various sizes.

5.5 Fast Trial with Primals being stacked in cartons

After optimising the speed of the pick and place operation, trials were conducted on stacking multiple primals into the cartons. This trial was done to simulate the more realistic conditions of the pick and place operation. These trials can be seen in videos *Trial9, Trial10 and Trial11.* To stack the primals into the cartons the six axis capability of the robot was utilized to angle the vacuum gripper so that the primals could be suitably placed. It was observed during testing that when held at an angle the larger primals were more susceptible to falling off the large suction cup on the vacuum gripper. This problem can be seen in *Trial9* where the large primal falls off the vacuum gripper prior to being placed. To accommodate this, the speed of the robot was reduced for the larger pieces to ensure that they did not fall off. A picture of the stacked meat is shown in Figure.

Figure19: The result of multiple primals being stacked in cartons

6. Discussion

In addition to the results discussed above, it was also observed that:

- During repeated pick and place operations the Cryovac bags stretched
- The bags would tear over repeated pick and place operations
- Circular impressions of the suction cup would be left in the meat during pick and place

When the bags stretched the suction cup would only grip the bag and not the meat. This can be seen in the videos *Trial6* and *Trial7*, where the small suction cups are unable to grab the meat. When gripping only the plastic the meat is less stable and is more likely to fall off. To accommodate the stretch in the bags the meat and stretched bag were wrapped tightly with clear tape. This resulted in a more realistic surface for the vacuum head to grip onto and resulted in the primals being easily able to be picked and placed as if the bag had not stretched. The bags only stretched after several repeat pick and place operations which would not occur in reality. Similarly the bags were observed to tear when picked and placed multiple times.

The meat was also deformed by the suction cup after being picked and placed. This can be seen in most of the trial videos but especially in *Trial1* and *Trial2,* where the cycle was slower. The meat is deformed as it is pulled all the way inside the suction cup during the pick and place. To solve this problem it is proposed that the suction cups can be redesigned with shallower vacuum heads. This will reduce the deformation of the meat. The deformation of the small and large pieces of meat is shown in Figure 19.

Figure 190: This image shows the deformation of meat by small and large suction cups

7. Conclusion

From the outcomes of the investigation, design and physical trials it can be concluded that:

- The vacuum gripper is able to pick up both large and small Cryovaced primals.
- The primals can be moved securely at fast speeds and fast acceleration.
- The primals can be accurately placed and stacked, using the six axis capability of the robot, into cartons. It is felt that some redesign would be required if a similar concept was to be used on a systems that did not have the 6 axis flexibility.
- Pressure switches on the vacuum gripper allow faster pick and place speeds to be achieved.
- When the primal is held at an angle by the vacuum gripper it is less secure and can possibly fall off, slower speeds and accelerations/decelerations are required for larger primals.
- Repeated pick and place operations on the same pieces of meat can result in the bags being stretched or torn.
- The suction cups can cause deformation of the meat. Shallower suction cups could reduce this deformation.

The proposed outcomes of the project have been met, and a concept design for incorporation of a Primal Cut Gripper into future development of an Automated Primal Pick and Pack System has been presented.

MAR's concept solution for the packing of Primals into Cartons is modular and expandable. As a concept design a number of challenges and unknowns need to be addressed through progression of staged trials, design and industry consultation to finalize the concept for production development

This Primal Cut Gripper system development project is one (1) of a number of key steps to be progressed prior to full system development. The following outlines areas of development that need to be addressed to progress Automated Packing of Primals into Cartons:

- Vision & Sensing Development Trials (product size, shape and orientation)
- Vision & Sensing Development Trials (Barcode Identification)
- Vision & Sensing on-site production Trials incorporating Full in depth production analysis
- Design, Build, Test & Trials of a product flipping unit
- Design, Build, Test & Trials of a Primal Product Gripper System
- Design, Build, Test & Trials of a Servo driven linear robot system
- Design, Build, Test & Trials of a Carton Load Stations and Primal product load preparation stations

- Design, Build, Test & Trials of Empty carton load magazines and servo driven distribution system
- Design, Build, Test & Trials of complete automated Primal Pack System
- Staged on-site production trials

8. Appendix

8.1. Appendix 1

Refer to soft copy – media files Trial1 – 11

8.2. Appendix 2

Refer to soft copy – excel spreadsheet