Final Report

Bung handling and cutting

Automatic equipment for handling of the bung in the lamb slaughter process – Phase 2

Project Code
2018-1031

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Date Submitted
15/08/2022

Published by
AMPC

Date Published
15/08/2022

Contents

Contents		**2**
1.0	**Executive Summary**	**3**
2.0	**Introduction**	**5**
3.0	**Project Objectives**	**5**
3.1	A. Bung handling	6
3.2	B. Bung cutting	6
4.0	**Methodology**	**6**
4.1	A. Bung handling	6
4.2	B. Bung cutting	11
5.0	**Project Outcomes**	**15**
6.0	**Discussion**	**15**
7.0	**Conclusions / Recommendations**	**18**
8.0	**Bibliography**	**19**
9.0	**Appendices**	**19**

1.0 Executive Summary

An automatic unit, which handles the bung, after the bung is cut free in a previous process, has been developed and is in use at pig slaughterhouses in Denmark, providing a hygienic improvement (link: Automatic handling of the bung).

The objective of this project was to design, manufacture, and test a modified version of the existing pig bung handling equipment (a factory prototype), to match slaughter lines for lamb under conventional Australian processing operations. In the bung handling process, the machine grabs the free-cut bung in the pelvic duct using a vacuum cup. As the cup is pushed further forward, the bung end is wrapped in the mesentery (inside itself) and left protected in the abdominal cavity. The primary objective for using the unit is to reduce the risk of faecal contamination, which is commonly associated with manual handling of the bung following bung dropping.

During the first part of this project, it was by variation agreement decided to extend the project to also research the options for developing a technical solution for automatic free cutting of the bung. This was done by, as a first step, developing a process and tool set to be demonstrated and tested in a mock up test unit at line at an AU host slaughterhouse. Thus, this project has two aims:

- A. To design, build, install, validate, and demonstrate the hygienic improvement of using the bung handling unit adapted for lamb, based on the original unit for pig processing (Figure 1)
- B. Developing a process and tool set to automatically cut free the bung, for a later full automation (Figure 2)

If deemed feasible, the bung cutter (B) should be developed with the ultimate goal of being integrated with the bung handling process (A), but both processes (A and B) should also be capable of implementation and operation independently.

Figure 1: The adapted bung handler equipment (A)

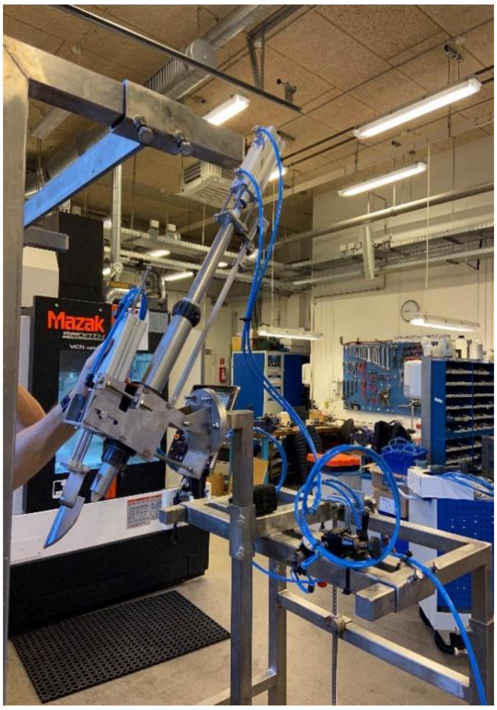

Figure 2: The semi-automatic bung cutting tool (B)

In Q1 and Q2 2019, the bung handler equipment (A) was adapted for lamb processing as described in the MS2 report. It was installed and tested running in-line at an AU host site Q1 2020. Results in terms of "bagging the bung" inside the mesentery were satisfactory and comparable with results obtained for pigs in Denmark. More than 10,000 carcasses were processed during the commissioning and fine-tuning at a line speed from 700-760 heads/hr. Some needs for improvements were identified to avoid clogging up the cleaning system. Also, minor mechanical design changes on brackets and the balancer system were necessary. The changes resulted in minor redesigns concerning expansions of the suction piston and vacuum line. The manufacturing of new components was completed in Q2 2020 and subsequently shipped to the AU host site for mounting, new test runs, and demonstration.

In Q2 2022, as Covid-19 travel restrictions were lifted, it was possible to restart activities at the AU host site. The machine was rebuilt and remounted to be tested in-line. Due to several unforeseen conditions at the host slaughter site, it was only possible to test the changes on a limited number of carcasses, as explained in the MS8 report. Overall, however it is the assessment of the project team, that given that the technical supplies are in place and the sufficient time for commissioning to the carcass variation is granted, the performance as observed in Q1 2020 would be achievable also with the new and improved set-up. As such, the technology could be taken further towards a commercialisation and adoption in the AU industry as desired.

The idea generation and background search for possible ways to automate the bung cutting (B) of lamb was initiated Q4 2019 and continued in Q1 2020 at the AU host site during the testing of the bung handler (A). Several ideas and concepts were pursued and tested with dedicated tools and processes at a local Danish lamb slaughterhouse during Q2-Q4 2020, before a process giving viable results was obtained as reported in MS3 and MS6.

The proposed bung cutting process consists of a set tools and steps, tested in a semi-automated test rig.

The steps of the process are:

1. Ensure correct entry position and angle for centre of sphincter
2. Restrain the tail(stump) (if present) to not get in the way of the process
3. Insert cone-shaped plug forcing the surrounding tissue of the rectum to become pinched between of the inner tube and the plug collar
4. Pull the bung backwards to stretch
5. Punch-cut with curved triangle cutter knife
6. Pull bung slightly for additional stretch
7. Drill around the bung for complete detachment/cutting ligaments
8. Lower the drill slightly and proceed to either alternative a or alternative b:
    a. Complete the bung handling process by pushing it forward inside its own mesentery. Subsequently, the pinch is released, and the tools are retracted.
    b. Release the pinch to let the bung drop inside the cavity, leaving it for a subsequent automatic bung handling process (A), or for an entirely manual bung dropping operation.

IP for both process and tools has been applied for. Results from at-line testing in a Danish lamb slaughterhouse and at an Australian host site in Q2 2022, were positive. For testing at the host site, the drill was mounted with a motor, which improved results further. Demonstrations made for AU stakeholders confirmed that the quality of the cut was similar or better than cuts performed by manual operators.

As an outcome of the demonstration of the cutting tool and principles, ideas for alternative directions and use of the cutting principles arose. It is a well-known issue that during the scouring season (runny faeces) it is extremely difficult to maintain a high slaughter line hygiene. In addition, it also known that albeit the use of plastic plugs inserted in the intestine will reduce contamination issues, the plugs also introduce a risk of damaging and tearing the intestine during the plugging operation. It was discussed that if the bung cutting process combined with the bung handling process, could be executed earlier on the slaughter line, in the cradle position, either as a semi-automatic or fully automated tool, several other benefits might be achieved:

- Faster adoption of the new technology
- Better working conditions compared to manual cutting
- Savings by omitting the plug insertion operation
- Elimination of ruptured intestines due to the plugging operation
- Implementation of the equipment without having to rebuild the slaughter line

2.0 Introduction

For many years, the standard slaughter process for pigs has included bung handling after the bung is cut free by drilling tool, either manually operated or by a robot. To prevent spillage during the bung dropping process, where viscera are removed from the carcass, some slaughterhouses have applied a plastic bag around the bung. In 2010, DMRI initiated a project to handle the bung automatically for improved hygiene, and to eliminate the need for safeguarding the bung with a plastic bag. The project outcome was a process involving an automated bung handling equipment developed by DMRI (link: Automatic handling of the bung).

In the automated bung handling process, the machine grabs the free-cut bung in the pelvic duct using a vacuum cup. As the cup is pushed further forward, the bung is bagged in the mesentery (inside itself) and left protected in the abdominal cavity (Figure 3). The primary objective for using the unit is to reduce the risk of faecal contamination, normally associated with manual handling of the bung following bung dropping.

In the AMPC 2017-1022 project (link: AMPC Snapshot), it was identified that the Danish bung handling equipment and process for pig slaughter could be adapted for processing on AU sheep lines. This deduction was based and validated on slaughter line reviews at some AU processors. The bung dropping process can be associated with contamination without care in the process or use of bags. Following a lengthy dialogue, the current project (code 1031-2018), to develop an automated equipment for handling the bung in the lamb slaughter process, was initiated in mid-2019.

After initiation of the 1031-2018 project and discussion with AU stakeholders, interest arose for automating the bung cutting process for the lamb slaughter process as well. The current manual process, where the bung is cut free using a handheld knife is difficult to execute at high quality on the moving carcass, requires a high degree of training, and is ergonomically not ideal. The high-capacity lines with approx. 600-700 carcasses per hour, will usually require two operators for cutting. Hence, as manual, and skilled labour is costly and in short supply, development of an automatic bung cutting process for the lamb slaughter process would be welcomed. Previous research (MLA 0157, 0630, 0535) aiming to adapt the processes and equipment used for pigs, involving both manual and robotic cutting by use of various drill types, combined with vacuum suction, like the process used for pigs has had limited success and has not reached commercial markets. Observations on handling biological variation, managing increasing carcass rates per hour, and cycle times for sufficient cleaning of tool parts were noted as challenges. By a variation agreement, new milestones were added to the project to develop a new principle and first manual tool set for automatic bung cutting commenced Q4 2019.

3.0 Project Objectives

The project has specific objectives for the process parts A. Bung handling and B. Bung cutting.

3.1 A. Bung handling

The objectives of the bung handling project are:

- To design and manufacture a modified version of the existing pork bung handling equipment (factory prototype) to slaughter lines for lamb under conventional Australian lamb processing operations
- To test and document the performance of the prototype in-line in an Australian lamb slaughter line
- To transfer knowledge of design and equipment adaptation for optimal lamb bung handler operations to an equipment supplier for commercialization to the Australian meat industry

3.2 B. Bung cutting

The objectives of the bung cutting project are:

- To demonstrate the feasibility of a cutting tool for cutting free the bung prior to the bung handling process (cutting is manually operated, to be fully automated in later milestones to be applied for)

4.0 Methodology

Descriptions of the bung handling and the bung cutting parts of the project are described separately in the following subsections.

4.1 A. Bung handling

The project was started with some very manual tests of the bung handling principle, at the AU host site. The tests were performed on 30 carcasses, demonstrating that the bung handling principle used in pig slaughter could be adapted to lamb slaughter, as reported in MS1.

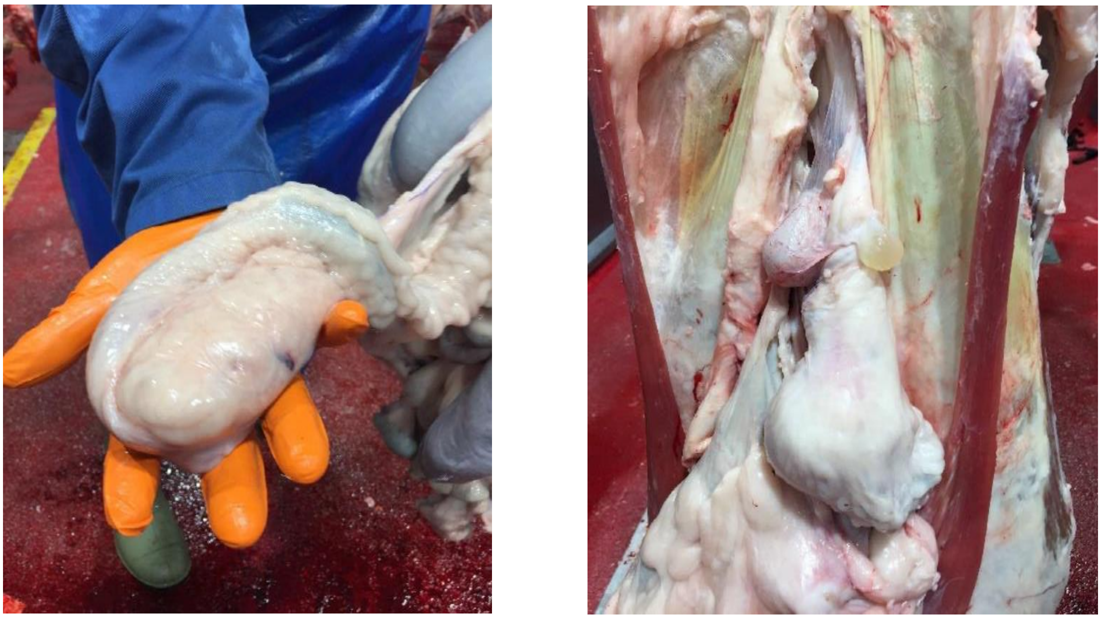

Figure 3: The bung bagged in the mesentery

At this initial visit, the options for adapting and installing the machine on the line were reviewed. Together with the maintenance team at the lamb abattoir, the maintenance capabilities were assessed and both the final position on the line and the needed space for the machinery were discussed. The following was evaluated:

- Reviewing the line for final positioning of the machinery
- Measurements and tests of dimensions, angles, variation of lambs
- Measurements of dimensions of present conveyor system, and proposed mounting
- Assessments of the physical impact of integrating these systems with the existing operations and conveyor line
- Identify any changes to current practices to ensure an easy implementation
- Identify any conflicts with existing equipment and contemplate probable solutions

After the bung handling equipment was redesigned according to the identified needs, it was manufactured assembled, preinstalled, configured, and FAT tested in Denmark and subsequently shipped to the AU host site, as reported from MS2.

The complete system consists of several components:

- The moving unit, following the carcass, with retractable vacuum cup and washing unit
- A frequency controlled vacuum pump, and control unit for pump to adjust vacuum
- A vacuum buffer tank (collecting the wash water, for daily release once)
- Collector tray for washing water under washing unit
- Stainless steel operator/technician control box (On/Off) and screen for adjusting the machine settings
- Stainless steel cabinet for control valves
- Stainless steel cabinet for PLC and relays
- HMI user panel for fine-tuning parameters

After assembly, during preparation for initial testing (FAT), some minor mechanical changes were made. After completing the changes, tests were performed on a small number of cold and semi-warm carcasses.

Figure 4: Cutting free the bung manually prior to initial workshop test with the bung handler prototype (left). Pump and tank components providing the controlled vacuum for the process (right)

The basic functionality was proven at a workshop test in DK (Figure 4), and equipment was dismantled for secure packing and shipping to the AU host site.

The bung handling machine was installed in-line at the AU host site by a collaborative team consisting of representatives from both DMRI and the host., After installing, extensive testing and commissioning during normal line processing was executed over a three-week period, as reported in MS4 (Figure 4 and 5). The testing was overall highly successful, especially after a redesign of the cup end grabbing the bung, thus enabling the team to demonstrate on-site, that the automatic bung handler could locate and grab the bung followed by an insertion of the bung into the mesentery in an in-line setup. The main outcomes of the on-site testing were:

- Approximately 10,000 carcasses were tested in total.
- The line speed during the test varied in the interval of 700-760 heads/hour.
- Minor adjustments and fine-tuning were done incrementally and iteratively during installation and testing.
- The testing was conducted in-line and without any interruptions/stoppages of the slaughter process.
- After completing the fine-tuning, the bung handler successfully located and pushed approx. 95% of the bungs and of these, approx. 90% were placed correctly in the mesentery. This performance is comparable or better than what is currently achieved with pigs.
- Initial hygiene testing of the bung handler tool performed by representatives from the host site was satisfactory.
- The bung handler was safety evaluated and approved by representatives from the host site.

Figure 5: Commissioning the bung handler at the host site in Australia

The testing also revealed further opportunities for minor adjustments and improvements to the design:

- Redesign of the wash box to accommodate the final angle of insertion, which is relatively steep compared to the pig bung handler
- Redesign of the tool balancer with an adjustment option to accommodate the biological variation of the lamb carcasses
- Redesign of the vacuum system, to optimize the vacuum and cleaning process.

It was agreed that the redesigns should be carried out and that the redesigned parts would be shipped to the host site prior to the next visit, for final completion of the commissioning. Due to Covid restrictions the next visit was delayed by 2 years. In the meantime, the machine tool had been removed from the line and stored.

During the visit in Q2 2022, the machine tool was disassembled, rebuilt, and reinstalled with the new components, including a larger vacuum line to avoid clogging of the line which would require manual cleaning, as reported in MS8.

Figure 6: Remounting and adjustment work, after processing hours at the AU host site

Several unexpected incidents and conditions caused extra work and delays at the host site (Figure 6 and 7), leaving very limited time for recommissioning the bung handler, and insufficient time for testing and validating the performance on the line. Some of the key issues are mentioned below:

- The two-year delay, due to Covid restrictions, required more work and service to get the mechanical parts back to normal working condition
- A partly faulty HMI control panel had to be replaced with an alternative product and software changes for the replacement product had to be performed
- It was necessary to change program steps and reload the PLC program remotely from DK
- Issues with contaminated pressured air for the actuator had caused blocked valves, resulting in abnormal function which required complete disassembly and cleaning before functionality could be restored
- The main cylinder for retracting the tool along the line had been damaged and was not working normally (possibly caused by contaminated air supply etc.)
- The site experienced during the reinstallation other challenges:

- Issues with compressed air pressure below the requirements of the equipment
- Issues with hot water pressure below the requirements of the equipment
- Multiple external audits and production days without slaughter, limiting the time for fine-tuning,
- Issues delaying re-establishment of the same workplace conditions for the manual bung cutting as during the first test in Q1 2020

As a result of all the above factors, the commissioning, preparation, and actual demonstration had to be kept at an absolute minimum.

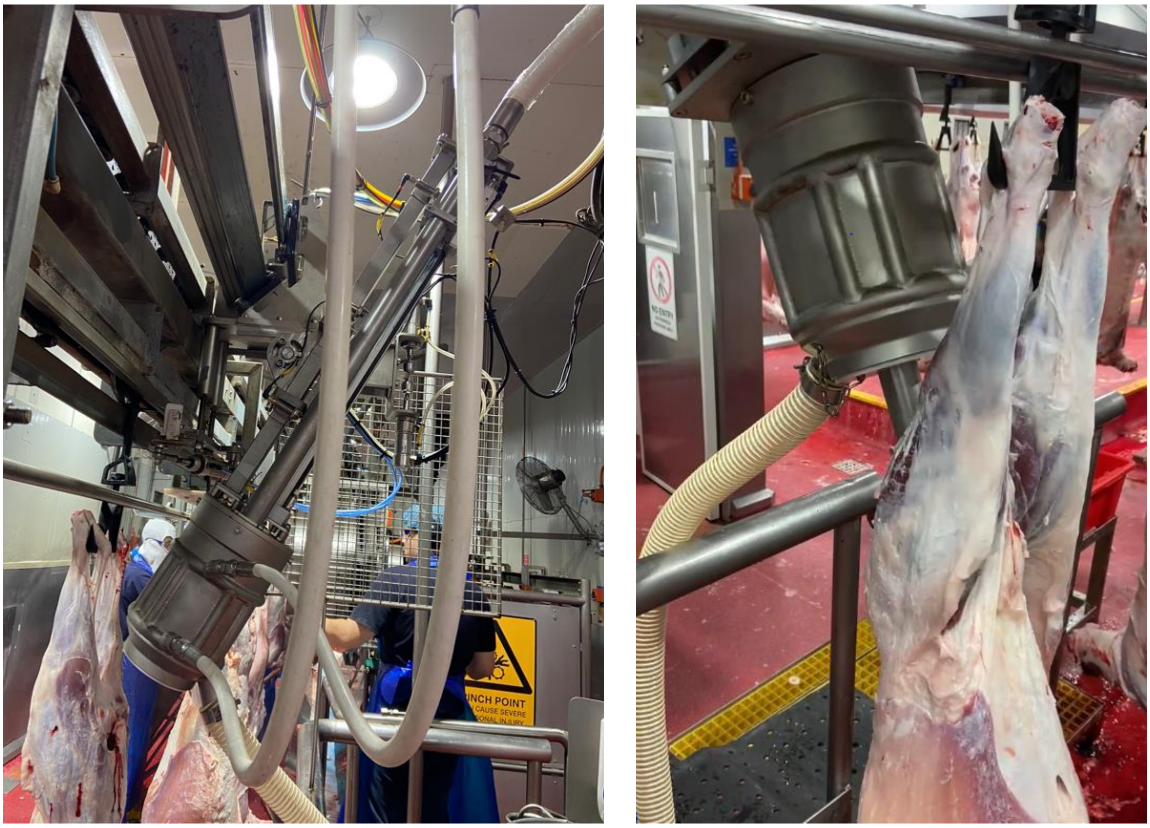

Figure 7: Rebuilt and remounted bung handler unit adapted for lamb slaughter

Based on the limited testing conducted with the changes that had been implemented between Q1 2020 and Q2 2022, the project team assessment was, that the same or better performance with the bung handler principle could be expected after a full commission. This evaluation is based on that the main change happening between the two periods was not in the bung handling processing, the vacuum line or cup head size, nor in the manual bung cutting process, but rather in the new preparation of the carcasses, where all skin/wool remnants around the sphincter were removed. In theory and practice it should provide for a better cup grip of the bung end and not cause additional difficulties in placing the bung inside the mesentery. Again, given the circumstances, the opportunity to test and demonstrate this fully was not presented.

In summary, it is the assessment of the project team, that given that the technical supplies are in place and the sufficient time for commissioning to the carcass variation is granted, the performance as observed in Q1 2020 would be achievable also with the new and improved set-up comprised of the rebuilt washing box, 1.5” cup, and 2” vacuum line, thus solving the issues observed in the first test.

To provide installation and maintenance services for the bung handling equipment from another continent is likely to be both difficult and more costly. Thus considerations have been made towards identifying a potential equipment providers or partners capable of providing installation and service of the bung handling equipment locally in AU (see MS8). Considering the limited size of equipment parts, except the tank, the main tools of the equipment could be manufactured outside AU by several different providers around the world and shipped to the site of operation. The provider merely would need insight into the technology, some knowledge of the industry, and could team up with a more local partner for service and installation. Knowledge transfer has not been executed as the options for potentially including automatic cutting in an integrated cutting/handling device have been given the main attention by stakeholders. Thus, it was deemed untimely to proceed with concrete knowhow transfer for the adapted bung handler alone, and this should await further advancements with regards to the automatic cutting of the bung and its potential integration with the bung handling process.

4.2 B. Bung cutting

Several alternative approaches for cutting free the bung, were tested at a local DK slaughterhouse using handheld and automated tool parts consecutively. The best concept was designed to address the possibility to carry out the bung cutting and handling operation as an integrated process.

During the tests in DK, it was identified important for a successful cut to acquire proper fixation and closing of the bung end by means of a plug and pinch procedure, not including any vacuum in the process. It was also deemed beneficial to use a semi-circular punch knife for cutting the ligaments prior to using a conventional drill whilst still stretching and maintaining the pinch sealing of the bund end. After the drilling, the pinched bung end may be pushed forward inside the mesentery (wrapped inside itself) after which it is released, and the tools are extracted, thus combining the bung cutting and handling processes into one. The test mock-up tool for at-line testing can be seen in Figures 8 and 9 and was in its final version tested on 42 Danish carcasses with good results.

Figure 8: Insertion of cone-shaped plug during testing at the Danish slaughterhouse.

Figure 9: Adjustments of equipment at the DMRI workshop prior to shipping to Australia. Note the curved punch knife as part of the process.

The test rig equipment was dismantled and shipped to the AU host site together with components for modifying the bung handling machine (see Sec. 4.1) and stored there until tests could be carried out in Q2 2022.

The test rig was assembled and based on some tests carried out prior to the visit it was possible, as part of the testing, to add a motor to the test rig drill and make some improvements on adjusters and suspension (Figure 10A), which improved the process, as reported in MS6.

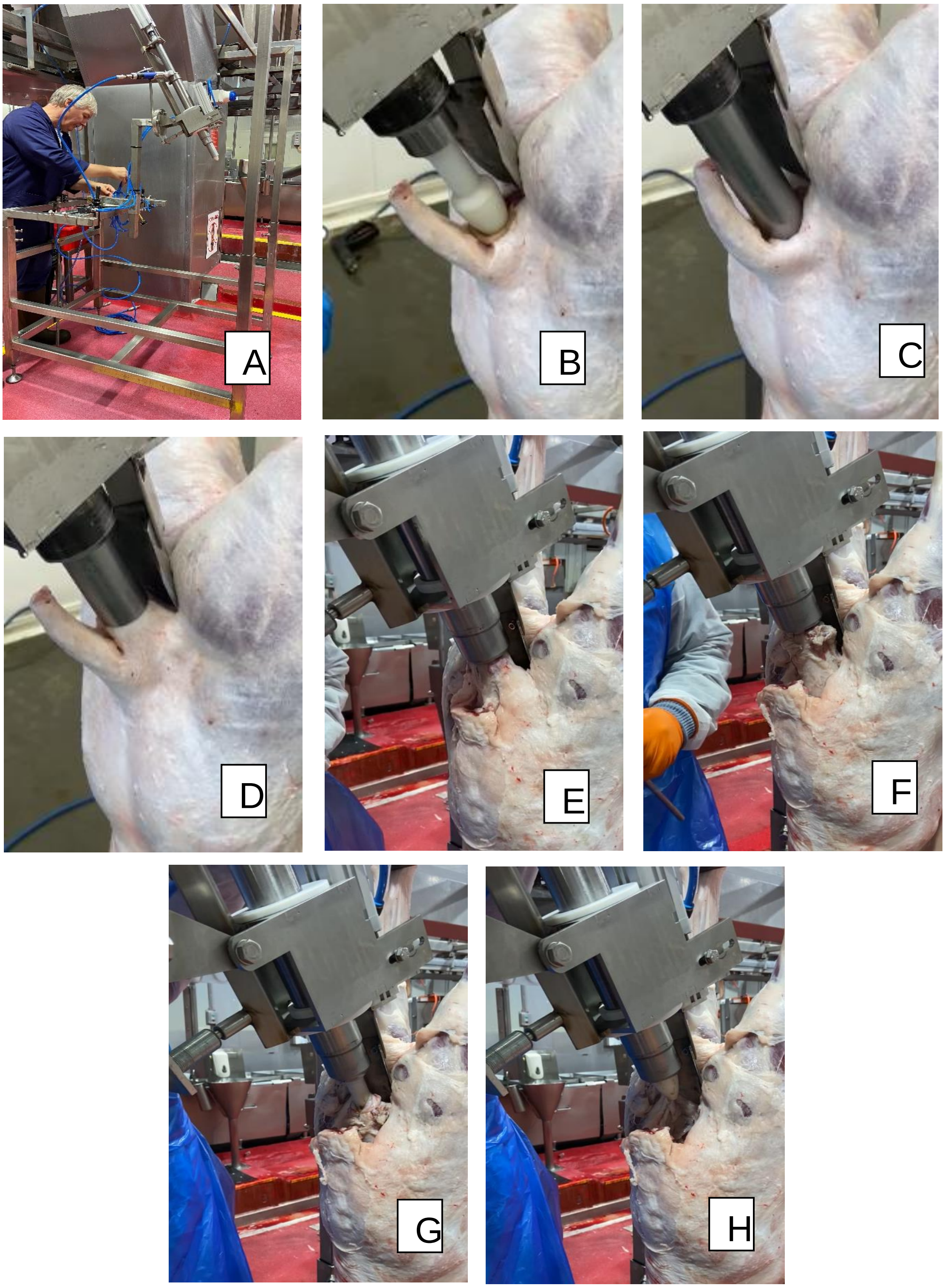

Figure 10: Mounting the equipment at-line (A), cone insertion (B), inner-tube insertion/pinching (C), pinching/stretching (D), punch-cut (E), post-drilling (F), retracting (G), releasing (H)

The full process testing was based on cutting of approximately 40 carcasses adjusted to the following steps below (see also Figure 10):

1. Ensure correct position
2. Restrain the tail(stump) (if present) to not get in the way of the process

3. Insert cone-shaped plug forcing the surrounding tissue of the rectum to become pinched between of the inner tube and the plug collar
4. Pull bung to stretch (app. 5-10 kg torque)
5. Punch-cut with curved triangle cutter knife
6. Pull bung for additional stretch (+ app. 2 kg torque/1-3 cm)
7. Drill around the bung for complete detachment/cutting ligaments finally
8. Lower the drill slightly and proceed to either alternative a or alternative b:
    a. Complete the bung handling process while the bung end is still fully sealed by the pinching, by pushing it forward inside its own mesentery. Subsequently, the pinch is released, and the cone plug is retracted fully into the tube and the drill before the drill is removed from the carcass.
    b. Release the pinch to let the bung drop inside the cavity, leaving it for further processing, for a subsequent automatic bung handling process via an automatic vacuum punch concept as in the installed and tested in-line equipment, or for a purely manual handling in the process e.g., when removing stomach and intestines from the carcass.

Despite some setbacks and needed improvements in the test set up, due to various circumstances, the team managed to cut (at-line) approximately 40 bungs on carcasses with a weight variation of approximately 20-80 kg. None of the cuts resulted in perforated intestines. The majority of these were only cut, and not pushed forward inside the mesentery, as tested, and validated in the test in Denmark.

On the last visit days, the bung cutting process was demonstrated on several carcasses, both for AMPC representatives and for the AU host management group. It was the general opinion that the cutting looked good and at or above the level what was achieved by the manual operation when cutting on the line.

The test rig tools are manually controlled and semi-manually actuated. However, a fully automated design with actuators has been generated (Figure 11).

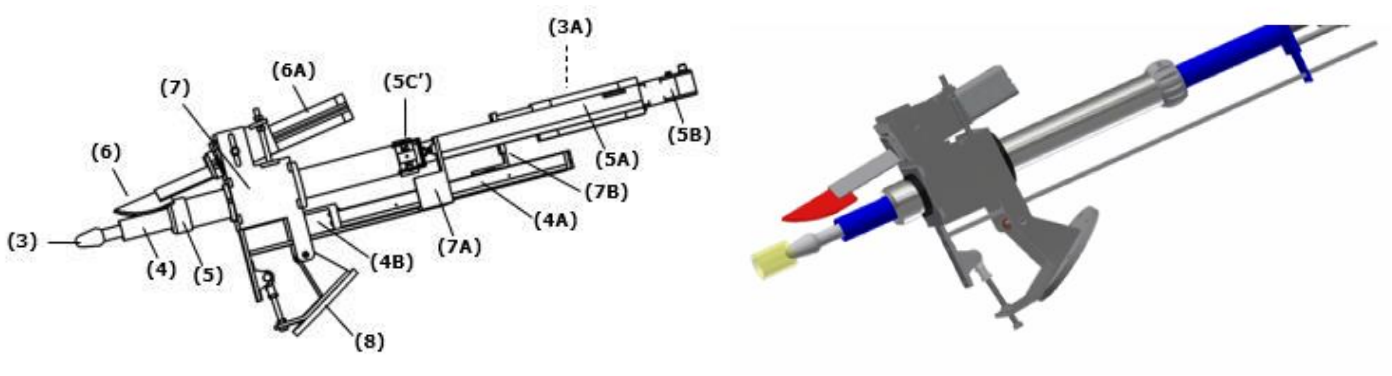

Figure 11: Technical drawing and design of fully automated bung cutter with actuators

The fully automated tool could be mounted on a robotic arm following the carcass or mounted on a tool holder design like the one used for the bung handler tool. It may also be adapted for semi-automatic use, to be controlled and pointed by an operator.

5.0 Project Outcomes

For the bung handling process (A, Sec. 4.1), a successful transformation and adaptation of the automatic bung handling equipment operating on some Danish pig slaughter lines has been achieved. The adapted equipment was demonstrated to run in-line at an AU lamb processing line, and the final commercialized equipment can be used on Australian lamb processing lines while obtaining a hygienic improvement as described in more detail in the MS8 report.

For the bung cutting process (B, Sec. 4.2), a new method and tool was developed and was able to cut the bung free automatically, either presented with skin surrounding the sphincter area or with the skin fully removed:

- Without the use of vacuum
- In a quality like manual cutting
- With minimal risk of perforating the intestines
- With the option to proceed with one of the following:

    1. Push the bung end inside the mesentery while it is still pinched, in an integrated bung cutting and handling process
    2. Releasing the bung end after cutting and placing it conveniently for bung dropping
    3. Releasing the bung end after cutting and placing it conveniently for a separate bung handling process (A, Sec. 4.1) prior to bung dropping

6.0 Discussion

The demonstration of the bung handler and the bung cutter tool (see MS6 & MS8 reports) was attended by the AU test site management team and AMPC representatives. The possibilities of implementing the bung cutter and bung handler, both separately and in combination, were discussed and innovative ideas were brought to the table. There was a notable interest in investigating the option of applying the bung cutting operation at an earlier stage of the slaughter process, namely when the carcasses are in the cradle position and to explore if implementing a semi-automated, operator assisted solution before implementing a fully automated version, could be the way forward.

In Table 1, a number of alternative directions for the next stage of project are listed. The table can serve as a roadmap for the industry to guide the decisions on the next stage(s) for bung handling and cutting alternatives, based on the given estimates. It should be noted that best estimates are formed from the knowledge available now. However, in these types of development projects, some degree of uncertainty is inherently present.

The estimates in Table 1 are based upon line processing speeds and manning currently representative for most AU slaughter lines in the order 400-760 heads/hour. Some companies may be considering aiming for increasing the line speed up to 900-1000 heads per hour. An increased line speed may require additional operators for the manual processes (e.g., intestine plugging and bung plugging). Additionally, an increased line speed would require additional hand tools and machines than indicated in the table above and require a larger line spacing footprint for both manual and automatic processing, that in many cases would need to be established. Overall, it should not significantly change the ranking of the above options (1-5).

Table 1 can be supplemented with the following observations and reflections, which might influence the preferred and optimal way forward:

- Proceeding with option 1 (bung handling alone): Seems technical and practical feasible to implement. The decision to apply would likely rely on the focus on slaughter hygiene at the individual slaughterhouses and on their current operations, including their performance on slaughter hygiene, especially if plastic bagging is not applied.
- Proceeding with option 3 (semi-automatic cutting solution at the hindleg hanging position): A successful outcome seems difficult as limited savings on labour and the need for additional line space would challenge the profitability.
- Executing the process in the cradle position as a semi-automatic (4) or fully automated (5) process seems interesting, if it is possible to implement without line rebuilding, which would be necessary if option 2 was chosen (processing in the hindleg hanging position), and especially if the plugging issues are solved. Also, pursuing option 4 (semi-automatic solution) could allow for a likely wider and slightly faster adoption of the method.
- It is likely slightly faster to validate the feasibility of executing the process in a semi-automatic tool first, option 4 in a feasibility stage, and then, based on experience gained, review if the process in its next stages should be completed as a semi-automatic or fully automated solution eg. Option 5. The review should focus on ease for the operator to correctly control the tool during execution, the need for multiple tools to leave ample time for wash cycles, and the practical issues of operator rotation. Experiences with handling multiple tools, operator rotation, and wash station(s) may reveal that, all things considered, a fully automated solution ultimately could turn out be the better choice.

Table 1 Roadmap for alternative directions for the next stage of the project.

# Proces options for bung cutting and bung handling	Equipment / operators	Task with bung	Line position	TRL	Estimated # operators needed for plugging+cutting+hygiene (clean carcasses)	Estimated # of operators saved	Footprint requires line rebuilding	# Machines/ tools required	Estimated price machine/tool incl. install, excl. line modifications (AUD)	Effective time to develop (floating funding) (YRS)	Estimated payback time (YRS) simple
Manual operation		Cut	Hindleg	-	2 + 2 + (x?)	0	No	-	-		
1. Install bung handler machine		Push	Hindleg	8	2 + 2 + (x? minus 1 or 2?)	1 or 2?	(No)	(1)	225-325K $	1	2.5 - 3
2. Develop bung **cutting** machine			Hindleg								
2.a. Cutting but include bung handling proces		Cut + push	Hindleg	3 - 5	2 + 0 + (x? minus 1 or 2?)	3 - 4	(Yes)	2 (w. dual heads)	2 x 275-400K $	2 - 3	2 - 3
2.b. Only cutting bung		Cut	Hindleg	4 - 5	2 + 0 + (x? minus 1 or 2?)	2	(Yes/No?)	2 (w. dual heads)	2 x 265-390K $	2 - 3	3 - 4
2.c. Cutting + separate Bung handling machine	+	Cut + push	Hindleg	4 - 5 +8	2 + 0 + (x? minus 1 or 2?)	3 - 4	(Yes)+	2 (w. dual heads) +1	2 x 500-800K $	2 - 3	4 - 6
3. Develop **semi-automatic bung Cutting** tool	+		Hindleg								
3.a. Cutting but include bung handling proces	+	Cut + push	Hindleg	3 - 4	2 + 2 + (x? minus 1 or 2?)	1 or 2?	(Yes)	4 tool min. plus wash station	4 x 90K? + 100K = 460K $	2 - 3	5
3.b. Only cutting bung	+	Cut	Hindleg	3 - 4	2 + 2 + (x? minus 1?)	(1?)	(Yes)	4 tool min. plus wash station(s)	4 x 80K? + 100K = 420K $	2 - 3	5
3.c. Cutting + separate bung handling machine	+ +	Cut + push	Hindleg	3 - 4	2 + 2 + (x? minus 1 or 2?)	1 or 2?	(Yes)+	4 tool min. plus wash station +1	420K + (225-325K) = 645-765K $	2 - 3	8
4. Develop **semi-automatic bung cutting** tool	+		Cradle								
4.a. Cutting but include bung handling proces	+	Cut + push	Cradle	1 - 3	0? + 2 + (x? minus 1 or 2?)	2? - 4?	(No?)	4 tool min.	4 x 90K? + 100K = 460K $	2 - 3	2
4.b. Only cutting bung	+	Cut	Cradle	1 - 3	0? + 2 + (x? minus 1?)	2? - 3?	(No?)	4 tool min.	4 x 80K? +100K = 420K $	2 - 3	2
4.c. Cutting + separate bung handling machine	+ +	Cut + push	Cradle	1 - 3 +8	0? + 2 + (x? minus 1 or 2?)	2? - 4?	(No?)	4 tool min. +1	420K + (225-325K) = 645-765K $	2 - 3	2.5 – 3.5
5. Develop **automatic bung cutting** tool			Cradle								
5.a. Cutting but include bung handling proces		Cut + push	Cradle	1 - 3	0? + 0 + (x? minus 1 or 2?)	5? - 6?	(No?)	2 (w. dual heads)	2 x 275-400K $	2.5 - 3.5	1.5 - 2
5.b. Only cutting bung		Cut	Cradle	1 - 3	0? + 0 + (x? minus 1?)	4? - 5?	(No?)	2 (w. dual heads)	2 x 265-390K $	2.5 - 3.5	1.5 - 2
5.c. Cutting + separate bung handling machine	+	Cut + push	Cradle	1 - 3 +8	0? + 0 + (x? minus 1 or 2?)	5? - 6?	(No?)	2 (w. dual heads) +1	2 x 500-800K $	2 - 3	2.5 - 3.5

Note 1: in any of above options (1-5), the bung dropping process (i.e., removing bung and viscera from the carcass) remains unchanged and is not part of any of the proposed developments
Note 2: the estimates above are based upon line processing speeds and manning currently representative for most AU slaughter lines in the order 400-760 heads/hour. Some companies may be considering aiming for increasing line speed up to 900-1000 heads per hour. An increased line speed may require additional operators for the manual processes (e.g., intestine plugging and bung plugging). Additionally, an increased line speed would require additional hand tools and machines than indicated in the table above and require a larger line spacing footprint for both manual and automatic processing, that in many cases would need to be established. Overall, it should not significantly change the ranking of the above options (1-5).

7.0 Conclusions / Recommendations

A machine designed for carrying out a bung handling process (A), i.e., placing the bung end inside the mesentery to obtain a hygienic improvement of the slaughter process, has successfully been designed and installed in-line at an Australian lamb processing line. The machine was tested at normal operating line speeds on two occasions: at the initial install and during later tests after some design improvements. A total of approximately 10,000 carcasses were processed, of which the bung handler successfully located and pushed approx. 95% of the bungs and of these, approx. 90% were placed correctly in the mesentery. This performance is comparable or better than what is currently achieved with pigs.

At the second commissioning, some necessary mechanical improvements and an enlargement of the vacuum line were implemented, to avoid clogging during operation. Due to ongoing site activities and supply issues, the testing of the improved equipment was limited to a minimum, however it is the assessment of the project team, that given that the technical supplies are in place and the sufficient time for commissioning to the carcass variation is granted, the performance as observed in Q1 2020 would be achievable also with the new and improved set-up. Consequently, the conclusion is that it is possible to build a final prototype and 0-series equipment, to pave the way for commercial adoption. Several technology companies have been identified as capable providers for manufacture, service, and installation and technology transfer can be duly completed once a provider has been chosen.

With regards to the target to develop a new method capable of automatically cutting the bung free (B), a new method and the necessary tool sets have been developed and at-line tested with satisfactory results. The developed test rig tools are manually controlled and semi-manually actuated, but with a design made for a fully automated process. The new method and tool is able to cut the bung free automatically, either presented with skin surrounding the sphincter area or with the skin fully removed:

- Without the use of vacuum
- In a quality like manual cutting
- With minimal risk of perforating the intestines
- With the option to proceed with one of the following:

    1. Push the bung end inside the mesentery while it is still pinched, in an integrated bung cutting and handling process
    2. Releasing the bung end after cutting and placing it conveniently for bung dropping
    3. Releasing the bung end after cutting and placing it conveniently for a separate bung handling process (A, Sec. 4.1) prior to bung dropping

DMRI has observed, that the potential benefits of processing earlier on the line if feasible here with a semi-automatic tool has a large potential and is therefore the preferred direction to go. Thus, for a next stage research proposal, DMRI recommends aiming at developing a semi-automatic solution to be used in the cradle position, as a first incremental step towards a possible later development of a fully automated solution.

Irrespective of the large potential, there are several unknown factors when performing the process earlier on the line and some of these factors may be insurmountable. But it is expected that many of the tools, actuators, and controlling soft- and hardware developed for performing the process in the cradle position, could be used for processing later the line as well. Thus, should the development of a cradle-position based method have a negative outcome, reusing the process and tools for a hindleg based method would be feasible, thereby ensuring that the investment will not be lost.

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9.0 Appendices

N/A