final report

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Alternative cutting techniques for the meat industry

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Background

Conventional Cutting technology in the red meat industry consists of tool (either knife or saw) which physically comes into contact with the product.

For slaughter applications, the tool is then required to be sterilised before it comes into contact with another product to stop contamination spread and increase shelf life and product integrity.

For boning room applications, problems that metal cutting tools incurs in portioning meat products are yield loss and bone chips if a saw is used and bone shattering on round bones if a knife is used.

Blade wear is common to most tools and causes deterioration in the quality of the cut, as well as slowing the cutting cycle time. Constant blade sharpening, product burn or replacement causes down time.

Long term, the use and application of steel on automated systems will be a limiting factor due to sharpening requirements.

Long term, the use of contact cutting processes on the slaughter floor will also inhibit automation due to the AQIS requirements of contact surface sterilisation.

Benefits

The benefits of this technology are

- non-tactile cutting will eliminate the need for sterilisation – slaughter floor (and some boning room - cysts) benefit
- no sharpening or tool replacement program required
- limiting sterilisation will reduce environmental impacts caused by the industry
- potentially develop alternative hand tools that are safer and easier to use that do not require sharpening
- possible food safety improvements

Objectives

- Search internet, food and other industry magazines and other mediums to find companies and end users using or investigating non contact cutting systems
- Contact companies, obtain relevant information and initiated relationship in order to find an appropriate partner or solution provider for possible future R&D.

Report

MAR will provide MLA and AMPC with a report of all the identified cutting alternatives that are used in industries around the world (not just food related).
The report will identify equipment suppliers or each technology and a high level recommendation of whether the technology may be applicable to the red meat industry. In addition where possible an indicative price will be provided for the cost of the equipment off the shelf.
The report is a high level report and MAR will not be held responsible for any recommendations that are made under this report.

Executive Summary

Machinery Automation & Robotics has been given the task of researching the non contact cutting technologies available in industry and to assess their ability to be applied in the meat industry. The cutting technologies involve plasma, ultrasonic's, laser and water jet cutting. Industries found using these technologies predominately are in the metal and fabrications where hard materials need to be cut welded with quite high accuracies and with minimal mechanical stresses or deformation. It was found that Water jet with Ice abrasion (otherwise know as Ice jet) as this technology has some specific advantages in that it cuts without causing stress either thermally or mechanically. Trials are still required as ice jet need to overcome the problems of water jet in terms of ability to cut through bone. Water jet also can be applied to the industry for boneless slicing tasks and research and development should start to exploit this technology for removing fat, portioning and other tasks.

Ultrasonic's have been trialled on meat with limited success and from reports it relies heavily on temperature. Temperatures of meat of between 0-5^{o}C have been recommended as above this temperature and the meat is too soft and below this temperature the ultrasonic's take too long to cut. These recommendations are based on a trial of average temperature well below zero. No trials have been carried out in the 0-5 degree range and hence the cut quality and technical feasibility of this technology as a solution is relatively unknown. Ultrasonic's have the potential to be used in the meat industry as they cause no thermal loading on the product. Further research into this area would be required before it could be considered as a technology to commercialise. Ultrasonic's has the distinct advantage over water jet in that it uses sound waves instead of water to do the cutting reducing contamination issues further.

Laser would be a good option, however, its flaw is that it cuts using energy to break bonds. The problem with this is that the meat will be changed, either burnt or cooked. Options presented to reduce this effect are pulsating laser and UV frequencies along with the laser being enclosed in a low pressure water jet. However to date there is no evidence of a successful trial were laser was used to cut meat without product deterioration. Plasma works by superheating the material and hence is not applicable to the meat industry as product quality will be compromised with the product burning, or cooking.

The areas the industry should look at are water jet for meat with no bones, trials with Ice jet for situations where the meat is quite thick or has bones. This technology presents as having the smallest risk of failure out of the non contact technologies. Also ultrasonic's should have a very preliminary "sink or swim" trial which conclusively proves technology at 05 degrees.

Current technologies for cutting

The meat industry has relied heavily on the cutting techniques which date more than 30 years, such as the bandsaw, circular saws, and knives. All of these techniques involve a human operator controlling the tool and the tool making contact with the product. Contact with the product causing issues with contamination spreading from one carcass or portion to another.

Bandsaws have been in the industry for a long time due to their flexibility and ability to cut cleanly and accurately. The disadvantages to the bandsaw are with operator safety, contamination spread, causes bone dust/chips, and loses yield through toothed blade (approximately 3mm wide on every cut).

Circular saws in the industry are also dangerous to the operator and cause contamination spread similar to the bandsaw due to the blade interfacing with the meat product.

Knives have the ability, through the 2 knives system, to be sterilised between every carcass.

The wish list for the industry in terms of cutting would be to satisfy the following criteria;

- the tool would not contact the product hence eliminate contamination spread
- blade life or cutting tool life would be extended, reduced wear or eliminated through non contact cutting
- cutting could be achieved quickly and accurately
- cutting would be able to cut through thick bones reducing bone dust and thin bones reducing bone shattering
- the tool would not negatively effect the quality of the product
- minimum yield loss trough the thickness of the blade

The future of automation at this stage relies on improvements in the sensing and in the cutting tool to start to automate tasks that pose large OH&S risks.

New Blade Technology (Currently Available)

Ceramic Blades

Circular Blades made out of Zirconia Ceramic which has 100 times the wear resistance of steel. Ceramics are also do not heat as quickly as steel as the friction coefficient is considerably less. Ceramics also have the benefit in being far more abrasive than steel which means smoother cut and reduced bone chips.

Meat trials

None found to date

Blades slicing

Blades design is being trialled through the MAR 6 way cut project in which we are working with Freund in Germany to develop a blade which reduces bone dust and stops the shattering of bones. Blades designs such as slicing, scalloped designs to determine the optimal cutting arrangement.

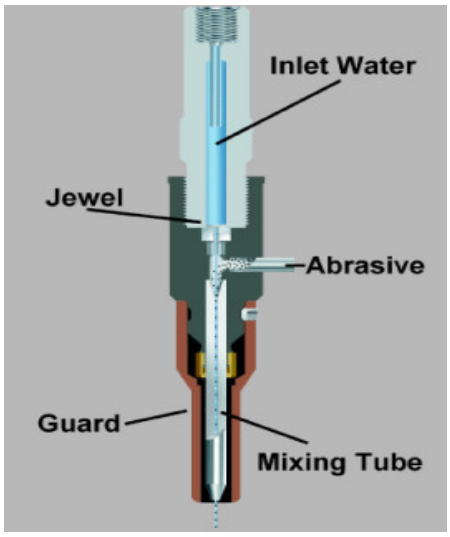
Non contact cutting

Water Jet Technology

Companies distributing technology

Water Jet

Originally developed in the 1960s, for the aerospace industry, due to its ability to precision cut without causing thermal or mechanical stresses.



Technology

In water jet cutting, water is directed through an orifice as small as 0.003 and as large as 0.09 inch in diameter at pressures up to 60,000 psi, and directed at a material in much the same way as a laser or band saw.

The technology of the water jet works on an accelerated erosion principle involving 5,000 to 60,000 psi. The water is forced through a 0.03 inch orifice of hard material such as diamond to provide the high velocity required to cut. The stream exists around 2,700 feet per second or 2.5 times the speed of sound.

The water jet was designed to cut through material too hard to cut through by conventional methods. The cutting speed of the water jet depends on the material and thickness and ranges from 0.01 to 750 inches per minute (based on metals). Vision systems for the water jet involve laser sensors which pinpoint the position as well as height sensors which evaluate the distance the water jet must travel and adjusts the velocity accordingly.

Cost

The cost ranges from $275,000 to $350,000. However this is for the table and linear rails system of which would not be required due to the robotic arm.

Food Applications

Foodstuffs: pastry, meat, fish, baked goods, deep-frozen products

Flow Corp – Food application of chicken slitting, chicken nuggets profile cutting FMC –
Chicken and meat profiling products such as slicing

Advantages

- cleaner than conventional cutting with a band saw
- increased accuracy over cut
- reduced contamination caused from airborne bone dust
- no replacement cutting tools needed
- no mechanical and thermal degradation of product
- easier cutting into soft material

“The technology offers processors sanitary advantages over other mechanical cutting methods, since there is no bacterial transfer from food to food or from tool to food. There is also no downtime for sharpening as there is with knives. Operator safety is improved because water jets can be remotely controlled by robotics.”

Water Jet Trials

Trials at Flow Systems (supplier) & Agresearch NZ (Research Organisation)

Flow Systems trialled with Agresearch, some years ago, the possibility of using water jet cutting for portioning of meat. The trials were deemed to be a failure as the cutting area would be small and accurate at the entry point and would flare out at the exit. If the water jet encountered either one or cartilage it would deflect the stream and cut the surrounding meat. Cutting through large bones such as the femur would pressurise and explode sending bone shards through the meat once it had been penetrated.

Water jet worked well on soft meats such as bacon, ribs, and rib meat and it was recommended that thin bones it could be used on but not thick bones. The quality of the cut at the entry point was good, however, it did leave cut blood vessels that were striated across the surface.

MLC UK- Meat and Live Corporation (Research Organisation)

MLC looked at improving the abrasiveness of the water jet without causing contamination. The two options it had were dried blood and ice. The ice requires specially designed nozzles to reduce wear. The technology was said to be impressive but of no use and shelved. The pressure was run at 40000psi through nozzles 0.2 to 0.5mm in diameter and the equipment was a “Diajet”. The reports for this trial are lost.

UNSW (Research into Water jet)

Research has proved the technology works on meat, however, has concurred with the research of Agresearch in regards to deflection problems associated to “bone in” meat. They advised that while ice abrasion would have benefits the technology is not mature as only crushed ice has some success as the particle size is too large.

The limitations of water jet cutting seem to be in the depth that it cuts before the accuracy deteriorates quite considerably. The depth that ice abrasive water jet can cut through will be between 100-150mm without impeding accuracy. Flaring of the spray can be controlled within 0.1mm. Areas unknown are in terms of the thickness of meat the jet can cut before it hits bone. The reason for this if the pressure drop is significantly large before the ice and water reach the bone (buried in meat) it may force a channel between the meat and bone. This occurs as it requires less force to delaminate meat from bone than to cut bone.

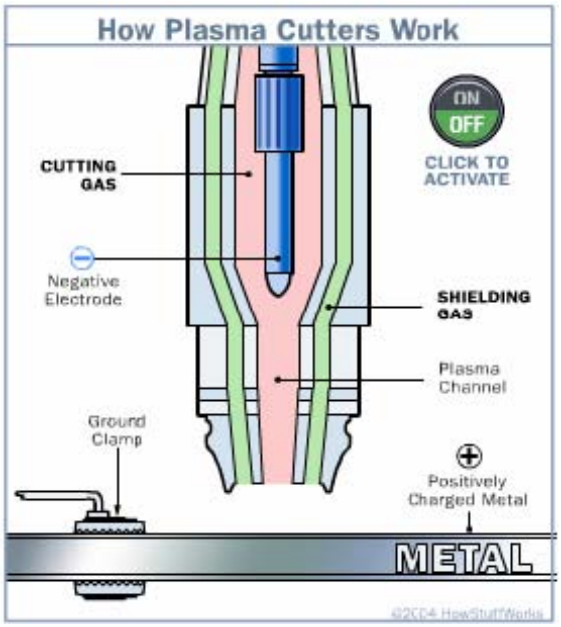
Potential for Water jet Cutting

Water jet has potential and is used in small portioning of chicken and other food products. It works on consistent thickness product without heavy bones which deflect the water jet. Water Jet is used in consistent topography products such as metal and not varying topography products such as found in the meat industry.

One application of waterjet is removal of intercostals from French rack using a lower pressure higher/water volume system than most waterjet cutters. This machine received much criticism for using too much water and causes product spoilage or reduced shelf life which is most noticeable in export.

Plasma Technology

Plasma cutting operates on the principle of a highly charged cathode and a positively charged material (metal) that come in contact through a pressurised gas such as argon, nitrogen or oxygen. Once the connection is made it creates a electrical circuit and a powerful spark. This spark heats the gas until it reaches plasma approximately 16649 °C which is he forth state of matter.



Surrounding the plasma is a shielding gas which controls and focuses the plasma beam.

Plasma in the Meat industry

Plasma technology is unsuitable for the meat industry for it heats to 16649°C which would cook/burn the meat. It is also far more expensive to run than water jet cutting.

The meat would have to be positively charged to cause the electric arc and it also need a ground clamp which does not solve the contamination issues.

Trials for Meat Industry

None found working or have trialed this area.

Ultrasonic Cutting

Ultrasonic Cutting works on the principal of sound waves emitted from the Device and passes through to the material of the blunt blade causing vibrations and blade to oscillate, melting the product without causing heat. The melt however maybe just the juices from the meat cells escaping (apparent melt rather than a real). Ultrasonic cutters apply ultra high frequencies (20-35 Hz) in compared with diagnostic ultrasounds (1- 5Hz) and achieves melting without burning and due to the tool not using heaters there is no cool down period for tooling changes.

Industries using Ultrasonic Cutting

- used in medical eye surgery where the impact on cutting and reduced heating into the eye
- synthetic material Plastics, rubber and leather
- food products such as cakes

One application cutting plastic 8mm in depth at a speed of 60mm per second which is indicative of what the technology can achieve. Ultrasonic's is great at cutting soft and sticky material cleanly

Ultrasonic Cutting and the Meat Industry

Trials at Mercer in New Zealand with ultrasound have proved to have limited success. Ultra high frequency ultrasonic's causes melting of the bone and meat. Metal was seen to take energy away from the side of the blade before it reached the tip causing the ultrasound to cease cutting. It was recommended that shielding of the tip be looked at. This problem maybe negated by forcing the meat to peel away from the cutting tip as does naturally in cheese.

One of the biggest problems for the meat industry is using ultrasound to cut meat is the temperature as the temperature range suitable for cutting would be 0°C to +5°C. Consonic the supplier believe that of this range the applicability of ultrasonics will diminish.

Meat Trials

Trials by were conducted in this area which a blade or horn of 250mm and depth of 25mm this achieved a cut depth of 30mm in the meat. However cut quality was an issue and the meat was trialled on a uniform minus 40 degrees. Recommendations from this were to trial at the temperature range of between 0 and 5 degrees and that the blade was not the preferred blade for this situation. Information supplied by Consonic.

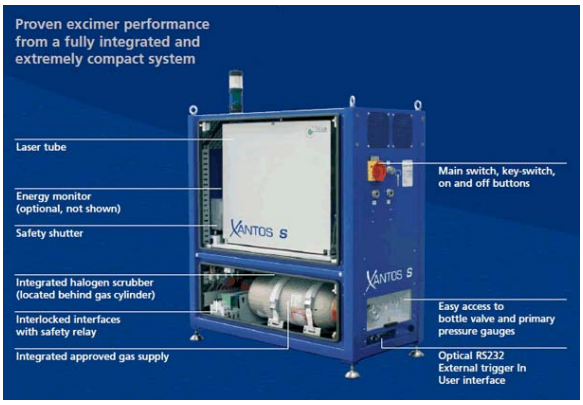
Potential for Ultrasound Cutting

Ultrasound has some great advantages in that it cuts easily and accurately without heating the material that it cuts. It has been used in cheese cutting and cutting of sponge cakes without drawing the jam through with the cut.

Another potential problem for ultrasonic is the sides of the blade may still touch the meat as it cuts deeper. As the blade is shaped in a wedge and it the meat doesn't peel away then the sides of the blade will contact the product and so sterilisation is required.

The blades for the ultrasonic (or otherwise known as the horn) are large and have limited the technology to planar cuts. Eye surgery have implemented ultrasonic's to provide safer eye surgery as there is minimal thermal loading when compared to laser eye surgery.

Laser Technologies



Lasers work on the principle that if electrons are stimulated enough by an energy source they will move to a higher energy orbit (closer to the atom). After energy source is removed the electrons will return to their original orbit releasing large amount of energy in the format of a photon. How lasers work is a gas like Carbon Dioxide (CO_2) is held in a chamber and an energy source is applied to the chamber. The photons are reflected and focused into a fine beam.

Another Gas used is neodymium doped, yttrium aluminum garnet (Nd:YAG) both this and CO_2 produce a small focused beam usually 0.5mm in diameter. Gas is also used to clean the cutting area and is forced out co-axially through the cutting nozzle. Laser technology has become increasingly more popular as the ability to manipulate the laser through Cadd programs has reduced setup time and operational times. Lasers can quickly and accurately cut 3 dimensional profiles accurately requiring minimal finishing work if any.

Industries using Laser

Application for laser is with cutting metal, foam, plastics, stone and composite materials making up most of the lasers application in the manufacturing industry. However laser is also used in eye, skin, hair and other forms of surgery.

Benefits of laser

- cutting tool that does not require sharpening
- sterilisation not required as the cutting device is remote to the contamination surface
- accuracy as the beam can be as small as 0.5 mm in diameter

Lasers and the Meat industry

Lasers work on using energy to break the bonds in the material and hence penetrating through, this causes the use in the meat industry some problems as laser burns or cooks the meat where it cuts. Therefore cannot be used in the meat industry as product quality is compromised. There are applications of engraving shapes in biscuits less than 2mm deep.

Work has been done with UV lasers which are lasers utilising the UV frequency which focuses the energy on the carbon atoms which break the bonds more efficiently reducing heat penetrating the product. The project was investigated several years ago by AgResearch and was shelved for higher priorities however the leading researcher reported that it is a possibility to work needs more work to determine either way.

Companies now have commercial close to UV frequency lasers by the brand of Excimer which are the lasers used in eye surgery.

Potential for Lasers

Laser is an ideal cutting mechanism due to its high accuracy, high speed and excellent cutting finish. Before Lasers can be used in large portioning tasks (attached to a robot) concept and design of proper requirements according to shielding needs to be completed. This is to prevent misdirection and reflection of the laser beam causing damage to workers.

Lasers have the problem with variation of product that the focus of beam needs to be continually adjusted to allow for the variance in the topography of the meat.

Conclusion

Plasma can not be used for food as it reaches huge temperatures which would deteriorate, cook or burnt the product. Also when compared with water jet the operating costs are very large.

Laser has the advantages of accuracy (+/- 0.5 mm), speeds achieved 600mm/s (depending on material and depth) and The major disadvantage to laser is that it heats the product while it is cutting. Ways of reducing this would be to pulsate the laser beam and tune the laser frequency to water. As water is a major component of meat the water will boil and hence cut causing enough energy to break bonds and cut the meat. Issues of product variation will cause the focus point of the laser to change. No Laser technology has been trialed in meat trials that have been successful in cutting without burning or cooking the meat.

Ultra Violet (UV) Laser frequencies of 10^{-1} to 10^{-2} nm are equivalent to heat the carbon bonds without heating surrounding molecules. Research was carried out years ago through the Agresearch into UV laser cutting meat. This research was shelved for more important priorities at the time. Also another method is to use a frequency that targets water 10.6 microns and pulsate the laser to reduce heat. The topography of the meat varies greatly and so adjustments in depth laser will be required to maintain accuracy and quality of cut. The UV laser has the problem that they have limitations on power and so they will have limitations on applications. Infra Red (IR) lasers have enormous power and will be able to cut through all applications required in the meat industry however it will tend to have a higher thermal loading. No Laser technology has been trialed in meat trials that have been successful in cutting without burning or cooking the meat.

Water Jet in trials was deemed to be a failure with product integrity and cut quality. Trials revealed that an abrasive substance is needed to penetrate through thick bones and meat. The abrasive option is ice.

Water Jet with abrasive Ice or (Ice jet) this technology is in its infancy stage as the ice requires crushing to fine abrasion to allow the required cutting properties to exist. Trials have been done with large particles in a low pressure cleaning however fine particles are needed with high pressure to cut through meat and bone. Trials have been completed at MLC and technology was labeled as clever but of no use to them. The reports are lost due to the segregation of the MLC UK and hence the trialed variables and the outcomes from this are lost.

Ultrasonic’s has the advantage of laser in that it is non contact and cuts accurately and it does so without heating the product (which is superior to lasers). However the Ultrasonic’s have a limited temperature scope to 0 to 5 degree Celsius which will be acceptable for chilled product but not for fresh or frozen product. Ultrasonic’s have the potential to be used in the meat industry as they cause no thermal loading on the product. However no trials recorded have been carried out at 0-5 degree Celsius and hence the technology is unproven and holds a higher risk than water jet despite the potential benefits.

Recommendations

Ultrasonic

For product in the temperature range of 0°C to 5°C ultrasonic's is thought to be the best operating conditions as long as the cuts are quite simple. At this stage the horn is quite large in cutting of meat and causes cuts to be limited to profile cuts however the eye surgery ultrasonic's have shown the possibility of a small cutting horn being very flexible and accurate in cutting. Cutting trials in the past required the meat to be excessively frozen before the product was cut and the quality of the cut was not to standard. This technology must be investigated further before it is used in a commercial application as the thickness of meat it can cut and at what temperatures must be established along with the cut quality. On the information gained it suggest that the ultrasonic cutting was abandoned however there is not enough evidence to suggest that ultrasonic's could not work at a different temperature. The meat must be rigid to allow the vibrations to cut so the ultrasonic's cannot be used on the slaughter floor; however it may prove that ultrasonic's can be used in the Boning room.

Laser

Laser could be a quite good option in terms of accuracy, speed and being non contact, however laser will also thermally load the product, whether this be cooking or charring around the cut line. UV lasers are untested in the their ability to stop this from occurring however UV have limitations on power and so would not be applicable for larger portioning (beef splitting as an example). Infra Red at the frequency of water 3-10 microns could be pulsated to reduce the thermal loading and trials could be set up to determine the success of this. The fact is that laser will always in someway burn or deform due the heat that is required to cut the meat. One way of reducing this is to use laser in a water jet however it may be similar to just use the water jet. Laser has the most advantages however it holds the biggest risk of failing due to the thermal loading of the product.

Water Jet

Water jet can be used in Fine slicing meats and for portioning but cannot be used on products that have large bones as deflection of the spray can cause problems. Water jet must be explored more as an option and reducing some of the problems with it such as bone shattering, deflection problems, being able to cut through bone, being able to cut through large depths of meat such as for splitting a carcass. Water jet can be used for slicing meat products trials will need to be done to determine the limitations of this technology in terms of meat thickness. This technology can be applied to meat applications with some research and development in the short term.

Ice Jet

Ice jet needs to be explored as it contains the abrasiveness that will help cut through thick bones. Trials are required to determine the limitations of this technology and feasibility in developing the required ice particle size. Test are enquired to determine if product quality is compromised by adding the water, however ice jet can used very high pressured low volume water which will reduce the water exposure to the product. Ice Jet requires more research and development however it holds more potential to succeed than the other technologies and it would be the one to invest in trials in the near term.