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Advanced Low Voltage Stimulation (ALVS)

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Abstract

Meat & Livestock Australia has developed a suite of new generation, electronic meat processing technologies (i.e. electrical stimulation, immobilisation, electronic bleeding) using a computer-controlled waveform to give exactly the same electrical “dose” to each carcass. This ”dose” is determined experimentally as the best “dose” for a particular carcass type. Although better than the earlier variable dose stimulation systems, this approach does not allow for variations between carcasses of a particular carcass type. A new development pioneered in New Zealand has shown that by using carcass feedback techniques, an optimum “dose” may be delivered on a carcass-by-carcass basis.

The new generation, MLA computer controlled electronic meat systems are now being commercialised and with suitable programming changes this technology could be upgraded with these new carcass feedback techniques to further enhance processing quality as the technology matures.

Advanced Low Voltage Stimulation (ALVS; currently referred to as Smart Stimulation) provides a unique combination of an on-line and automated carcass measurement system, and the commercialisation and commercial benefits of this technology are underway. As part of identifying further opportunities for the technology, a muscle calcium contraction model has been developed to understand the mechanism underlying the predictive ability of the technology and identify further opportunities and developments.

In the current research, systems were developed and commissioned in beef and lamb processing plants in Australia and New Zealand over a range of processing scenarios. Data collected over a period to optimise programs for individual plants. Key outcomes of this research were:

- Develop procedures to immobilise cattle and sheep without substantial effects on pH decline
- Commercialise procedures for feedback stimulation of cattle and sheep
- Develop procedures for electrically enhanced bleeding
- Develop procedures for feedback stimulation of cattle and sheep, based on stimulation during bleeding
- Install and evaluate a fully commercial implementation of feedback stimulation of sheep, based on stimulation following dressing
- Test under commercial conditions feedback stimulation of cattle based on stimulation during bleeding

Technical information and data pertaining to ALVS was collated and the information for the provisional patent was submitted in May 2006.

In addition, recommendations for ALVS to be commercially ready are made in the report.

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1 Background

MLA has developed a new generation of electronic meat processing technologies (electrical stimulation, immobilisation, electronic bleeding) using a computer-controlled waveform to give exactly the same electrical “dose” to each carcass. This”dose” is determined experimentally as the best “dose” for a particular carcass type. Although better than the earlier variable dose stimulation systems, this approach does not allow for variations between carcasses of a particular carcass type. A new development pioneered in New Zealand has shown that by using carcass feedback techniques, an optimum “dose” may be delivered on a carcass-by-carcass basis.

The new generation, MLA computer controlled electronic meat systems are now being commercialised and with suitable programming changes this technology could be upgraded with these new carcass feedback techniques to further enhance processing quality as the technology matures.

MIRINZ Inc has sole ownership of the feedback technique at this stage and with the current level of funding there will be some time before the technology is demonstrated in sheep and even longer before beef versions are developed. By partnering MIRINZ Inc, MLA has the opportunity to add value to its existing electronics technologies and fast track the commercialisation of the next generation of electronic processing technologies.

This approach is consistent with the program plan approved for the “New Generation Process Innovation Program” and the program will rely on MDC funding for much of the applied research. The developments in this project will draw on results developed at a strategic level by other researchers funded by industry sources which is consistent with the program model where industry funded theoretical research is fed into MDC funded applied developments.

Electrical stimulation of carcasses has become a standard processing technology for the red meat industry. Originally devised primarily as a means of accelerating the rate of pH decline, to accelerate the tenderisation process, the use of electrical inputs to carcasses now also includes electrical stunning, stimulation and back stiffening. There are two important implications for the use of electrical stimulation of carcasses in the context of current and future processing for quality meat:

- Too much electrical stimulation has important adverse effects on meat quality. Excess electrical inputs produce exaggerated rate of pH decline, and produce meat with poor eating quality, poor colour stability and high purge losses.
- The pH response of carcasses to electrical stimulation is highly variable and unpredictable. This phenomenon is particularly evident in high-value grain fed cattle, where even minimal electrical stimulation can produce exaggerated rates of pH decline

These risks associated with using stimulation technologies need to be weighed against their substantial benefits, relating particularly to processing efficiencies (accelerated tenderisation; reduced damage during hide pulling) and worker safety (carcass immobilisation following stunning). Ensuring high quality and consistency in meat products is increasingly recognised to depend on managing the pH and temperature changes in the carcass post mortem, and the need for stimulation procedures that give the required control over pH changes are becoming increasingly evident.

This programme will develop a new generation of electrical stimulation technology to resolve these issues. Two main strategies will be employed:

1. The waveforms used in electrical stimulation (typically 15 Hz, 10 m-sec pulses) were designed to produce a maximal pH effect. New waveforms will be designed to produce reproducibly graded pH responses that can be applied according to specified needs
2. Because the response of each carcass to electrical inputs varies, a full control of the pH changes will depend on monitoring the response and modifying the stimulation parameters accordingly (feedback stimulation). This technology will allow the stimulation to be tailored to the specific needs of each carcass, so as to produce a consistent and predictable pH decline.

The development of the feedback stimulation technology for lambs has received significant funding from Meat & Wool New Zealand (M&WNZ) and is approaching commercial trial stage. Additional benefits identified from the work so far are the ability to use characteristics of the response of the carcasses to stimulation procedures to predict ultimate pH and aspects of tenderness.

Further improvement of the interpretation of the responses of individual muscles to electrical stimulation will be to model muscular responses to electrical stimulation. The contribution of this project will be an interpretative framework to analyse the response characteristics of specific carcass muscles in response to designed stimulation parameters. The objective will be to define the biochemical basis for individual differences in the responses to stimulation and link these with differences in meat quality attributes.

Ongoing research in the current year will include:

- Install feedback stimulation systems into commercial beef and sheep plants
- Monitor their performance and refine
- Undertake a theoretical assessment of the feasibility of magnetic stimulation of carcasses
- Develop an invasive method of monitoring the responses of individual muscles under commercial conditions (based on muscle pressure measurement)
- Undertake a preliminary assessment of measuring localised responses to stimulation using not contact methods (image analysis; magnetic field distortion)
- Assess the use of muscle contraction models to interpret the muscle response characteristic
- Define relevance to predicting commercially important meat quality attributes

2 Project Objectives

The objectives of the research were to:

- Install an Advanced Low Voltage stimulation system for cattle in Australian plant. Installation and initial data collection from ALVS systems in Australia at Australian Country Choice (ACC) (Beef). Working party established to identify suitable Australian candidate plant for sheep installation based on plant equipment and QA capabilities.

- Install Advanced Low Voltage stimulation system for sheep at Auckland Meat Processors.
- Beef installation in New Zealand (AMP) completed and data collection in place. Sheep plant installation in Australia.
- Preliminary data from all beef & lamb on ultimate pH prediction and software algorithm refinement based on data collected from all sites. Sheep installation in Australian plant completed
- Interim report on all industry data on ALVS systems (beef & sheep).
- Data from all installations formatted and reported in a form suitable to aid in filing of full patent specification
- Provide technical input and all necessary documentation to support application for provisional Australian & New Zealand patents filings on ALVS technology

3 Methodology

3.1. Hardware installation

The load cell installation and design of the rubbing bars performed well for the large carcasses. The main concern with the arrangement of the rubbing bars is to ensure that the carcass do not break contact when the stimulation current is first initiated as this can cause the carcass to bounce uncontrollably. In this regard, the installation performed well for the adult carcasses. However, the veal carcasses regularly broke contact and bounced excessively, so a redesign of the electrodes will be needed for this class of stock.

The load cells had been installed for some weeks before the trial, so were regularly carrying the load of the carcasses without signs of problems. For the period of the commissioning and calibration, their performance was consistent and reliable, and their calibration was maintained.

Two additional small modifications were identified. First, the upper electrode, in contact with the shank, needed some further bracing to stop it shaking during the stimulation of the carcasses. Second, the transfer of the carcass off the second rail was often uncontrolled if the rail was electrically live at the time: the muscle contractions caused by the stimulation as the carcass lost the support of the rubbing bars caused the carcass to swing and could potentially cause a safety hazard.

3.2. Control system installation

Some modifications to the software were needed to accommodate the requirements of the ACC installation. These were not major, but contribute to defining the critical specifications for the hardware design to ensure a simpler process for future installation. Two electrical modifications are currently being completed to provide a more consistent performance of the system: first, the software needs to monitor and count the pulses to be sure of extracting the load cell responses at the time of the test pulses: some difficulties were experienced with electrical interference in the test pulse signal line, and improved circuitry is being constructed to cleanup the signal. Second, the change in the software to allow more frequent pH tests has created a short time interval between the end of one cycle and the start of the next during which the stimulator is turned off. Although this interval is only 300 m-sec, it is sufficient to allow the carcass to relax fully, and then jolt back to the contracted state; this process increases the risk of broken electrical contacts and created unnecessary bouncing of the carcass, and some simple external electronics will ensure that this delay period is avoided.

In all other respects, the system performed well: the load cell signal responded well through the required frequency range, without any mechanical or electrical interference.

3.3. Calibration of the Smart Stimulation system

The main requirement for the Smart Stimulation calibration is to produce a range of carcass pHs that correlate with the carcass responses. The control system was set up to provide stimulation periods of either 2 or 10 seconds and, at the end of each period, the test pulses were initiated and the carcass responses acquired. Two seconds is a minimum period of stimulation required to ensure that the carcass is physically 'stabilised' before the test pulses are initiated. Stimulation periods longer than 10 seconds were not used as the carcass pHs had reached a sufficiently low value.

The pH measurements were made from the caudal end of the *M. Longissimus dorsi*, as developed in the MSA methodology. The pH values were measured immediately following stimulation and some two hours later. The two hour interval is based on the time at which the carcasses are expected to reach the appropriate 'window' temperature for the temperature-pH curve. This is the temperature at which the carcass should reach the target of pH 6, and the stimulation needs to be tailored to attain this value.

4 Results and Discussion

4.1 Install an Advanced Low Voltage stimulation system for cattle in Australian plant

An ALVS system has been successfully installed at ACC, Brisbane. A two unit system has been installed with associated rubbing bar and load cells. The software has been modified to accommodate the particular requirements of this plant and the calibration has been carried out. This system constitutes the first 'continuous flow' ALV system, using 2 electrical segments, compared with the static, single load cell systems used previously for cattle. The installation, calibration and results are detailed in the attachment (see Appendix 1).

Significant delays were encountered reaching an agreement with plant management on the site for the ALV system. The final decision was to position the system at the bottom of the lowerator, just prior to the chillers and approximately 50 minutes following slaughter.

Two single-point load cells were used to support two consecutive lengths of rail. Together, they provided 30 seconds of stimulation. A two module Applied Sorting Technologies stimulation unit, with modified software to permit control using the external software, was installed.

The standard beef animal processed at ACC is grain fed for 60 days. The use of grain feeding is recognized as causing an accelerated pH decline and increased sensitivity to the effects of electrical stimulation. The current processing specification at ACC is to use 15 seconds of stimulation during bleeding, a very short period by NZ standards. In order to provide better resolution of the pH decline during stimulation at ACC, the software was modified to speed up the test procedures: a user-defined option to define the time period between test pulses to test carcass pH, and a period of 5 seconds of 15 Hz stimulation between tests pulses.

Pictures 1 & 2 – Installation of ALVS at ACC plant showing critical system components including rub bar electrodes, load cells and controller.

4.1.2 Sheep Installation – Australia

It has been agreed that the ALV system will be installed at the Gathercoles Tatura plant in Australia which currently runs 45 seconds of simulation delivered by a four-channel stimulator. Millers Mechanical carried out the installation of this system and has therefore drawings of the set-up readily available. The detailed requirements for this installation are currently being developed in collaboration with Millers.

Concerns have been raised by RealCold Milmech regarding the suitability of the plant to host the smart stimulation system. They are currently working to identify an alternative plant for this installation. It is anticipated that some agreement should be in place by the end of September with installation occurring shortly thereafter.

4.2 Install an Advanced Low Voltage stimulation system for cattle in Australian plant

An ALV stimulation system has been successfully installed on the sheep line at Auckland Meat Processors (AMP). The stimulation has been placed at the site of the former high voltage tunnel, which was made redundant by a change of the processing specification to a slower process from the original AC&A process.

The throughput rate at AMP is approximately 7/minute, but uses a separate chain after inspection which also runs at a slower rate. Consequently, the carcass separation is reduced to approximately 400 mm, and producing a stimulation time of 60 seconds would require 8 electrically isolated stimulation segments and an equivalent number of load cells. To avoid this level of complication, a new configuration was developed:

1. A load cell was introduced into the rail on alternate stimulation segments, therefore requiring only 4 load cells.
2. At each load cell, the carcass pH was determined, and the intervening stimulation segments were used only to introduce a further period of stimulation before the next pH determination at the next load cell station.
3. Two constant voltage electrical stimulation units were used to drive the whole system. One unit is used to provide the test pulses on the load cell rails, the second to provide a continuous 15 Hz waveform.
4. The delivery of the stimulation voltage to each stimulation segment is managed using relays controlled by the control system. The software was modified to provide the additional controls for the relays.

The load cell installations, assembly of the control system and modifications to the software have now been completed.

Pictures 3 & 4 – Installation of ALVS at AMP plant showing critical system components including rub bar electrodes, load cells and controller.

4.3 Update on all current commercial installations

4.3.1 Australian beef plant: Australian Country Choice

This installation uses two load cells, each controlling 13 seconds of stimulation. The carcasses are transferred directly from one load cell rail to the next, without an intervening stimulation rail. The installation of the load cells is now complete.

Two modifications to the software were required for this installation.

1. The original configuration required that sequential carcasses were to be presented within a specified time interval (<1 sec) in order for the programme to initiate the test pulse protocol for the two carcasses simultaneously. This interval was exceeded and a significant redesign of the control system was necessary. This is now complete, and will provide a more flexible architecture for future installations.
2. Because the pH response of grain-fed cattle to electrical stimulation is expected to be faster than grass-fed NZ cattle, the software was modified to allow multiple test pulse sequences at user-defined intervals. This new configuration will allow 2-3 test pulse sequences to be carried out on each load cell and will provide more resolution in measuring the pH responses to stimulation.

Although the preliminary calibrations, described in Milestone 2, were promising, there were concerns about the configuration of the stimulation electrodes. The original electrode configuration positioned the live electrode at the leg-end of the carcass, and two separate earth electrodes, one at the level of the rump and the other in the shoulder region. It became apparent from the responses of the carcasses that the current flow through the loin of the carcasses was variable, due to both direct leakage of the current through the hock to the carcass rail, as well as to the rump electrode depending on the contact resistance. Modification of the stimulating electrodes are underway, with the primary intension of dispensing with the rump electrode altogether.

The software modifications, identified in the previous milestone, have been completed and tested, and found to be working correctly. Discussions to improve the electrode configuration to ensure more consistent current flow led to the removal of the middle earth rail. Unfortunately, this caused problems in maintaining electrical contact during the stimulation and the system no longer worked consistently. The necessary modification of the electrode configuration is currently under evaluation and an agreement as to the next steps is expected to be reached between RealCold, MLA, ACC and Carne Technologies, within the next few days.

These modifications to the stimulating electrodes are expected to be completed during November, and the completion of the calibration of the system will be completed by January 2007.

4.3.2 Australian Sheep installation: Hardwick's Meat Works

This installation has been delayed, but is scheduled to be completed during November 2006. Commissioning and calibration will be completed by February 2007.

4.3.3 New Zealand Sheep Installation: Auckland Meat Processors.

i) Auckland Meat Processors (AMP) – Sheep Chain

The AMP sheep line operates at 5.5-6 ccs/minutes. However, the stimulation takes place on a separate chain that operates at about half the rate of the main chain and the distance between carcasses is therefore reduced to 400 mm. To address this particular difficulty, the stimulation rail has been split into 8 segments: each of the 4 load cell segments is separated by an independently controlled stimulation rail. Because of the high cost of an 8 unit constant current stimulation system, 2 independent constant voltage units are employed: one provides the test pulses to the load cell rails while the other provides a continuous 15 Hz stimulation waveform. Each rail is independently controlled through relays in the control system.

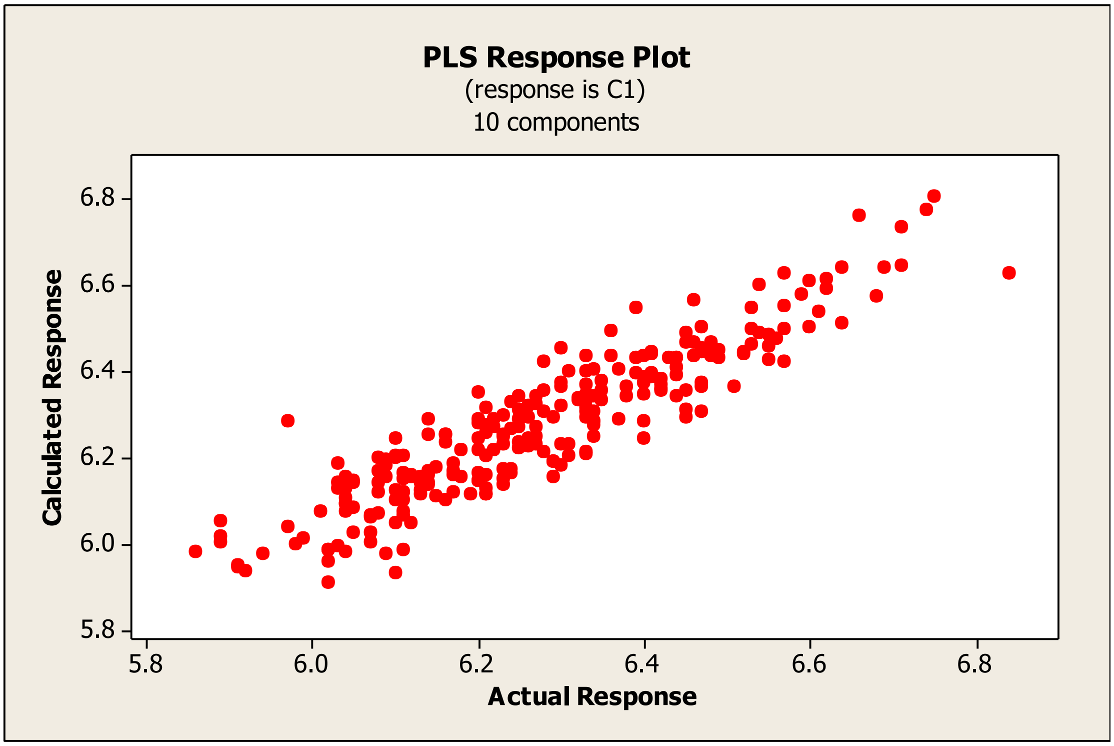
This installation is fully complete and is undergoing on-going evaluation. The design for the sheep chain required that 8 independent stimulation rails be used: 4 of these are associated with the load cells, and between each is a independent stimulation rails. Because of the large number of rails, a constant voltage stimulation system was employed, rather than the SAT constant current equipment and, by controlling the output to each rail through relays, only two stimulation modules were required: one to deliver the test pulses for the load cell segments, and a continuous 15 Hz stimulation unit for the remaining rails. At 300 V, the pulse amplitudes were consistently between 1 and 1-2 Amps.

Calibration for pH response is completed and the system is operational for pH responses. The most recent trials have addressed ultimate pH prediction, and a calibration for this procedure has been developed and is undergoing evaluation.

The system is now fully installed and operational. The load cell responses were calibrated to the post stimulation pH measurements from a total of 517 carcasses over three different days. The resultant relationship between measured and calculated pH values are shown in Figure 1 (r^2 =0.82)

Current trials are focussing on testing the accuracy of the system during normal operation, and being calibrated for prediction of time to onset of rigor mortis and ultimate pH.

Figure 1. Results of calibration of the load cell responses.



ii) Auckland Meat Processors - beef line.

The plant already used a high voltage system, and the medium voltage system has been introduced as a direct replacement. The existing site is in the lowerator, which added to the complexity of the installation but this has been successfully accomplished. The load cell was changed from a single point arrangement in the middle of the rail segment to one which uses two separate load cells at each end of the rail segment. This provides a more stable support for the rail segment and avoids large torsion stresses when the carcass is at the ends of the rail segments.

The original installation used the hook and rail as the earth and a live electrode in contact with the shoulder. Our initial tests found that the electrical resistance in this pathway was high and variable, and we have therefore installed an additional rubbing bar at the hock to produce more consistent results. This additional rubbing bar has now been installed, and calibration is due to begin in November.

The main commercial interest at AMP for the Smart Stimulation is for ultimate pH prediction. Their chosen processing specification is for a very rapid pH decline to produce rapid tenderisation, and an intermediate level of pH decline is not particularly important at this plant. However, to meet the Quality Mark specification, considerable effort is needed to undertake the chiller assessment, and it is the opportunity of dispensing with this process that is the main driver for the installation. A validation of the ultimate pH prediction will be completed by February 2007.

Recently, it was established that some modifications of the original installation were necessary to prevent the carcasses breaking contract with the electrodes. An additional earth rubbing bar is also being installed to improve the electrical contacts. These last modifications are due to be carried out by the firm of engineering contractors that carry out all work for AMP. As soon as this is complete, the system will calibrated and data collection with begin.

5 Impact of this Research

The information for the provisional patent was submitted in May 2006. The document was developed in an iterative process with input from Drs C. Daly, N Simmons, G. Jarvis and the Patent Attorney from A. J Park. The attachment is the document, as submitted to the patent attorneys, with comments and corrections included.

6 Conclusions

ALVS systems have been installed at beef and lamb processing plants in Australia and New Zealand. The calibrations were carried out successfully and the system appears to operate effectively.

Some further small modifications are needed to the hardware and the control system to improve the reliability of the system. The necessary modifications to the electronics are currently in hand.

Key outcomes of this research were:

- Develop procedures to immobilise cattle and sheep without substantial effects on pH decline
- Commercialise procedures for feedback stimulation of cattle and sheep
- Develop procedures for electrically enhanced bleeding
- Develop procedures for feedback stimulation of cattle and sheep, based on stimulation during bleeding
- Install and evaluate a fully commercial implementation of feedback stimulation of sheep, based on stimulation following dressing
- Test under commercial conditions feedback stimulation of cattle based on stimulation during bleeding

7 Recommendations

Smart Stimulation provides a unique combination of an on-line and automated carcass measurement system, and the commercialisation and commercial benefits of this technology are underway. As part of identifying further opportunities for the technology, a muscle calcium contraction model has been developed to understand the mechanism underlying the predictive ability of the technology and identify further opportunities and developments. This model will be developed further, and methods to enhance the technology will be identified. Future research and development is proposed:

- Validate and optimise tenderness prediction in commercial Smart Stimulation installations
- Use the calcium contraction model to understand the tenderness prediction
- Identify opportunities for partial carcass stimulation as part of the Smart Stimulation system.

Appendices

Appendix 2 – Validation and preliminary data from Australian Country Choice Smart Stimulation installation

1. Background

ACC was the first Australian installation of the Smart Stimulation technology. A two unit system was installed: essentially two electrically isolated stimulation units, with associated rubbing bar and load cell.

The load cell installation was carried out by RealCold MilMech. Each load cell was connected to the rail, and these were made consecutive to allow the carcass to be transferred from the first rail directly to the second. This arrangement provided a total of 28 seconds of stimulation.

The stimulation equipment was based on the conventional Applied Sorting Technologies medium voltage stimulation. The software was modified to allow the unit to develop the required test pulse sequence, and for the sequence to be initiated by the software. The standard stimulation parameters of 300 V, 1 A, 1 msec pulses were used throughout.

The software used at ACC was modified in anticipation of the possibility that the carcasses processed at the plant will respond more vigorously to the stimulation than typical prime carcasses in New Zealand. The majority of carcasses processed at ACC have been grain-fed for 60 days, and it is possible that even this limited period of grain feeding will be sufficient to produce an accelerated rate of pH decline and an exaggerated response to electrical inputs. To address this, the software was modified to cycle through the test pulse sequence more rapidly: a user defined option was introduced to allow a cycle time of between 5 and 15 seconds.

Therefore, the control system that is now in place at ACC undertakes the following steps in each cycle:

1. Detect carcass by weight change on load cell
2. Initiate stimulation sequence
3. Identify the start of the test pulse sequence
4. Extract the load cell responses during the test pulse sequence
5. Calculate the Fast Fourier Transform of the response waveform
6. Calculate pH prediction using pre-determined coefficients
7. If the pH prediction shows the pH to be above the target value, stimulate for 5 seconds, then return to step 2
8. If the pH prediction shows the pH to be below the target value, turn off stimulator
9. If the carcass weight disappears (carcass transferred off load cell), turn off stimulator.

2. Performance and calibration of the installation

2.1. Hardware installation

The load cell installation and design of the rubbing bars performed well for the large carcasses. The main concern with the arrangement of the rubbing bars is to ensure that the carcass do not break contact when the stimulation current is first initiated as this can cause the carcass to bounce uncontrollably. In this regard, the installation performed well for the adult carcasses. However, the veal carcasses regularly broke contact and bounced excessively, so a redesign of the electrodes will be needed for this class of stock.

The load cells had been installed for some weeks before the trial, so were regularly carrying the load of the carcasses without signs of problems. For the period of the commissioning and calibration, their performance was consistent and reliable, and their calibration was maintained.

Two additional small modifications were identified. First, the upper electrode, in contact with the shank, needed some further bracing to stop it shaking during the stimulation of the carcasses. Second, the transfer of the carcass off the second rail was often uncontrolled if the rail was electrically live at the time: the muscle contractions caused by the stimulation as the carcass lost the support of the rubbing bars caused the carcass to swing and could potentially cause a safety hazard.

2.2. Control system installation

Some modifications to the software were needed to accommodate the requirements of the ACC installation. These were not major, but contribute to defining the critical specifications for the hardware design to ensure a simpler process for future installation. Two electrical modifications are currently being completed to provide a more consistent performance of the system: first, the software needs to monitor and count the pulses to be sure of extracting the load cell responses at the time of the test pulses: some difficulties were experienced with electrical interference in the test pulse signal line, and improved circuitry is being constructed to cleanup the signal. Second, the change in the software to allow more frequent pH tests has created a short time interval between the end of one cycle and the start of the next during which the stimulator is turned off. Although this interval is only 300 m-sec, it is sufficient to allow the carcass to relax fully, and then jolt back to the contracted state; this process increases the risk of broken electrical contacts and created unnecessary bouncing of the carcass, and some simple external electronics will ensure that this delay period is avoided.

In all other respects, the system performed well: the load cell signal responded well through the required frequency range, without any mechanical or electrical interference.

2.3. Calibration of the Smart Stimulation system

The main requirement for the Smart Stimulation calibration is to produce a range of carcass pHs that correlate with the carcass responses. The control system was set up to provide stimulation periods of either 2 or 10 seconds and, at the end of each period, the test pulses were initiated and the carcass responses acquired. Two seconds is a minimum period of stimulation required to ensure that the carcass is physically ‘stabilised’ before the test pulses are initiated. Stimulation periods longer than 10 seconds were not used as the carcass pHs had reached a sufficiently low value.

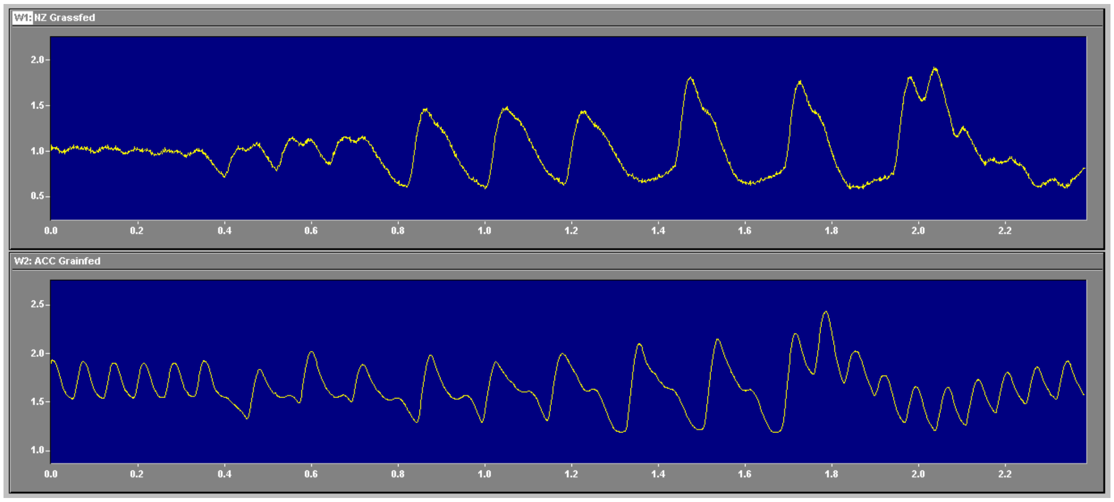
The pH measurements were made from the caudal end of the M. Longissimus dorsi, as developed in the MSA methodology. The pH values were measured immediately following stimulation and some two hours later. The two hour interval is based on the time at which the carcasses are expected to reach the appropriate ‘window’ temperature for the temperature-pH curve. This is the temperature at which the carcass should reach the target of pH 6, and the stimulation needs to be tailored to attain this value.

3. Results

3.1 Responses to test pulses

The preliminary observations demonstrated some clear differences between NZ grassfed beef and the ACC cattle. These are illustrated by two representative traces in Figure 1.

Figure 1: Comparison of responses from NZ and ACC cattle.



This is particularly notable in the responses to the 15 Hz stimulation, found in the time interval between 0 and 0.38 sec: where the NZ grass-fed cattle barely show a physical response, because the 70msec time interval is not sufficient to allow much muscle relaxation, the ACC grain-fed cattle show a very distinct 15 Hz response and demonstrate therefore a much faster relaxation rate.

The test pulses, which begin at 0.38 sec, constitute three pulses each of three increasing pulse intervals. For the NZ beef, we normally use intervals of 120, 180 and 250 m-sec, but, in view of the faster responses in the ACC cattle, these were changed to 120, 150 and 180 msec. The responses in the NZ beef animals show a clear increase in magnitude with each triplet, and the pulses were largely a simple monophasic response. The ACC carcasses show a less marked increase in magnitude and the response is more clearly biphasic. Again, this difference is likely to reflect a faster contraction and relaxation rate in the ACC beef animals.

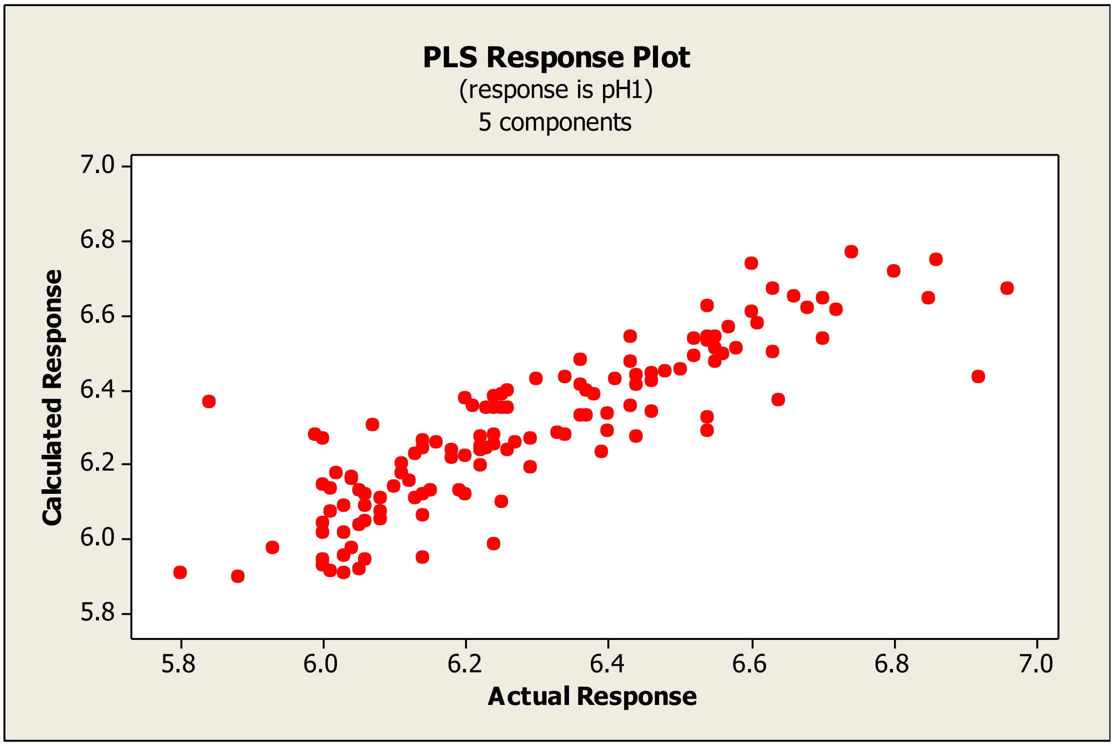
The implication of this difference is not totally clear at this stage. If this reflects an effect of grain feeding, then the pH prediction from the small number of grass-fed animals processed at ACC may be at risk. Alternatively, this may be a breed effect, since the majority of ACC cattle are >50% Bos indicus and, again, the prediction for predominantly European breeds may be compromised. Some further calibration will be needed to confirm this, but the calibration results so far look acceptable.

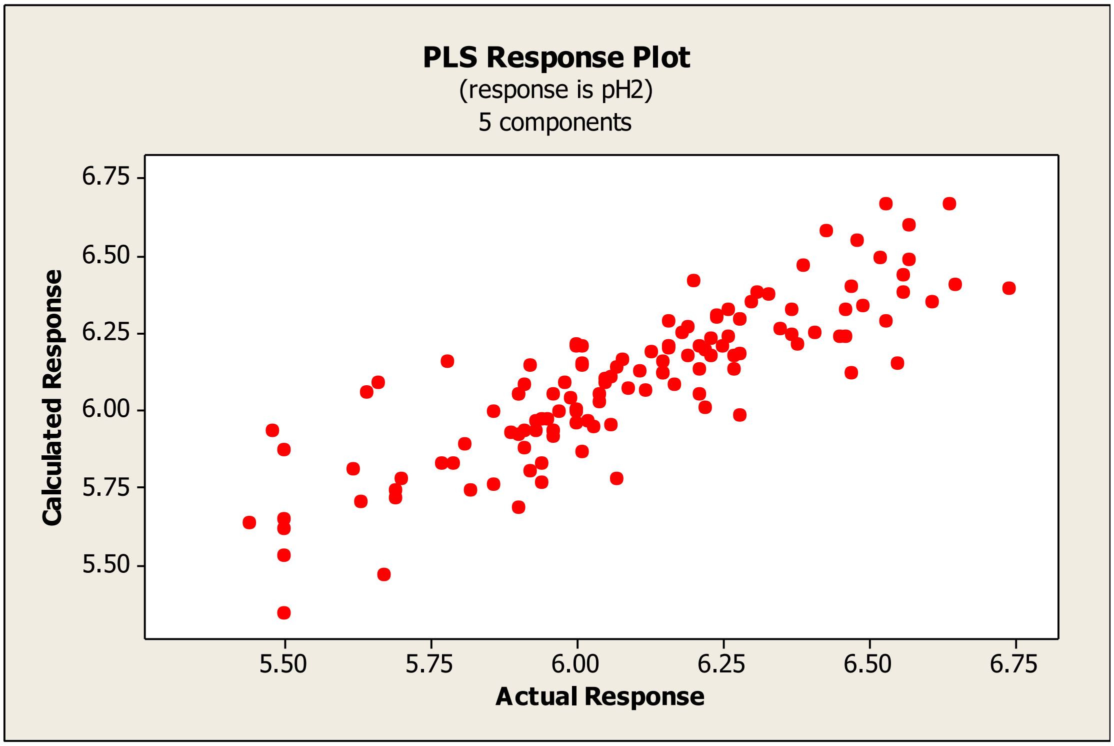
3.2 Calibration

A total of 176 carcasses were used for the calibration, on 3 separate days. This means 342 stimulation recordings but, because the pH was measured only on the left side of each carcass, the calibration is limited to the number of pH measurements. Although a statistical comparison was not attempted on this data set, the similarities between the two sides of the same carcass were very evident and offered reassurance that the stimulation system was operating reproducibly.

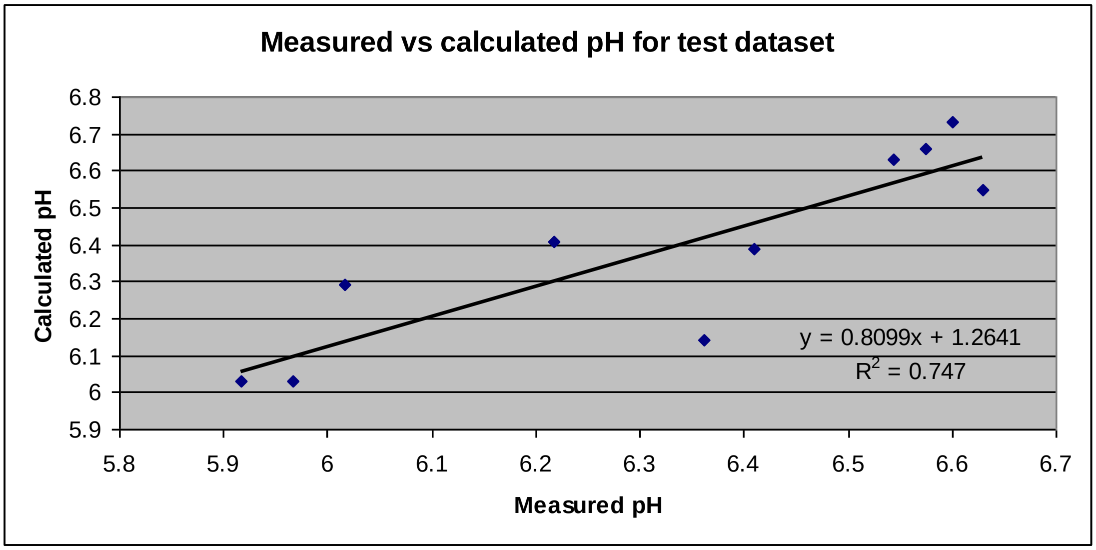
A Partial Least Squares method was used to produce the coefficients that convert the frequency spectrum to a calculated pH value. From this dataset, 5 components provided the maximum statistically significant correlation for both the pH 1 (immediately post stimulation) and pH 2 (2 hours post stimulation), and produced similar correlation coefficients (r^2 = 0.75 and 0.72 respectively)

Figure 2: Measured pH versus calculated pH: immediately post stimulation (pH1) and 2 hours post stimulation (pH2).





To test the validity of the prediction, 10 responses were selected at random and excluded from the correlation coefficient, and the resultant algorithm was used to calculate the predicted pH of the test data. The results are shown in Figure 3 for the post stimulation pH: the results showed a comparable correlation coefficient for the test set as for the complete dataset, suggesting that the predictions are likely to be robust.



4. Overall Conclusion

The Smart Stimulation system has been installed at ACC Brisbane. The calibrations were carried out successfully and the system appears to operate effectively.

Some further small modifications are needed to the hardware and the control system to improve the reliability of the system. The necessary modifications to the electronics are currently in hand.

Once these modifications are complete, the calibration dataset will be increased to include grassfed and Bos Taurus carcasses and ensure that the calibration can accommodate the full range of animal types processed at ACC beef.

A modification to the rubbing bars is needed before vealers can be successfully stimulated. This carcass type will need to undergo a further calibration procedure before they can be evaluated for the Smart Stimulation system.

Appendix 2 – Patent Application and detailed description of Advanced Low Voltage Stimulation (ALVS)

ELECTRICAL STIMULATION OF CARCASSES

FIELD OF THE INVENTION

The present invention relates to electrical stimulation of carcasses and in particular, but not limited to, electrical stimulation of carcasses after slaughter to derive information relating to the pH of one or more key muscles in the carcass.

BACKGROUND TO THE INVENTION

The muscles of a live animal generate energy by breaking down glycogen from supplies in the animal's body. After death, glycogen breakdown continues and lactic acid accumulates. This results in a reduction of the muscle pH, from around 7.0 in the live animal to an ultimate pH of about 5.5 in normal muscle after rigor mortis.

If the animal's muscles cool rapidly before entering rigor, there is typically insufficient time for the stored glycogen to be converted to lactic acid before the muscle becomes cold. Conditions of minimal acidification coincident with cold temperatures causes an irreversible contraction of the muscles occurs. This contraction is referred to as 'cold shortening' and is undesirable because it results in a toughening of the animal's meat.

The traditional preventative measure for cold shortening has been to apply electrical stimulation to the carcass. The stimulation of the carcass' muscles via electrical signals accelerates the breakdown of glycogen after death, minimising the amount of remnant glycogen while raising the amount of lactic acid. In this way, electrical stimulation allows a rapid decline in carcass pH. The rapidity of the pH decline means that the carcass' stored glycogen can be exhausted before the muscle cools, preventing the occurrence of cold shortening.

The application of electrical stimulation also accelerates the rate of tenderisation of carcass meat. This is because the proteolytic events that cause tenderisation start at or near the onset of rigor mortis. Because electrical stimulation accelerates the onset of rigor, it also initiates the tenderisation process earlier while the carcass is warmer, which then results in faster tenderisation.

The objective of electrical stimulation in prior art systems is to produce the greatest possible pH decline during electrical stimulation. An example of this is the Accelerated Conditioning and Ageing (AC&A) process developed by the Meat Industry Research Institute of New Zealand (MIRINZ) as a processing specification for exported New Zealand frozen lamb. The intention there was to produce an acceptable level of tenderness before the meat was frozen. As such, a maximal pH decline allowed the opportunity to freeze the meat at the earliest opportunity. Hence, high voltage stimulation based on a 1143 peak voltage was developed.

There are also systems in the prior art where information relating to a carcass is obtained before application of electrical stimulation. In US Patent No. 5,104,352 to Dransfield, the degree to which rigor has developed prior to electrical stimulation is taken into account during electrical stimulation. The development of rigor is evaluated by dropping the carcass along a rail and observing the behaviour of the carcass.

It is an object of the present invention to provide a method, apparatus and system for electrical stimulation of carcasses that either provides improved control over the electrical stimulation process or that at least provide the public with a useful choice.

SUMMARY OF THE INVENTION

In a first aspect, the present invention broadly consists of a method of electrical stimulation of a carcass, the method comprising the steps of:

- stimulating the carcass with a first electrical signal;
- measuring the response of the carcass to the first electrical signal; and
- deriving, from the response, information relating to the pH of at least part of the carcass.

Preferably, the method comprises the further steps of:

- determining, based on the derived information, if further electrical stimulation is necessary; and
- stimulating the carcass with a second electrical signal if further electrical stimulation is deemed to be necessary.

Preferably, the step of determining if further electrical stimulation is necessary comprises determining if the information relating to the pH of the carcass substantially matches predefined data.

Preferably, the first electrical signal is a test signal. In another form, the first electrical signal is a combination of a test signal and a second electrical signal.

Preferably, the frequency of the second electrical signal is higher than the frequency of the test signal.

Preferably, the step of deriving information relating to the pH of at least part of the carcass comprises the step of deriving information relating to the pH of the *longissimus dorsi* muscle in the carcass.

Preferably, the method further comprises the step of repeating the first aspect of the invention after stimulating the carcass with the second electrical signal.

Preferably, the method further comprises the steps of:

- defining a target pH or a target range of pH; and
- repeating, until the target pH or the target range of pH is met, the steps of the first aspect and the step of stimulating the carcass with the second electrical signal.

Preferably, the step of measuring the response of the carcass comprises the step of measuring the force of contraction and rate of relaxation of the carcass muscles in response to the stimulation.

Preferably, the step of measuring the response of the carcass comprises the steps of:

- removing the application of the first electrical signal on the carcass; and
- measuring the force of contraction and rate of relaxation of the carcass muscles. [This isn't quite right: the carcass responses are measured throughout the period of

the application of the first electrical signal: the muscle responses are measured during the intervals between the electrical pulses that constitute the waveform of the first signal.]

Preferably, the step of stimulating the carcass with a first electrical signal comprises stimulating the carcass with one or more predetermined electrical pulses. In this form, the step of measuring the response of the carcass preferably comprises the step of measuring the force of contraction and rate of relaxation of the carcass muscles during the application of two or more predetermined electrical pulses.

Preferably, the step of stimulating the carcass with a first electrical signal comprises stimulating the carcass with one or more sets of predetermined electrical pulses. In this form, the step of measuring the response of the carcass preferably comprises the step of measuring the force of contraction and rate of relaxation of the carcass muscles during the application of two or more sets of predetermined electrical pulses.

Preferably, the step of deriving information relating to the pH of at least part of the carcass comprises the steps of:

- receiving a waveform representative of the force of contraction or the rate of relaxation of the carcass muscles;
- extracting one or more frequency components from the waveform; and
- comparing the one or more frequency components against a database of frequency components and pH information.

Preferably, the step of stimulating the carcass with a first electrical signal comprises stimulating the carcass with an electrical signal that has little or no effect on the pH of the carcass.

Preferably, the method further comprises the step of deriving, from the response, information relating to the ultimate pH of at least part of the carcass.

Preferably, the method further comprises the step of deriving, from the response, information relating to the tenderness of at least part of the carcass.

In a second aspect, the present invention broadly consists of an apparatus for electrical stimulation a carcass, the apparatus comprising:

- an input means;
- an electrical signal generator to generate electrical signals to stimulate the carcass; and
- a processor arranged to control the generation of signals from the electrical signal generator, and arranged to receive signals from the input means and signals representing the carcass' response to the electrical signals, and arranged to derive information relating to the pH of the carcass from the signals representing the carcass' response.

Preferably, the electrical signal generator is a constant current electrical stimulation device.

Preferably, the processor controls the generation of signals based on signals received from the input means. Preferably, the processor is arranged to control the electrical signal generator such that two or more predetermined electrical signals may be generated.

Preferably, the processor is arranged to receive signals representing the contraction or the rate of relaxation of the carcass after stimulation by the electrical signals. In this form, the processor may be arranged to receive a waveform representing the force contraction or the rate of relaxation of the carcass muscles, extract one or more frequency components from the waveform, and compare the one or more frequency components against a database of frequency components and pH information.

In a third aspect, the present invention broadly consists of a system for electrical stimulation of a carcass, the system comprising:

- an electrical stimulation device to deliver electrical energy to the carcass;
- one or more sensors to measure the response of the carcass to the electrical energy; and
- a computing device to derive information relating to the pH of at least part of the carcass based on the measured response of the carcass.

Preferably, the electrical stimulation device is a constant current electrical stimulation device. In one form, the electrical stimulation device is arranged to provide electrical stimuli in the form of one or more predetermined electrical pulses.

Preferably, the one or more sensors comprise one or more load cells. The one or more load cells preferably measure the force of contraction or the rate of relaxation of the carcass muscles during stimulation by each of the one or more predetermined electrical pulses.

Preferably, the computing device is arranged to receive a waveform representing the contraction or the rate of relaxation of the carcass, extract one or more frequency components from the waveform, and compare the one or more frequency components against a database of frequency components and pH information.

The term ‘comprising’ as used in this specification means ‘consisting at least in part of’, that is to say when interpreting statements in this specification which include that term, the features, prefaced by that term in each statement, all need to be present but other features can also be present.

In this specification, where reference has been made to patent specifications, other external documents, or other sources of information, this is generally for the purpose of providing a context for discussing the features of the invention. Unless specifically stated otherwise, reference to such external documents or sources of information is not to be construed as an admission that such documents or sources of information in any jurisdiction are prior art, or form part of the common general knowledge in the art.

This invention may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, and any or all combinations of any two or more said parts, elements or features. Where specific integers are mentioned herein which have known equivalents in the art to which this invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth.

BRIEF DESCRIPTION OF THE FIGURES

Preferred forms of the method, apparatus and system of the invention will now be described with reference to the accompanying figures in which:

Figure 1 shows a flow chart of one form of the method of the invention;

Figure 2 shows a flow chart of another form of the method of the invention;

Figure 3 shows a schematic of one form of the apparatus of the invention; and

Figure 4 shows a schematic of one form of the system of the invention.

DETAILED DESCRIPTION OF PREFERRED FORMS

The Preferred Form Method

One preferred form of the method of the invention will now be described with reference to Figure 1. In the form shown, the method of the invention involves electrical stimulation of a carcass to derive information relating to the pH of the carcass. The method begins at step 100, where the carcass is stimulated using a first electrical signal.

Preferably, the first electrical signal is a combination of a test signal and a second electrical signal. The first electrical signal, in one form, comprises one or more predetermined electrical pulses. In another form, the first electrical signal comprises one or more sets of predetermined electrical pulses. Example forms of the first electrical signal will be described later in this specification.

During stimulation, the method proceeds to step 102, where the response of the carcass is measured. In one form, the response of the carcass is the force of muscle contraction during stimulation. This allows repeated testing of the carcass while the stimulation process is carried out, which in turn makes it possible to stop the stimulation at the appropriate time. As will be described later, the stimulation may be stopped when the derived pH information substantially matches predefined data.

In another form, step 102 comprises the step of removing the application of the first electrical signal before the carcass' response is measured. Where the first electrical signal is a pulse or a set of pulses, the application of the first electrical signal will automatically be reduced or removed in accordance with the pulse(s). As such, step 102 in such an embodiment need not expressly provide for the removal of the application of the first electrical signal. This isn't a proposed embodiment.

Preferably, in the above form, as soon as the application of the first electrical signal is removed, the rate of relaxation of the carcass is measured. As will be known in the art, the application of a suitably strong electrical signal to a carcass causes muscles in the carcass to contract. The removal of the application of such an electric signal allows the muscles to relax. This isn't a proposed embodiment. The rate of relaxation, as is the case with contraction, has been found to be related to the development of rigor mortis and the pH of at least certain muscles in the carcass. This is correct: but it is the contractions and relaxations between pulses, rather than between signals, that are being measured.

The measurement of force of contraction or rate of relaxation allows the present invention to derive information relating to the pH of at least part of the carcass, as will be described later. In the preferred form, the part of the carcass for which pH information is derived is the *longissimus dorsi* muscles of the carcass.

The force of contraction and rate of relaxation of the carcass muscles can be measured in a multitude of ways. In one form, as will be described with reference to the apparatus of the invention in Figure 3, the contraction or rate of relaxation is measured using a load cell. In this form, the carcass is hung from a rail via one or more load cells. As the first electrical signal is applied, the muscles in the carcass contract and relax. The forces associated with contraction and rate of relaxation of the carcass' muscles are then measured. By appropriately processing the forces measured, the contraction and rate of relaxation may be measured. The contraction and rate of relaxation may also be measured using other sensors, such as force sensors, strain sensors, or visual imaging means, such as a charge coupled device (CCD) imaging and processing means.

Once the response of the carcass is measured, the preferred form method derives information relating to the pH of the carcass in step 104. The derivation of information may involve comparing the response measured with information in a database providing details of carcass response and likely pH values or ranges. In the preferred form, the response measured is processed to extract relevant data prior to deriving information relating to the pH of the carcass. For instance, the measured response may be a waveform that is signal-processed using Fast Fourier Transform (FFT) or like processes to extract one or more frequency components. In one example, the extracted frequency component(s) may be compared to frequency components in a database to derive the pH information.

The method illustrated in Figure 1 may be used as part of, or independently of, conventional electrical stimulation processes to improve meat quality. For instance, the method may be implemented between applications of conventional electrical stimulation so that information relating to the pH of the carcass may be derived while electrical stimulation is being performed. Specific example applications of the method will be later described in this specification.

Another form of the method of the invention will now be described with reference to Figure 2. In this form, the method not only derives pH information, but also includes steps to reduce the pH of the carcass by electrical stimulation. Steps 200, 202 and 204 are equivalent to steps 100, 102 and 104 of Figure 1. In step 206, the method of Figure 2 includes an enquiry as to whether the pH information derived in step 204 is acceptable. The acceptability of the pH information is typically based on whether the derived pH meets a target pH. The acceptability of the pH information may also be based on whether the derived pH is within a range of acceptable pH values.

If the pH information derived in step 204 is found to be unacceptable, the method of Figure 2 proceeds to step 208, where the carcass is stimulated with a second electrical signal. The second electrical signal preferably has a higher voltage and signal frequency compared to the test signal forming part of the first electrical signal. The second electrical signal may be based on signals used in conventional electrical stimulation to reduce the pH of a carcass.

Once stimulated with the second electrical signal, which may be applied in one or more cycles, the method returns to steps 200, 202 and 204 again to derive pH information. If the pH information derived is acceptable, the method ends in step 210. If the pH information derived is still unacceptable, the method repeats from step 208 onwards again.

The Preferred Form Apparatus

Referring to Figure 3, the preferred form apparatus of the invention is shown generally as 300. The apparatus includes an input means 302, which may be one or more buttons, switches, keypads, touch screens or the like. The apparatus also includes an electrical signal generator 304. The electrical signal generator 304 is used to generate electrical signals 305 to stimulate a carcass, and may be a conventional constant voltage or a constant current electrical stimulation device.

A processor 306 is provided to control the generation of signals from the electrical signal generator 304. In addition, the processor 306 receives input signals from the input means

302 and signals representing the carcass' response to the electrical signals via line 308. The signals on line 308 may be signals received from one or more load cells or like sensors that are arranged to measure the response of the carcass.

To use the apparatus 300, an operator will typically first connect the apparatus 300 to sensors via one or more lines, such as line 308. If necessary, the electrical signal generator 304 may be connected to a voltage generation device. The operator may begin using the apparatus 300 by inputting, via input means 302, a desired command. In one form, the desired command is for the apparatus to carry out the method of Figure 2 to bring the pH of a carcass down to a specified target pH. The processor may present to the operator via display means 310 further options, if applicable. For instance, the processor may be programmed to display and execute a variety of programs to produce different electrical signals via electrical signal generator 304. Examples of such programs include a 'sheep' program to produce electrical signals with a peak voltage, V_{sheep}, to derive pH information of a sheep carcass, and a 'bovine' program to produce electrical signals with a peak voltage, V_{bovinw}, that is higher than V_{sheep}, to derive pH information of a bovine carcass.

The electrical signals generated and outputted from the apparatus are sent to the carcass for stimulation. The response of the carcass to the stimulation is measured, and signals representing this response are fed back into the apparatus 300 via line 308. The response signals are then analysed by the processor 306 to derive information relating to the pH of the carcass. Preferably, the information derived are displayed on display means 310.

The Preferred Form System

The system of the present invention will now be described with reference to Figure 4. The system includes an electrical stimulation device 400 to deliver electrical energy to one or more carcasses. In the preferred form, the electrical energy is delivered in pulses.

Four carcasses 402 are shown in Figure 4. The carcasses 402 are suspended from a rail 404, which may be part of a conventional overhead rail that is used to transport carcasses in a facility.

To measure the response of the carcass to electrical stimulation, one or more load cells 406 are mounted in the rail 404 at points where electrical stimulation will take place. The load cell(s) 406 measures the rate of relaxation of the carcass 402 between pulses of electrical energy, and the force generated by the carcass 402 when it contracts in response to each pulse.

Signals representing the rate of relaxation, contraction force, or any other parameters indicative of the carcass' response as measured are sent via lines 408 to the electrical stimulation device 400 for analysis. In the preferred embodiment, the electrical stimulation device 400 includes a computing device to analyse the measured response. Alternatively, the computing device is provided separate to the electrical stimulation device 400. In that form, the signals may be directed to the computing device by the electrical stimulation device 400, or may be directly sent from the load cell(s) to the computing device. For simplicity and ease of reference, only single lines 408 are shown to connect the electrical stimulation device 400 and each of the load cells 406. In practice, two or more lines for each load cell 406 would be typically employed.

The electrical stimulation device 400, or separate computing device, analyses the signals from the sensors to derive pH information relating to the carcass. In one form, the analysis involves correlating the signals, which are received as waveforms, with pH information provided in a database or lookup table.

Example Signals and Responses

In the preferred form, the test signals are a range of lower frequency pulses used to ‘interrogate’ the carcass. At intervals of 10-15 seconds, for instance, and while the carcass is hanging from a load cell, a defined set of ‘test’ pulses may be introduced into the carcass. Electrical pulses are typically unipolar square waves, between 0.1 and 10 m-sec duration, with a minimum pulse amplitude of 1 Ampere. Test signals are produced from pulses with pulse intervals varying between 100 and 250 m m-sec which allow a sufficient time interval between pulses to allow the relaxation rates of the carcass muscles to be measured, and to generate differentiated contractions in response to each stimulation pulse.

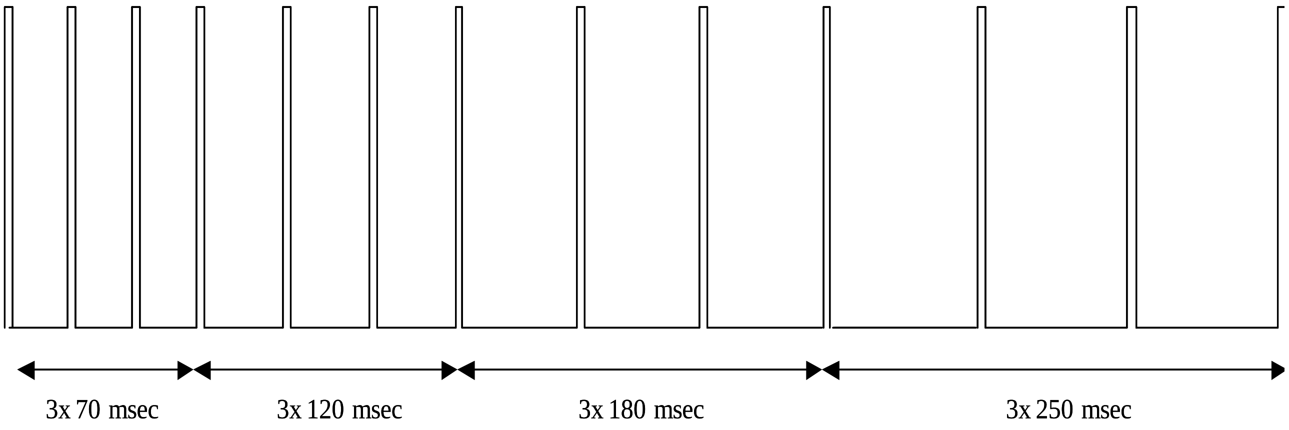
The test pulses are preferably introduced into a normal stimulation waveform that is used to stimulate and reduce the pH of the carcass.

In one form, the response measured is treated as a waveform whose frequency components are correlated with pH data. Alternatively, the response may be checked against a database of a known mechanistic relationship between the contractile events in carcass muscle and carcass responses.

The frequency components of the responses are calculated using a Fast Fourier Transform. Correlations are established between measured pH values individual frequency responses using conventional statistical regression techniques.

Example of a test pulse series to determine carcass pH.

Pulses comprise 1 msec duration, 1 Ampere amplitude. Pulse intervals are increased every third pulse to increase the relaxation time between stimuli.



Example Applications of the Present Invention

The present invention may be used to control the pH-temperature decline of a carcass during processing. The pH-temperature decline is the rate at which carcass pH level falls from about 7 (live animal pH) to the level, typically 5.5, at which it will not fall any further (known as the ultimate pH) against the temperature of the carcass.

There is an ideal ‘window’ that describes the ideal relationship between carcass pH and temperature from slaughter to when ultimate pH is reached. If the rate of pH–temperature decline does not fall through the ideal window, the quality of the meat obtained from the carcass can be compromised. By deriving information of carcass pH using the present invention, and combining with conventional temperature sensing, the present invention allows the monitoring and recordable of a pH-temperature history for carcasses, which can be progressively checked in real-time or close to real-time against the ideal window.

The above application can be implemented as part of the usual electrical stimulation process, or independently with no, or minimum, effect on the pH of the carcass. The latter may be used in circumstances when stimulation is not desired but, instead, pH needs to be measured to assure that the pH-temperature history fits within a defined specification, such as the ideal window.

The present invention may also be used to predict the ultimate pH. That is to say, the information obtained using the present invention may be utilised to predict the pH that the carcass will reach in the end.

Attributes of tenderness may also be predicted from the response characteristics of carcasses. For instance, initial tenderness, which is the tenderness at rigor mortis, and the rate of tenderisation, may be predicted. A prediction on the rate of tenderisation may be used to control how the carcass, or meat from the carcass, is further processed. For instance, if the rate of tenderisation is predicted to be high, the carcass or its meat will be distributed locally, so that it is sold and consumed within a relatively short time frame. If the rate of tenderisation is predicted to be low, the carcass or its meat will be chilled and shipped internationally so that the delay in transportation allows optimum tenderisation.

Given the above, the present invention in its basic form may be used allow effective processing of carcass whereby insufficient or excessive electrical stimulation is avoided. In other words, the present invention provides effective mechanisms to produce, consistently, a level of stimulation that forms a critical part of effective processing for high value markets. In particular, the present invention allows the production and control of stimulation that provide tailored levels of pH decline to allow the pH-temperature decline to be optimised for specific markets of product types.

The foregoing describes the invention including preferred forms thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof. For example, the components illustrated schematically for the preferred form apparatus and system of the invention need not necessarily be in the form illustrated. One or more of the components may be incorporated together to function as a single component. Alternatively, any one component illustrated may be implemented with two or more components.