final report

Project code: P.PIP.0195

Prepared by: Graham Treffone

JBS Australia Pty Ltd

Date submitted: April 2012

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

New Generation Sheep Meat Electronics

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

ABSTRACT

This new initiative has led to the development of lower cost (but equal performance) electronics using new developments in technology which will see the price of the electronics drop significantly. The new electronics will go some way towards reducing the cost of meat electronics installations, however, an equally important consideration is the mechanical costs associated with electrode installation. Another initiative with MLA commercialiser, StimTech to streamline the mechanical installations by developing "do it yourself kits" is also nearing completion and these two initiatives together will enable SME's to install meat electronics in a cost effective way.

The first electronics ready for testing was applied to sheep (single and multi-channel stimulator/bleeders) and this project is nearing completion Because of the success of the SME sheep electronics projects the same developments are now being applied to Beef (single channel stimulators and immobilisers. It is envisioned that if this project is successful we will develop a final project in a similar vein with a new back stiffener.

To prove this approach three aspects need to be established during the trial phase:-

- The electronics (beta prototypes) must be proven in a commercial environment and then production electronics produced at an economical price.
- "Self-managed" installation procedures minimising commercialiser involvement must be demonstrated in a variety of processing regimes with an emphasis on installation assistance by phone contact with StimTech.
- Meat quality and OH&S performance needs to be established using a series of scientific investigations.

To test the practicality of this lower cost approach and gain experience of the varied requirements across the processing sector SME's are invited to join a group prepared to install R&D production prototype equipment of the new technologies on a "self-managed" basis.

Participants can choose a beef technology most suited to them (one technology per plant but subject to level of interest) and in return for long term use of the technology provide installation, operational and reliability feedback to MLA, AMPC and StimTech.

MLA has an existing project to develop a new generation of meat electronic technologies which will be cheaper than the current technologies using mass production techniques. The new electronics will also be designed to satisfy the new electrical safety standards being developed for the industry and make the electronics consistent with Government regulations for the foreseeable future.

The outcomes of this project were:
- Confirm electrical performance of production prototype meat electronics for beef.
- Develop data on "do it yourself" installations in a variety of SME's.
- Confirm eating quality and OH&S performance of the equipment.

At the conclusion of the investigative work, the four channel stimulation system at JBS Longford were reinstated to fully operational.

Executive summary

MLA has an existing project to develop a new generation of meat electronic technologies which will be cheaper than the current technologies using mass production techniques. The new electronics will also be designed to satisfy the new electrical safety standards being developed for the industry and make the electronics consistent with Government regulations for the foreseeable future.

MLA also has an existing project to develop "do it yourself" meat electronics kits with its meat electronics commercialiser, StimTech. This project is designed to systemise the mechanical components (including electrodes) of the electronics installations to make the installations affordable for the SME's.

This project capitalised on the outcomes of the two projects mentioned above by setting up a series of trial installations for the sheep components of the electronics aimed specifically at SME's.

A four module low voltage stimulation system was installed by StimTech in the bleed area of JBS Longford plant immediately following exsanguination and hang up. The system had been operating well, however, water ingress to the remote control had led to the failure of the Graphical User Display (GUI) to display the selected programmed parameter set although was still able to control the stimulation. On StimTech's previous visit a replacement GUI was installed and although it powered up, it did not communicate with the power output modules and therefore was not left installed. The GUI was returned to the manufacturer and investigations undertaken into the compatibility of the replacement GUI hardware and software with the power output module hardware and software. These investigations resulted in no issue of compatibility being found.

The outcomes of this project were:

- Confirm electrical performance of production prototype meat electronics for beef.
- Develop data on "do it yourself" installations in a variety of SME's.
- Confirm eating quality and OH&S performance of the equipment.

This project should be considered as the second in a series of three projects; the first being for sheep, which is now fully subscribed. The final series of projects will be for a new electronic back stiffener and these projects will commence after the beef electronics is fully subscribed.

Table of Contents

1 Background

Meat & Livestock Australia (MLA) has, in the past, developed a suite of meat electronics technologies which have contributed to an improvement in eating quality, meat colour, bleeding, and carcase movement control. These technologies have been widely installed in the medium to large processors for both sheep and beef but little uptake has been experienced in the Small to Medium Enterprises (SMEs). The potential improvements in eating quality through application of controlled dose electrical stimulation is shown in the below Figure (See Figure 1).

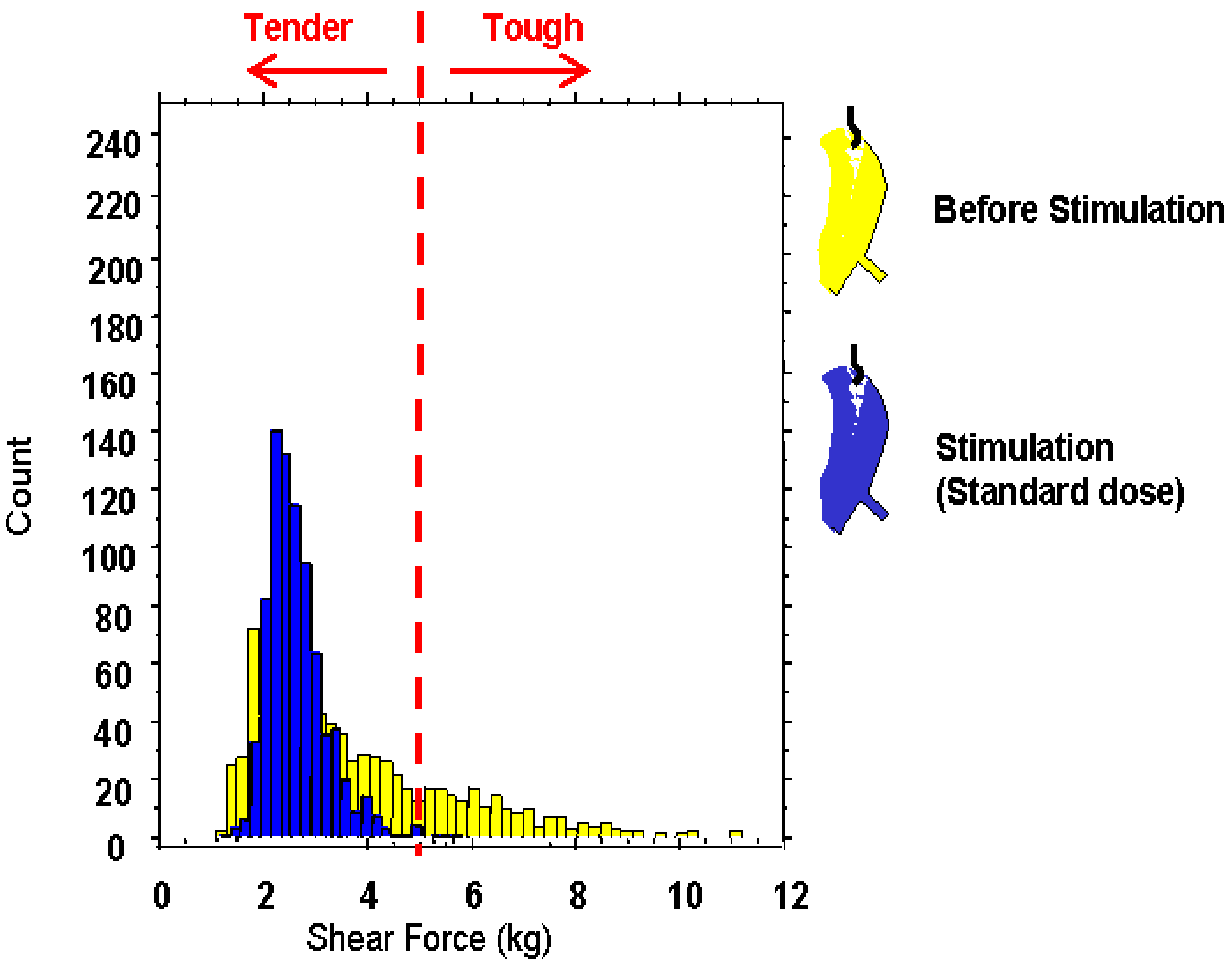


Figure 1: Shear force of lamb loins before and after electrical stimulation (standard dose).

Cost considerations have limited the uptake of meat electronics because the commercialiser, StimTech, has had to charge for the multiple site visits required for each installation and the relatively high price of the electronics.

This new initiative has led to the development of lower cost (but equal performance) electronics using new developments in technology which will see the price of the electronics drop significantly. The new electronics will go some way towards reducing the cost of meat electronics installations, however, an equally important consideration is the mechanical costs associated with electrode installation. Another initiative with MLA commercialiser, StimTech to streamline the mechanical installations by developing "do it yourself kits" is also nearing completion and these two initiatives together will enable SME's to install meat electronics in a cost effective way.

The first electronics ready for testing was applied to sheep (single and multi-channel stimulator/bleeders) and this project is nearing completion Because of the success of the SME sheep electronics projects the same developments are now being applied to Beef (single channel stimulators and immobilisers. It is envisioned that if this project is successful we will develop a final project in a similar vein with a new back stiffener.

To prove this approach three aspects need to be established during the trial phase:-

- The electronics (beta prototypes) must be proven in a commercial environment and then production electronics produced at an economical price.\
- "Self-managed" installation procedures minimising commercialiser involvement must be demonstrated in a variety of processing regimes with an emphasis on installation assistance by phone contact with StimTech.

Meat quality and OH&S performance needs to be established using a series of scientific investigations.

To test the practicality of this lower cost approach and gain experience of the varied requirements across the processing sector, SME's are invited to join a group prepared to install R&D production prototype equipment of the new technologies on a "self-managed" basis.

Participants can choose a beef technology most suited to them (one technology per plant but subject to level of interest) and in return for long term use of the technology provide installation, operational and reliability feedback to MLA, AMPC and StimTech.

2 Project objectives

The project objectives were:

1) Production prototype electronics tested for reliability and design optimised for subsequent commercial production.
2) Each technology installed and operating reliably within the budget constraints.
3) Technology tested to perform according to industry best practice for eating quality and OH&S.
4) Viable low cost (do it yourself) installation procedures documented and incorporated into the commercialiser's (StimTech) business plan.

3 Method

A four module low voltage stimulation system was installed by StimTech in the bleed area of JBS Longford plant immediately following exsanguination and hang up. The process of commissioning and testing the new alternative meat electronics were:

- Installation designed and working drawings approved
- Mechanical and electrical components manufactured
- Mechanical and electrical components installed
- Complete system tested and documented

4 Results and discussion

A number of operational issues were experienced throughout the installation and commercial adoption phases of the project. A summary of this visit is presented below:

- StimTech attended site to return the 4 channel small sock stimulation system to “normal” operation.
- The system had been operating well, however, water ingress to the remote control had led to the failure of the Graphical User Display (GUI) to display the selected programmed parameter set although was still able to control the stimulation. On StimTech’s previous visit a replacement GUI was installed and although it powered up, it did not communicate with the power output modules and therefore was not left installed. The GUI was returned to the manufacturer and investigations undertaken into the compatibility of the replacement GUI hardware and software with the power output module hardware and software. These investigations resulted in no issue of compatibility being found.
- As such with a complete range of spares StimTech returned to site to reinstate the stimulation system to complete operability.
- The system was continuing to operate although the GUI was back lit but not displaying.

The actions undertaken on site were:

- The replacement GUI was installed and communication with all power output modules established, returning the system to full operation.
- On testing module one was measured to be outputting DC voltage and further testing at the PCB level suggested the likely failure of the output mosfet. This module was replaced and has been returned to the manufacturer for assessment.
- Attempted programming of the programmed parameter sets established that the USB to RS232 serial interface had failed. This module was replaced and has been returned to the manufacturer for assessment.
- The remote control was relocated to a “dry” area as on installation of the replacement components there was considerable moisture in the enclosure and appeared to have been such for some period of time by the oxidation on the GUI and USB to RS232 converter PCB’s.

Additional further actions required (by the provider) was required, including:

- StimTech’s manufacturer is to confirm the failure of the output power module and possible causes. The manufacturer will also investigate failure of the GUI and

USB to RS232 serial interface PCB's with regard to moisture damage. The findings of this will be forwarded on completion.
  - StimTech is to investigate an alternate remote control enclosure to survive the environment it is exposed to of high temperature water and chemicals. Although the current polyethylene enclosure should be a suitable unit it is not providing prolonged functionality in the abattoir environment.
  - Further to the issue of water ingress of the remote control enclosure, investigation into a sealant for the PCB's will also be undertaken. With the progression of PCB's from large components installed by hand to small surface mount components installed by pick and place equipment the spacing of components and tracks has decreased markedly. The reduced spacing between components leaves little margin for oxides to occur on components etc. before it is possible for conductive bridging to occur.

At the conclusion of the investigative work, the four channel stimulation system at JBS Longford were reinstated to fully operational.

The following outcomes were achieved:

- New low cost meat electronics equipment proven in a commercial environment.
- Installation designs established covering a wide variety of beef processing environments.

Know-how, design and project management for remote meat electronics installations (with a significant "do it yourself" component) documented and incorporated into the StimTech operating procedures.

A third party audit by MSA Development officers has been conducted and shown the ES system to be operative effectively to deliver the required pH decline window on a specified number of lamb carcases within the MSA requirements (see Appendix, Section 6.1). A Procedures and Safety Manual has been developed (refer to Appendix, Section 6.2). Subsequently a MSA accreditation has been licenced to the Longford operation with ongoing QA requirements for assessment of pH decline compliance and reported to MSA offices.

Other supporting independent reference documents and standards are referred in the Appendix (See Sections 6.3 & 6.4).

5 Conclusion

This new initiative has led to the development of lower cost (but equal performance) electronics using new developments in technology which will see the price of the electronics drop significantly. The new electronics will go some way towards reducing the cost of meat electronics installations, however, an equally important consideration is the mechanical costs associated with electrode installation. Another initiative with MLA commercialiser, StimTech to streamline the mechanical installations by developing "do it yourself kits" is also nearing completion and these two initiatives together will enable SME's to install meat electronics in a cost effective way.

The first electronics ready for testing was applied to sheep (single and multi-channel stimulator/bleeders) and this project is nearing completion Because of the success of the SME sheep electronics projects the same developments are now being applied to Beef (single channel stimulators and immobilisers. It is envisioned that if this project is successful we will develop a final project in a similar vein with a new back stiffener.

To prove this approach three aspects need to be established during the trial phase:-

- The electronics (beta prototypes) must be proven in a commercial environment and then production electronics produced at an economical price.
- "Self-managed" installation procedures minimising commercialiser involvement must be demonstrated in a variety of processing regimes with an emphasis on installation assistance by phone contact with StimTech.
- Meat quality and OH&S performance needs to be established using a series of scientific investigations.

The outcomes of this project were:

- Confirm electrical performance of production prototype meat electronics for beef.
- Develop data on "do it yourself" installations in a variety of SME's.
- Confirm eating quality and OH&S performance of the equipment.

The outcome of the project that as a result of evaluating the new alternative formats of meat electronics, four channel stimulation system at the JBS Longford operation has been reinstated to fully operational.

6 Appendix

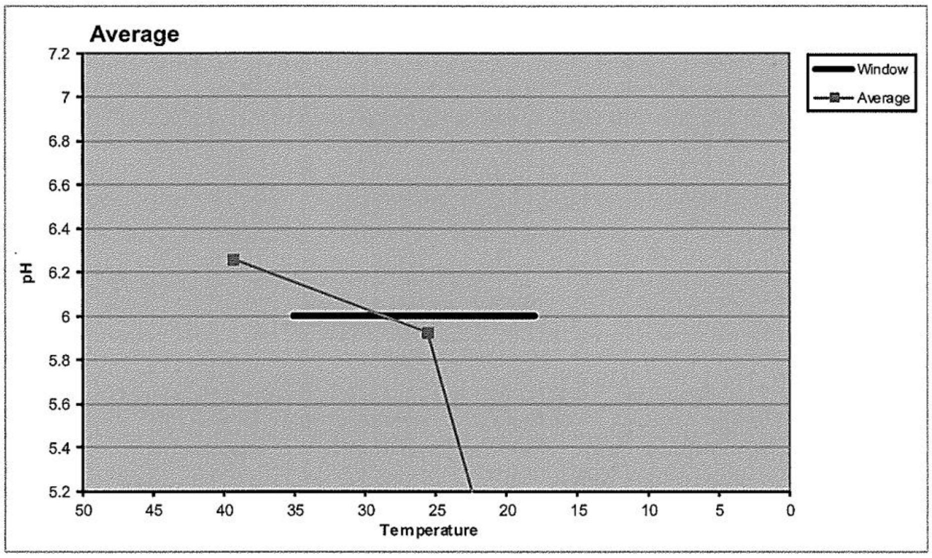
6.1 Appendix – Third Party Audit by MSA Development Officer

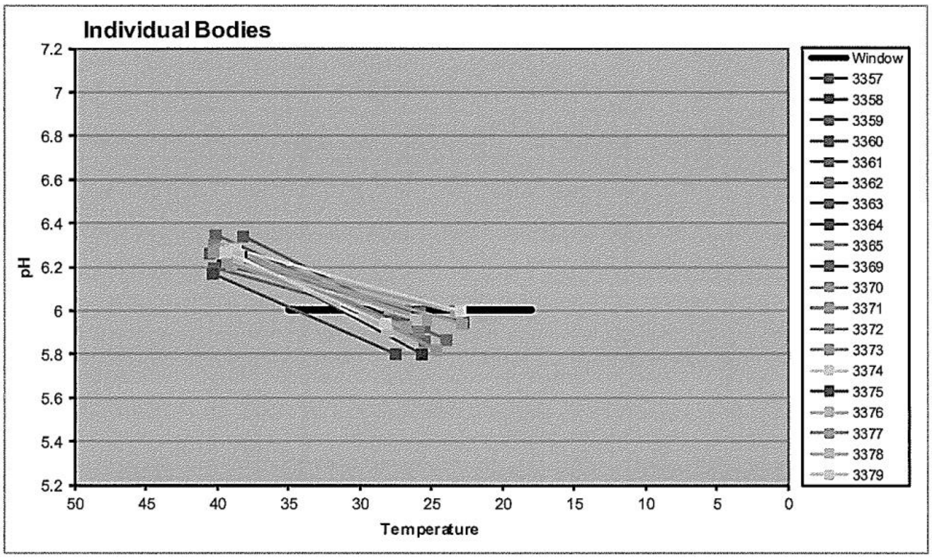
Meat and Livestock Australia
Meat and Livestock Australia Limited ABN - 39 081 678 364
MSA Office - Brisbane QLD PO Box 2363 FORTITUDE VALLEY BC QLD 4006 Phone (07) 3620 5200 Fax (07) 3620 5250
MSA Office - Perth WA 278 Camboon Road Malaga, WA 6090 Phone (08) 9209 2890 Fax (08) 9248 1900
MSA Office - Kew East VIC Locked Bag 8000 MDC KEW VIC 3101 Phone (03) 9249 9694 Fax (03) 9249 9614
Email: msaenquiries@mla.com.au Internet: www.mla.com.au/msa Toll Free Call: 1800 111 672

Achilles Tendon - 5 Days Age

Plant:	C507	**Stim Type:**	MVS	**Trip Duration:**	2
Date:	02/08/12	**Stim Duration:**	25	**Time in Lairage:**	13
Grader:	6e32	**Stim Frequency:**	1100	**Animal Category:**	Lamb

Comments:





6.2 Appendix - Procedures & Safety Manual

PROCEDURE AND SAFETY MANUAL StimTech

PROCEDURE AND SAFETY MANUAL

For

MULTIFUNCTIONAL MODEL

LOW VOLTAGE ELECTRONIC STIMULATOR

(LVES)

HIGH FREQUENCY IMMOBILISER (HFI)

Prepared by StimTech Pty Ltd
PO Box 51, COOPERS PLAINS, QLD, 4108
AUSTRALIA
www.StimTech.com.au
Phone: +61 418 104 077

TABLE OF CONTENTS

1. MULTIFUNCTIONAL STIMULATOR / IMMOBILISER

1.1 General

The multifunctional stimulator / immobiliser is capable of being programmed to operate as a Low Voltage Electronic Stimulator (LVES), Mid Voltage Electronic Stimulator (MVES) or a High Frequency Immobiliser (HFI).

Utilising LVES parameters enables the system to produce an output suitable for applying pre-evisceration. The purpose of applying the LVES is to stimulate the living muscles via the nervous system, accelerating the breakdown of glycogen and hastening the onset of rigor. The application of LVES pre-evisceration has been shown to improve bleeding and therefore blood recovery. The intervention of a LVES system can avoid the problems of cold or heat shortening, while improving blood recovery with reduced blood on the slaughter board, as well as reducing the incidence of dark cutting carcases

The Mid Voltage Electrical Stimulator (MVES) produces an output suitable for applying post-evisceration. As the nerves have ceased being active, stimulation is via direct muscle stimulation and generally requires wider pulses at higher currents to achieve the same stimulation effect as LVES. The purpose of the MVES is to stimulate the muscles, accelerating the breakdown of glycogen and hastening the onset of rigor.

High Frequency immobilisation of carcases is often required to provide a safe working environment for processing personnel. Historically immobilisation has been achieved through the application of electrical stimulation waveforms, post slaughter, as an electrical current applied to the carcass. These forms of electrical current have had a major effect on pH decline and therefore meat quality. The newly developed High Frequency Immobiliser (HFI) has minimal / no effect on pH decline and therefore offers the ability to immobilise all types of stock processed, including grain fed animals.

The intervention of a HFI system can avoid the problems of heat toughening with the added advantage of enhancing the effectiveness of electrical back stiffening and other stimulation applications.

1.2 Controls, Indicators and Functions

MAIN ELECTRICAL UNIT

The Multifunctional Stimulator / immobiliser is comprised of a set of electrodes (Nose & Anal, Nose & Rail, or Static Rail) located at the chain, pre-avisaration and a stainless steel enclosure (400mm x 400mm x 200mm – 'main unit') with an IP65 rating containing 1 control board and 1 output interface board and a optional but recommended remote control. The Multifunction units are programmable by on site personnel to suit individual plants requirements. Programming and Wiring instructions are contained in Appendix 1.

1) The unit is powered by a internal 24VDC power supply, which is plugged into a general purpose outlet.

2) **Remote Warning Lamp** contacts are provided for plant installation of a prominent external 'operating lamp'.

3) Terminals for a Latching **Process Stop Button which** removes the 24VDC supply to the control board.

4) A **PLC** interface is available in this design to facilitate plant control and units are provided with a remote control.

REMOTE CONTROL UNIT

5) Waveform output ON/OFF **Control buttons**.

6) **LED Indicator** (Output ON) that shows that the output is active and that caution must be exercised when working near the electrodes.

7) Rotary six position internal **Selector Switch** allowing one of six sets of stored parameters to be selected.

8) **LCD Screen** inside the remote control unit allows verification of the programmed current setting and status of operation. i.e. Standby, Active PLC, Stopped PLC.

9) Latching **Process Stop Button** removes the 24VDC supply to the control board. The action of this latching process stop button is; press to disconnect and twist and release to reconnect 24VDC.

1.3 Low Voltage ELECTRONIC STIMULATOR, OPERATIONAL DESCRIPTION AND HAZARD MANAGEMENT

This equipment is designed to accelerate the natural ageing process in muscle and increase bleeding when the muscles are activated by an electrical current. These currents have been designed and tested by scientists in consultation with the International Electrical Safety Standards which are identical to Australian Standard AS/NZS 60479 and follow the requirements of the Safe Application of Electricity in the Meat Processing Industry NZS 6116:2006. The equipment was also designed with consideration to the standard literature which describes the effects of various types of current waveforms on animal and human nerves and muscle.

1.4 Safety in design

To ensure the highest standards of operational safety a multi-faceted design approach has been taken:

1) The LVES Electronic Stimulator waveforms have been designed to satisfy the guidelines of the Safety Standard when used to specify the maximum electrical output which satisfies the definition of “unlikely to cause ventricular fibrillation”.

2) The application of the electric current to the carcass is designed in such a way as to maximise efficiencies and minimise electrical leakage. This is achieved by connecting the lower electrode positioned near the shoulder to the plus voltage and connecting the upper electrode positioned near the rump to the zero voltage. Consideration must be given to personnel activities and the proximity to grounded steel work while the LVES is active to minimise the risk of personnel receiving a shock.

3) The equipment was designed using approved isolation transformers and failsafe technology and runs on a maximum internal supply of 24VDC. The LVES has been designed, built and certified to meet applicable electrical safety standards to protect the user even in a fault condition.

1.5 Minimum Installation Requirements

1) A latching process stop switch must be installed close to the electrode assembly and operators who are able to see anyone near the equipment. Dependent on the location of the main unit the front mounted enclosure latching process stop switch may be used or an additional switch can be installed.

2) Signs warning of an Electrical Safety Hazard must be installed in prominent positions close to the live electrodes.

3) A clearly visible warning light must be installed close to the equipment and connected so that the light is on when the electrodes are live.

1.6 TRAINING

To complement the safety features of the equipment and installation, operator training is an integral component of the installation. This focuses on behaviour in the vicinity of the installation which minimises exposure to any electrical current. The following training guidelines must be followed:

1) Emphasise to all people who come into the area that no voltage is safe. It would be wise to over-exaggerate the danger of touching the equipment or the energised carcass.

2) Explain that the greatest risk would occur if the plus voltage electrode or the carcass in the vicinity of the plus voltage electrode was touched while simultaneously touching the zero voltage electrode or grounded steel work and that this should never be attempted even though the waveforms/voltages are designed not to be lethal.

3) All personnel must wear electrically isolated rubber boots when within arms reach of the carcass and the electrodes i.e. leak free rubber boots.

4) All warning lights must be complied with. A warning light will tell when the equipment is active. Extra care must be taken when the light is on.

5) Location and operation of Latching Process Stop switches must be explained to all staff that have access to the area and operators close to the switches must be trained to monitor the stimulation zone and activate the switch if there is a dangerous situation developing.

2. BACKGROUND SAFETY DESIGN CRITERIA

The background development of the new technology ensures that every effort has been made to ensure a safe installation. It should also be pointed out that the equipment has been designed with a failsafe approach whereby no dangerous voltages can reach the output due to a low source voltage and an approved isolating pulse transformer.

2.1 Justification for the Electrical Energies Used

The standards IEC 60364.4.41 and AS/NZS 3000:2000 refer to a voltage of 6 volts r.m.s. a.c. or 15 volts ripple free d.c. as the limiting voltage if there is no protection from human contact and large area contact in a wet environment is possible. These voltages have also been adopted in NZS 6116:2006 at the point of operator contact for “Equipment Class” classification as to the types of protection required.

When considering the design of the LVES for the meat industry, two of Australia’s most senior electrical safety consultants were contracted to advise on the safety aspects of the designs. Both consultants independently concluded that the waveforms in use could not be related directly to r.m.s. voltages at 50 Hertz or ripple free d.c. and that calculations using procedures and data outlined in AS/NZS 60479.2, AS/NZS 3350.2.76, ANSI/IEEE Std 80 – 1986, J Patrick Reilly, Electrical Stimulation and Pathology be used.

It should be noted that the industry standard Electrical Stimulation equipment used in Australia and New Zealand for the past 20 years and used in wet areas without protection outputs 80 volts d.c. pulses of 7 millisecond duration with a repetition frequency of 14 Hertz. The r.m.s. voltage for this waveform is greater then 6 volts r.m.s. a.c. and is actually 26 volts r.m.s. a.c.

The new stimulation equipment operates with higher peak voltages but much narrower pulse widths. For application to cattle 300 volts d.c. (25 volts r.m.s) peak pulses are used, while for sheep 550 volts d.c.(46 volts r.m.s), both applications utilising 500 microsecond pulse durations with a repetition frequency of 14 Hertz (bleed applications use as low as 3 Hertz).

Multifunctional (Appendix)

Low Voltage Electronic Stimulator (LVES)

Wiring Instructions

Main Unit

1. Connect mains supply to white connector block with inline phase fuse (250v 5amp). It is recommended that the 240 volt single phase supply be protected at the distribution board with a 10amp circuit breaker and be connected to the main unit through a GPO/isolation switch.

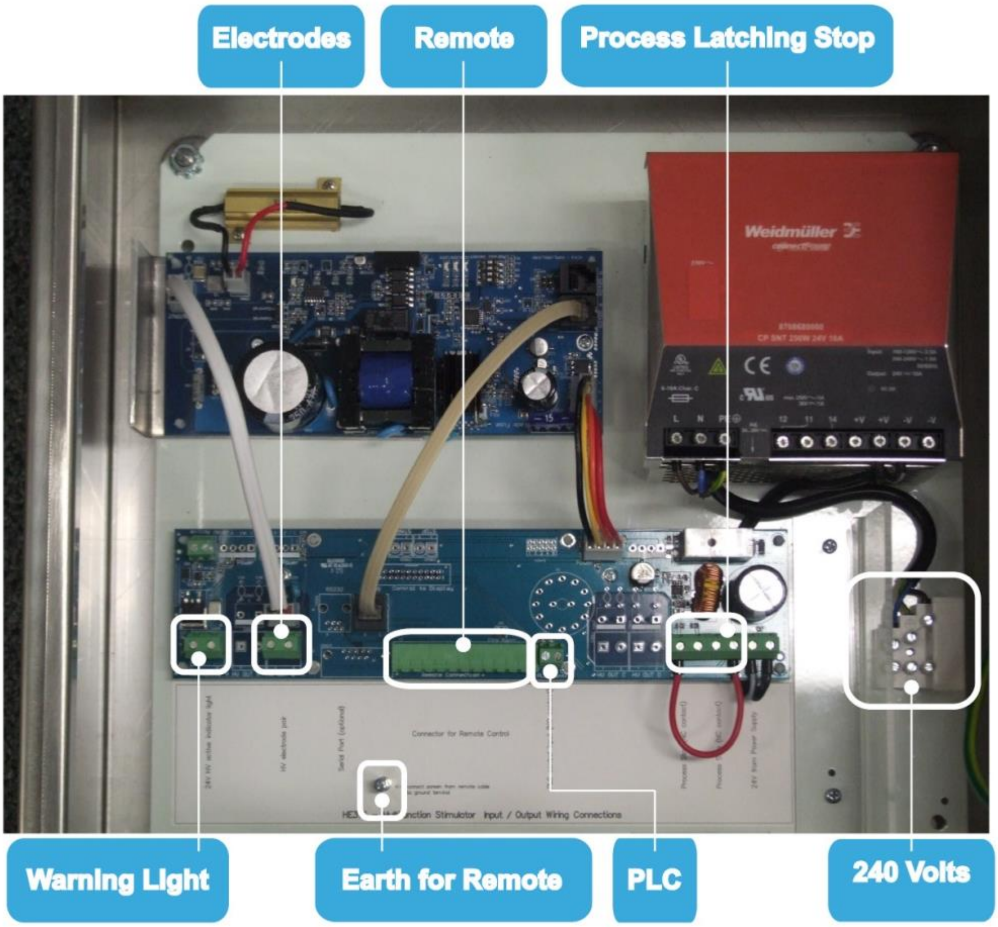
2. Connect electrodes to “HV **OUT”** (note “2” = positive).

3. Connect red LED warning light to **“HV ACTIVE”** (note “2” =+24 VDC when output active).

4. Connect Process stop button to **“E-Stop” (voltage free contact, closed to energise)**.

5. Connect chain interlock to **“PLC” (voltage free contact, closed to output)**.

DIAGRAM 1



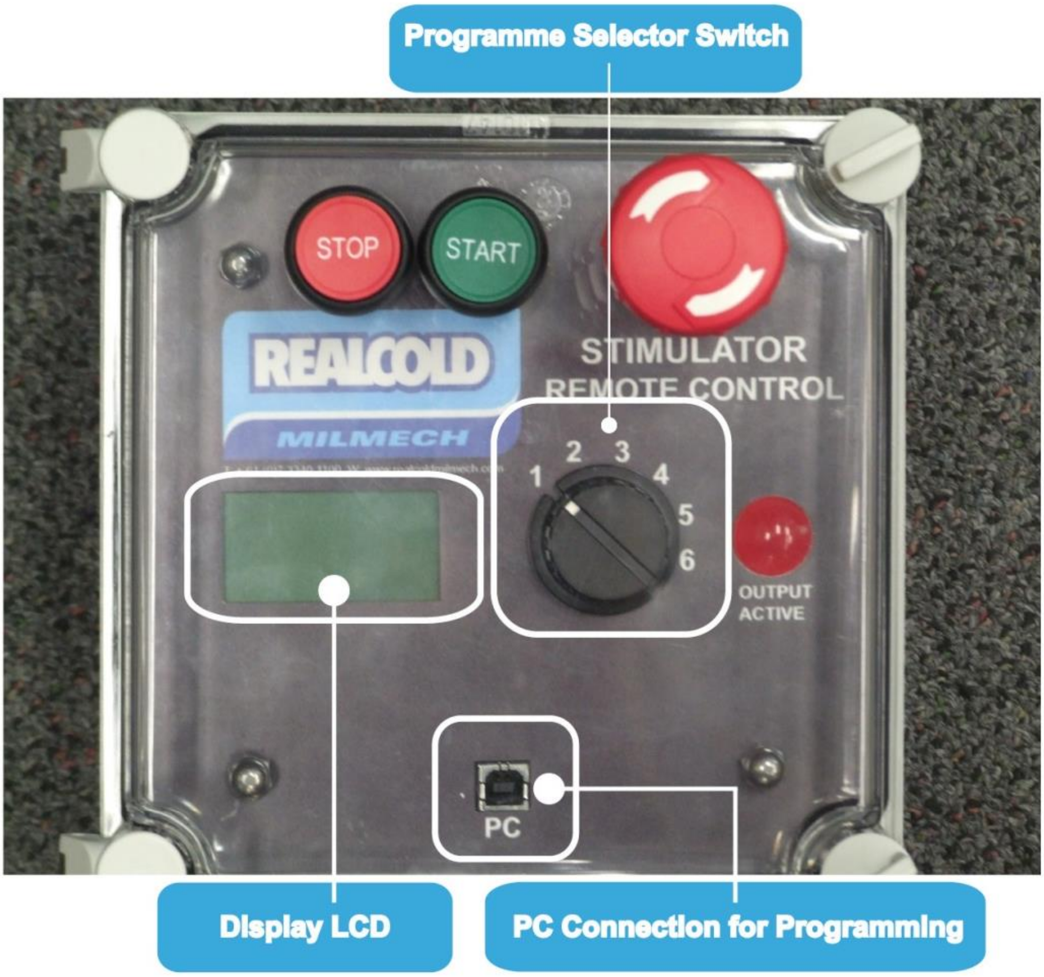
Remote Wiring Instructions

1. Using the shielded multicore cable provided, strip approximately 70mm of outer insulation from both ends to expose shield. The shield is “teased” off the wires and connected to the ground terminal in the main unit and commoned with wire “1” at the remote control.

2. Apply 0.5mm Boot Lace Ferrel to the control wires and connect to the 12 pin screw terminal blocks (**NOTE;** Individual wires are numbered and must be connected in the same sequence at both ends of the cable).

3. A ferrite is provided and must be connected around all individual wires where the shield has been teased away at the remote control only.

DIAGRAM 2:



Safety

1. **Warning light**(Output ON) shows that the output is active and that caution must be exercised when working near the electrodes, The warning light should be install in a prominent position visible to all personnel entering the vicinity of the electrodes.

2. **Caution** must be exercised when working in the vicinity of the electrode. Touching electrodes and grounded steel work will result in an electrical shock (about the strength of a severe electrical fence) While this is unlikely to cause “ventricular fibrillation” or serious risk to health to a normally healthy person it will cause pain. People with heart conditions are advised to avoid contact with the electrodes or the cattle whilst stimulator is active.

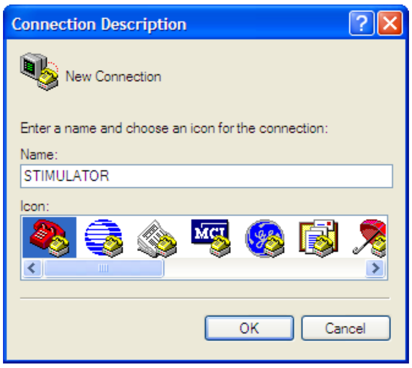
3. **Warning signs** must be installed in a prominent position visible to all personnel entering the area.

Programming Instructions (Appendix 2)

To program the Multifunctional Stimulator requires connecting a laptop to the remote control using a "A-B USB CABLE" as supplied. Should the cable be misplaced it can be obtained from Dick Smith Electronics as catalogue number XH3362.

NOTE, the stimulator must be turned on but NOT "active" when programming.

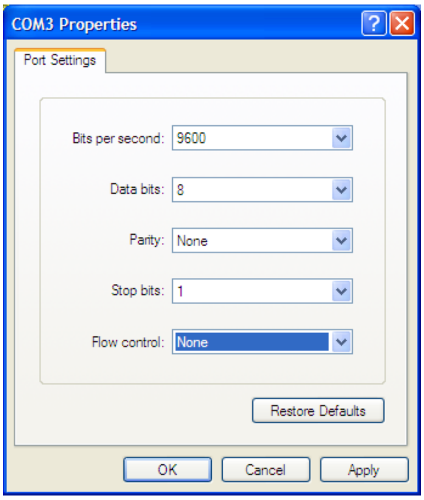
1. On the Laptop select "**ALL PROGRAMS" → "ACCESSORIES" → "COMMUNICATIONS" → "HYPERTERMINAL"**.
2. Connection Description, Enter name e.g. STIMULATOR and select an icon, then click "ok".



3. Connect to; use allocated **"COM"** port.
   (NOTE com port can be checked via "control panel", "systems properties", "hardware", "device manager", "ports").

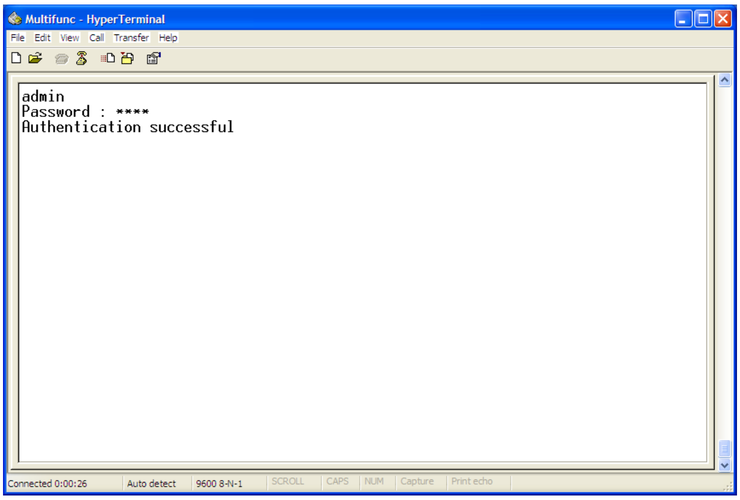
4. PORT SETTINGS;
   BITS PER SECOND "9600"
   DATA BITS "8"
   PARITY "NONE"
   STOP BITS "1"
   FLOW CONTROL "NONE"

Then click “APPLY” and “OK”



5. Enter user name and password.

   USERNAME; “admin”   PASSWORD; “test”
   “authentication sucessful” will be displayed.
   Programming can commence.



STIMULATOR INTERFACE COMMANDS

1. To Set Pulse Width; enter “**SPW”** program number. board number. value enter
   e.g. to set program 1 for board 1 to 50ms enter **SPW1.1.50,** (NOTE values are in o.1ms). This will need to be done for all programs and all boards.

2. Set Pulse Period; enter “**SPP”** program number. board number. value   enter
   i.e. **SPP1.1.200 --- SPP6.1. 200**   (NOTE values are in ms)

3. Set Pulse Current; enter “**SPC”** program number. board number. value enter
   i.e. **SPC1.1.500 ---SPC6.1.500**   (NOTE values are in mA)

4. Set Run Time; enter “**SRT”** board number. value enter
   i.e. **SRT1.200** (NOTE values are in 0.1s, a 0 value = continuous runtime)

5. Set Log Mode; enter “**SLM”** enter, toggles on/off. Data can be captured via “transfer” on HyperTerminal window.

6. To Change master/slave status enter “**SPLC”** then enter (NOTE for the PLC (chain) to have full control the stimulator needs to be in “MASTER” status)Is this detailed anywhere i.e. how master and slave settings effect things?

7. To check programming of each module; enter “**GS”** program number e.g. to check program 1 enter **GS1 and the data will be returned. See example below**.

8. Log Out; enter “**LO”**.

Minimum Safety Requirements for StimTech Electronic Equipment

Applicable for the following StimTech electronic equipment

- **Low Voltage Electrical Stimulation.**
- **Electronic Bleeding.**
- **Immobilisation.**
- **Mid Voltage Electrical Stimulation.**

1. General

1.1 The equipment fits into the category of "unlikely to cause ventricular fibrillation" when subjected to calculations presented in AS/NZS 60479.2:2002 and referenced to data in: *"Electrical Stimulation and Electropathology"* by J. Patrick Reilly.

This does not mean that the equipment is 100% safe but only that there is a relatively small risk. As a consequence, contact with the electric energy should always be regarded as having a risk and treated accordingly.

1.2 Interpretation of the standard and how it applies to the MLA/HETECH equipment has been performed by Associate Professor Colin Grantham and Associate Professor Trevor Blackburn, both of the University of NSW, (two separate reports), and their calculations show that the equipment is relatively safe when used within specified limits of the electrical parameters and the following safety measures are followed.

2. Minimum Installation Requirements

2.1 Safety switches must be installed at either end of the equipment close to operators who could see anyone near the equipment.

2.2 Signs warning of an Electrical Safety Hazard must be installed in prominent positions close to the live electrodes.

2.3 The stimulation should be interlocked to the chain so that if the chain stops the stimulation circuits are deactivated, (with the exception of immobilisation prior to the chain).

2.4 A clearly visible warning light should be installed close to the equipment and connected so that the light is on when the electrodes are live.

2.5 Barriers should be installed to prevent anyone touching the live carcasses or the electrodes. If it is only possible to reach an earth electrode or the earthed zone of a carcass, barriers are not essential. For High Frequency Immobilisation installations, where energy is applied as a balanced floating input isolated from earth then barriers are not essential but operator training must be carried out in all cases.

3. Training

If barriers are not in place to prevent anyone touching the electrodes or live carcasses then anyone who has access to the area needs to be trained to behave in an appropriate way when in the vicinity of the electrodes. This training should include the following:

3.1 Emphasis that the voltages in the equipment can be dangerous. It would be wise to over-exaggerate the danger of touching the equipment or live carcasses.

3.2 All personnel need to keep beyond arms reach of the carcasses and the electrodes while the equipment is in operation.

Note: An exception to this rule applies to High Frequency Immobilisation applied soon after sticking. With the additional safety margin available with this equipment due to the high frequencies, contact may be made with the carcass such as in shackling provided: - Either the electrical energy is isolated from ground or the active connection is connected at the end of the carcass away from the contact. In these cases anyone contacting the carcass must wear intact rubber gloves and watertight rubber boots.

3.3 All warning lights must be complied with. A warning light will tell when the equipment is active. Electrodes or carcasses in the vicinity must not be contacted unless the warning lights are off and a supervisor is observing the situation and has turned the emergency switch off. (See exception in 3.2).

3.4 Warning signs must be observed.

3.5 Location and operation of safety switches must be explained to all staff that has access to the area with operators close to the switches trained to monitor the danger zone and activate the switch if there is a dangerous situation developing.

4. Safety and training questions

1) What does the warning light indicate?

2) Where are the safety switches located and how are they operated?

3) What do the warning signs indicate?

4) When is it safe to contact the electrodes?

Please see Safety / Induction Training Sheet available to print out in Appendix C3

Safety and training questions

What does the warning light indicate?

____

____

____

____

Where are the safety switches located and how are they operated?

____

____

____

____

What do the warning signs indicate?

____

____

____

____

When is it safe to contact the electrodes?

____

____

____

____

I have discussed and read the above information and fully understand its content:

Name: ______________________________

Signature: ______________________________ **Date:** ____________

DANGER

ELECTRICAL HAZARD

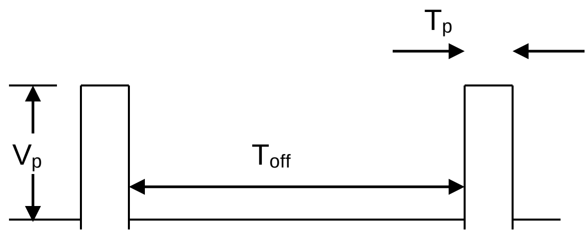
AUTHORISED PERSONNEL ONLY

CPMS MEAT ELECTRONICS, ELECTRICAL SAFETY CALCULATIONS

(CALCULATIONS BASED ON BOTH THE COLIN GRANTHAM AND TREVOR BLACKBURN CONSULTANTS REPORTS)

Grantham Safety Calculation Method #1
Consider the generalised waveform, [Figure 1 below] of the type utilised in the Low Voltage Stimulator / Bleeder and High Frequency Immobiliser.

FIGURE 1



f pulses per second.

<u>Figure 1.</u>

T_{tot} = Pulse Width (T_p) + Off Period (T_{off})

= Period of waveform

= 1 / Pulse Frequency (f)

Power Factor = p = $\dfrac{T_p}{T_p + T_{off}}$

Body Current = I_b

$$= \frac{\text{Maximum Peak Voltage } (V_p)}{\text{Human Impedance (assume a minimum = 500 ohms)}}$$

$$= \frac{V_p}{500 \text{ ohms}}$$ (375 Volts for this example)

= 0.6 Amps @ 300 Volts (worst case peak current)

Using the multicycle control calculations and figure 18 of AS/NZS 60479.2:2002 and making the assumption that a multicycle controlled sinusoid is equivalent to the generalised waveform above then:

> If p is less than or equal to 0.12 then the maximum I_b to remain below the threshold for ventricular fibrillation is 1.3 amps. V_p may be more than doubled and I_b will remain below the safe limit of 1.3 amps.

With this calculation, provided the pulse width (T_p) is no more than seven times the off period (T_{off}) and the peak voltage V_p does not exceed 600 volts the waveform will be unlikely to cause ventricular fibrillation.

Blackburn's opinion is that this method is very conservative considering the use of AC multi-cycle control calculations. MLA/StimTech will take this conservative calculation method as one approach to calculating safety for all technologies and stick to a maximum "p" value of 0.12 for the power control as defined in AS/NZS 60479.2:2002.

Grantham Safety Method #2 – Single Pulse Specific Fibrillating Method

By treating the waveform as a single pulse the maximum energy per pulse which is below the threshold of ventricular fibrillation is less than 48×10^{-3}.

The specific fibrillating energy of a pulse at 300 volts peak and 1 msec width is:-

$$= I_b^2 \times T_p$$

$$= 0.6^2 \times 1 \times 10^{-3} = 0.36 \times 10^{-3}$$

This is several orders of magnitude below the danger zone.

Grantham Safety Method #3 – Total Energy / Second Method

The Grantham method 3 does not cause safety calculation issues with many of the meat electronics technologies when the pulse frequency is relatively low (2 to 60 Hz). However, a particular technology, "High Frequency Immobilisation", has a higher total energy/second than the lower frequency technologies.

Grantham relates this calculation to the standard which covers electric fences. As will be discussed by Blackburn later, this is unrealistic for low energy pulses at higher frequencies than electric fence energisers. See the Blackburn discussion below.

Analysis of the Grantham Calculations by Blackburn

The Blackburn Report states that the Grantham method number 3 is not applicable to waveforms of the type shown in figure 1. When the pulse repetition rate increases significantly above the rate for electric fences then different calculations are more relevant.

Blackburn states that the two most significant effects on ventricular fibrillation risk for the types of waveform shown in figure 1. are the size of the pulse and the time between pulses. The cited reference by J P Reilly gives precise data for 10 to 100 μsec pulse width (T_p) waveforms with different pulse frequencies. At these pulse widths the ventricular fibrillation risk is the same as for one isolated pulse provided the space between the pulses is at least 500 μsec. The risk (Threshold multiplier) increases as the space between the pulses decreases and at a 200 μsec space between pulses the risk has increased by 5%. It should be noted that for pulse widths in the order of 100 μsec and 300 Volts peak the specific fibrillating energy which represents the fibrillation risk is still less than 1/1000 of that energy which could be a danger so increasing the risk by 5% is insignificant.

Because the High Frequency Immobilisation technology waveform is specifically referred to in the Reilly reference, the only safety calculation necessary is Grantham's method 2 which calculates the specific fibrillating energy. Provided the pulse width T_p is close to100 μsec and the period between pulses is sufficient to define individual pulses (assume a minimum T_{off} of 100 μsec for example) then Grantham's Method 2 should be used in conjunction with the Reilly Threshold multiplying factor.

NOTE: using a 100 μsec pulse and a100 μsec off period as a worst case, the risk is only increased 15% over the risk for much larger T_{off}.

In order to maintain a conservative approach to safety we nominate to limit the off period (T_{off}) to 100 μsec using 100 μsec pulses.

The lower frequency meat electronics technologies have pulse widths in the range 200 to 1000 μsec at frequencies of 2 to 60 Hz. Because of the much lower pulse frequencies Grantham's Method 3 is not a limiting factor and Blackburn's discussion, although relevant, need not be considered. Grantham's Methods 1 and 2 should be used to calculate safety.

High Frequency Example:

Assume the pulse width is 100 μsec and the off period is 400 μsec (100 μsec at 2000 Hz), then the energy in a single pulse in this case is:

= $V_p \times I_b \times T_p$
= $300 \times 0.6 \times 100 \times 10^{-6}$
= 0.018 Joules
divided by the threshold multiplier (Reilly:- 0.97)
= 0.019 Joules

The specific fibrillating energy assuming a 500 ohm body impedance is:

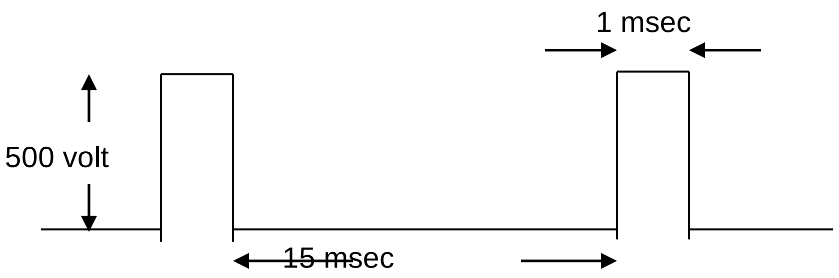
= 0.019 / 500

= 0.038×10^{-3} Joules/ohm

This is significantly less than the limit of 48×10^{-3}.

Low Frequency Example:

The worst case low frequency electronics technology has the following waveform:



Grantham Method 1.

Power Factor p = 1/16 which is less than 0.12

therefore the body current I_b must be less than 1.3 amps.

$I_b = \frac{500 \text{ volts}}{500 \text{ ohm}}$ = 1 amp which is less than the limit of 1.3 amps.

Grantham Method 2.

Specific fibrillating energy = $1^2 \times 1 \times 10^{-3} = 1 \times 10^{-3}$

which is significantly less than 48×10^{-3}.

Conclusion

For low frequency waveforms with pulse widths between 200 and 1000 μsec and pulse frequencies up to 60 Hz, use Grantham's Methods 1. and 2. to assess the waveform safety.

For high frequency waveforms with maximum pulse widths of 100 μsec and a minimum off period of 100 μsec, use Blackburn's interpretation, the Reilly reference and Grantham's Method 2. to assess the waveform safety.

6.3 APPENDIX – INTERPRETATION OF AUSTRALIAN/ NEW ZEALAND STANDARDS AS/NZS 60479.2:2002

Report prepared on behalf of
Unisearch Limited

Your reference: Ian Richards

on

INTERPRETATION OF AUSTRALIAN/ NEW ZEALAND STANDARDS AS/NZS 60479.2:2002

by

Associate Professor C Grantham
School of Electrical Engineering and Telecommunications
The University of New South Wales

for

Meat & Livestock Australia (QLD)

17 February 2003

J054616

COMMERCIAL-IN-CONFIDENCE

CONTENTS

Page

QUALIFICATIONS

I have a PhD and BSc with first class honours in Electrical Engineering and have over 40 years experience in the electrical industry. I am a chartered engineer and a Fellow of the Institution of Electrical Engineers (UK). My abbreviated curriculum vitae is attached at Appendix C.

EXECUTIVE SUMMARY

Australian/New Zealand Standard AS/NZS 60479.2:2002 does not specifically cover rectangular voltage waveforms with an on/off duty cycle. However, in my opinion such a waveform is similar to multicycle control where the multicycle control produces a single positive or negative half cycle in each period.

INTRODUCTION

Meat & Livestock Australia (QLD) is interested in an interpretation of Australian/New Zealand Standard AS/NZS 60479.2:2002 with respect to DC pulsed waveforms with variable magnitudes and 'on' to 'off' times. In particular it is required that a method of routinely identifying whether a waveform of specific magnitude and duration and with specified 'off' time between pulses presents a risk with respect to ventricular fibrillation.

Some basic background information on electric shock taken from my Electrical Safety notes appears at Appendix B.

AUSTRALIAN/NEW ZEALAND STANDARD AS/NZS 60479.1:2002

AS/NZS 60479.1:2002 is the Australian and New Zealand standard which covers the effects of current passing through the human body from a general perspective. Because most electric shocks are associated with mains frequency the above standard presents detailed data associated with effects of alternating current (AC) magnitude and duration for AC currents in the frequency range 15 Hz to 100 Hz. This data is reproduced in Figure 1 (Appendix A). Figure 1 makes reference to ventricular fibrillation, because it is ventricular fibrillation, which often causes death in electric shock situations.

It is the combined effect of current magnitude and the duration of this current through the body, which leads to the risk of ventricular fibrillation. The greater the current magnitude and its duration the greater is the risk.

Mains frequency is generally close to the worst frequency for electric shock severity and for a given current magnitude and duration, electric shocks are relatively less severe as the frequency is increased and decreased (including direct current [DC]).

CURRENT MAGNITUDE

As illustrated in Appendix B, the shock voltage divided by the impedance of the shock circuit gives electric shock current. For a given shock voltage the most severe shock currents occur when the body resistance is the only impedance limiting the electric shock current. Most of the body's resistance is presented by the skin and the resistance is also dependent upon the voltage as illustrated in Figure 2 which is taken from AS/NZS 60479.1:2002.

A figure of 1000 Ohms is usually taken for 240-volts (i.e. the nominal mains voltage). Table 1 of AS/NZS 60479.1:2002 indicates that 5% of the population can have a total body impedance as low as 700 Ohms for a touch voltage of 1000 Volts and where the current path is hand to hand. For the case where the current path is hand to foot, AS/NZS 60479.1:2002 indicates that the body resistance can be 10% to 30% lower than for the hand-to-hand case.

For short duration pulses the skin is effectively short circuited by the skin's capacitance and the body's impedance is reduced to its internal impedance, which is usually taken to be 500 Ohms for the 5% percentile group (Clause 2.6, Page 7 of AS/NZS 60479.1:2002).

SHORT DURATION PULSES

AS/NZS 60479.2:2002 is the Australian and New Zealand standard which covers the effects of current passing through the human body relative to special waveforms.

A typical voltage stimulation waveform is shown in Figure 3. The waveform shows a voltage magnitude of 300-volts with an 'on' period of less than 1 msecs and an 'off' period greater than 50 msecs.

Such a waveform is not specifically covered in AS/NZS 60479.2:2002 but, in my opinion, it is similar to multicycle control with a single positive or negative pulse in each period. Such control is shown in Figure 17 of AS/NZS 60479.2:2002 and is reproduced in Figure 4.

Normally multicycle control is used with mains frequency supplies, which implies a single pulse would have a duration of 10 msec. This is a pulse duration more than an order of magnitude greater than the typical voltage stimulation waveform referred to above. Consequently in the cases of interest, the 'off' period would occur more quickly after the initial shock than with conventional multicycle control.

Multicycle control in AS/NZS 60479.2:2002 takes account of the 'on' to 'off' time of the waveform by using a power control factor 'p', which is equal to the duty cycle
(i.e. the 'on' time divided by the 'on' plus 'off' time).

Although similar to multicycle control a rectangular pulse has a conducting r.m.s. current equal to the peak current, whereas with multicycle control the r.m.s. current is the peak current divided by the square root of two.

Taking into account the figure of 500 Ohms for the initial body resistance the maximum current with the above waveform would be 0.6A (i.e. 300/500).

Figure 18 of AS/NZS 60479.2:2002 shows the threshold of ventricular fibrillation with multicycle control and is reproduced in Figure 5. This figure shows that the threshold of ventricular fibrillation falls sharply for shock durations greater than about one heart period, provided that the factor 'p' is greater than 0.12.

Figure 5 shows that for 'p' = 0.12 the threshold of ventricular fibrillation is not affected by shock duration and therefore with the example waveform considered above
(i.e. 'p' = 0.02) the threshold of ventricular fibrillation would stay at the initial value of approximately 1.5 A and the electric shock resulting from such a waveform would not normally lead to ventricular fibrillation.

Note that the specific fibrillating energy (i.e. the shock current squared multiplied by time) for a single 0.6A, 1 ms pulse is 0.00036. Page 16 of AS/NZS 60479.2:2002 indicates that whilst such a specific energy would not lead to ventricular fibrillation, it would be painful.

It is also interesting to compare the actual energy during an electric shock, with the energy imparted by an electric fence energizer. AS/NZS 3350.2.76:1998, Particular requirements - Electric fence energizers, is the standard that covers electric fence energizer requirements. This standard specifies that for medium power energizes the energy per impulse in the 500-Ohm load must not exceed 5 joules. The energy per impulse with the example waveform considered above is

300 V x 0.6 A x 0.001 Sec. = 0.18 joules. This energy is more than an order of magnitude less than with medium power fence energizers. However, with electric fence energizers the pulse rate is limited to a maximum of one pulse/second. In the case under consideration the pulse rate would be approximately 20/second in which case the total energy/sec (i.e. power) would be 3.6 joules, which is still less than with medium power fence energizers.

GENERAL METHOD OF ANALYSIS

Because repetitive short duration pulses are not specifically covered in AS/NZS 60479.2:2002, any general method of analysis should, in my opinion, include three methods of calculation namely:

i. the equivalent multicycle control method,
ii. the specific fibrillating energy method, and
iii. the total energy/second (i.e. power) method.

The steps in the calculation would be as follows:

Equivalent multicycle control method

(i) Divide the pulse voltage magnitude in volts by 500 Ohms to give the shock current value in amps.

(ii) Divide the pulse 'on' time by the total 'on' plus 'off' time to give the power control factor 'p'.

(iii) For the power control factor 'p' calculated in (ii) above, use Figure 5 to ensure that the current calculated in (i) is less than the threshold of ventricular fibrillation. (Note: if p is less than 0.12, this check is simple in that the shock current simply needs to be compared with a fixed value of 1.5 amps).

Example Calculation

A pulsed DC waveform has 550 volts peak with each pulse having a maximum 'on' time of 0.2 msecs and a period of 100 msecs between pulses.

(i) The shock current is 550/500 = 1.1 amps.

(ii) The power control factor is 0.2/100 = 0.002.

The power control factor is less than 0.12, therefore from Figure 5 the threshold of ventricular fibrillation is 1.5 amps. The current of 1.1 amps is less than 1.5 amps and is therefore less than the threshold of ventricular fibrillation.

As a further example suppose the period between pulses is reduced to 1msec. The calculation now becomes as follows:

(iii) The shock current is 550/500 = 1.1 amps.

(iv) The power control factor is 0.2/1 = 0.2.

In this case the power control factor is greater than 0.12 and from Figure 5 the threshold of ventricular fibrillation is reduced to approximately 0.35 amps. The current of 1.1 amps is greater than 0.35 amps and is therefore above the threshold of ventricular fibrillation.

Specific fibrillating energy method

(i) Multiply the shock current in amps by itself and then by the duration of a single pulse in seconds.

(ii) Compare the answer obtained at (i) above with the following physiological effects specified at page 16 of AS/NZS 60479.2:2002.

a. $48x10^{-3}$ - ventricular fibrillation likely

b. $0.48x10^{-3}$ - painful

c. $4.8x10^{-6}$ - disagreeable

d. $0.048x10^{-6}$ - slight

Example Calculation

A pulsed DC waveform has 550 volts peak with each pulse having a maximum 'on' time of 0.2 msecs and a period of 100 msecs between pulses.

1. The specific fibrillating energy for a single pulse is 1.1 x 1.1 x 0.0002 = 0.00024 = $0.24x10^{-3}$.

(ii) The answer at (i) is about two orders of magnitude less than the threshold of ventricular fibrillation. The answer at (i) is of the same order as the threshold indicating a painful shock.

Now as a further example if the period between pulses is reduced to 1msec as in the previous equivalent multicycle control method example, the calculation remains unchanged. This is because with this method the calculation covers a single pulse only. However, in this latter case the danger would be additionally identified by the 'Energy per second method', which takes account of the number of pulses/second (see worked example below).

If as an additional example the time 'on' in the above example was increased to
40 msecs, the specific fibrillating energy for a single pulse becomes
1.1 x 1.1 x 0.04 = 0.048 = 48x10-3. This specific fibrillating energy indicates that ventricular fibrillation is likely. Furthermore, if the equivalent multicycle control method is used for this case the power control factor becomes 40/100 = 0.4. In this case the power control factor is greater than 0.12 and from Figure 5 the threshold of ventricular fibrillation is reduced to approximately 0.3 amps. The current of 1.1 amps is significantly greater than 0.3 amps and is therefore well above the threshold of ventricular fibrillation.

Note that this calculation using the equivalent multicycle control method implies multiple pulses. If the equivalent multicycle control method method were to be used for a single pulse in the previous example, the duration of the shock would be 40 msecs. The base of Figure 5 shows that for 0.1 of a heart period (i.e. approximately 80 msecs) the threshold of ventricular fibrillation is about 1.3 amps which is greater than 1.1 amps and indicates that ventricular fibrillation is not likely using the equivalent multicycle control method for a single pulse. This indicates some slight inconsistency between the methods and emphasises the need to use each method and the worse result should always be used (i.e. if ventricular fibrillation is indicated by any method, the waveform should be deemed to be dangerous).

Energy per second method

i) Multiply the magnitude of the pulse voltage in volts by the shock current in amps and then by the duration of a single pulse in seconds.
ii) Divide 1 second by the period of the pulses to find the number of pulses per second.

iii) Multiple the number calculated at (i) above by the number of pulses per second obtained at (ii) above to give the total energy per second.

iv) Compare the number calculated at (iii) above with 5 joules, which is the maximum energy per impulse for medium power electric fence energizers.

Example Calculation

A pulsed DC waveform has 550 volts peak with each pulse having a maximum 'on' time of 0.2 msecs and a period of 100 msecs between pulses.

(i) The energy per impulse is 550 x 1.1 x 0.0002 = 0.12 joules.

(ii) The number of pulses per second is 1/0.1 = 10.

(iii) The total energy per second is 0.12 x 10 = 1.2 joules.

(iv) 1.2 joules is significantly less than 5 joules which implies that the waveform is not as dangerous as a medium power electric fence energizer.

Now if the period between pulses is reduced to 1 msec, as in the previous equivalent multicycle control method example, the number of pulses per second increases to 1000 and the total energy per second becomes 0.12 x 1000 = 120 joules. This is significantly more than 5 joules, which implies that the waveform is more dangerous than a medium power electric fence energizer. This result is consistent with the equivalent multicycle control method calculation, which indicates that ventricular fibrillation is likely for this particular example.

EXAMPLE CALCULATION USING INDUSTRY STANDARd WAVEFORM

The industry standard waveform is a pulsed DC 80 volts peak, rectangular pulse of 7 msecs and a period of 65 msecs.

Equivalent multicycle control method

(i) The shock current is 80/500 = 0.16 amps.

(ii) The power control factor is 7/65 = 0.11.

The power control factor is less than 0.12 therefore from Figure 5 the threshold of ventricular fibrillation is 1.5 amps. The current of 0.16 amps is significantly less than 1.5 amps and is therefore less than the threshold of ventricular fibrillation.

Specific fibrillating energy method

(i) The specific fibrillating energy for a single pulse is 0.16 x 0.16 x 0.007 = 0.00018 = 0.18×10^{-3}.

(ii) 0.18×10^{-3} is more than two orders of magnitude less than the threshold of ventricular fibrillation. 0.18×10^{-3} is of the same order as the threshold indicating a painful shock.

Energy per second method

(i) The energy per impulse is 80 x 0.16 x 0.007 = 0.09 joules.

(ii) The number of pulses per second is 1/0.065 = 15.4.

(iii) The total energy per second is 0.09 x 15.4 = 1.4.

(iv) 1.4 joules is significantly less than 5 joules which implies that the waveform is not as dangerous as a medium power electric fence energizer.

CONCLUSIONS

Australian/New Zealand Standard AS/NZS 60479.2:2002 does not specifically cover rectangular voltage waveforms with an on/off duty cycle. However, in my opinion such a waveform is similar to multicycle control where the multicycle control produces a single positive or negative half cycle in each period.

Although similar to multicycle control a rectangular pulse has a conducting r.m.s. current equal to the peak current, whereas with multicycle control the r.m.s. current is the peak current divided by the square root of two.

A general method of analysis using a multicycle control approach has been presented to establish whether a particular waveform is likely to lead to ventricular fibrillation.

In addition to the general method of analysis using a multicycle control approach, it is recommended that the result is substantiated by using the specific fibrillating energy method, and the total energy/sec method. If any of the three methods give a result above the prescribed thresholds, the waveform should be deemed to be dangerous.

Associate Professor C Grantham

PhD, BSc, FIEE, CEng

School of Electrical Engineering and Telecommunications

The University of New South Wales

6.4 APPENDIX - BLACKBURN REPORT

Executive Summary

This report provides discussion and comment on the Occupational Health and Safety assessment of the potential electrocution hazard to personnel related to the use of a particular form of repetitive square wave voltage waveform proposed for use in process lines of the meat and livestock industry.

A previous report by A/Prof C Grantham (Unisearch J054616: *Interpretation of Australian/New Zealand Standard AS/NZS 60479.2:2002*) discussed possible methods of evaluation of the possible electrocution hazards of general non-sinusoidal voltage waveforms. That report proposed three different methods of hazard assessment of such non-sinusoidal waveforms in general and gave some examples of their application to various specific waveforms. The examples given did not include the particular waveform that is the subject of this report. The proposed methods are based on data and guidelines available in two Australian Standards. However they do not cover precisely the particular repetitive pulse waveform that is under consideration for use by Meat & Livestock Australia. When the three methods are applied to the waveform in question two of them conclude that the waveform will not be a hazard but the third raises some question as to the potential for fibrillation.

For this report, further published data has been obtained that provides some information that is more relevant to the type of repetitive waveform under consideration here. There is experimental/modelling data on the responsivity of tissue to repetitive current pulses that shows that the remnant effects of a pulse last for only about four times the width of the pulse. For the waveform in question the quiescent period is nine times the current pulse duration. Thus, the overall effect of the repetitive train of pulses would be effectively the same as that of an individual pulse.

On this basis the second of the methods proposed by Grantham would be appropriate. This method considers the energy content of one pulse as the fibrillation-determining factor. In this case the energy of one pulse delivered to a typical human body is 0.018 Joules in total. Based on the information in the Standard AS/NZS 60479.2 for capacitor discharges an energy of 0.02 joules will have an effect of only some discomfort and mild pain. There would be no possibility of fibrillation.

When compared with the total fibrillating energy level used by North American Standards such as ANSI/IEEE Std 80 - 1986, the total energy in the body required to initiate fibrillation is 10-15 joules for a 500 ohm body resistance. This is almost three orders of magnitude higher than the single pulse energy in question here. The fibrillating energy of 10-15 ohms is based on sinusoidal

current data, but it is quite consistent with pulse energy data such as that used for the safety compliance of electric fence energisers (Standard AS/NZS 3350.2.76).

Thus, the waveform that is proposed for use by Meat & Livestock Australia, namely a 100 microsecond 300 volt pulse repeated every thousand microseconds would not, on the basis of current known evidence, present any fibrillation hazard. It would cause some discomfort and possible pain if applied directly to the human body, but it would not cause fibrillation and would thus not represent an electrocution hazard.

1 Introduction

This report provides discussion and comment on the Occupational Health and Safety assessment of the potential electrocution hazard to personnel related to the use of a particular form of repetitive square wave voltage waveform proposed for use in process lines of the meat and livestock industry.

A previous report by A/Prof C Grantham (Unisearch J054616: *Interpretation of Australian/New Zealand Standard AS/NZS 60479.2:2002*) discussed possible methods of evaluation of the possible electrocution hazards of general non-sinusoidal voltage waveforms. That report proposed three different methods of hazard assessment of such non-sinusoidal waveforms in general and gave some examples of their application to various specific waveforms. The examples given did not include the particular waveform which is the subject of this report.

Two of the methods proposed in that report were based primarily on material in the Australian Standard AS/NZS 60479 (parts 1 and 2)-2002: *"Effects of current on human beings and livestock".* Part 1 covers "*General aspects"*, mainly related to sinusoidal current waveforms of 50/60 Hz AC power frequencies and to DC currents. Part 2 covers *"Special aspects",* related to high frequency sinusoidal current waveforms and to non-sinusoidal waveforms, including unidirectional single transient impulse current events. It is Part 2 of the Standard that was used as the basis for two pf the assessment methods proposed by the Grantham report.

The third method proposed was based on the safety requirements to prevent electrocution by the output currents of electric fence energisers. Such energisers produce an output which consists of repetitive single high current pulses. The safety requirements to prevent potential electrocution are contained in the Australian Standard AS/NZS 3350.2.76: "*Safety of household and similar electrical appliances: Particular requirements – Electric fence energisers"*.

When these three methods of risk assessment are applied to the particular waveform in question here, the two methods based on AS/NZS 60479.2 indicate the particular waveform to be non-hazardous but the third method of analysis, based on the electric fence safety requirements gives a result that indicates that there may be possible hazards associated with the waveform in question.

The hazard to be assessed is that of inadvertent contact by workers in the slaughterhouse with the electrical wires/electrodes that supply the specific voltage waveform to the animal carcass. The matter is thus an OHS matter to assess the possibility of electrocution should a worker be exposed to the particular voltage waveform for any prolonged period of time. In the following the discussion will assume a worst-case situation with the electrical resistance of the body being at a minimum level with maximum current passage in the body for the voltage applied. No ameliorating effects such as external current limiting resistance will be assumed.

This report provides discussion on the methods of assessment used in the Grantham report and their application in this case. It also uses other sources of reference material relating to work on electric shock hazards and effects to provide some wider range of background information on which to assess comprehensively the potential hazard.

The information provided and used in the discussion of this report is the Grantham report, the above-mentioned Australian Standards and an email, dated February 20, from Ian Richards, Manager Technology Development of Meat & Livestock Australia, giving details of the voltage waveform that is proposed for use. In addition to the above, a number of other monographs and Standards were used in the preparation of this report: they will be listed in the following discussions.

2 Discussion of the proposed analysis methods of the Grantham report

The general form of repetitive current pulses considered by the Grantham report were square wave (rectangular) pulses of constant amplitude and of constant ratio (p) of the "on" period of voltage to the "off" period of voltage of the waveform.

The first two methods used to analyse the hazard of such waveforms in the Grantham report were based on data contained in Australian Standard AS/NZS 60479: 2002. In particular, Part 2, which covers non-sinusoidal waveforms and in particular single short duration pulses, was used to assess the hazard in the case of such repetitive pulses as described above.

However the above Standard does not specifically cover repetitive square wave current pulses and so the electric fence energiser Standard AS/NZS 3350.2 76 which provides requirements to prevent electrocution due to electric fence energisers was also considered and its safety requirements were used as a criterion for the third method of hazard assessment.

Method 1

The first method proposed in the Grantham report considered the constant amplitude square wave pulses as an analogue of a multi-cycle burst of constant amplitude 50 Hz AC voltage. Such a multicycle burst of AC waveforms are covered by the AS60479.2 Standard and a method of electrocution hazard assessment is described and evaluated in detail in the Standard. While this is not a close analogy with a train of single short duration rectangular DC pulses, it is a reasonable method to try and is likely to give a conservative result in terms of hazard assessment.

The differences that occur between the waveform considered here and the multicycle burst is that the burst consists of a number of continuous cycles of bi-polar (that is bi-directional or symmetric) voltage amplitude oscillation about zero voltage, while in this case the square pulses are individual pulses of constant amplitude and are unidirectional (monopolar) with a significant period of zero voltage between pulses.

The human heart, in its response to electrical currents, is more sensitive to bipolar forms of voltage variation and to continuous cycles of excitation. For example, in the book by Reilly [1] on "*Electrical Stimulation and Electropathology"*, he states on page 125, in discussing sinusoidal stimuli,

"An oscillating stimulus has the ability to produce a train of APs [Action Potentials] *which can greatly enhance the intensity of electrical response in nerve, cardiac and skeletal muscle responses".*

Thus, use of this method as described in the Grantham report will provide a conservative evaluation of the potential for electrocution of a repetitive square wave of voltage/current.

Method 2

The second method used in the Grantham report is based on the electrocution energy criteria method of assessment. This method considers both the body current magnitude and the current flow duration in the body as the defining requirements. In particular the method calculates the specific energy [I^2t (joules per ohm of the body's electrical resistance)] deposited in the body by a single pulse of the repetitive impulses train and compares this to the energy levels that will cause known general responses in the human body, including fibrillation of the heart (the fibrillation I^2t).

This method of specific energy as the electrocution criterion is widely used by North American Safety Standards such as those of the American National Standards Institute (ANSI), the Institute of Electrical and Electronic Engineers (IEEE) and the Underwriters Laboratory (UL). There are thus well-defined criteria for such an approach. Although this information and criterion is only well-documented at power frequencies of 50/60 Hertz AC [e.g. see [2]], there is data available for single pulse effects and AS/NZS 60479.2 has some information relating to this in the case of single transient capacitor discharge currents [a table on page 16 and Figure 21 in the above Standard (also used on page 7 of the Grantham report)].

However this method, as developed in the Grantham report, does not relate specifically to the case in question as it considers only one single pulse and not the potential effects of the accumulation of the energy from a repetitive train of pulses.

It is well known that the potential for electrocution is enhanced considerably when the electrical impulses occur during the relaxation period of the heart after its excitation beat: this is the so-called T period of the overall heart-beat. [See Figures 12 and 13 on page 18 of AS/NZS 60479.1 (Part 1-general Aspects)]. This period occupies about 25% of the full heart-beat period of typically about 800 milliseconds, so it is the total energy deposited in about 200 milliseconds during one heart-beat that is important. At other times during the heart beat the heart is relatively resistant to electrical impulses. In terms of the waveform under consideration this period of 200 milliseconds would allow time for 200 square wave pulses of this particular waveform to operate on the heart during the T period. Thus it would appear that the energy of these 200 pulses must be considered rather than that of a single pulse.

As this method of hazard assessment uses only one pulse it may thus appear to underestimate the potential hazard. A full evaluation should then require some further consideration of the impact of higher frequency current waveforms on the heart. However, as will be seen later, it is the duration of the quiescent (non voltage) period of the repetitive pulse train that is important in this case.

Method 3

The third method does extend the above (Method 2) procedure to attempt to assess the effect of multiple repetitive pulses during a one second period. It does this by using the analogy of the total energy supplied in one second with the total required energy limitation per pulse of an electric fence energiser.

The Australian Standard AS/NZS 3350.2.76 refers to the safety requirements of the repetitive electrical discharges that are supplied to an electric fence from such energisers. In particular the Standard gives an upper limit of energy supplied per pulse. This limit is chosen so that it will not present an electrocution hazard when inadvertent contact is made by the human body with a live electric fence.

Although the electric fence energiser produces a repetitive train of individual pulses, the repetition rate of these single pulses is required to be no higher than about one pulse per second. This is done with the aim being to allow a person in inadvertent contact with the fence adequate time to release him/herself before the next pulse arrives. The effect of the energiser pulse magnitude is significant enough to induce a “no let-go” condition and thus the one second “off” period will allow time to release a grip on fence wire. Thus the energy limit requirement of 5 joules is designed only as the maximum energy in a single pulse, with the inter-pulse (no voltage) period being very much greater than the actual single pulse duration. The energy limit stated is thus not designed to refer to an acceptable total energy limit of a train of individual pulses such as the case of the waveform in question here.

There is some known potential decrease in the responsivity of the heart to repetitive pulses that have a period of less than the heart-beat period. This is associated with the fact that the heart is only responsive to electrical current pulses during the recovery or T-period of the heart-beat. Thus the hazard assessment given by this method is likely to be conservative or to overestimate the hazard as it does not take account of this decreased responsivity of the heart to repetitive pulses. In the simplest case of sinusoidal excitation there is very significant decrease in response at higher frequencies.

3 Details of the proposed waveform to be assessed and the associated electrical quantities in the body response

The voltage waveform to be assessed by this report is intended to be used to quieten any possible muscular reaction of the animal after being killed. The proposed waveform comprises a repetitive series of uni-directional (mono-polar) rectangular voltage pulses of 300 volts amplitude with a duration of 100 microseconds and with a repetition rate of one thousand pulses per second. There is thus a total period of one millisecond (or 1000 microseconds) between consecutive pulses and an interval of 0.9 milliseconds (or 900 microseconds) between the pulses when there is no voltage applied to the animal carcass. The total number of pulses will depend on the time of application of the voltage to the carcass.

The response of the human body to the application of such a pulse will be a repetitive train of current pulses through the body. Using the standard resistance of the body of 500 ohms as defined in the two Standards noted previously, the magnitude of the current pulses will be 300/500 = 0.6 amperes or 600 milliamperes. This ignores the capacitance of the skin of the body and also the skin resistance as the 500 ohms is essentially the constant internal resistance of the body. As such it will give a maximum value of the current level likely to be seen by the human body and the response to such a current level will thus be at a maximum. In all likelihood the actual current due to any inadvertent contact will be a lower level.

The energy associated with each single pulse will be the voltage x current x duration of the pulse (V.I.t). Thus

Energy per pulse = 300 x 0.6 x 100×10^{-6}
= 0.018 Joules/pulse

Note that this is the total energy deposited in the body by the pulse: it is not the specific energy (I^2t) in joules per ohm that is generally quoted in relation to the fibrillation energy safety criterion.

The total energy dissipated over one second by such a current in the body by the one thousand pulses in that second is then:

Energy total per second = 0.018 x 1000
= 18 Joules/second.

The total electrical charge transferred to the body by one single pulse is:

Charge = current x time = I.t = 0.6 x 100×10^{-6}
= 60 micro-coulombs

In one second the charge transferred = 60 x 10^{-6} x 1000
= 60 milli-coulombs

4 Assessment of the risk hazard

The assessment of the hazard of the voltage waveform using each of the methods of the Grantham report is detailed in the following section.

Use of the multicycle burst pulse method.

This method uses figure 18 of AS/NZS 60479: Part 2-Special aspects. This diagram is attached as Figure 1 in this report. A hazardous potential fibrillation situation occurs if the electrical current and its flow duration give an operating point which falls to the right of the appropriate curves shown in the figure.

For the waveform in this case, p (the ratio of the voltage "on" period (100 microseconds) to the total single cycle period (1000 microseconds)) is:

$$p = 100/1000 = 0.1$$

The RMS current during the "on" period is simply the current magnitude, so that

$$I_{RMS} = 0.6 \text{ amps}$$

From the figure the fibrillating current will about 1.4-1.5 amps even for 10 heartbeat periods or about 8 seconds (the limit of the curves). At 0.6 amps there is no fibrillation likely. While the fibrillation data given on the graph refers to experiments with pigs, they are similar to the human body in their response to electrical current.

Thus, the application of this assessment method indicates that there are no fibrillation problems with the proposed current waveform

Application of the single pulse energy criterion.

In this case the single pulse energy is the quantity that is relevant. As was calculated above the energy of a single 100 microsecond pulse is 0.018 joules.

In the Grantham report the fibrillating energy is taken from Figure 21 and the table on page 16 of the Standard AS/NZS 60479 Part 2. This figure, reproduced as Figure 2 in this report plots the effects of various energies associated with capacitor discharges into the human body and plots lines of equi-energy at 45^o to the vertical as 5 □J (micro-joules), 0.5 mJ (milli-joules) and 0.05 J (joules). Note that in this case the energies are total energies deposited in the body, not specific energies. The shaded area AA is the threshold of perception of an electric current and the curve BB is the threshold of pain.

The figure thus gives a "pain threshold" energy as being somewhat greater than about 0.02 joules for a voltage of 300 V. The diagram does not give a fibrillating energy for the body, but the specific fibrillating energy or I^2t value often used in American Standards such as [2] is about 0.02 - 0.03 Joules per ohm. Note that this value is the specific energy and must be multiplied by the body resistance (assumed 500 ohms in our case) to get total energy for fibrillation. Thus the fibrillation energy according to [2] will be (0.02 – 0.3) x 500 = 10 – 15 joules.

Thus, for the waveform under consideration here, which gives 0.018 joules per pulse, a single pulse will perhaps give a slight pain but no possibility of any fibrillation. If the charge of 60 microcoulombs and a voltage of 300 V is used, the operating point on the graph is shown by the triangle.

However the Figure 2 graph covers capacitor discharges and not constant current discharges and it is only for one pulse whereas we need to assess the situation for a repetitive pulse of frequency 1000 per second. This will be considered later.

Application of the total energy per second method

In this case the total energy per second delivered by the pulses is calculated and compared to the safety criterion of 5 joules per pulse taken from the electric fence energiser Standard AS/NZS 3350.2.76:1998.

The calculated total energy for the 1000 pulses per second in this waveform case is thus 0.018 x 1000 = 18 joules as calculated in section 3. This is greater than the 5 joule safety limit in that

Standard and so would appear to indicate some potential possibility of fibrillation. It must be noted that, as indicated earlier, the 5 joules of energy is above the "no let-go" threshold: however it is well below the fibrillation threshold of 10 – 15 joules noted above from the American Standards.

However in this case, as before, the above single pulse criterion is not specifically applicable to this repetitive pulse case and we must make further investigations. In particular the 5 joules is for one single pulse and in the case here there are 1000 pulses. Further, it is well known from the Part 2 of AS/NZS 60479 that the human heart is less responsive to higher frequencies than to 50/60 hertz and this must also be factored into the assessment.

4.4 Summary of proposed assessments

From the above we can see that although the first two methods say that the repetitive waveform is not a fibrillation problem, the third method does raise some questions about the safety of the waveform.

However it is also clear from the above that the three methods used from the Grantham report are based on interpretations and analysis that are not strictly relevant to the repetitive waveform case in question. This difference requires some further refinement of the safety assessment process.

The effects of repetitive current waveforms.

Although there is no detail in current electrical safety Standards relating to repetitive waveforms and their effect on the human body, there is some published information available on work that has been done relating to the effects of repetitive waveforms on various components of the body.

The key questions that arise in this consideration are:

- How long does the effect on the heart of a single pulse of current last? and
- What is the time delay, before the next pulse comes along, that will cause the responsivity of the heart to be lowered (or alternately, what time period between pulses is needed for the heart to recover)?

These questions are somewhat different to that of the effect of increased frequency of sinusoidal waveforms on the heart. In the increased frequency case excitation current is applied continuously and is bipolar in direction. This quite different to the case of repetitive pulses where the monopolar current pulse is then followed by a quiescent period when no current is applied to the body, thus allowing some recovery time of the heart tissue and muscles to occur before the next pulse arrives.

In the case of increased frequency there is some evidence that, in addition to the increased levels of current required to cause fibrillation onset, the impedance of the body decreases somewhat at higher frequencies thus counteracting, to an extent, the increased levels by causing an increased high frequency current. However as is shown in the effects of higher frequency in AS/NZS 60479.2, the result is a decreased fibrillation probability at higher frequencies of sinusoidal current.

[3] provides a method of calculation of a multiplying factor that should be used to determine the response to non-sinusoidal but continuous current waveforms. This calculation is derived from use of harmonic analysis of the body impedance equivalent circuit, including the capacitance of the skin. This method will give an apparent increased sensitivity at higher frequency. However it is not applicable to a repetitive waveform because of the ability of the body tissue to recover during the quiescent period of a repetitive current as opposed to a continuous current.

Reilly [4] in discussing experimental work and nerve models reports that for repetitive pulses the effect of the single pulse is effectively dissipated after a period of about four times the duration of the pulse. After such delays there is no accumulation of the effect of the pulse. However, if the next pulse occurs before about another 4 pulse periods duration, there is some residual effect and this can accumulate if the pulses repeat at such a frequency. However after about 4 times the pulse duration the integrated effect is zero and then the response to each pulse in the train is the same as that if there were only one single pulse. Thus, in this case there is no reduction of the fibrillation level.

In his book, Reilly gives examples of modelling, based on experimental data, of response to square current pulses of identical configuration to those in the proposed waveform. Figure 3 is taken from Reilly and shows the effects of such pulses with different "off" or quiescent periods after the pulse.

It can be seen that for a pulse of 100 microsecond duration and 500 microsecond "off" period the multiplier (relating to the effect of the single pulse) is just 1.0. This means that for a quiet period of

900 microseconds as in this case the residual memory of the pulse will be totally lost and the effect on the heart can be taken to be just that of one single pulse for repetitive waveform with a 1:10 ratio.

Note that when the ratio is 1:3, the multiplier is 0.86 indicating reduction of the response threshold. At a ratio of 1:0.5 the multiplier is 0.73 and when there is no interval the effect is a reduction to about 0.5.

Thus it can be concluded that the second method proposed by the Grantham report is most applicable and that on the basis of this method there is no fibrillation likelihood of the repetitive pulse waveform that is under consideration.

The above information also provides some explanation of the reasoning behind the required characteristics of electric fence type pulse waveform. In the fence energiser the duration of the individual pulse is required to be no more than 10 milliseconds and the repetition frequency is to be no more than one pulse per second. Thus the quiescent period in this case is 990 milliseconds giving a ratio of 1:100. Thus the response to the first pulse will have certainly dissipated long before the next one arrives. This is certainly the case with the “no let-go” effect. The quiescent period is designed to allow recovery and removal of hands before the next pulse.

Thus, in conclusion there should be no possible fibrillation problem with the repetitive waveform proposed in this case.

Summary and Conclusions

From a consideration of the proposed methods of fibrillation hazard assessment as outlined in the report by Prof Grantham, it appears that those methods are essentially based on data and guidelines available in two Australian Standards (which are in fact identical to International IEC Standards). However the methods do not cover precisely the particular repetitive current pulse waveform that is under consideration for use by Meat & Livestock Australia. When the three methods are applied to the waveform in question two of them conclude that the waveform will not be a hazard but the third raises some question as to the potential for fibrillation.

For this report, further published data has been obtained that provides some information that is more relevant to the type of repetitive waveform under consideration here. In particular there is some documentation of experimental/modelling results on the responsivity of nerves to repetitive current pulses that shows that the remnant effects of a single pulse last for only about four times the width of the pulse if there is no excitation in that after-pulse period. For the waveform in question the quiescent period between consecutive pulses is nine times the current pulse duration. Thus, the overall effect of the repetitive train of pulses is the effectively the same as that of an individual pulse.

As such, the second of the methods proposed by Grantham would be appropriate. This method considers the energy content of one pulse as the fibrillation-determining factor. In this case the energy of one pulse delivered to a typical human body is 0.018 Joules in total. Based on the information in AS/NZS 60479.2 for capacitor discharges (not an exact analogy but a reasonably close one) an energy of 0.02 joules will have an effect of only some discomfort and mild pain. There would be no possibility of fibrillation.

When compared with the total fibrillating energy level used by North American Standards such as ANSI/IEEE Std 80 [2], the total energy in the body required to initiate fibrillation is 10-15 joules for a 500 ohm body resistance. This is almost three orders of magnitude higher than the single pulse energy in question. The fibrillating energy of 10-15 ohms is based on sinusoidal current data, but it is quite consistent with pulse energy data such as that used for the safety compliance of electric fence energisers.

Thus, in conclusion, the waveform that is proposed for use by Meat & Livestock, namely a 100 microsecond 300 volt pulse repeated every thousand microseconds would not, on the basis of current known evidence, present any fibrillation hazard. It would cause some discomfort if applied directly to the human body, but it would not cause fibrillation.

References

1 J Patrick Reilly
Electrical Stimulation and Electropathology
Cambridge University Press. 1992.

2 American National Standards Institute and the Institute of Electrical and Electronic Engineers (ANSI/IEEE)
IEEE Guide for Safety in AC Substation Grounding
ANSI/IEEE Std 80 – 1986.

3 R C Menendez
An "Equivalent Voltage" for Sinusoidal and Non-sinusoidal voltage waveform
In Bridges, Ford, Sherman and Vainberg (ed.)
Electrical Shock Safety Criteria. pp 203-213. Pergamon Press 1985.

4 J Patrick Reilly
op. cit. pp128-131.

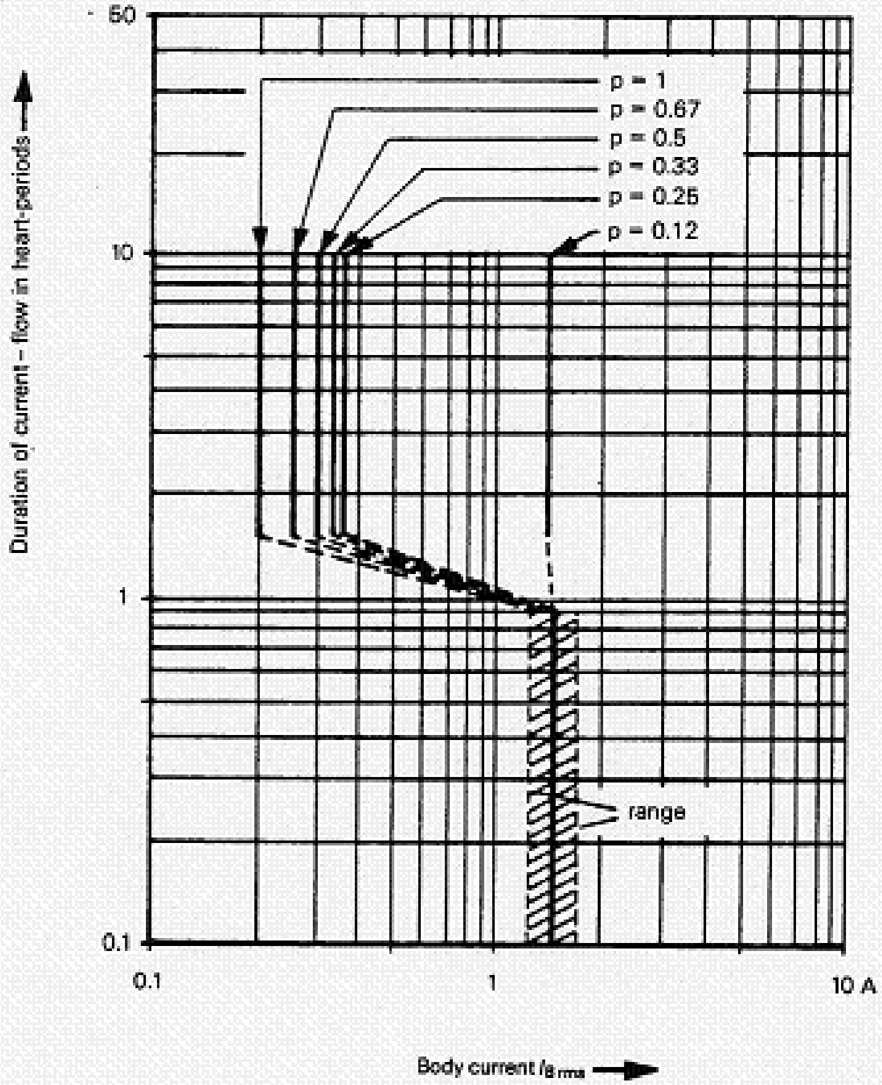


Figure 18 – Threshold of ventricular fibrillation (average values) for alternating current with multicycle control for various degrees of power control (results of experiments with young pigs)

NOTE – Body current I_{Brms} is the r.m.s. value of the current during current conduction $I_{t\,rms}$.

Figure 1

Fibrillation threshold of multicycle AC bursts of current

(from AS/NZS 60479.2-2002)

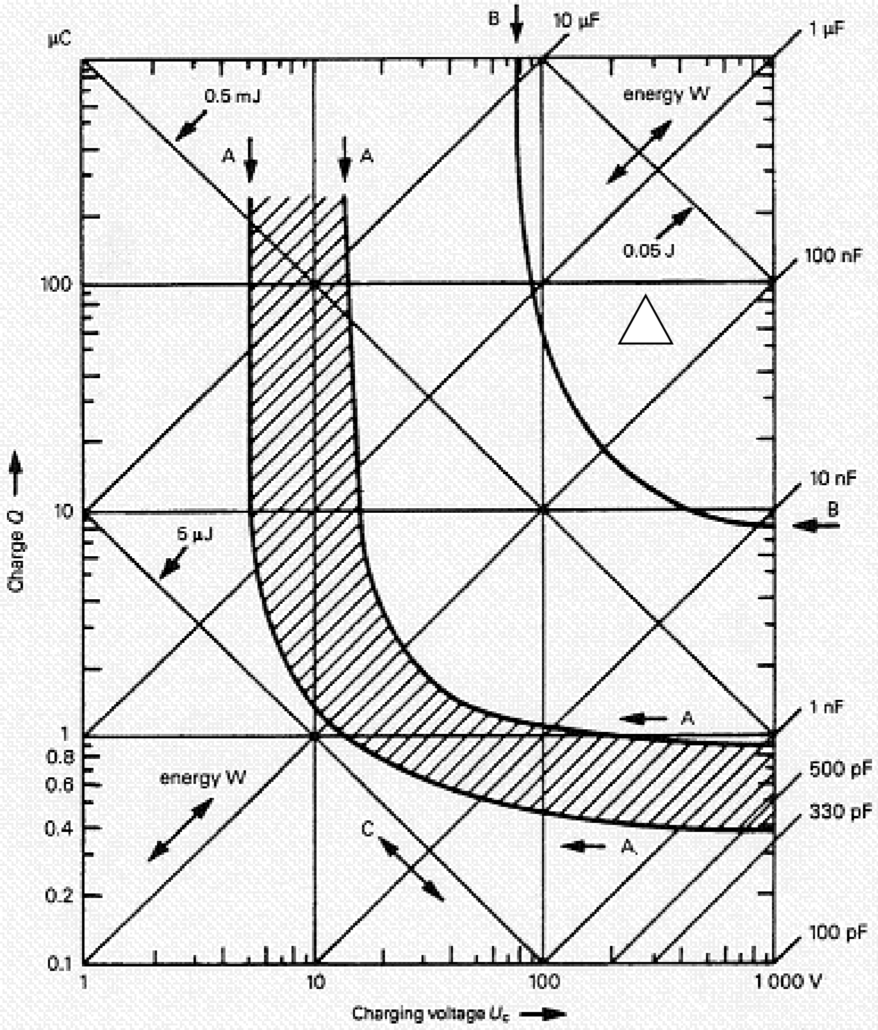


Figure 21 – Threshold of perception and threshold of pain for capacitor discharges (dry hands, large contact areas)

Zone A: Threshold of perception. Curve B: Typical threshold of pain

NOTE – The diagonal axes are scaled for capacitance (C) and energy (W). From the intersection of the co-ordinates for charging voltage and capacitance the charge and the energy of the impulse can be read on the appropriate axes.

Figure 2

Threshold energy levels (not fibrillation) for capacitor discharges

(from AS/NZS 60479.2-2002)

The approximate point corresponding to a single pulse of the proposed waveform is shown as △

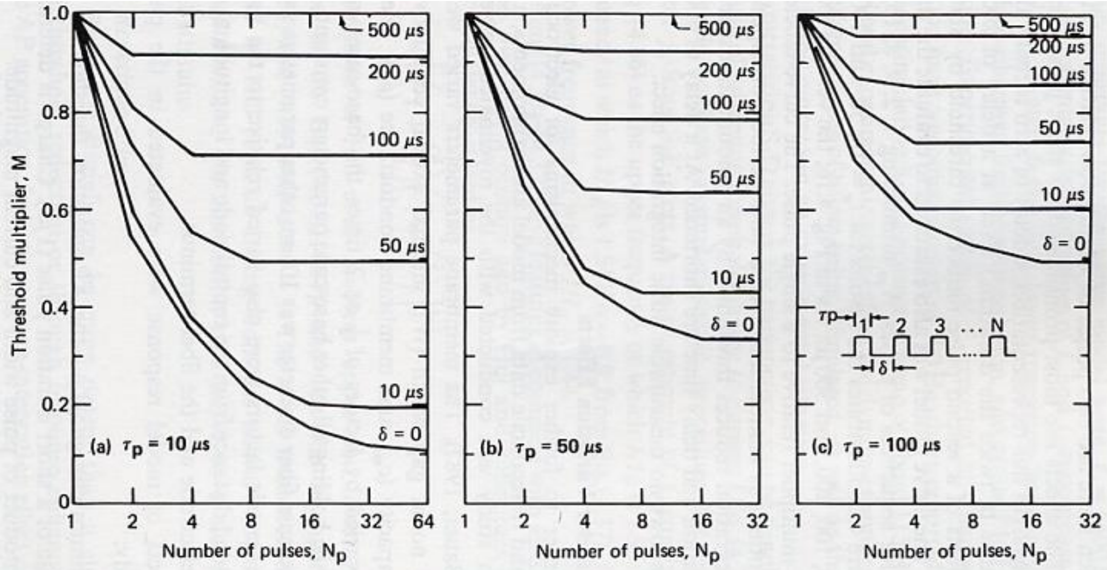


Figure 4.21 Threshold multiplier for repetitive pulse sequences—thresholds evaluated at $N_p = 1, 2, 4, 8, 16,$ 32, and 64. Uniform field excitation. (From Reilly, 1988.)

Figure 3

Threshold multipliers (of single pulse threshold) for repetitive rectangular pulses

(The right hand graph covers 100 microsecond pules with varying quiescent periods)

(from Reilly [4])

APPENDIX C8 - COMMISSIONING NOTES

Commissioning Settings

Program Number	**1**	**2**	**3**	**4**	**5**	**6**
Current (mA)						
Period (ms)						
Width (microsec)						
Ramp (ms)						
Timeout						

Notes: