

# Meat technology update

2/09 – April 2009

## Update on electrical stunning

The aim of electrical stunning is to induce epilepsy in the brain that will render the animal unconscious until sticking causes it to die through exsanguination. The basic principle is that an electric current is passed through the brain, disrupting the normal brain function. There are two basic methods of delivery—head only, and head-to-back. Stunning currents are supplied either as alternating currents (AC) or pulsed direct current (DC). The usual frequency is 50 Hz AC, which is the mains frequency. More recently, researchers have developed high-frequency stunning systems which aim to reduce meat-quality problems associated with electrical stunning.

This Update discusses the principles of electrical stunning along with factors that influence its effectiveness. It also discusses recent developments that improve the reliability of electrical stunning for sheep and lambs, and may make it more suitable for the eventual use on cattle.

### Head-only electrical stun

The head-only electrical stun involves passing a current across the brain from one side of the head to the other. It is a reversible stun and therefore accepted by the Halal market. An effective and fast bleed is required to kill the animal. As with all stunning methods, when it is used well, meat quality and animal welfare are optimised; however, some problems may be encountered. These may include the following.

- If insufficient current flows, the brain patterns will not be pushed into epilepsy, and the animal could maintain consciousness when it is being bled. The suggested minimum current required for all mature ruminants is 1.5 amps, and this should be delivered for 2 seconds. Slightly lower figures are suggested for young lambs to minimise the incidence of ecchymosis—0.9 amps for 1.5 seconds.
- If the current passes through the spinal cord, but not the frontal part of the brain, the animal could be paralysed, but still be conscious.
- If stray currents pass into the body, they can cause ecchymosis (blood splash) in the meat (figure 1). They could also stop the heart by inducing fibrillation. If the animal is still conscious, fibrillation is a very painful heart attack!

Note that it can be difficult to ascertain whether the animal is conscious or not—it may just be immobilised. In the



Figure 1: Blood splash (ecchymosis) in beef muscle associated with electrical stun. Note the dark discolouration where blood capillaries have burst.

laboratory, EEG techniques are used to show a lack of brain responses to external stimuli such as: bright flashes of light, noise or pin-pricks. Under commercial conditions, the most reliable practical predictor of an animal regaining brain response to these stimuli is a return to rhythmic breathing, but it is impossible to tell exactly how long it then takes for the animal to be actually aware of the stimulus. So, when monitoring a stun, lack of rhythmic breathing can be considered to mean that the stun is effective, but the presence of rhythmic breathing should be a cause for investigation. With electrical stunning, if the animal is showing epilepsy, it is unconscious.

### Stray currents

When a voltage is applied, the initial path of the current is a straight line between the electrodes. With time, a current field builds up that spreads out around that straight line into the body of the animal (figure 2). This current field can stimulate the skeletal muscles directly, and the resultant contractions are the main source of carcass damage, such as broken bones and haemorrhages (blood splash or ecchymosis) in the meat. These 'stray currents' can also stop the heart, meaning that the carcass would not be suitable for the Halal market.

### Head-to-body electrical stun

In head-to-body electrical stunning, the current initially passes through the brain to produce epilepsy, and this is quickly followed by cardiac fibrillation induced by the expanding electrical field (figure 3). Because the heart is stopped, this is a non-reversible stun and is not acceptable to the Halal market. The advantage of head-to-back stunning in commercial meat processing is that the current passed along the spinal cord suppresses the visible convulsions of epilepsy. Because there is immobilisation and cardiac arrest, it is vital that the current passes through the brain so that epilepsy is induced first, and the animal is rendered unconscious.

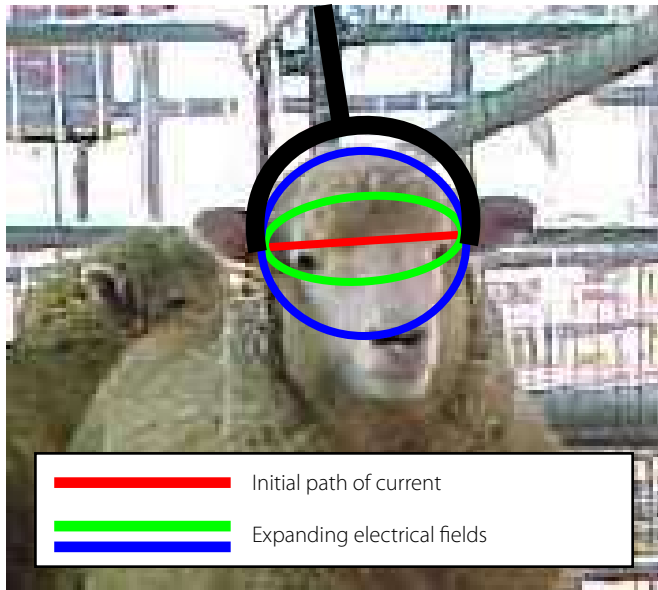


Figure 2: At first the electric current passes in a straight line between the electrodes (red line), but as the stun progresses, an electric field widens to encompass the entire brain (green and blue lines).

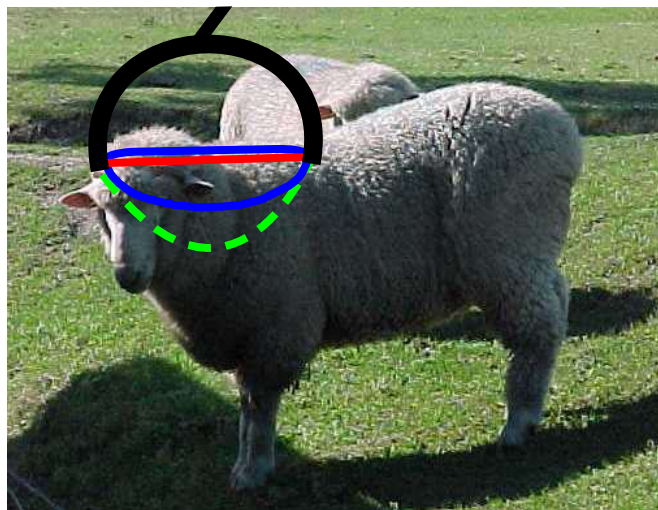


Figure 3: Head-to-back stunning: initially the current flows in a direct line between the electrodes, which should be placed to span the brain. The electric field builds up to stop the heart.

## High frequency stunning

Stunning currents are supplied either as alternating currents (AC) or pulsed direct current (DC). The waveform can be sinusoidal or square wave, and the frequency can be varied. High frequency denotes frequencies over 300 Hz when used to stun animals, and low frequency less than that. The most common stunning frequency is 50 Hz AC, which is the mains frequency. It is classified as low frequency. One of the major problems of stunning an animal with an alternating sinusoidal current at 50 Hz is the production of carcass and meat-quality problems which may occur as a direct result of muscle stimulation.

Tissue type	Maximum response frequency
Central nervous system	>10,000 Hz
Skeletal muscle	1000—1500 Hz
Cardiac muscle	500 Hz

The main reason for using high frequencies is to prevent carcass damage. So, increasing the frequency of the waveform to a level that will still produce a stunned animal, but will not produce the same level of direct muscle stimulation, has commercial advantages. The table (below left) gives approximate maximum stimulation frequencies at which selected tissues respond. A frequency above 1500 Hz will not produce the same degree of muscle stimulation as a similar current at 50 Hz.

Increasing the frequency of a waveform decreases the duration of each individual pulse. As the pulse duration decreases, the voltage required to boost the resting cell-membrane potential—sufficient to cause the neurons to discharge—increases. The same principle applies to muscle cells, although they are naturally more resistant to stimulation than neurons, and have a higher threshold for discharge. This means that changing the pulse duration in stunning can have a significant effect on the likelihood of direct muscle stimulation. Increasing the frequency of the waveform also shortens the wavelength—i.e. pulses occur more frequently—so the neurons are discharged more often in a specific time period. This means some cells will reach their 'exhaustion point', at which time they can no longer keep up with the demands of the external stimulus. Cardiac muscle and skeletal muscle reach this point well before neurons, so it is possible to bring on epilepsy without fibrillation or muscular contractions when using higher frequencies.

Because manipulation of the frequency of the waveform that is applied affects both pulse duration and wavelength, an appropriate voltage and frequency combination can be chosen to produce an effective stun with less direct muscle stimulation, and therefore much reduce the incidence of fractures and blood splash. Using 50 Hz, the muscles go into full contraction and pull against one another, which results in carcass damage. At frequencies above 1000 Hz, the peak force produced by the muscles is much less, which reduces the amount of damage caused. At 1500 Hz, the peak force is about half that produced at 50 Hz, while at 10,000 Hz, the muscle contraction is barely noticeable. Ecchymosis cannot be totally prevented at this stage, only minimised, because there is also the effect of increased blood pressure as a result of the stun which may burst small blood vessels.

Also, selecting the appropriate frequency and voltage can ensure that the heart is not stopped by stray currents, meaning that the stun is reversible and thus fully compliant with the requirements of the Halal market.

Note that it is the current passed through the brain that is important for the production of insensibility, not the voltage per se. The voltage must be sufficient to overcome the resistance of the skin, skull and brain to deliver the required current, and this resistance depends on the species and age of animal concerned. A higher voltage will overcome a greater resistance, but inspire greater safety concerns in the workplace. If the voltage is too low for a particular animal, insufficient current will flow and a good stun will not be achieved. Electrical stunning equipment should operate at voltages of 240V or more to achieve an effective stun.

## Interrupted stuns

Another possible problem with electrical stunning is that the current flow is interrupted—usually because the electrodes lose contact with the animal. In a good stun, where the current is applied evenly (figure 4), the brain waves very quickly go into stable, high amplitude epilepsy. The EEG trace should almost immediately change from low amplitude to high amplitude. When the current is interrupted, or there is poor contact between the electrodes and the animal, the current flow changes more

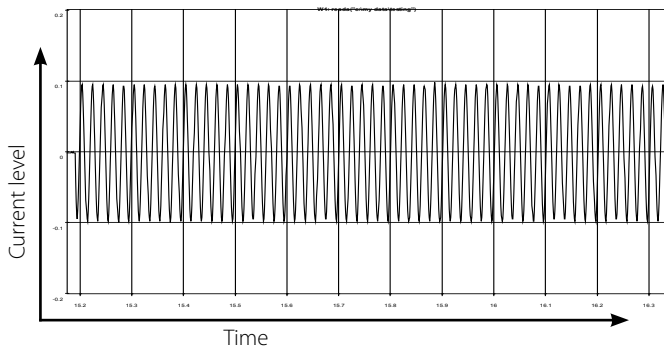


Figure 4: Current delivery in a good stun—a sudden onset of stable amplitude

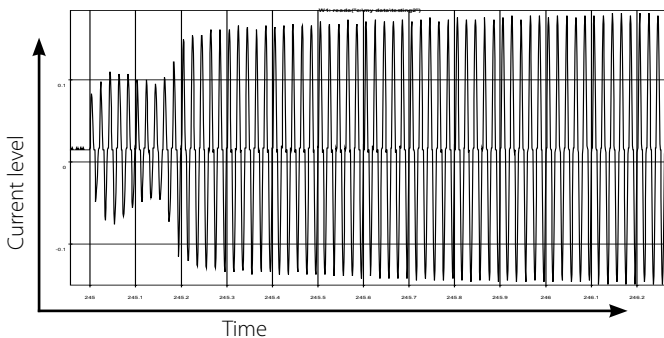


Figure 5: Current delivery in a poor stun—slow increase to stable amplitude

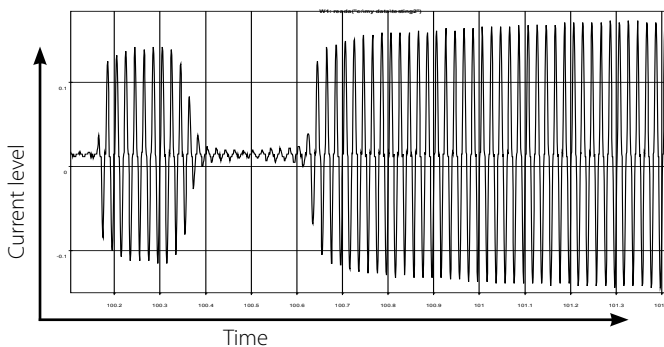


Figure 6: Current delivery in a poor stun—a marked interruption in current flow

slowly (figure 5), and there may even be a distinct interruption in the current flow (figure 6). In both these cases it is possible that the animal retains some degree of consciousness at the onset of the stun, and could be experiencing significant pain.

### Mechanical versus electrical stunning

Mechanical stunning is by far the quickest, causing insensibility in 1.5 ms, while electrical stunning will require 15 ms at 50 Hz to effect a stun. In welfare terms; however, **it is important to bear in mind that it would take ten times that long—150 ms**—for the brain to register that the tongs were in position, based on the speed of conduction of impulses within the nervous tissue. Electrical stunning also causes no visible damage to the brain, whereas mechanical stunning (both penetrative and non-penetrative) causes extensive bruising, which is unacceptable if brains are to be marketed for human consumption. Furthermore, in countries where BSE is a problem, the damage caused by mechanical stunning (particularly penetrative) can lead to scraps of brain tissue being released into the blood stream and transferred to the meat and offals while the heart is still beating.



Figure 7: Prototype stunning tongs

A new design of head-only stunning tongs for sheep and bobby calves (figure 7) has been developed recently. They have an automated pneumatic ‘hold and release’ mechanism. Once applied, they remain in full contact with the head until the stun is complete, without the risk of slippage. Research trials have shown that they consistently deliver a good stun as shown in figure 4, and commercial trials are under way. Also, personnel involved in the trials comment that they experience a marked reduction in fatigue of the arm used to apply the tongs.

### How electrical stunning works—the neuroscience

Many body tissues, particularly nerves and muscles, use electrical signals to communicate. The cells maintain a voltage of around -70 mV across the cell membrane when at rest, by actively pumping charged ions across the membrane. To transmit the signal along nerves and between muscle cells, the electrical impulse causes a sudden discharge of this resting voltage, by opening channels in the membrane and thus allowing the ions to equilibrate across the membrane. As soon as the impulse has passed, the channels close and the pumping mechanism brings the membrane back to its resting potential. This entire process of depolarisation and repolarisation is called an **action potential** (figure 8). Not every electrical impulse will cause an action potential; there is a threshold level that has to be exceeded for the action potential to occur. So, if the voltage delivered to the cell is too low, nothing happens.

When a voltage is applied from externally, such as through an electric stunner, an electric field forms which forces the channels to open. This disturbs the functioning of the cells, forcing them to discharge action potentials in a pattern that is determined by the voltage and waveform applied. If the voltage applied is too small, the threshold needed to stimulate the action potential is not reached, and neurones will fail to discharge.

There is an ‘exhaustion point’, at which the neurons can no longer keep up with the demands of the external stimulus. When a neuron discharges, it produces an **action potential**. The action potential has three phases (figure 8). First, from the resting phase, the membrane is depolarising—the absolute refractory period (the ion channels are open and the membrane potential is changing to zero). During this phase, applying another pulse can do nothing at all—the channels are already open. After this there is the relative

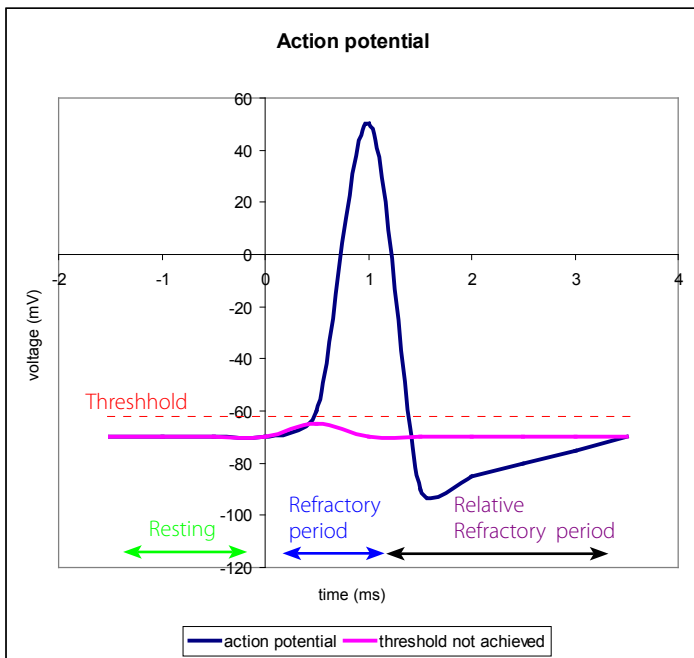


Figure 8: Action potential

refractory period (the ion channels have closed), and the ions are pumped back to return the membrane to its resting potential. During this phase, a second action potential *could* be triggered, but it needs a higher voltage, because the membrane is still above its resting potential and the threshold is higher. Finally, the membrane returns to its normal resting potential and its normal sensitivity. The same principles apply to muscle cells. Different sizes and types of cells have action potentials of different durations. For example, action potentials in the motor neurons (that signal movement) last 0.4–0.5 ms; those in small neurons last up to 2 ms; those in skeletal muscle last around 10 ms; and those in cardiac muscle last about 200 ms. So, if a waveform of 50 Hz (one pulse every 20 ms) is applied, each pulse will result in an action potential in motor neurons, small neurons and skeletal muscle, but in cardiac muscle, nine out of ten pulses will occur in the absolute or relative refractory periods, and be less likely to result in an action potential. If the frequency is increased to 1,000 Hz (one pulse every ms), each pulse will stimulate an action potential in motor neurons, every other pulse will do so in small neurons, and the muscle cells will rarely be stimulated to contract.

The majority of electrical stunners deliver a sinusoidal waveform at a frequency of 50 Hz (50 cycles per second). Each full waveform alternates positively and negatively around 0 volts, and is therefore known as alternating current (AC). Each waveform takes 20 ms to complete. This frequency and waveform is simple to generate from mains supply. It will produce an effective stun by stimulating the brain and will maximise the stimulatory response of both skeletal muscle and cardiac muscle, producing muscle contraction and, with sufficient current, cardiac arrest.

This applied current forces the neurons to discharge every 20 ms, making it impossible for the brain to carry out the more complex patterns required for consciousness. When the neurons discharge, they rapidly release excitatory neurotransmitters (aspartame and glutamate), which are responsible for maintaining excitation after the stunning voltage is removed (figure 9). This excitation is no longer fixed to the frequency of the stunning voltage, and epilepsy results. It is vital that the stunning voltage is applied for long enough to release sufficient excitatory neurotransmitters to induce epilepsy (and therefore insensibility).

The cells also simultaneously release an inhibitory neurotransmitter (GABA—gamma amino butyric acid), whose job it is to shut down the epileptic activity. Aspartame and glutamate are quickly mopped up by the cells, but GABA persists for a period of time and contributes to a prolonged analgesic (pain-reducing) phase after the electrical stun, that can last for 5–15 minutes. GABA can also be released as a result of stress prior to slaughter, and high levels inhibit the excitation of aspartame and glutamate. This is why stressed animals do not respond so well to electrical stunning, and ineffective stuns are seen.

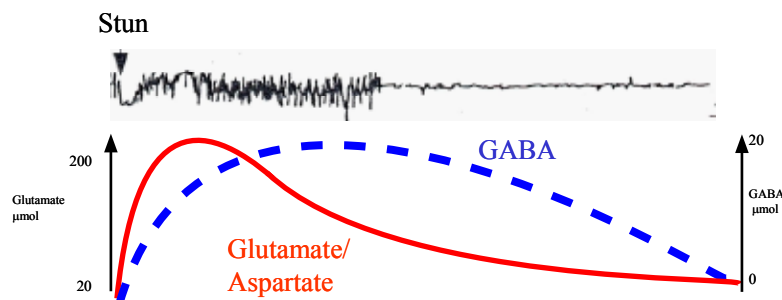


Figure 9: Release of neurotransmitters during stun (adapted from Cook et al., 1995)

The information contained herein is an outline only and should not be relied upon in place of professional advice on any specific matter.

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