The Smart Position on Stray Voltage

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Summary

- The causes and cures for stray voltage are well understood.
- The effects of electrical exposure on farm animals are also well understood and have been studied in great detail for over 50 years.
- Voltages can be developed by both electric utility wiring and farm wiring systems and both must be assessed to properly deal with stray voltage issues.
- Investigative techniques are well developed and the vast majority of stray voltage problems will be solved by applying accepted codes and practices on farm wiring and electrical distribution systems.
- While voltage is the main field measurement at animal contact locations, the current passing through an animal is the cause of response.
- Fifty years of research has resulted in the practical recommendation that dairy herds show no adverse response when cow contact voltage levels are below 2 volts (50 Hz rms) in low resistance environments or 4 volts (50 Hz rms) in typical farm environments. These voltage exposure levels are equivalent to 4 milliamps of current passing through a cow. After series of experiments in 1962, Doug Phillips from New Zealand concluded that 3 volts would be a likely minimum level for response. How smart is that?
- There have been a steady stream of unorthodox approaches to stray voltage measurement and mitigation that are not based on sound scientific principles. These approaches have produced a great deal of mistrust in the agricultural community and have not stood the test of time as effective means to address stray voltage concerns.
- The soundness and repeatability of scientific research and the success of its practical application has been validated over the past 25 years on over 9000 stray voltage investigations on farms in Wisconsin.

Introduction

The term stray voltage describes a special case of voltage developed on the multi-earthed-neutral (MEN) system of a farm. If this voltage reaches sufficient levels, animals coming into contact with earthed devices may receive a mild electric shock that can cause a behavioural response. The term stray voltage is often applied incorrectly to other electrical phenomena such as electric fields, magnetic fields, and electric current flowing in the earth or on earthling systems.

The magnitude of stray voltage developed from on-farm sources is a combination of voltage drops from many neutral wires. Each neutral voltage source is determined by the current flowing on a neutral wire and the resistance of that neutral wire and all of its connections. The resulting animal contact voltage is determined by the complex interconnection of neutral wires on a farm and the degree and location of earthing on the farm.

The magnitude of stray voltage developed from off-farm sources is the result of the level current flowing on the electrical distribution MEN system, the resistance of that neutral system and the degree and location of earthing on that system.

Earthing is provided to keep the voltage potential between the MEN system and the earth below levels that could be harmful to people or animals as well as to provide a path for fault current to activate safety devices in the event of an inadvertent contact between a phase (high voltage) wire and a neutral wire. Earthing also improves safety and reliability in the event of lightning strikes.

Neutral-to-earth or stray voltage can be reduced in three fundamental ways:

- Reduce the current flow on the MEN system,
- Reduce the resistance of the MEN system, or
- Improve the earthing of the MEN system

The first step in a competent stray voltage investigation is to determine the major sources of neutral-earth voltage. Any major faults or code violations in the wiring system that could pose an electrocution hazard or are a major source of neutral to earth voltage should be corrected immediately. If the wiring systems (farm and utility) are operating correctly then the above three actions can be assessed to determine which is most practical, safe and efficient way to reduce neutral-earth voltage. Equipotential planes are effective in eliminating contact potentials even if substantial levels of neutral-to-earth voltage are present.

Nerve Stimulation and Animal Responses

The widely accepted understanding of the way that stray voltage affects animals is through nerve stimulation. The bio-mechanics of nerve stimulation with electrical exposure has been widely studied and is well understood. The 1998 Reilly text cited in the references is a definitive reference on the biomechanics of nerve stimulation and resulting pathologies. Both sensation and muscle reactions can be elicited with electric currents conducted through the skin. These effects occur when nerves (or neurons) are excited – sensory neurons in the case of sensation, or motor neurons in the case of muscle reactions. Sensory effects are usually elicited with lower stimuli than are motor effects.

Nerve stimulation is characterised by a current threshold. Current applied below the threshold will not produce nerve excitation, and hence no sensation, motor response or behavioural response can occur. At the current level just above the threshold of nerve excitation sensation will result, which may be perceived but is not painful. As the current level is increased above the threshold involuntary muscle contraction begins to occur. This lower margin of muscle contraction is not painful. Pain can be experienced as current exposures are increased further due to both increased sensory stimulation and more intense muscle contraction.

Studies have shown that each animals exhibit behavioural responses at animal specific threshold current exposures for a particular contact pathway. Levels of current exposure just above the threshold will result in mild behavioural reactions, such as the blink of an eye, which tend to become less pronounced over time as animals become accustomed to the sensation. As current exposure is increased above this threshold, behavioural responses become more pronounced and more persistent, indicative of annoyance, pain or involuntary muscle contraction (twitches).

Basic concepts of Voltage, current, and Resistance

Ohms Law describes the relationship between voltage exposure and current conducted through the animal. A common form of Ohm's Law is:

$$Current\ (Amps) = \frac{Voltage\ (Volts)}{Resistance\ (Ohms)}$$

Ohms law indicates that if the voltage (across animal contact points) is increased, the current flowing through the animal will increase. Likewise, if the resistance (of contact points) is increased, the current flowing through the animal will decrease. The current measure used in many stray voltage studies is milliamps or 1/1000th of an amp. The measurement circuit used for field investigations uses a 500 Ohm Resistor to simulate the combined resistance of a cow's body + conservative estimates of the resistance of the two contact points. Using these values a cow contact current of 2 milliamps would result from a cow contact voltage of 1 V and a cow+ contact resistance of 500 Ohms.

$$Current\ \left(\frac{1}{500}\ Amps = \frac{2}{1000} Amps = 2\ Milliamps\right) = \frac{1\ Volt}{500\ Ohms}$$

It is important to use a realistic value of animal resistance (or impedance) to relate voltage exposures to the level of current conducted through an animal and the resulting effects on nerve stimulation, sensation and behavioural reaction. The body resistance of cows has been measured in several studies. Measures of an animal's body resistance depends on the pathway between the 2 contact points (e.g. muzzle-hoof or hoof-hoof) and the way in which the contact is made including factors such as the area over which the contact is made, pressure applied to the contact, and use of conductive liquids or gels on the measurement connection.

Some studies have tried to isolate the body resistance of animals using contact conditions not encountered in normal farm operations. Contact resistances are the most difficult value to predict in real-world farm situations. Fewer studies have been done to characterize real-world contact resistances. It is clear, however from these studies as well as physical principles, that real-world contact resistances have enormous variability. The lowest contact resistances would be expected if a clean, wet body part (such as a cow's muzzle) comes into contact with a clean, wet, metallic object with a substantial mutual contact area and substantial contact pressure. Contact resistances will increase with:

- Smaller contact surface area (e.g. a point contact the size of a pencil eraser compared to a metal plate applied over a surface the size of your hand)
- Reduced contact surface pressure (e.g. a light touch versus a contact applied with the weight of an animal)
- Drier contact surfaces
- Amount of debris on either the animal contact point (e.g. bedding/manure impacted in hooves or feed at the muzzle)
- Resistance value of the debris at the contact margin (e.g. dry straw compared with wet manure)

The accepted practice by researchers and regulators has been to assume worst-case (lowest practical values) for contact resistances. Studies done to measure more typical body + contact resistances that would occur on farms have shown that 500 Ohms is a reasonable value to use in a measurement circuit to estimate the current that would flow through a cow's body. Although the resistance of the cows body is typically less than 500 Ohms for the muzzle to hoof pathway (other pathways have a higher resistance), it has been shown to be a 'worst case' or minimum resistance value for the combination of a dairy cows body + real-world contact resistance in the farm environment.

Effects of Voltage/Current Exposure

The direct effect of animal contact with electrical voltage can range from:

- Mild behavioural reactions indicative of sensation occur at exposure levels that are just perceptible to the animal. Behaviours indicative of perception (e.g., flinches) may result with little change in normal routines.
- Involuntary muscle contraction – or twitching, that occurs at exposure levels somewhat above the exposure threshold for perception.
- Intense behavioural responses indicative of pain at levels considerably above the exposure threshold for perception.

The indirect effects of these behaviours can vary considerably depending on the specifics of the contact location, level of current flow, body pathway, frequency of occurrence, and many other factors related to the daily activities of animals. There are several common situations of concern in animal environments:

- Animals avoiding certain exposure locations which may result in,
  - Reduced water intake that may result if painful exposure is required for animals to access watering devices,
  - Reduced feed intake that may result if painful exposure is required for animals to accesses feeding devices or locations,
- Difficulty of moving or handling animals in areas of annoying voltage/current exposure,
- The release of stress hormones produced by contact with painful stimuli.

The majority of stray voltage research has been done on dairy cows. The accepted practice by researchers and regulators has been to assume worst-case (lowest practical values) for cow contact resistances. Studies done to measure typical body + contact resistances that would occur on farms have shown that 500 Ohms to 1000 Ohms is a reasonable range to use in a measurement circuit to estimate the current that would flow through a cow's body.

The most sensitive dairy cows (<1%) begin to experience mild behavioural modifications at current exposures exceeding 2 milli-Amps (50 or 60 Hz AC rms) corresponding to 1 V to 2 V (50 or 60 Hz, AC rms) of cow contact exposure in farm exposure situations. Animal sensitivity is the same for 50 Hz currents as for 60 Hz currents. As the voltage and current increase, a larger percentage of cows react with behavioural responses that become more pronounced. The results of threshold responses in dairy cows from numerous research studies are summarized in Figure 1.

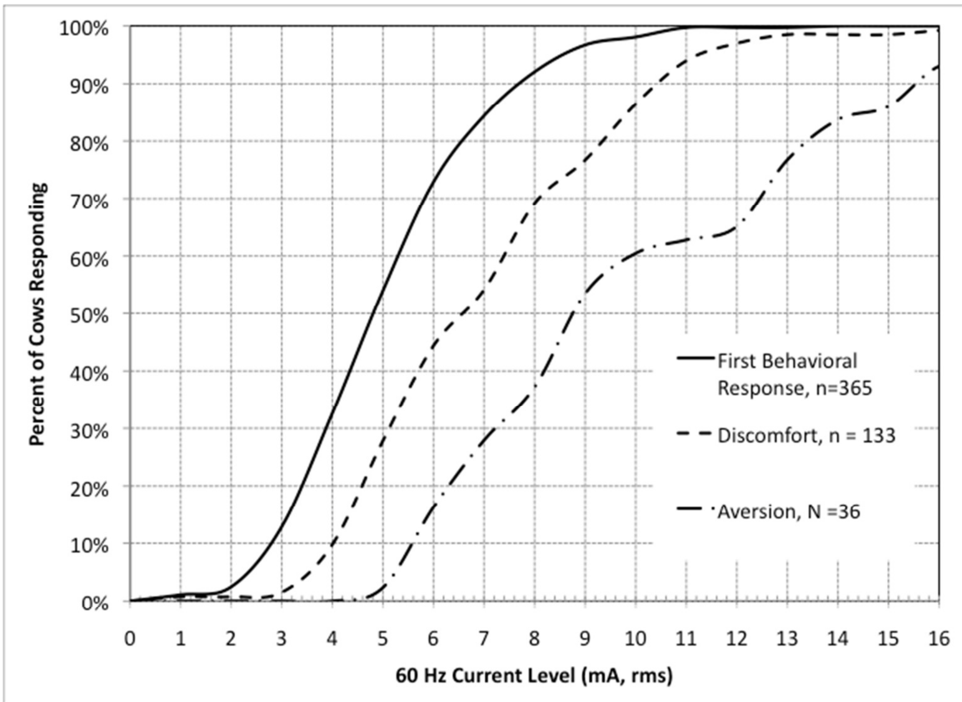

Figure 1. Behavioural response of dairy cows to current exposure.

Aversion has been documented to require substantially higher voltage and current exposures than the levels that produce behavioural modification. Numerous studies have documented avoidance behaviours at levels above the first reaction threshold. The median avoidance threshold for 60 Hz current flowing through a cow is about 8 milliamps (or 4 to 8 Vrms). This response assumes that the cow comes into contact with objects that have different voltages and that this voltage causes sufficient current to flow through the cow. Even when the threshold is exceeded, not all the animals respond behaviourally all the time, nor do they exhibit the same signs; however, as the voltage increases, signs in the herd become more widespread and uniform. Cows have been shown to resume normal behaviours within 1 day of removal of adverse voltage and current levels.

Cows present a larger cross sectional area than humans so it requires more total current to produce the same current density. In a study of the sensitivity of cows and people to 60 Hz current it was found that the average current perceived by people when applied to two adjacent fingers was 0.37 milliamperes, with discomfort noted at 0.45 milliamperes. The average current for which cows showed a behavioural response, when applied from one hoof to another was 3.7 milliamperes. It thus took about 10 times the current to elicit a response from a cow than from a person. This is mainly due to the smaller cross section of humans when compared to cows.
While the resistance of cow and human tissues is similar, the contact resistance is generally lower for cows than for humans, particularly if cows are in a wet environment. The resistance of a cow's body plus the contact resistance with the floor is commonly estimated as 500 Ohms. The resistance of a human can be as low as 1000 ohms for wet hand - foot contact to higher than 10,000 ohms for dry hand - foot contact. The contact voltage to produce sensation can therefore be higher for humans than for cows, depending on the conditions of the contact points.

In most situations cows are less sensitive to current and more sensitive to voltage than people are.

	Cows	Humans
Average steady 60 Hz rms current to elicit response	3.7 mA	0.45 mA
Average steady 60 Hz Voltage to elicit response	1.9 V	0.9 - 9 V

It has also been shown that the equivalent to 2 milli-Amps of 60 Hz AC current (2 V 60 Hz AC rms) is about 2.8 mA of DC current (2.8 V DC). In addition dairy cows are much less sensitive to high frequency or short duration electrical exposures than for 60 Hz rms AC current (A much higher current is required to elicit the same response). Relative response thresholds for high frequency (or short phase duration) events are illustrated in Figure 2.

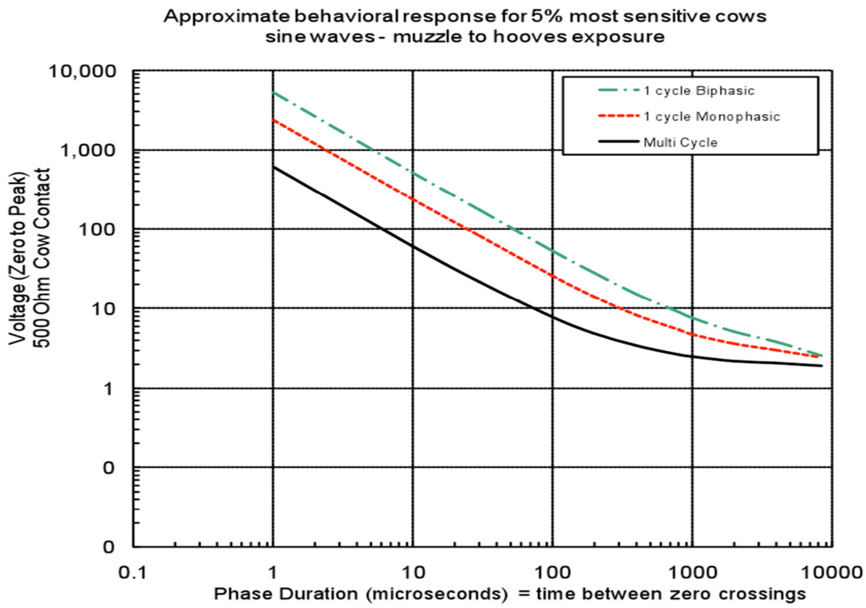

Figure 2. Relative response thresholds for long phase duration (low frequency) voltage and short phase duration (high frequency) voltage exposure with different waveforms. Note: 50 Hz voltage appears on the far right of this graph.

Numerous studies have documented that cows rapidly acclimate very quickly to even very high levels of voltage/current exposure and behavioural modifications become less pronounced in a matter of several days. A number of studies have been done to investigate direct physiological effects that may be produced at levels above those that produce behavioural changes, as well as potential detrimental physiological responses that may result from animals' exposure to voltage/current below levels which may produce sensation and behavioural response. These studies have shown that increased concentrations of the stress hormones do not occur at levels below behavioural response levels and only become apparent in some, but not all cows, at substantially higher voltage/current exposures than the threshold required for behavioural modification, and typically at levels that produce severe behavioural changes and probably at current levels that produce discomfort and/or pain. Furthermore, the failure of several experimental and field studies to demonstrate detrimental effects of current exposure on the incidence of mastitis and immune function response indicate that the levels of voltage/current exposure that elicit behavioural changes do not compromise the immune function of dairy cows.

Exposure at watering devices

Farm animals' Contact with watering devices has been the most widely studied area of stray voltage exposure. Water intake is essential for animal productivity and health. Metallic water pipes are required by electrical codes to be bonded, or electrically connected, to the grounded neutral system of a farm. This connection to the grounded neutral system provides a path for fault current in the event that an energized or 'live' wire comes into contact with metal pipes. This fault path allows the circuit breakers to activate and de-energize the faulted wire to prevent the risk of electrocution. This connection also provides a conduit for neutral voltage to access watering devices. Watering devices are therefore one of the more likely points of contact between farm animals and neutral to earth voltage. This animal contact location will be irrelevant if watering devices have no electrical connection to the farm wiring system, as is the case on many New Zealand pasture based farms. This situation may change with the introduction of automatic milking machines and the location of waterers nearer to electrified milking facilities.

The watering device provides one contact point to the animals' mouth or muzzle. The resistance of this contact point is quite variable depending on the specific type or watering device. For example, in a large concrete tank from which cows can drink without making physical contact with the concrete, the contact resistance is quite high, as water is a relatively poor conductor of electricity. When drinking from a metallic water bowl, typical of a tie-stall or stanchion barn application, a large area of a cow's muzzle must make firm contact with a large metallic paddle in order to start the flow of water into the bowl. The contact resistance in this scenario is quite low. There are other types of watering devices that have intermediate muzzle contact resistance such as heated waterers that may use a float to control water levels. Some watering devices are made of plastic, which is a relative poor conductor of electric current.

The second contact point at watering locations is usually the floor surrounding the watering device. The contact resistance of this surface will be influenced by the type of flooring (usually concrete), the amount and type of debris that may be present of the floor and the wetness of the floor. Some experiments that have been done using floor conditions designed to minimize this contact resistance, commonly a clean, wet metal plate with some contouring to clean hooves and provide points of high pressure and facilitate a low resistance electrical connection. In these experiments measurements have confirmed that it is difficult to maintain low resistances during the course of a day with resistances typically ranging from a few Ohms up to several hundred Ohms. Other experiments using concrete floor surfaces have indicated that contact resistance on concrete typically range from several hundred and several thousand Ohms, depending mainly on the amount of debris, water and/or urine on the floor surface.

The 'worst case' or lowest resistance value for the contact resistance recommended by the authors of USDA handbook 696 is about 150 Ohms. This combined with that average cow body resistance from muzzle to 4 hooves provides a cow + contact resistance of 500 Ohms. This value is supported well by experimental evidence and is a reasonable value to use for cow + contact resistance at watering devices. Exposure risks can be reduced by:

- Using watering devices that do not require animals to make firm contact with grounded metallic components, or using non-metallic watering devices

- Avoid the use of electric heating elements in watering devices if possible.
- Provide an equipotential plane around watering devices containing electrified and/or electrically conductive materials, as required by electric codes.
- Providing good drainage around watering devices to avoid standing water and urine on floor surfaces
- Provide several watering locations that are easily accessible to animals in the event that voltage exposures are excessive at one of the watering locations.

The primary symptoms of stray voltages at watering are changes in drinking behaviours. Mild changes in drinking behaviours, such as reduced number of drinks per day and longer interval between drinks have been documented in several studies. These changes in behaviour may not be sufficient to affect total daily water intake. More severe aversions have also been observed at extreme levels of voltage/current exposure resulting in depressed daily total water intake and in some cases refusal to drink for an entire day.

Experiments have shown that when given free choice, cows show a preference to warmed water over cold water (ground water temperature) that may be perceived as an avoidance of the cold-water locations. There are a number of other sensory differences that may incline cows to show a preference to one watering location rather than another, which may be perceived as avoidance of that alternate source. Avoidance of watering locations could also be due to unpleasant tastes or smells, however, the powerful drive to drink will normally overcome all but the most foul of tastes.

Lapping or playing at a watering device has been attributed to stray voltage exposure, but no controlled study has ever confirmed this behaviour in the presence of voltage/current exposure. Cows may demonstrate avoidance or modified drinking behaviours in response to group dominance challenges. Cows have been shown to develop what may appear to be unusual behaviours as a way to cope with stressors such as confinement and for many other unknown reasons.

There are well developed experimental techniques to establish cause and affect relationships between a specific stimulus and a specific behaviour or avoidance. It is very difficult to establish these relationships on an operating farm unless careful measurement of behaviours is done and sources variability and confounding effects are controlled for.

Mild behavioural modification would be expected at current levels of 2 mA for the most sensitive dairy cows, 5 mA for 50% of cows, and about 8 mA for the least sensitive cows. Using a worst case cow+contact resistance of 500 Ohms at poorly drained, wet locations surrounding watering devices, this corresponds to voltage exposure levels from 1 V for the most sensitive, 2.5 V for 50% of cows and 4 V for the least sensitive cows. While these levels have been well documented for dairy cows, it is expected that they would also apply to beef cattle. In well designed, constructed and managed facilities in which higher contact resistances are more typical this would correspond to voltage exposure levels of 2 V for the most sensitive cows, 6 V for 50% of cows and 8 V for the least sensitive cows.

Short-term avoidance behaviours, which may result in short term depression of milk production, would be expected at about 3 mA for the most sensitive cattle (1.5 to 3 V), 7.5 mA (3.8 to 7.5 V) for 50% of cattle and 12 mA (6 to 12 V) for the least sensitive cattle. Reduction in water intake and resulting decreases in milk production would only be expected if there were no other source of water than that which applied this level of current during drinking and if the current dose was consistent enough during the course of a day so that cows could not fulfil their water needs during periods of low exposure.

Exposure at feeding devices

There have been relatively few studies that have specifically examined animal responses to voltage exposure at feeding devices. Notable in the literature are the recent studies performed in France in which Holsteins showed preference for non-electrified feed bowls when exposures exceeded 2.3 V, and behavioural modification (but not feed reduction) was noted at exposure levels of 3.3 V. These studies indicate that dairy cows have similar sensitivity to feeding exposures as to drinking exposures; however, the feed bowls used in these studies were not typical of those used in farm practice as they were specifically chosen to be small enough and deep enough so that cows would make contact with the electrified surface when eating.

While there are many ways in which feed is delivered to animals, it is relatively uncommon to have feeding devices that require animals to come into direct contact with metallic or conductive elements in order to obtain feed. This may change with the introduction of automatic milking machines that dispense feed in the milking stall. Feeding locations also pose less of a risk because both mouth and floor contact resistances are typically higher than for watering locations because both are dryer and covered with a high resistance, dry feed or feed debris. Situations in which feed is placed on a concrete floor (feed manger) are unlikely location for problems because, even if an equipotential plane has not been purposefully installed, conductive elements are almost always present in concrete creating at least a partial equipotential plane in some areas of the barn.

The primary symptoms associated with voltage exposures at feeding locations would be the same sorts of avoidance behaviours produced by excessive voltage present at watering locations. These behaviours may be very difficult to observe in situations in which animals have free choice of several feeding locations and/or large feed mangers. The behaviours would be more apparent for situations in which animals had only one feeding location, as may occur for swine.

Exposure during milking

Several studies have been done on behavioural responses to voltage/current exposure during milking. Voltage exposures are less likely to occur for dairy cows in milking parlours than at drinking locations because the metallic components of milking parlour stalls are more likely to be bonded to conductive elements in concrete floors and the floors are more likely to contain a substantial number of conductive elements. This will act to reduce both touch and step potentials.

The milking machine has been shown to be a very unlikely pathway for problematic current flow because of the very large resistance values of the milk hose and milking machine components. Milking machine components, including the long and short milk tubes, long and short pulse tubes and milking liners are good electrical insulators. The mixture of milk and air in milk tubes also has relative high resistance making milk hose resistance in the range of 30,000 Ohms to 80,000 Ohms depending on the milk flow rate. Several studies have documented these resistance values and the unlikely path of voltage/current exposure through the milking machine unless source voltages are well in excess of those commonly considered stray voltage, up to hundreds of V for 60 Hz and thousands of V for high frequency sensing pulses.

Cows are not required to make muzzle contact with any metallic components during milking, except in the uncommon situations in which feed might be provided during milking. The contact resistance through a pathway that includes dairy cow's coat is much higher than for muzzle contact resistance because it is drier and hair covered, thus making stall to floor potentials of less concern that water bowl potentials.

Current sensitivity levels are similar for udder-hooves pathways as for muzzle-hooves pathways but cow+contact resistance values are typically higher. A cow + contact resistance value of 1000 Ohms or more is appropriate for milking machine exposure estimation. There are numerous behavioural symptoms associated with cow's unease during milking due to fear of operators, unfamiliar surroundings or aggressive or faulty milking machine settings. Very careful measurement technique and comparison with a negative control condition would be required to differentiate electrical exposures from the many other causes of behavioural modification during milking in a field situation.

Exposure at building transitions

Step potentials may occur at building transitions where animals are walking onto concrete floors or walking from one section of floor to another which are not electrically bonded by an equipotential plane. Cows are somewhat more sensitive to single hoof-single hoof exposures than to muzzle-to-all-hooves exposures

The contact points for this exposure are from front to rear hooves. The same considerations for hoof contact resistance as was discussed in the feeding exposure section apply here. If floors are well drained and contain organic debris, the hoof contact resistance can be considerable. Cows have been shown to be slightly more sensitive to currents applied from one front to one rear hoof than for muzzle-all-hooves pathway because of the concentration of current in one hoof.

The symptoms of step potential exposure would likely be cows' hesitation to cross building entrances, exits, or transitions. The discomfort associated with step potentials less than 10 V would not cause most cows to completely avoid the transition but could cause balking at the transition and/or rapid passing through the transition. The author had a report of a milking parlour that had in excess of 50 V of step potential at the entrance to the parlour. The reported behavioural modification was cows hesitating at the entrance and then 'jumping' into and out of the parlour. There were no apparent effects on milk yield or milking performance, likely because cows had developed adaptive behaviours to avoid undue stress from voltage/current exposure and once the cows were inside the relatively well-bonded milking parlour the step potential was eliminated.

There are also a number of other reasons that animals might hesitate to enter or leave a building or move from one part of a building to another including; changes in light levels, shadows on the floor that may appear as obstacles, exploration of a new environment, identification of dominant herd mates and changes in temperature or ventilation levels.

The consequences of a step potential at a building transition are not likely as problematic for animal performance as similarly annoying exposures at watering devices. This exposure pathway is much less of a concern with beef cattle, swine, sheep and poultry that typically stay in the same housing area during the day, than for dairy cows that are moved 2 or 3 times per day to a different building location for milking. Beef cattle are less likely to be housed in buildings that have a concentration of electrical equipment.

Ground Currents, Electric, and Magnetic Fields:

The electric and magnetic fields (EMF) caused by current flowing on the farm grounding system has been raised as a possible concern. Problems with utility and farm wiring can increase both the voltage on the neutral wire as well as the current flowing on the grounding system. The electric and magnetic fields produced by these currents are not perceptible to animals or humans and are much lower than normal household exposure. Electric and magnetic fields act on animals in a different way than the mild shock associated with stray voltage.

A team of experts was assembled by the State of Minnesota to review the evidence on the possible effects of currents flowing in the earth on the health and productivity of dairy cows. A survey of dairy producers conducted as part of the Science Advisors study revealed that the vast majority of dairy producers do not consider stray voltage or other forms of electrical exposure a problem on their farms. Several field studies have shown that the electric and magnetic field levels found on dairy farms are well below those shown to produce biological effects. Although the science advisors found no evidence to suggest that earth currents or EMF produced by them were harmful, one mechanism was postulated that could produce a biological effect; current flowing through a cow producing small internal electric fields. Research conducted to examine this possibility showed no ill effect on cows exposed to these low level currents. The Science Advisors gave three main findings in their report:

- "We have not found credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds."
- "At the present time, there is no basis for altering the PUC-approved standards by which electric utilities distribute power onto or in the vicinity of individual dairy farms."
- "There are many well-documented non-electrical factors that are known and accepted by the scientific community, and by most farmers as well, to cause dairy cow health and production problems. Among the most noteworthy factors are; poor nutrition, poor cow comfort and hygiene, and low or no use of vaccinations and related preventive veterinary practices. These factors should always be addressed by those who want to improve performance of dairy herds."

Variable frequency motor controllers

The introduction of many new technologies has raised concerns about their possible contribution to stray voltage problems. Variable frequency controllers for electric motors are among the latest of these technologies. A variable frequency controller converts 50 or 60 Hz alternating current (AC) electrical power into high voltage direct current (DC) power and then ‘rebuilds’ AC power to an appropriate frequency. This is accomplished by a sophisticated electronic switching system.

The speed of the electrical motor is thus controlled by the varying frequency of the electrical power delivered to it. Advantages of variable speed control are energy savings and improved process efficiency. For example, a vacuum pump on a conventional milking machine runs continuously at it maximum capacity. Much of this capacity is ‘wasted’ by admitting air into the milking machine through a regulator. With variable speed control the capacity of the vacuum pump is matched to the airflow requirements of the milking machine. A vacuum pump using a variable speed controller will reduce the power demand by 40% to 80%. This reduced electrical power also translates into a reduction of neutral current and contribution to neutral-to-earth voltage by a similar amount. Variable frequency controllers also reduce or eliminate the large starting current of electrical motors and eliminate 'starting transients' when the pump is switched on.

The high frequency electronic switching that occurs in variable speed controllers will produce some distortion of the 50 Hz voltage and current waveforms on both phase and neutral wires. It also produces high frequency EMF emissions. These EMF emissions can interfere with cow identification systems or other farm electronics if proper shielding is not provided on the cabling from the controller to the motor. Numerous farm investigations have shown, however, that the waveform distortion on the electrical power system and high frequency noise induced on metallic objects on the farm are far below levels that are problematic for dairy cows. The same investigative procedures are used to determine the contribution of variable frequency controllers as for other electrical devices. An oscilloscope and careful measurement technique is required to properly assess waveform distortion and high frequency signals. The chart in Figure 2 was developed as an aid to stray voltage investigators to determine the effects of these phenomena.

Summary

If animal contact voltage reaches sufficient levels, animals coming into contact with grounded devices may receive a mild electric shock that can cause a behavioural response. At voltage levels that are just perceptible to the animal, behaviours indicative of perception (e.g., flinches) may result with little change in normal routines. At higher exposure levels, avoidance behaviours may result. The indirect effects of these behaviours can vary considerably depending on the specifics of the contact location, level of current flow, body pathway, frequency of occurrence, and many other factors related to the daily activities of animals.

The severity of response will depend upon the amount of electrical current (measured in milliamps, mA) flowing through the animal's body, the pathway it takes through the body and the sensitivity of the individual animal. The results of the combined current dose response experiments, voltage exposure response experiments, and measurements of body and contact resistances is consistent with the lowest (worst case) cow + contact resistance as low as 500 Ohms as estimated by the authors of USDA handbook 696 (Lefcourt, 1991) that may occur in some unusual situations on farms (firm application of the muzzle to a wet metallic watering device and hoof contact on a clean, wet, contoured metallic plate on the floor). These studies on responses of dairy cows to electrical exposure agree well with each other and with predictions from neuro-electric theory and practice. There is a high degree of repeatability across studies in which exposures and responses have been appropriately quantified.

For confirmation, a potential of 2-4 volt (60 Hz, rms) must be measured between 2 points that an animal might contact (or animal contact measurement), and some animals should exhibit signs of avoidance behaviour. The animal contact voltage measurement with an appropriate shunt resistor value provides the only reliable indication of exposure levels. Voltage readings at cow contact points should be made with a 500 or 1,000 Ohm resistor across the 2 measuring leads to the cow contact points in addition to open circuit measurements.

The only studies that have documented adverse effects of voltage and current on cows had both sufficient current applied to cause aversion and forced exposures (i.e., animals could not eat or drink without being exposed to voltage and current) and all of the indirect responses (reduced water or intake and milk production) were behaviourally mediated. It is typical for voltage levels to vary considerably at different locations on a farm. Decreased water and/or feed intake or undesired behaviours result only if current levels are sufficient to produce aversion at locations that are critical to daily animal activity, e.g., feeders, waterers, and milking areas. If an aversive current occurs only a few times per day, it is not likely to have an adverse effect on cow behaviour. The more often an aversive voltage occurs in areas critical to cows' normal feeding, drinking, or resting, the more likely it is to affect cows.

A number of studies have been done to investigate potential detrimental physiological responses that may result from animals' exposure to voltage and current. A literature review presented by Reinemann (2012) summarizes 46 research trials on groups of cows exposed to know levels of voltage and/or current. None of these trials or experiments (some using aggressive exposure of cows to mastitis organisms) showed a significant effect of voltage/current exposure on SCC or the incidence of mastitis. Many of these studies showed behavioural modification and some showed minor changes in milk yield, milk composition or stress hormones (especially cortisol). These studies have shown that increased concentrations of the stress hormone cortisol do not occur at levels below behavioural response levels and only become apparent in some, but not all, cows at substantially higher voltage/current exposures than the threshold required for behavioural modification. This body of research indicates that while exposure to stray voltage at levels of 2 V to 4 V may be a mild stressor to dairy cows it does not contribute to increased SCC or incidence of mastitis, or reduced milk yield.

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