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Effects of Electrical Voltage/Current on Farm Animals

How To Detect and Remedy Problems

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This handbook examines 1) the history of stray voltage/current problems on farms, 2) the physical and electrical sources of stray voltage/current phenomena, 3) the physiological and behavioral bases for losses in milk production, 4) methods for identifying and detecting stray voltage/current problems, 5) methods for mitigating such problems, and 6) areas where further research may be warranted. While the primary emphasis is on cattle and dairy farms, the theories and procedures discussed are completely relevant to all types of livestock and livestock housing facilities. Recommendations are made for action levels and concerning mitigation techniques. The fundamental conclusion of this handbook is that stray voltages/currents can be reduced to acceptable levels.

KEYWORDS: Stray voltage/current, neutral-to-earth voltage, electrical shock, history, sources, physiological effects, behavioral modifications, mitigation, dairy farms, cows.

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There were two primary reasons for publishing this handbook. First, we, as scientists, were distressed that our research results were being misinterpreted and misconstrued in media and in courtrooms. Second, we were disheartened by the animosity that sometimes arose among livestock farmers, dairy equipment manufacturers, and public utilities companies because of a lack of understanding of the causes and effects of stray voltages on farms. For these reasons, we met at Cornell University in May of 1988 to review our opinions and concerns, and to discuss the possibility of publishing a "white paper" on stray voltage. At this meeting, we concluded that there was an excellent possibility that a consensus could be reached, and a second meeting was scheduled for October in Minneapolis.

At the first meeting, the question of funding for future meetings and, if relevant, publication of the "white paper" was raised. Several foundations and agencies funded principally by utilities or dairy cooperatives had offered financial support. However, to eliminate any and all potential for even the appearance of bias, we decided to accept *no* industry funding whatsoever. All travel and meeting expenses were borne by individuals, generally by utilizing university or Government funds.

At the second meeting, a firm consensus was reached that a "white paper" should be published and that it be published as a U.S. Department of Agriculture (USDA) Handbook. The Department was chosen as publisher because it represents an unbiased source of funds to pay for publication, because it has a mechanism for making available publications to the public through the Government Printing Office, and because federal publications are 1) understood by the general population to be unbiased and 2) normally viewed as expert testimony in legal proceedings.

To guarantee that the oral consensus reached at the second meeting was faithfully transferred to paper, we decided on a rather complex procedure for actually writing the manuscript. Chapters were written under the guidance of chapter editors, who then distributed copies of the chapters to all participants for comment. Next, these chapter editors revised their chapters and sent copies to the editor in chief, who assembled and integrated the chapters into a manuscript. The manuscript was distributed to all participants to ensure that all comments had been dealt with satisfactorily by the chapter editors. In addition, as part of the original agreement among contributors, Lloyd B. Craine served as the in-depth reviewer. Remaining problems were addressed to the editor in chief for reconciliation. Subsequently, the USDA's Agricultural Research Service Information Staff and Office of Public Affairs reviewed the manuscript. Ultimately, the edited manuscript was distributed for final approval, and each contributor signed a notice acknowledging that the manuscript was factually correct and a faithful represention.

Alan M. Lefcourt
Editor in chief

Warning

Identification and, particularly, diagnosis of stray voltage problems can require considerable electrical expertise. That is not to say that the input of farmers is not necessary and valuable. Often, the input and observations of people in daily association with a stray voltage/current problem are critically important to its solution. *However, electrical systems can be dangerous. Persons without special training should never attempt investigation of the electrical distribution or farm electrical systems.* For example, persons without special training should never open electrical service panels nor should they even contemplate altering any wiring.

Using a voltage measuring device with well insulated probes to measure voltages between possible points of animal or human contact should not result in a safety hazard with one important exception. Voltages that cause stray voltage/current problems are normally so low that they cannot be detected without special instruments. If an electrical shock can actually be felt or if animals are knocked down, a possible hazard to life exists. The device or electric circuit responsible for the shock should be disconnected by unplugging the device or by deenergizing the circuit at the service panel. The situation should be examined by an electrical professional as soon as possible.

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Summary

Although cows and humans may be similarly sensitive to electric current, cows are more susceptible to stray voltages primarily because they have much lower body impedances (resistances) compared to humans. From Ohm's law, current is equal to voltage divided by impedance. Therefore, for a given voltage, a lower body impedance results in a larger current. *Current level is of critical importance because animals respond to the current passing through their bodies, and not directly to the voltage that generated the current.*

During electrical contact, it is actually the total series impedance that limits the current cows or humans receive and not just body impedance. The total series impedance is the sum of source, path, contact, and body impedances. Body plus contact impedances of cows are much lower than impedances of humans. Furthermore, the wet environment in which cows are housed can accentuate differences in contact impedances, e.g., cows standing in manure make better electrical contact with the earth than farmers wearing rubber boots. A lower body impedance plus lower contact impedances means that more current is delivered to a cow than to a human for a fixed voltage.

There are several sets of cow contact points or areas between which a cow is likely to contact voltage and allow a pathway for current. The impedances of most of these pathways have been studied. The path of least impedance is the mouth-to-all-hooves pathway. No studies have been reported on the effects of environmental conditions on contact impedance. However, it is known that water or wet environments allow better electrical contact (lower contact impedance). All reported measurements of cow impedances involved making some form of cow contact (certainly not standardized) and therefore include a value, albeit somewhat variable, for contact impedance.

The magnitude of current needed to elicit minimal behavioral responses is very similar to the magnitude of current that can just be perceived by humans (0.5-2 mA). Because cows cannot tell a researcher when they perceive a current, researchers look for responses they can see or measure such as changes in behavior. The minimum current needed to cause cows to lift their legs or open their mouths more often than they do normally can be as low as 0.5 mA to as much as 5 mA.

The voltages needed to deliver these currents depend on the body impedance of the cow, the contact impedances between the cow and the conductive structures, any impedance of the conductive structures, and the impedance of the voltage source. If the sum of these series impedances is assumed to range from 500 to 1,000 ohms, then the range of voltages over which a cow first perceives current (shows a minimal behavioral response) is 0.25 to 5 V. If the source impedance is high, in the thousands to millions of ohms, as from a leakage source, then much greater voltages are needed to provide currents that can be sensed. Older recommendations for tolerable levels of cow contact voltages (0.5 V (1980) and 0.7 V (1987)) were based on the lowest values for perceived currents and low values for body, contact, path, and source impedances.

These past voltage recommendations need to be reviewed in light of recent research which indicates that when currents are below 6 mA for a short term (21 days), production, reproduction, and animal health are not affected; nor is there a significent effect on the levels of hormones naturally released during milking or in response to stress. Some moderate behavioral changes are evident, however, at currents between 3 and 6 mA, and as currents approach 4 ma, these changes may require an additional investment of time from the dairy operator. When currents above 7 mA are delivered through the milk, milking machines are kicked off. Although there is no conclusive evidence, it appears that behavioral changes which might require additional labor could occur at voltages as low as 1.5 V (3 mA). However, it also appears that the large majority of cows probably do not demonstrate problem behaviors until voltages are about 3 or 4 V. These voltage estimates are based on total impedances of 500 or 1,000 ohms. Direct economic effects have

been shown at voltages of 4 V and above, but only in a small percentage of cases where animals refused to drink for 36 hours (6 out of 90 animals). For these six animals, production dropped rapidly during this period and significant health problems would have occurred if the animals had not been given alternate sources of water. Experiments involving long-term exposures of cows to voltage also indicate that cows acclimate physiologically and behaviorally to constant and intermittent currents below 6 mA.

Based on current research, cow contact voltages from low impedance sources should be kept less than 2 to 4 V. Cow contact voltages between 1 and 4 V from low impedance sources may cause behavioral effects resulting in increased labor costs and/or inappropriate responses of farmers to the changes in behavior. These possible increased costs have to be balanced against the cost of reducing voltages in the range of 1 to 4 V. Once cow contact voltages reach 1.0 V, a program of routine monitoring should be initiated to ensure that the voltages do not increase significantly.

Attempts have been made to link stray voltage/current problems with herd health problems. Cows normally experience various health problems, including mastitis. Mastitis, or infection of the mammary gland, is a fact of life in the dairy industry. Animal susceptibility and treatment as well as milking and hygiene practices are directly related to problems with mastitis. Electrical current cannot directly cause infections. It can affect the etiology of mastitis only indirectly, e.g., when a milking machine kicked off by a cow is reattached without first being cleaned.

It should be emphasized that factors such as mistreatment of cows, milking machine problems, disease, poor sanitation, and nutritional disorders can cause cows to exhibit all the symptoms that have been reported to occur on farms reporting stray voltage.

Introduction

The effects of electric current on cows depend on the characteristics (magnitude, duration, and waveform) of the current; electrical properties (impedance) and sensitivity of the cows through which the current passes; and the environmental conditions. The sensitivity of cows can vary, depending on their prior experiences. Our task is to summarize the existing literature and knowledge and provide some reasoned judgment as to the effects of electric currents on dairy cows and on the profitability of a dairy operation. Specifically, we intend to review how dairy cows are affected by electric currents and predict the consequences of these effects. Effects are related to electric currents, therefore, the electrical characteristics of the voltage sources that provide the current and electrical characteristics of the subject are crucial in determining the effects. *Although electric currents can cause death, currents that do so are much higher than those associated with stray voltage/current problems. Such high currents result from electrical problems or disturbances that are beyond the scope of our discussion.* Data available on human sensitivity will be compared with those available on dairy cow sensitivity, and appropriate comparisons made. The effect of duration and pattern of exposure to current will be examined with respect to conditioned responses.

Physiological Basis for Sensitivity to Currents

The nervous systems of all animals communicate by way of electrochemical signals. Therefore, it is not surprising that electrical currents can be perceived, cause muscles to contract, and disturb control mechanisms within animals. Humans perceive electrical current as one or more of the following: a vibration (tingling), burning sensation, or pain. The perception depends on the type of receptor stimulated by the electrical current. We can only surmise that perceptions of animals and humans are similar. The catastrophic effects of electrical shock (muscle contractions, ventricular fibrillation, and burns) are similar for humans and animals. Currents that cause catastrophic effects are much higher than those associated with stray voltage/current problems.

Reviews of research and information on stray voltage have been published (Hansen and Endahl 1983, Appleman and Gustafson 1985b, Majerus et al. 1985), and our review is now added to the literature.

Human Sensitivity

Human safety has been a concern ever since the commercial distribution of electric power was begun. Therefore, the effects of electricity on humans have been well studied (Bridges et al. 1985). Much of the information gained from these studies relates to our sensitivity to 50- and 60-Hz currents — not unexpectedly, as these are the two frequencies at which electrical power is generated in the world.

Human sensitivity to electrical currents of increasing strength is generally stated in terms of a continuum of effects. We can just perceive electricity at currents between 0.5 and 2.0 mA. Such currents are generally perceived as a tingling sensation or as heat. The next distinguishable effect in the continuum is muscle contraction. The maximum current (6 to 23 mA) at which persons are able to overcome muscle contraction to the extent that they can release their hold on live conductors is referred to as the "let-go current." Higher currents cause muscle contractions that do not permit such release. Currents (20 to 30 mA) that pass through the thorax can cause prolonged contraction of the respiratory muscles and arrest breathing. Breathing can also be stopped by currents to that part of the nervous system that controls breathing. Currents that pass through the thorax can disrupt the heart muscle and cause cardiac failure, simple arrest, or, most commonly, ventricular fibrillation. It has been suggested that the threshold for ventricular fibrillation in vertebrates is proportional to body weight and dependent upon the duration of the current flow. For currents greater than 500 mA, current flows lasting less than 0.2 seconds can cause ventricular fibrillation; for currents between 50 and 500 mA, flows lasting more than 2 seconds can also cause ventricular fibrillation.

The impedance of the body is critical for estimating the effects of stray voltages. From Ohm's law, we know that current is inversely proportional to impedance and directly proportional to the voltage, i.e., current equals voltage divided by impedance. Since animals come in contact with voltages rather than currents, the body impedance will determine the magnitude of current flow and, hence, the animal response. The impedance of the body depends to some extent on the points of contact, i.e., the path the current takes within the body.

Only 50/60-Hz currents have been considered to this point. Contact with currents of higher and lower frequencies is also possible. Interestingly, human sensitivity decreases for currents of higher and lower frequencies. Perception thresholds increase from 1 mA at 50/60 Hz, to 2 mA at 1,000 Hz and to 10 mA at 10,000 Hz. Let-go currents also increase at higher frequencies. For frequencies below 10 Hz, our sensitivity appears to be diminished as well. Direct currents (0 Hz) cause a different phenomenon from that caused by alternating currents. Direct currents are felt only when they are established or interrupted. Perception depends greatly on the conditions of contact with voltage, the individual, and the duration of the current flow. The average threshold for perceiving direct current is 5.2 mA for men and 3.5 mA for women, values which compare with 1.0 mA at 60 Hz for both men and women. Direct currents of 40 to 60 mA are called release currents, rather than let-go currents, because in tests, subjects could let go but refused to do so in apprehension of the severe shock that would occur on release. At higher levels, direct currents can also cause burns.

Electrical Currents That Affect Dairy Cows

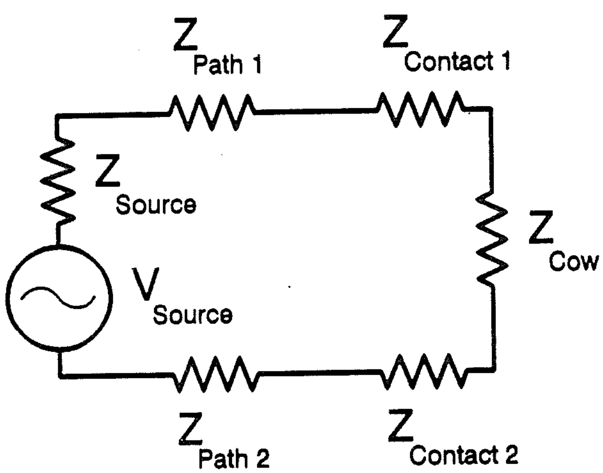
Electrical currents can be produced with almost any waveform desired. Typical waveforms include fixed amplitude with no time variation (dc, or direct currents), sinusoidal (ac, or alternating currents), exponential decay, pulsed (single and continuous), damped sinusoidal, and direct current resulting from half-wave-rectified sinusoids. In the commercial and residential sectors, the most prevalent waveform of electrical energy is sinusoidal at 50/60 Hz. As discussed in chapter 2, the electrical power distribution system is the ultimate source of almost all stray voltages, and the most common source of stray voltage is an elevated neutral-to-earth voltage at the service panel. Therefore, discussions will emphasize the effects of 50/60-Hz currents.

However, we cannot simply dismiss other types of waveforms. If the magnitude and duration of an electrical event are sufficient, it can have an effect on animals. There is evidence that like humans, animals are not highly sensitive to direct currents and to alternating currents at higher frequencies. The sources of non-50/60-Hz currents present in the farm animal's environment have been discussed (see chapter 2). However, animal sensitivity to these currents is low, and the currents would have to be of greater magnitude to produce effects similar to those of 50/60-Hz alternating currents. To the best of our knowledge, non-50/60-Hz currents exist on farms but not at levels to which animals are sensitive unless for planned and accepted uses (cow trainers, electrified fences). Unfortunately, most voltmeters respond to waveforms over a wide range of frequencies (at least to 20,000 Hz), but in different ways. As these voltmeters may "average" all waveforms across most frequencies, they may indicate voltages that are not solely 60 Hz. Caution must be exercised when such voltage measurements are compared with values given for animal sensitivity because those values were measured at 60 Hz. As cows are less sensitive to higher frequency currents, such comparisons are very conservative and possibly meaningless, depending on the frequency components of the measured voltages. In some cases an oscilloscope may be needed to measure actual waveforms (see chapter 5).

Temporal variation of 50/60-Hz waveforms also needs to be considered. Dairy cows are generally not subjected to continuous currents but rather to 50/60-Hz currents that change in amplitude and duration. Thus, we will emphasize 50/60-Hz currents that exist for at least one complete cycle, e.g., 1/60 of a second for 60-Hz ac, and currents that are continuous when discussing possible electrical contacts.

Voltage Sensitivity

Contact with electricity by humans or cows is generally made across a part of an impedance network to which a voltage source is attached. The current delivered by the voltage source will depend upon the magnitude of the voltage source, the source impedance, the series impedance of the paths connecting the voltage source to contact areas, the contact impedance, and the impedance of the body pathway (fig. 3-1). Animals and humans alike are current sensitive; therefore these impedances are crucial in determining the effect of a voltage.



Series Impedance =

$$Z_{Source} + Z_{Paths} + Z_{Contacts} + Z_{Cow}$$

Figure 3-1. An equivalent electrical circuit showing the elements that must be in place for a stray voltage problem to exist. V is the voltage source and Z's are circuit impedances. Current equals V divided by series impedance.

Body impedance varies both with current pathway within the individual and with the individual. Studies have been carried out to characterize the impedances of pathways within cows (Phillips and Parkinson 1963, Craine et al. 1970, Woolford 1972, Whittlestone et al. 1975, Lefcourt 1982, Norell et al. 1983, Henke Drenkard et al. 1985).

The impedances reported for 60 Hz differed among cows and among pathways and ranged from 250 to 3,000 ohms (table 3-1). Thus, at least two sources of variation determine the effect of a voltage on an individual dairy cow: the current sensitivity of that animal and the impedance of the body pathway through which the current is delivered.

Dairy cows have a much lower body impedance (resistance) than humans, i.e., less than one-tenth the impedance of the human body. Furthermore, in the farm environment, contact impedances of cows are likely to be lower. Cows are nearly always in contact with moisture. Their four hooves are in close association with urine, water, and feces on concrete surfaces; and they eat and drink with moist mouths. In contrast, humans in the same environment as dairy cows generally wear shoes or rubber boots and have dry skin.

Controlled Research

Behavior and Physiology

We feel that it is necessary to comment on normal cow behavior before summarizing the extensive series of experiments which examined adverse effects of currents on cows.

Normal Cow Behavior

Cows exhibit wide differences in temperament. Some are always gentle, others are quite active, alert, and somewhat nervous under normal conditions, and very excitable under stress. Between these two extremes are animals that are usually quiet, but tend to react strongly to changes in their normal routine. Temperament is about 50 percent heritable; thus, selection for this trait would be effective. Its correlation (relationship) with milk yield, however, is close to zero.

Feeding behavior is affected by environmental temperature, kind of feed, age of cattle, condition of teeth, and other health conditions. In general, feed consumption decreases with increasing environmental temperature. Cows receiving a total

Table 3-1. Resistances of various electrical pathways through the cow[1]

Pathway	n[2]	Resistance Mean (ohms)	Resistance Range (ohms)	Current Frequency (Hz)	References
Mouth to all hooves	70	350	324-393	60	Craine et al. 1970
	28	361	244-525[3]	60	Norell et al. 1983
Mouth to rear hooves	28	475	345-776[3]	60	Norell et al. 1983
Mouth to front hooves	28	624	420-851	60	Norell et al. 1983
Front leg to rear leg	5	300	250-405	60	Lefcourt, 1982
	13	362	302-412	60	Lefcourt et al. 1985
Front to rear hooves	28	734	496-1152[3]	60	Norell et al. 1983
Rump to all hooves	7	680	420-1220	50	Whittlestone et al. 1975
Chest to all hooves	5	980	700-1230	50	Whittlestone et al. 1975
	?	1000	?	50	Woolford, 1972
Teat to mouth	28	433	294-713[3]	60	Norell et al. 1983
Teat to all hooves	28	594	402-953	60	Norell et al. 1983
	4	880	640-1150	50	Whittlestone et al. 1975
Teat to rear hooves	28	594	402-953[3]	60	Norell et al. 1983
Teat to front hooves	28	874	593-1508	60	Norell et al. 1983
All teats to all hooves[4]	6	1320	860-1960	50	Whittestone et al. 1975
	?	1000	?	50	Phillips et al. 1963
Udder to all hooves	12	1700	650-3000	60	Henke Drenkard et al. 1985

[1] Adapted from Appleman and Gustafson (1985b).

[2] Number of animals.

[3] Ranges given are for 10-90% percentile, or percent of cows with measured resistance between the reported limit.

[4] Measured during milk flow.

mixed ration (TMR) typically eat about 12 meals per day, each lasting over 20 minutes; thus they spend 4.2 hours per day consuming feed. When hay and silage are offered, cows spend an average of 6.4 hours per day consuming feed. In most herd operations, competition for feed doesn't limit productivity. When cattle are fed adequately, dominant cattle may eat first and faster, but subordinates will obtain their fill during times of low competition. Individual feed intakes of group-fed cattle appear to be more dependent on physiological need than social advantage.

Rumination is the act of regurgitating, remasticating, and reswallowing previously ingested feed. Rumination time varies from 4 to 9 hours, with large variations both within and among animals. Rumination time is reduced when cows are fed ground hay or concentrates instead of long hay.

Cattle drink by dipping their muzzle into the water and sucking the fluid into the mouth. The tongue plays only a passive role in drinking. Cows may tend to splash or "play" with the water when drinking. Drinking frequency tends to increase when cattle are dependent on supplementary feeds and when housed. Water intake is a function of dry matter ingestion, environmental temperature, and level of milk production. The volume of water consumed daily by a Holstein cow producing 60 pounds of milk may be 17 gallons when ambient temperatures average 68°F, but over 30 gallons when temperatures average 95°F.

Normal, healthy cows urinate 9 or 10 times and defecate 12 to 18 times daily. Environmental conditions can affect these processes. Cows will urinate less frequently in hot, dry environments, 3 or 4 times daily.

Adult cattle do not appear to sleep; but they typically spend 9 to 12 hours per day lying down. Their head is generally held erect or turned to the side for eructation of gasses from the rumen. On the other hand, calves have been observed sleeping for up to 3.2 hours daily.

Concentrating animals, by decreasing the surface area per animal, or introducing new animals into the herd can increase aggressiveness in the herd. Keeping animals together from an early age, limiting introductions, and keeping disturbances to a minimum are of importance in limiting aggressiveness and social stress.

Tail-switching is sometimes used to express intense emotion. Restrained animals in a fearful situation tail-switch more than usual as they struggle against restraint.

Cows are often called creatures of habit. They notice any unusual change in their routine, and they often stare at or smell unfamiliar objects.

Kicking is a common behavior that can be a problem. In some cases, the herdsman may choose to apply antikicking devices. Most cows kick because they are frightened, are in pain, or have been mistreated.

While most cows exhibit normal behavior patterns and respond to kindness and superior herd management, a few animals in every herd will from time to time develop behaviors which interfere with the regular herd routine. Stray voltage/current problems can accentuate normal differences in behavior.

Behavioral Responses to Current

The basic behavioral response of any organism to an annoying stimulus is avoidance. The response to a pleasurable stimulus is to seek it out and attempt reexposure to it.

Electrical current can be perceived in a variety of ways by humans. It is usually an annoying stimulus. However, it can be used therapeutically. For example, in humans, tonic electrical neural stimulation (TENS) relieves back and leg pain when it is used to saturate the specific part of the nervous system that transmits signals of pain to the brain.

Humans can avoid an objectionable voltage much more easily than cows can. Humans can walk away from or remember not to come in contact with a voltage source. The dairy cow, however, lives in a restricted environment. Under some conditions, cows, like humans, may avoid the voltage by moving their body or appendages away from the source or simply tolerate it if it is not too bothersome. However, because of management procedures, cows may not be able to avoid voltage sources despite their desire to do so.

Behavioral changes are manifestations of physiological reactions occurring within the organism. In cows, the extent of the behavioral change resulting from exposure to stray voltage/current can range from subtle (leg lifting or twitching) to dramatic (muscle spasms, seizures) and is related to the intensity of the current. We must understand that what appears to be bothersome to humans may not be a problem for cows. *Care should be taken not to assume that cows perceive their environment the same way we perceive ours.*

As discussed throughout this document, the relation between voltage and current is determined by the familiar Ohm's law: E = IxZ, where E is the voltage potential (volts), I is the current flow (amperes), and Z is the impedance of the total circuit in ohms. Impedance often simplifies to pure resistance, R. However, R is more generally the real part of the complex impedance of the total circuit at 50/60 Hz and is expressed in ohms.

The effect of a specific voltage on a cow is influenced by many factors, which together determine the distribution of current flow through the cow's body, namely, 1) voltage that is measurable between two points of contact, 2) source impedance, 3) the impedances of the electrical pathways between the cow's contact points and source voltage, 4) the contact impedances at the two points where the cow makes contact with the electrical conductors, 5) resistance of the cow's body pathway, and 6) the sensitivity of the cow.

Because these many factors cannot be determined in the field, scientists have sampled groups of cows and determined the currents necessary to elicit a response from each cow. The data obtained provide a basis upon which to estimate the statistical distribution of response-eliciting currents for all cows. Likewise, groups of cows can be sampled, and the resistance of a specified pathway within each cow can be measured. These data provide a basis upon which to estimate the statistical distribution of resistances for the specified pathway for all cows. In fact, distributions of all the variables that influence the response of animals can be estimated and in most cases have been. With these estimates, it would be possible to select a sensitive cow (most sensitive in 100 animals), a low resistance cow (lowest in 100 animals for the lowest resistance pathway), and lowest circuit impedance (lowest in 100 conditions, where circuit impedance includes items 2-4 above). By multiplying these factors together, an estimate can be made of the lowest voltage that will cause 1 animal in a million animals to respond.

Over the years, many experiments have been performed to examine the effects of currents on the behavior and physiology of dairy cattle. It is often difficult to separate behavioral changes from physiological responses. Therefore, some of the research trials examined the effects of currents on physiology and behavior. In the paragraphs that follow, a summary will be given of those experimental trials that focused on the behavioral and physiological effects of stray voltage on cows.

Behavioral Research

New Zealand: Whittlestone et al. (1975) showed that cows would break their trained behavior of pushing a metal plate to receive food when this activity was coupled with the application of 2.5 mA of current over a four-teat-to-all-hooves pathway.

University of Minnesota: Norell et al. (1983) taught cows to press a plate to receive grain rewards. Then they administered a current of up to 6 mA over the front-to-rear-hooves pathway whenever the plate was pushed. Applying the current did not affect the learned plate-pressing behavior. In a similar test, but with the muzzle-to-all hooves pathway, plate pressing was delayed by current varying from 1 to 4.5 mA on the first test day and from 3 to 4.5 mA on subsequent days. In a second experiment, cows were trained to raise their front hoof to avoid continuation of a front-to-rear-hooves exposure to current. Ninety-seven percent of the animals showed the learned escape response at currents above 2 mA. To avoid shock over the mouth-to-all-hooves pathway, mouth opening was the specific response. Fifteen percent of the cows responded to 1.0 mA and 90 percent to 5.0 mA. In other experiments, cows subjected to a 4-mA current required twice as much time to cross a grid from the preparation stall to a milking stall compared to control animals.

USDA and Cornell University: Lefcourt (1982) and Lefcourt et al. (1986) examined a front-leg-to-rear-leg pathway. Most of the cows in his experiments exhibited mild responses such as flinching or vocalization at 3.0 mA of current. The most sensitive cows responded to 1.0 mA of current. Henke Drenkard et al. (1985) at Cornell University used an udder-to-all-hooves pathway on four lactating cows. Their results suggested that some cows were sensitive to 2 mA, but most responded to 4 mA.

University of Minnesota: Gustafson et al. (1985b) found that for the front-to-rear-hooves and mouth-to-all-hooves pathways, the avoidance responses (front leg raising and mouth opening, respectively) were obtained over a range of ac and dc currents, 0 to 5 mA ac and 0 to 6 mA dc. The response rate fo- the front-to-rear-hooves pathway was statistically significant above 2 mA ac, and above 1 mA dc. The response rate for the mouth-to-all-hooves pathwaywas significantly greater above 2 mA ac, and above 4 mA dc. Response rates for the body-to-all-hooves pathway, with currents from 0 to 7.5 mA ac and from 0 to 9 mA dc were inconclusive. No reliable response pattern was obtained for the body pathway.

Combined Physiological and Behavioral Research

Hormones are chemicals that are produced in specific organs, and they enter the blood and react with various tissues in the body. Basically, there are two types of hormones. Those produced in ductless glands are called endocrine hormones. Hormones that are manufactured in glands with ducts are called exocrine hormones. Hormones influence many biological functions of the body, including growth, development, and metabolism.

Certain endocrine hormones are very important for development of the udder and its day-to-day function. These hormones are insulin, growth hormone, adrenal glucocorticoids, prolactin, thyroid hormones, ovarian hormones, oxytocin, and catecholamines such as epinephrine (adrenaline). Ovarian hormones, insulin, prolactin, growth hormone, glucocorticoids, and prolactin are also involved in mammary development. Oxytocin and catecholamines are involved in milk ejection, or let-down. Cortisol, prolactin, and oxytocin are released during normal milking of dairy cows. During stress, catecholamines, cortisol, and prolactin are all released. Catecholamines can block the effects of oxytocin and thereby decrease milk yields. Incomplete milk removal, in turn, can increase the chance that the cows will get mastitis if their udders are exposed to microorganisms.

As mentioned in chapter 1, stray voltage has been associated with problems in milk let-down and an overall decrease in milk production. If stray voltages are a stress to lactating dairy cows, one would assume that exposure to these voltages under controlled experimental situations would result in the elevation of stress hormone levels in blood. Workers at USDA and Cornell University have carried out several experiments which were specifically designed to measure the effects of various currents and voltages on the levels of hormones naturally released during stress in the dairy cow and on their relationship to blood flow, milk flow, milk yield, milk composition, and release of oxytocin, prolactin, cortisol, and catecholamines.

Cornell University[1]: Holstein cows were exposed during milkings to electrical current to assess its effects on behavior, health, milking performance, and endocrine responses (Henke Drenkard et al. 1985). Treatments consisted of 60-Hz square-wave current of 5 seconds' duration applied every 30 seconds from udder to hooves. Three treatments (0, 4, and 8 mA; 0, 1.6, and 3.2 V) were applied over three consecutive 1-week periods. A cow received the same current treatment during 14 consecutive milkings, beginning with the evening

[1]Studies at Cornell prior to 1986 used alternating, constant current sources for stimulation. Subsequently, sinusoidal currents were used. Responses to both types of currents were similar.

milking and ending with the morning milking. Treatments began 5 minutes before milking and continued until milking unit removal. Milk accumulation curves provided information about milk yields, milking times (durations), peak milk flow rates, and times of peak milk flow. Residual milk yields also were measured. Milk was analyzed for protein, fat, and somatic cells. Blood samples from 60 minutes before to 60 minutes after treatment were collected, and oxytocin, prolactin, and cortisol concentrations were measured.

Behavioral responses to current decreased after initiation of milking and with repeated trials. Changes in milk production, milking performance, and milk composition were not significant. Changes in milking-related cortisol responses during 8-mA current stimulation were significant. Oxytocin release was delayed during 8-mA treatments. Current treatments did not affect prolactin concentrations or animal health.

The Cornell group also examined the effects of three intensities of current (4, 6, and 8 mA; 1.6, 2.4, and 3.2 V) on milk production, milk composition, health, and levels of hormones normally released at milking in cows. No significant changes in health, hormone levels, or milk production or composition were seen after cows were exposed to electrical current. Once more, cows quickly became acclimated treatments.

In order to randomize the exposure of cows to electrical current and eliminate their ability to avoid exposure to treatments, Gorewit et al. (1984a) performed the following experiment. Holstein cows were assigned to two groups of four each. Treatments were 4 mA (3.5-3.8 V) or no current for four 96-hour periods. The current was applied across electrodes penetrating the hide of the animals, one electrode on each side of the spine in the lumbar area. For 5 minutes current was given for 30-second durations between 30-second rest periods. Cows received current every 4 hours for four 24-hour intervals. No individual cow received current at the same time every day. Milk yield was reduced 0.16 kg (0.32 lb) per milking by exposure to a 4-mA current. This decrease was not statistically significant. Percentages of milk fat and milk protein were not changed by current. Overall numbers of milk somatic cells were variable during the experiment. Feed and water consumption were not influenced by treatments. The greatest behavioral response to current was shown upon initial exposure. Cows became accustomed to shock within 24 hours of exposure. By the end of the fourth 96-hour period, behavioral responses to current were almost extinct. It was concluded that exposing cows to 4 mA (3.5-3.8 V) of alternating current in a semirandomized nonavoidance environment for four consecutive 24-hour intervals (96 hours) does not alter milk yield, milk composition, or intake of feed and water.

Gorewit and Aromando (1985) examined the effects of electrical current on cardiovascular responses. They found that normal milking causes the release of oxytocin, which causes an increase in mammary blood flow, and that epinephrine can reduce this normal milking-induced change in blood flow. Cows were tested to see whether they would show a change in heart rate and mammary blood flow upon exposure to current. If electrical shock is stressful, no increase in blood flow during milking would be expected because of epinephrine release. An experiment to determine the effects of 4 mA (3-6 V) of square-wave ac exposure on mammary-gland blood-flow rate, heart rate, and blood pressure of cows at rest and throughout milking was performed. Current was administered to cows through electrodes located near the spine beginning 10 seconds prior to udder massage and throughout milking. Without current, a single rise in mammary-blood-flow rate occurred during milkings, and mammary blood flow increased within 40 seconds of milking — heart rate and blood pressure did not change significantly. Cows subjected to current showed abrupt increases in mammary blood flow rate, heart rate, and blood pressure immediately upon current application prior to milking. A second rise in mammary blood flow occurred during milking within 42 seconds of milking machine attachment. Milk yield was not influenced by current. The experimental data showed that 4 mA (3.6 V) of alternating current applied prior to and during milking does not influence normal physiological changes in mammary-gland blood flow during milking.

USDA-Agricultural Research Service (ARS): As mentioned previously, catecholamine release has been considered to be a causative factor for decreased milk production and lactational inhibition in cows exposed to stress. However, Lefcourt et al. (1982) found no change in plasma concentrations of epinephrine (adrenalin) and norepinephrine in cows subjected to electrical current between milkings. Six cows were subjected to 5-mA-ac treatments starting 10 minutes prior to milking and lasting for 20 minutes. Current was supplied either continuously or intermittently for 5 of every 30 seconds. Voltage was applied to abraded skin on front and rear legs via electrocardiogram electrodes and ranged from 1.1 to 2 V. During intermittent voltage treatment, milking time decreased by 50 seconds and milk yield decreased by 10 percent. Analysis of blood samples revealed no change in norepinephrine, epinephrine, or oxytocin concentrations. Neither the USDA-ARS group nor any other research team has been able to reproduce this drop in milk production since this study was published.

In a subsequent study (Lefcourt et al. 1985), seven cows were subjected to 3.6-mA-ac and six cows to 6.0-mA-ac treatments for 7 days. Current was applied intermittently as described above at both morning and evening milkings. Comparsion of data obtained during the 7-day treatment periods with data obtained during the 5-day pretreatment and 5-day posttreatment period; showed that milk yield, milking time, and Wisconsin Mastitis Test scores were not affected by either treatment. It was concluded that "milk yield can be maintained, at least in the short term, in cows subjected to electrical shock due to power-line problems if dairy producers take exceptional care to accommodate behavioral responses." It should be noted that the original experimental design called for a 12-mA treatment. This treatment was dropped from the experimental protocol after the first set of cows were exposed to 12 mA because of the severe behavioral responses elicited. These responses, if even slightly exaggerated, might have resulted in an animal catching a leg between crossbars normally used to contruct stalls and possibly being injured.

In another study, cows were subjected for 10 seconds to current treatments of 0, 2.5, 5.0, 7.5., 10.0, and then 12.5 mA (Lefcourt et al. 1986). Current was applied between milkings as described above. Norepinephrine concentrations remained unaffected. Epinephrine concentrations increased for two cows during the 10-mA (5-V) treatments. There were transient increases in heart rate immediately after the 10- and 12.5-mA treatments. Milk production was not reduced by any of the treatments in this study.

Production, Reproduction, and Health

Water Bowl Research

Milk is 87 percent water. A reduction in water intake reduces milk production. Feed consumption is also reduced when water intake decreases, thus decreasing milk yields even further.

Washington State University: Craine et al. (1970) found that cows choose to drink less often from water troughs carrying an applied voltage. Water troughs at 3 and 6 V relative to earth were visited 20 and 68 percent less often, respectively, than troughs without voltage. Also, heifers did not drink for more than 8 hours from a water trough with 8 V relative to earth, and then they only drank from the trough reluctantly.

Cornell University: Since 1985, Cornell researchers have emphasized examining the effects of voltage applied between the water source and hooves of cows. A number of long-term and short-term studies have been conducted. Cows were exposed to constant voltages (0.5 to 4 V for 21 days and 3 to 6 V for 2 days) (Aneshansley et al. 1987, Gorewit et al. 1987, Gorewit et al. 1988, Gorewit et al. 1989) and discontinuous voltages (6 V, 12 hours of the day for 7 days; 8-V pulses every 20 seconds, 12 hours of the day for 7 days) (Aneshansley et al. 1988b).

The first water bowl experiment involved 21-day exposures to 0, 0.5, 1.0, 2.0, and 4.0 V. These exposures were preceded and followed by 2-week pretreatment and 2-week posttreatment periods. Water and feed intake, milk yield and quality, and aspects of udder and animal health were monitored throughout the 7-week trial. The path of current was between the mouth and rear hooves. The results of this study indicated no significant differences in milk yield, milk conductivity, milk protein and fat levels, somatic cell counts, feed intake, and water consumption in cows and heifers that drank within 36 hours of their initial exposure to voltage. However, behavioral changes were observed. Drinking was significantly delayed by the application of voltages greater than 0.5 V, and the delays increased with the magnitude of the voltage (fig. 3-2). All of the animals tolerated 0.5, 1.0, or 2.0 V on their water cups without showing deleterious effects. One heifer and one cow did not drink for 36 hours while being exposed to 4 V. These animals were given water from an alternative source and were not exposed further to voltage. Drinking delays in excess of 36 hours were considered to deleteriously affect the cows. Therefore, these delays were considered to indicate a significant effect. The continuous application of voltage to the water bowl may have made adaptation to the voltage easier, as the experience was predictable for the cows (they knew after some time that they would receive current if they drank).

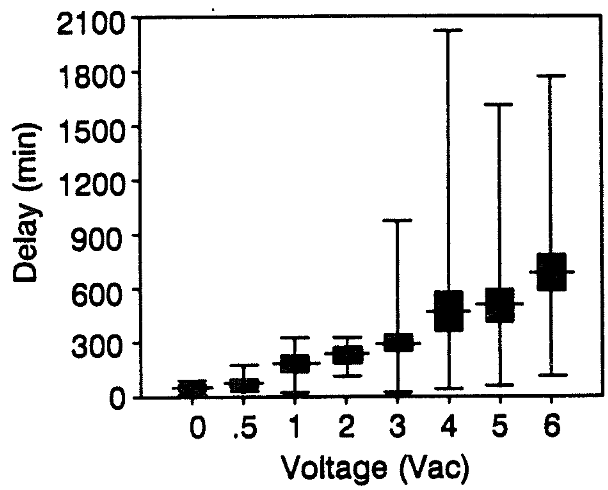


Figure 3-2. Time elapsed before a cow drank 1 gallon of water as a function of the voltage applied between the waterer and the rear hooves of the cow. The extremes at each voltage represent the range of responses for all animals. The solid areas represent the standard errors of the means. (From Gorewit et al. 1989. Reprinted by permission.)

The Cornell team then carried out a dose response trial in which 84 animals were subjected to a range of voltages. Forty-four heifers and forty cows were subjected to one of four treatments (3 to 6 V of alternating current) for 2 days. Four heifers receiving 5.0 or 6.0 V did not drink for 36 hours. Eighty animals did drink, and by the end of the treatment period, water consumption was not significantly different from that before treatment. Again, delays in drinking increased with voltage (fig. 3-2). Of 108 Holsteins subjected to voltage in another experiment, 102 adapted within 2 days to voltages as high as 6 V. Again, adaptation may have been enhanced by the constant presence of the voltage.

Aneshansley et al. (1988b) examined the effects of discontinuous voltages applied to water bowls. In the first of three trials, the effects of 5 V on the water bowls for 50 percent of the day were examined. The second trial examined the effects of 8-V pulses, 1 second in duration and 20 seconds apart, during 50 percent of the day. The third trial examined the effects of having random 8-V, 1-second pulses administered randomly throughout the day, with the number of pulses being approximately equal to the number of pulses generated in the second trial. Voltage exposures were for 7 days. Discontinuous voltages applied for 7 days did not have an impact on economic factors, milk production, milk quality, or somatic cell counts. There were no significant differences in water intake, milk production, milk fat level, milk protein level, or somatic cell counts among the three trials.

Milking Machine Research

New Zealand: There has been concern by dairymen that the milking machine is a source or "carrier" of stray voltage. This concern is based on early reports by Whittlestone (1951), Phillips (1962 a and b) and Phillips and Parkinson (1963) that cows gave less milk when subjected to voltage treatments at the milking claw. However, Woolford (1972) reported no production losses, despite strong behavioral responses to some treatments.

Cornell University: To determine the effects of ac voltages applied through the milking machine, researchers at Cornell exposed eight cows to 0, 4, 8, and 16 V and eight heifers to 0, 2, 4, and 8 V applied through electrodes at the distal end of the milking machine inflations (Aneshansley et al. 1988b). Each cow received all treatments in a Latin square design on four consecutive milkings over 2 days. Behavioral response, milk production, residual milk, machine-on time, milk composition, and current (temporal pattern during milking and maximum value) were recorded. Only behavioral response was significantly affected by differences in the voltage. Behavioral responses (kicking machine off and "dancing") were observed with 8 V for the heifers and 16 V for the cows and only when these voltages produced currents in excess of 6 mA for the heifers and 8 mA for the cows. Current during milking increased with milk flow and with increased numbers of somatic cells.

In another set of experiments, 3 mA of current was applied through the milk to 8 heifers and 5 mA to 8 cows for 14 consecutive milkings. Milk production was not significantly affected by current exposure.

University of Minnesota: Gustafson et al. (1983) showed that the minimum resistances from high- and low-line milking systems are 79.9 and 30.3 kohms, respectively. They also showed that the minimum resistance from the metal claw through the cow to the floor is 3 kohms. Between a milking system and the concrete floor, the voltages that would generate perceived currents (1 mA) through the cow would have to be about 50 Vac and 25 Vac for high and low lines, respectively. Thus, it would be very difficult for cows to receive perceptible currents from these stray voltage sources when bucket milked.

Long-Term and Full-Lactation Research

Two research groups have studied the long-term effects of voltage exposure on behavior, milk production, reproduction, and health of cows.

New Liskeard College, Ontario, Canada: Two trials were performed to examine the effects of voltage on milk production, incidence of mastitis, feed and water consumption, fertility, and behavior. Each trial was run according to a switchback design involving four consecutive 4-week periods (112 days).

Cows were randomly placed into one of six groups between 10 and 14 days postpartum. Each cow was exposed to two 4-week periods of voltage and two 4-week periods without voltage. Voltage was applied between the floor and the water bowls, stanchions, and head rails, the last three types of fixtures being electrically connected. During the voltage periods, cows received the test voltage (1.0 V, trial 1 and 2.5 V, trial 2) from 5 a.m. to 8 a.m. and 5 p.m. to 8 p.m. During the remaining time they received a base level voltage which was 30 percent of test voltage (0.3 and 0.75 volt for trials 1 and 2, respectively). The variation in voltage was used to represent the changes in peak load on most dairy farms.

Parameters measured were voltage level; daily milk production; milking speed; milk composition; water consumption; feed consumption; estrus behavior; behavior, including number of times each animal urinated, defecated, and drank and the amount of time the animal spent lying or standing; and environmental temperature and relative humidity.

In subsequent trials, cows were subjected to up to 5 V. Preliminary analysis of the results showed no significant changes in any of the parameters measured as a function of voltage.

Cornell University: Researchers exposed 40 cows (2d-5th lactation) in groups of 10 to 0, 1, 2, or 4 V for a full lactation. The voltage for each group of 10 was applied between the water bowl and front hooves. Milk production, water and feed intake, reproduction, and animal health were not affected at any treatment level. In addition, analysis of blood samples showed no change in the immune system of the animals. Pregnancies, days-open, abortions, and other reproductive data were normal for all treatments compared to nonexperimental cows in the university dairy herd.

Observations From Dairy Farms

The symptoms shown by animals subjected to stray voltages vary, depending on the pathway through the animals and the magnitude of the voltage. There are three general classifications of symptoms, and they are related to 1) behavior modification, 2) milking characteristics, and 3) production performance. *It must be remembered, however, that many factors other than stray voltage can cause behavior, health, or production problems.* These factors include management and cow handling methods, environmental conditions, nutritional disorders, mastitis control methods, sanitation, and disease. The following are the most common symptoms reported in field observations.

Symptoms Attributed to Stray Voltage

Behavior

Excessive or Unusual Nervousness in Milking Parlor or Stall Barn at Milking: Unusual nervousness at milking is often characterized by cows dancing or stepping around while in the stall. If this behavior is caused by stray voltage, it is usually due to a voltage between the stall pipes (which the cow touches) and the concrete floor (on which the cow is standing). There *must be* contact between the voltage source and the cow. However, dairy farmers are reminded that cows may become nervous for reasons other than stray voltage, such as malfunctioning milking equipment (too high vacuum or inappropriate pulsation ratios) or operator abuse. Even a change in milking routine may result in cows temporarily appearing nervous.

Reluctance To Enter and/or Eagerness To Flee Milking Parlor: Cows subjected to stray voltages in the parlor stalls soon become reluctant to enter the parlor. In extreme cases, nearly all cows have to be driven into the parlor, and they may tend to stampede out upon release. But again, reluctance to enter the parlor is not specific to stray voltage/current problems because cows may be trained to expect the parlor operator to chase them into the milking stalls.

Increased Frequency of Defecation and/or Urination in Milking Parlor: It is well documented that nervous cattle will excrete body wastes more frequently. This phenomenon may be due to contact with stray voltage or to other causes, including operator abuse, presence of strangers, and change to green feed from dry roughages.

Reluctance To Consume Water or Feed: Any class of livestock that is subjected to stray voltage may exhibit the symptom of reduced intake of water and/or feed. Documented cases include dairy and beef cattle, swine, and poultry. Reduced intake may be manifested generally throughout the farmstead or only at a specific waterer or feeding location. Generally speaking, higher voltages are required to limit water or feed consumption than to alter the other behavioral characteristics discussed previously. A rather specific symptom indicative of a probable stray voltage/current problem is the uncharacteristic lapping of water during animals' attempts to meet their demand for water. Farmers must recognize, too, that there are other causes for these behaviors, especially boredom by cattle confined to stalls, change in water quality, the feeding of spoiled or unpalatable feeds, and sickness.

Milking Characteristics

Poor milk let-down, incomplete milk-out (leaving abnormal amounts of residual milk in one or more quarters), and increased milking time are common symptoms noted by dairy farmers having stray voltage/current problems. The physiological mechanisms preventing satisfactory milk-out are not fully understood. Researchers haven't been successful in identifying any significant hormonal changes. However, researchers have demonstrated that the milking-machine-hose/udder pathway, even under high flow rates, is not a likely pathway for electrical currents to the cow.

Poor Milk Let-Down and Incomplete or Uneven Milk-Out: The number of cows affected by and the severity of milk let-down problems appear to be dependent on the level of stray voltage present. When it is high enough to cause the cows to move or step about during the milking process, it is difficult to keep the milking unit properly aligned and adjusted to provide an even weight distribution necessary to promote fast, effective milk-out. On the other hand, a damaged teat canal may result in one quarter being consistently slow to milk-out. Milking machine dysfunction can also result in uneven or incomplete milk-out.

Increased Milking Time: If the stray voltage/current problem is severe enough to affect cows' behavior, such as kicking off the machine, milk-out may be influenced. This problem can result in additional time needed for milking.

Production Performance: Although stray voltage has not been shown to have a direct physiological effect on cows, severe behavioral responses will complicate management practices. As a result, labor efficiency and profitability may be lowered.

Increased Somatic Cell Count and Incidence of Clinical Mastitis: Mastitis, whether clinical or subclinical (indicated by high somatic cell counts), is the result of an infection of the mammary gland. Such infections aren't directly caused by stray voltages. However, if cows' behavior is modified, and if the milking routine is altered because of the change in cows' behavior, what may result is a less satisfactory milking performance, increased somatic cell counts, and increased incidence of clinical mastitis.

Lowered Milk Production: If cows drink less water, consume less food, or develop mastitis, they are likely to produce less milk. Whether or not milk production will be adversely affected by stray voltage depends on the extent to which the cows' behavior is altered and how management compensates. On the other hand, improvement in milk production is not always apparent after a stray voltage/current problem has been corrected (see "Farm Surveys," below).

Attempts have been made to associate the problems of unthrifty and unhealthly animals, poor reproduction, and weak calves with stray voltage. The failure of controlled research to find a direct physiological effect in animals subjected to stray voltages and the absence of documented case studies demonstrating a marked improvement in these traits upon correction of an existing problem lead to the conclusion that there is no direct and causal relationship.

In summary, recall that many nonelectrical conditions can cause symptoms similar to those resulting from the exposure of animals to stray voltage. *A careful analysis of all possible causes of unusual animal behavior and/or poor animal performance is necessary if proper corrective procedures are to be found.*

Farm Surveys

The national and worldwide nature of stray voltage/current problems has been recognized. Australian researchers implied in 1948 (Churchwood 1948) that current resulting from electrical equipment in the milking area may have affected cows negatively. New Zealand researchers published a similar statement in 1962 (Phillips 1962 a and b). Investigators from the Washington State University first reported stray voltages in the United States in 1969 (Craine et al. 1969a and 1970). Canadians reported incidences of stray voltage problems in 1975 (Feistman and White 1975).

Starting in 1980, problems from stray voltages began to surface throughout much of the United States and Canada. Some researchers estimated that 20 percent of all parlor operations were probably affected. Results from a survey of 131 Ontario dairy farms showed that 80 percent of the farms had voltages on the electrical neutral sufficiently high to be a possible problem. Based on the guidelines recommended in this handbook (see chapter 7), from 29 to 36 percent of those farms had a voltage differential between cow contact surfaces sufficient to be of concern. One problem with these statistics is that they are not based on uniform criteria and are therefore somewhat misleading.

Recently Appleman et al. (1987 a and b) surveyed a number of farms in west-central Minnesota. Through the cooperation of four rural electric cooperatives and one investor-owned utility, 394 of the farms were identified as having primary and secondary neutrals disconnected by use of isolation transformers before August 1986. Further investigation revealed that 121 of these farms had dairy herd improvement (DHI) data available for 24 months prior to and 12 months after isolation.

The farms were isolated at the distribution transformer. The general criterion for isolation by utilities was a neutral-to-earth voltage at the barn service entrance above 1.0 V, with an indication that the principal source was off-farm and that animals were able to access the voltage.

Assessment of DHI rolling herd averages (RHA's) showed that milk production per cow during the 12 months after isolation (16,030 lb) was significantly greater than milk production for the year ending 12 months before (15,185 lb) or at the time of isolation (15,418 lb). There was no significant change after isolation for the following traits: Peak milk production for first-lactation and older cows, percentage of cows leaving herd, calving interval, conception rate, heat detection index, somatic cell count (subclinical mastitis), and percentage of cows having a positive somatic cell count.

Upon further analysis of these data, 84 herds were found to be similar to all DHI herds in the region in regard to RHA trend (fig. 3-3). On the other hand, 37 herds (31 percent) showed a marked improvement in RHA after isolation, producing 14,616 lb of milk per cow during the year prior to isolation and 16,444 lb of milk per cow during the first year after isolation. No significant changes were detected for other management traits (table 3-2).

Based on the results of this Minnesota study, it was concluded that 69 percent of the herds isolated failed to show a response in milk production different from that of all herds in the region enrolled in the DHI program. Thus voltages present at the barn service entrance 1) failed to be accessed by the cows, 2) were insufficiently high to result in lowered milk production, or 3) were high enough to cause moderate behavioral problems, but the farm operator had been successful in coping with the problems to the extent that milk production was not increased by isolation. On the other hand, 31 percent of the herds isolated showed a marked improvement in milk production, namely, over 7 lb more milk per cow daily. With milk priced at $11.50/cwt, lost milk in a 50-cow herd was valued at nearly $12,500 annually.

Other researchers studied 31 Indiana dairy farms suspected of having stray voltage/current problems. Initial voltage values at the barn service entrance averaged 0.5 V, and increased to 1.1 V with electrical equipment turned on. Continuous 24-hour surveillance recordings on nine farms showed 1.5 V. Following the installation of a tingle voltage filter (TVF) on 10 problem farms, there was a 91-percent decrease in voltage from 0.7 to 0.06 V. Nine of ten TVF herds showed improvement in individual and group behavior of cows. Milk production per cow increased 549 lb annually. Annual gross income increased $4,800 in

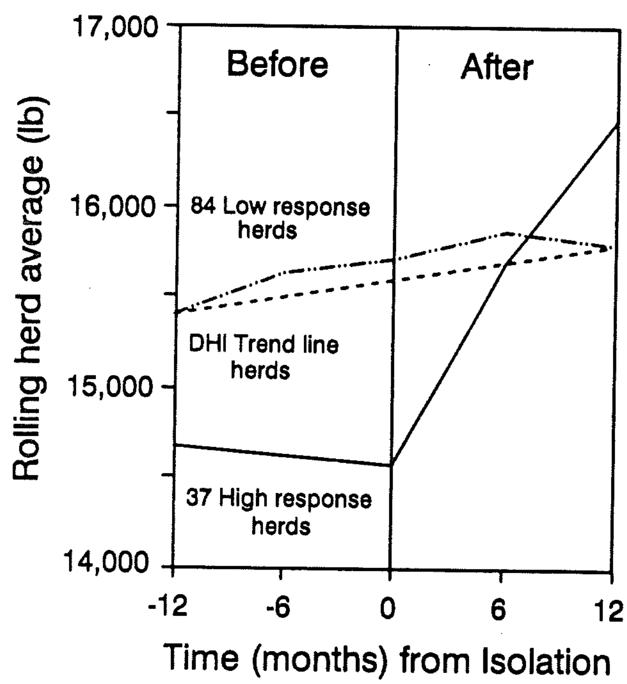


Figure 3-3. Changes in rolling herd average of cows before and after isolation. Herds are separated into two groups; those that showed an abrupt increase in rolling herd average after isolation and those that showed little change. Dairy Herd Improvement (DHI) trend for other herds in the region of the survey is also shown.

Table 3-2. Change in values of management parameters for the upper 31 percent of herds ranked according to percentage increase in rolling-herd-average milk production after isolation

Parameter	For the year ending: 1 year before isolation	Time of isolation	1 year after isolation
Production traits (lb)			
Annual milk/cow	14,687[a]	14,616[a]	16,444[b]
Peak milk, 1st-lactation cows	53.0	55.7	56.7
Peak milk, older cows	70.1	71.9	75.0
Herd size			
No. cows	50.0	51.3	53.5
Cows leaving herd, %	35.6	36.4	37.6
Mastitis			
Somatic cell count	408,300	300,600	340,600
Cows positive, %	26.2	26.8	24.6
Reproduction			
Calving interval, months	13.1	13.1	13.1
Heat detection index, %	48.0	47.0	46.4
Conception rate, %	58.9	59.9	58.2

[a,b]Means within a row differ ($P<0.05$) when superscripts differ.

the 10 TVF herds, which averaged 70 cows per herd.

Problems with Interpreting Survey Data

The most common form of survey involves a series of questions designed to detect or confirm relationships among known or suspected factors. The principal problem with surveys of this type is confirming that a detected relationship is causal, i.e., that one factor caused the second to occur as opposed to both factors being unrelated except by chance or by some shared input from a third agent. The critical problem for establishing causality is to determine the mechanism by which the factors are related. For example, if survey data indicates that an outbreak of food poisoning was caused by eating the daily special at "Ernie's" Friday night, the mechanism can be shown to be contaminated food if, and only if, it can be scientifically established that the food was contaminated and that the contaminated food was capable of producing symptoms of food poisoning.

A more complex type of survey might examine the effect of a treatment on a number of factors. For example, does lowering the neutral-to-earth voltage at the service entrance from 2.0 to 4.0 V to less than 0.5 V result in increased milk production? Besides establishing a mechanism as discussed above, there are two additional critical problems with establishing causality for this type of survey. First, the treatment must be specific. For the example, this would mean that nothing on the farm and no farm operations are altered except for the reduction in voltage at the service entrance. Second, a control group is needed to demonstrate that changes are due to the treatment rather than from random or unknown factors. For the example, this means that milk production would have to be monitored on two sets of identical farms, one set where the voltage is reduced and one set where no mitigation is performed.

The perfect survey situation does not exist and it is obvious that some compromise of the critical problems outlined above is inevitable. Still survey data is very valuable for suggesting new lines of inquiry. In terms of stray voltage/current problems, survey data is less useful. The inability to scientifically establish a direct effect of stray voltage/current on milk production violates the first critical problem with surveys, i.e. establishing the mechanism of a supposed causal relationship. The second critical problem requires that the treatment be specific. Farmers are constantly changing farm operations and when problems are known to exist on a farm, the farmer is even more likely to make changes. Under these conditions, it is impossible to attribute any increase in production to a single change. In figure 3-3, milk production following stray voltage mitigation increased only on farms with initially lower than average production. This suggests that these farms were not optimally managed and that the adoption of improved management techniques, which often accompanies intervention of county agents or others, was largely responsible for the increase in production. The third critical problem is the adequacy of the control group. For figure 3-3, as with most stray voltage surveys, no comparison was made to farms where elevated voltages were previously identified but not mitigated.

Factors Affecting Response

Responses of animals to electric current will vary from animal to animal. Differences in responses can be related to each animal's genetic heritage, past exposure to current and other noxious stimuli, and environment at the time of the exposure. The progression of responses as current levels increase — awareness, irritation, pain, and finally death — is similar for all cows. The principal challenge is to determine the maximum current level which results in awareness but not irritation for most cows under normal management conditions. *Therefore, the following discussions will focus on effects of low-intensity currents, i.e., currents that cause awareness or irritation; thus, some of the statements made below are not applicable for high-intensity currents.*

Perception and Interpretation of Stimuli

Cows feel the passage of small electrical currents through their bodies, and all cows have similar capabilities to feel these currents. Therefore, differences in how cows respond to current depend not on their ability to feel the current but, instead, on their perception and interpretation of it. One factor which influences how noxious stimuli like exposure to electrical current are perceived is the genetic heritage of the animal. In humans, responses to noxious stimuli vary from individual to individual, and genetic makeup and/or psychological profile can be correlated to type and degree of response. In cows, it has been shown that the level of current necessary to elicit behavioral changes varies from cow to cow. Of cows tested, a small percentage, less than 3 percent, showed behavioral changes at relatively low current levels. It is impossible to determine to what degree the sensitivity of these cows was due to genetic heritage or to past history. However, because the currents were administered under experimentally controlled conditions, differences in responses were not due to changes in the circumstances under which the currents were administered.

Prior experiences will most definitely influence how a cow responds to current. For example, the response to any novel stimulus will be exaggerated, and the initial response of cows to a very low intensity electric current is often exaggerated and sometimes even appears theatrical. If the current is sustained, the cows quickly adapt; and after a period of minutes, behavior appears normal. If, instead, currents of short duration are repeated, the greatest response is at the onset of the stimulus, and after a few exposures, even the response to the onset of the exposure is gone. A cow's history will also influence how she responds to electrical currents. Previous traumatic experiences will tend to diminish responses to currents. Furthermore, cows have often had prior exposure to electrical currents because of the accepted use of trainers and electrified fences. Perhaps electrical current is perceived as a minor irritation when compared with the trauma of dehorning or calving. Sometimes the particular way in which an animal is raised can influence its perception of the world. For example, chickens raised in small cages and then allowed to enter a large yard will initially express a preference for the confining cages. In contrast, chickens raised in a large yard will be quite distressed when placed in cages. There are probably many such environmental factors which can potentially influence a cow's responses to electric stimuli; however, it is difficult to identify specific factors and next to impossible to determine the relative importance of these factors in terms of their influence on responses to electrical stimuli.

Predictability and Controllability of Stimuli

Predictability and controllability of stimuli are important concepts which help us to understand how cows perceive and interpret electrical stimuli. Predictability involves the ability of a cow to predict when an exposure to current will occur. Controllability has to do with whether the cow can avoid the exposure. Both predictability and controllability are continuous functions with two extremes. One extreme for predictability is for the exposure to be associated with some easily recognizable event, e.g., attachment of the milking machine. The other extreme is that exposures are totally random, occurring at any time or place. The extremes for controllability are absolute control at essentially no cost in effort and no control regardless of energy expended.

Cost, or energy expenditure, is an important aspect of controllability. Often a noxious stimulus can be avoided if the animal is willing to expend the necessary time and energy. For example, shade might be available on a hot and sunny day if the cow is willing to leave the pasture and return to the barn.

The interactions between predictability and controllability are actually much more important in terms of responses to current than is either factor alone. One of the most distressing combinations arises when the advent of exposure is easily predictable but totally uncontrollable (or unavoidable). The distress is further increased if for some reason the animal believes the exposures can be avoided when in reality they cannot be avoided. Such a circumstance arose in an experiment where two monkeys in adjacent cages were shocked. One monkey could avoid the shocks if he pressed a button after hearing a buzzer. The second monkey was shocked whenever the first monkey was shocked, i.e., when the first monkey didn't bother to press his button. The second monkey became quite distressed. On a dairy farm, electrical stimuli are likely to be reasonably predictable.

Exposure to electrical currents depends on the existence of a voltage source. This voltage source will determine where and how exposures occur. Cows will normally know in which building they will be exposed and may even be able to reliably predict when each exposure will occur. The ability to predict exposures is not a problem by itself, as prior warnings tend to reduce the impact of noxious stimuli. Only when there is an appearance of controllability does predictability become a problem. For example, a cow might know that there is a good chance of her being exposed if she enters the milking parlor. She may decide to avoid the exposure by not entering the milking parlor. The farmer then force her into the parlor. Thus, the apparent ability of the cow to avoid the exposure has been thwarted. Forcing the cow into the parlor under these circumstances could result in significant physiological and psychological responses. These responses are much greater than the responses to the current itself. The best way to handle this particular problem is to cajole the animal into entering the parlor rather than forcing her to enter. This example is important for two reasons. First, it demonstrates that animal management techniques can significantly influence how cows respond to stray voltages. Second, it shows that exposure to stray voltages/currents can create secondary problems that have a greater impact on production than the current itself.

Another example of a possible on-farm problem is a voltage potential between the waterer and the floor. When the voltage is always present, the cow knows exactly what causes the stimulus and has absolute control over when each exposure will occur. In cases where the voltage is present at random intervals, the cow can test the waterer and decide whether or not to drink. Because the cow has control over when she will be exposed, the psychological impact of the current is reduced. Under experimental conditions, most cows rapidly adapt to a constant presence of voltage across the waterer, and drinking patterns quickly return to normal. When the voltage is present at random intervals, drinking patterns also return to normal, and there is no difference in drinking patterns between periods when the voltage is present and when it is not. The cows will ignore the currents and drink when they are thirsty.

Genetic Selection

Evidence from stray voltage experiments suggests that as a result of the genetic selection of animals for productivity, the ability of those animals to respond to noxious stimuli has been reduced. In dairy cows, electrical stimuli during milking and between milkings do not cause any significant physiological response despite exaggerated behavioral responses. In other species of animals, electrical stimuli of similar magnitude cause large and easily detectable physiological changes, including increases in heart rate, respiration rate, and levels of stress hormones in blood.

Lactation

In some species, such as humans and rats, physiological and behavioral responses to noxious stimuli are reduced during lactation. It has been suggested that differences in the magnitude of responses are not due to differences in physiological capacities to respond, but may result because lactating animals are not as "aware" of the noxious stimuli.

Learned Behavior

In Pavlov's classical experiment on conditioning, a buzzer was sounded whenever a dog was fed. After a short time, the dog salivated whenever the buzzer was sounded whether or not food was present. Electric shock is an excellent conditioning stimulus and is used extensively as such in scientific experiments. The conditioning aspect of electric shock has important consequences for stray voltage/current problems on farms. First, adverse behavioral changes may actually be the result of shock but may not be directly correlated with individual shocks. Second, even when the shock stimulus is removed by fixing the underlying electrical problem, the animals may continue to show behavior problems. These behavioral problems may have been "learned" or, alternatively, the cow may be responding to some other stimulus which the cow had previously associated with shock, in analogy to the buzzer in Pavlov's experiment.

Animal-Operator Interaction

Dairy cows must be trained to the milking routine. Key aspects during milking are that they stand quietly, allow the udder to be handled without kicking, and avoid defecating or urinating. They should have good milk let-down with minimal stimulation and milk out quickly.

As shown by research under controlled conditions and by many field observations, the primary reason for any loss in milk production by cows exposed to currents of 4.0 to 6.0 mA appears to be due to the operator and the way affected animals are handled. Affected animals may cause milking machine operators to become frustrated and less patient and to employ inconsistent, hurried, and less desirable milking practices.

Table 3-3 shows the extra time required for milking cows exposed to current in a milking parlor. With twice daily milking of 100 cows, the prolongation of the milking routine increases the annual milking labor requirement by nearly 250 hours. Let us assume that in an attempt to make up the time lost, the parlor operator alters the milking routine by taking shortcuts in the washing, drying, massaging, and forestripping of teats before milking and also hurries the teat-dipping procedure after the milker unit has been removed. Likely consequences of these actions are an increase in the number of bacteria remaining on the

Table 3-3. Time required for activities in a double-6 herringbone parlor with detachers, as operated under normal conditions and under stray voltage/current conditions causing cows to kickoff milking units or to delay entering the parlor

Activity	Normal milking	Reattach milking unit	Delay entering parlor
	....	(Seconds/cow)	....
Wash, dry, massage & forestrip teats	30	30	30
Attach unit	13	13	13
Reattach unit	0	12	0
Subtotal	43	55	43
Postmilking teat dipping	9	9	9
Cow entry	10	10	22
Cow exit	10	10	10
Subtotal	29	29	41
Total	72	84	84
Time required to handle 1 cow (min.)	1.2	1.4	1.4
Cows per hour (steady state)	50	43	43
Time required to handle 100 cows	2 h, 0 min	2 h, 20 min	2 h, 20 min

udders and an increase in the incidence of new mastitis infections.

Conclusion

Cows are considered to be more susceptible to stray voltage/current than humans because cows have a lower body resistance. A voltage cannot pose a problem for cows unless they come into contact with the voltage. Even then, the source, path, contact, and body impedances have to be such that the voltage will result in a current that will affect the animals (fig. 3-1). There are several pathways for currents to pass through the cows. The resistances of these pathways have been studied, and the pathway of lowest resistance is from the mouth to the hooves.

Older recommendations for tolerable levels of cow contact voltages (0.5 V (1980) and 0.7 V (1987)) were based on the lowest values for perceived currents and low values for body, contact, path, and source impedances. These past voltage recommendations need to be reviewed in light of recent research. The effects of current (and voltage) on behavioral response and milk production are shown graphically in figure 3-4. The information given in the figure is the consensus opinion of animal scientists representing most of the research completed or under way in the United States and Canada. In general, 1- to 2-mA currents are required to elicit a behavioral response in a dairy cow. These currents correspond to about 0.5 to 2 V. Currents up to 4.0 mA do not appear to inhibit the milk ejection reflex, depress milk production significantly, or increase the incidence of mastitis or other diseases of the cow. Cows must be exposed to at least 4 V on their water bowls before approximately 7 percent of the cows will continue, after 2 days, to drink less

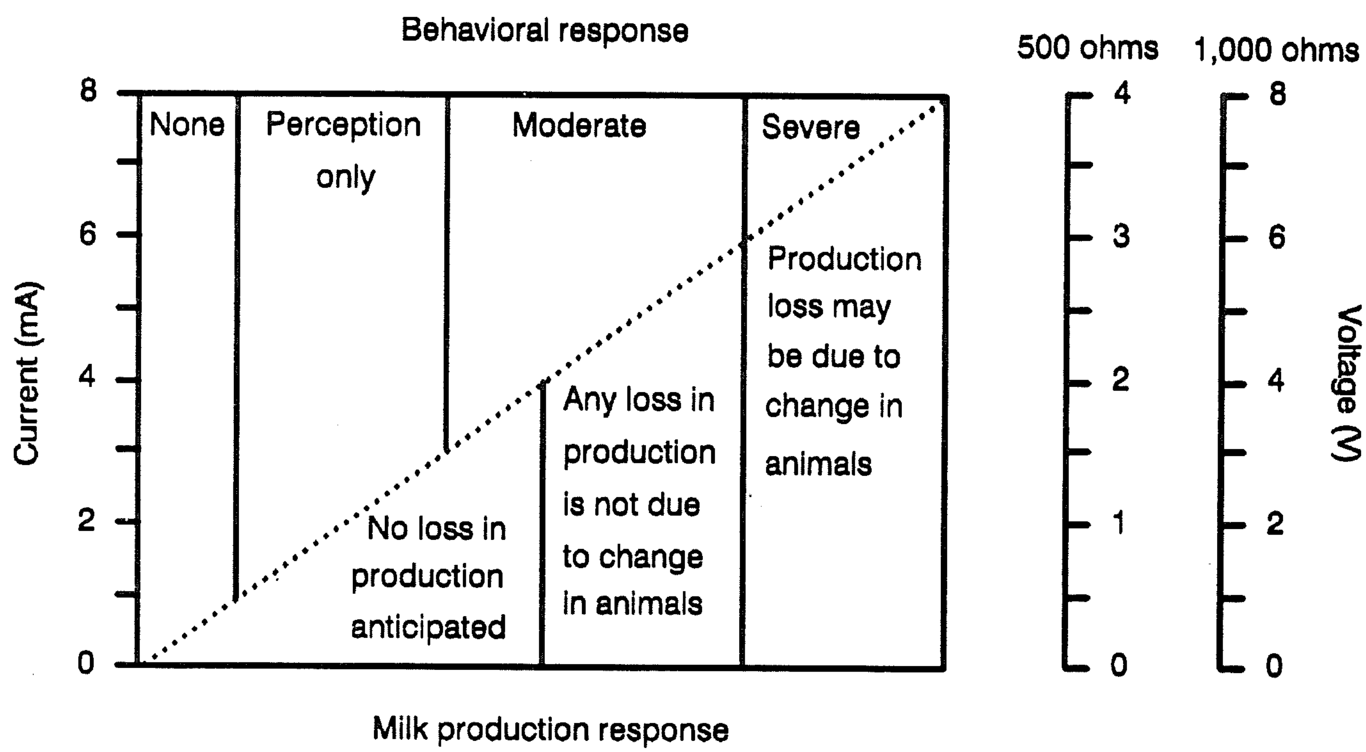


Figure 3-4. Behavioral and milk production responses to increasing current levels. Voltages (right vertical axis) were estimated using a worst-case circuit impedance (500 ohms) and a more realistic impedance (1,000 ohms).

water. Most cows (more than 90 percent) adapt within 2 days to constant voltages as high as 6 V on the water bowls.

Based on current research, cow contact voltages from low impedance sources should be kept less than 2 to 4 V. Cow contact voltages between 1 and 4 V from low impedance sources may cause behavioral effects resulting in increased labor costs and/or inappropriate responses of farmers to the changes in behavior. These possible increased costs have to be balanced against the cost of reducing voltages in the range of 1 to 4 V. Once cow contact voltages reach 1.0 V, a program of routine monitoring should be initiated to ensure that the voltages do not increase significantly.

It is doubtful that the milking machine plays a role in the exposure of cows to stray voltage. The voltage necessary to override the resistance of the milking path would be in excess of neutral-to-earth voltages.

Since cows acclimate physiologically and behaviorally to the current or voltage levels mentioned herein, it is very doubtful that they would react differently upon continuous long-term (more than 50 days) or intermittent long-term current exposure (more than 96 consecutive hours) to those currents.

Preliminary results from long-term experiments (21-day, 28-day, and full lactation exposures) support this conclusion.

As mentioned earlier, cows experience various health problems, including mastitis. Mastitis is a fact of life in the dairy industry, and it is caused by infection of the udder and not electricity.

It should be reemphasized that factors such as mistreatment of cows, milking machine problems, disease, poor sanitation, and nutritional disorders may cause cows to manifest any of the symptoms that are associated with stray voltage/current problems.

Animals are quite variable in response to a specific current. Minnesota researchers found that mouth opening is a specific, current-elicited response for the mouth-to-all-hooves pathway. No responses were observed during control (no current) trials; specific avoidance responses were exhibited 13.8 percent of the time at 1.0 mA of current, 30.0 percent of the time at 2.0 mA, 92.3 percent of the time at 4.0 mA; and 98.4 percent of the time at 5.0 mA.

The voltage required to elicit a response depends on the resistance of the pathway taken by the current through the cow's body. A number of such pathways have been examined. Differences among pathway resistances, including cow contact resistance, have been shown to be as great as sixfold or greater. While some pathway resistances approach 1,000 ohms or more, worst-case resistances of specific cows on specific farms may be as low as 500 ohms. Voltage levels required to elicit the various behavioral responses are shown in figure 3-4.

Behavioral responses to stray voltage vary by cow and circumstance. Variations in responses are due to how the cows perceive current and not to differences in the ability of cows to feel current. Some important considerations in dealing with behavioral responses to electrical stimulation are 1) that the farmer's reaction to behavioral changes may magnify existing problems or even create new and more serious problems and 2) that even when the stray voltage is eliminated or effectively suppressed, behavioral problems may continue because of the effects of conditioning.

We also consider 500 ohms to be a conservative estimate of total source and path impedances. Adding these two impedances results in an estimate of 1,000 ohms for the more realistic impedance (table 7-2).

Neutral-to-Earth Voltages

Neutral-to-earth voltages are a consequence of the mechanisms used to distribute electrical power, notably, the periodic connection of specific wires with the earth (ground) to allow electric faults and lightning strikes to be dissipated in the earth with minimal harm. Excessive neutral-to-earth voltages can result from normal interactions in the electrical power distribution system, as well as from flaws in the electrical system. Neutral-to-earth voltages approach zero only under unusual circumstances.

Factors which normally affect neutral-to-earth voltages on a specific farm are voltages and phases in distribution lines, type of distribution transformer(s), load balance along the distribution lines and within farms, impedance of the earth, and impedances of wires and connectors within the electrical distribution system. Because of the complexity of the interaction of these variables, it is tempting to try to classify problems as "on-farm" or "off-farm." Unfortunately, this is not really possible. Often problems are the result of interactions between on-farm and off-farm factors. However, in the majority of cases, excessive neutral-to-earth voltages are the result of flaws in the electrical system which can be either off-farm, e.g., a high-impedance distribution neutral wire, or on-farm, e.g., an electrical fault on the farm (or on an adjacent farm).

Determining the actual source(s) of an elevated neutral-to-earth voltage requires specific knowledge of local on-farm and off-farm electrical systems as well as a thorough understanding of electrical power distribution systems in general.

Leakage or Coupled Sources

Because it is usually moist and dirty, the farm environment often leads to the development of leakage paths across normally insulating structures. These leakage paths almost always have a high resistance; however, a meter with a high input impedance may measure voltages across these paths. Capacitive coupling between circuits and/or structures may also lead to the existence of measurable voltages. To differentiate between a true problem voltage and a high resistance leakage/coupling source, it is necessary to place an electrical load across the two points of contact. A 1-kohm resistor is an appropriate load (chapter 5, "Detection and Measurement").

Physiological and Behavioral Effects

Cows and humans appear to be equally sensitive to electric current; i.e., both respond similarly to similar current levels flowing through their respective bodies. However, cows are much more susceptible to stray voltages because the body impedances (resistances) of cows are much lower than those of humans. In accordance with Ohm's law, therefore, a given voltage across a lower body impedance results in a larger current.

One critical problem faced by stray voltage researchers was to determine the current levels that can be perceived by cows and, more importantly, the levels that cause irritation and economically significant physiological or behavioral responses.

Because cows cannot tell a researcher when they perceive a current, researchers looked at responses they could measure, such as physiological responses or changes in behavior. They found that the magnitude of current needed to elicit minimal behavioral responses in cows is very similar to the lowest currents that can be perceived by humans. The lowest current which causes a detectable change in behavior varies from cow to cow and depends to a lesser degree on the points of contact, e.g., mouth to four hooves or front leg to rear hock. Similar variations are found for perception in humans.

The voltage needed to deliver these currents depends on the body impedance of the cow, the contact impedances between the cow and the conductive structures, any impedance of the conductive structures, and the impedance of the voltage source. A very conservative estimate for a worst-case total-series impedance would be to assume that all impedances are zero except for body and contact impedances. Thus, it was necessary for researchers to determine values for body and contact impedances.

Sensitivity to Electric Currents

The effects of electric current on cows depend on the characteristics (magnitude, duration, and waveform) of the current, the electrical properties (impedance) and sensitivity of the cows through which the current passes, and the environmental conditions. Furthermore, the sensitivity of cows can vary depending upon their past experiences. In humans, current levels equivalent to those associated with stray voltage are perceived as one or more of the following: Vibration (tingling), burning sensations, or pain. We can only assume that perceptions of cows are similar.

Electrical Currents That Affect Dairy Cows

The ultimate source of most stray voltages is the power distribution system, i.e., the system that distributes 50/60-Hz alternating current. However, we cannot arbitrarily dismiss currents of other types of waveforms. If the magnitude and duration of any electrical event are sufficient, it can affect an animal. Present research strongly suggests that the responses of animals to other forms of electrical energy will be similar to or less severe than responses to 50/60-Hz alternating current when comparisons are made on the basis of energy content (I^2t, where t=time). Responses to direct currents seem to be attenuated and will depend on the manner in which the current is turned on and off.

Impedance of Cows

The absolute maximum current that a stray voltage can produce is that voltage divided by the sum of the contact and body impedances. Recall that animals respond to the current produced by a voltage and not to that voltage directly. A number of studies have been carried out to characterize impedances for cows. Impedances vary from cow to cow and depend on the points of contact, e.g., mouth to all four hooves or front leg to rear leg. Under conditions likely to be encountered on a farm, a conservative estimate for contact plus body impedances is 500 ohms. A more realistic estimate for total circuit impedance is 1,000 ohms (table 7-2).

Normal Cow Behavior

Cows differ widely in temperament. Some are always gentle; others are quite active, alert, and somewhat nervous under normal conditions and very excitable under stress. Most cows exhibit normal behavior patterns and respond to kindness and superior herd management; from time to time, however, a few animals in every herd develop behaviors which interfere with regular herd routine.

Stray voltage/current problems can accentuate differences in temperament. However, other management problems can have similar effects. Concentrating animals, by decreasing the surface area per animal, or introducing new animals into the herd, can increase aggressiveness in the herd. Most cows kick because they are frightened, are in pain, or have been mistreated. Tail-switching is sometimes used to express intense emotion. Restrained animals in a fearful situation tail-switch more than usual as they struggle against restraint. Cows are often called creatures of habit. They notice and respond to *any* unusual change in their routine.

Behavioral Responses to Current

Scientists have sampled groups of cows and determined the currents necessary to elicit different types of behavioral responses. Cows were subjected to currents under controlled experimental conditions that were designed to replicate stray voltage/current problems that might exist on farms. Researchers looked at factors such as the magnitude of, and duration of exposure to, currents as well as when and where currents were administered. The data obtained provide a basis for estimating the statistical distribution of response-eliciting currents for all cows. Like any

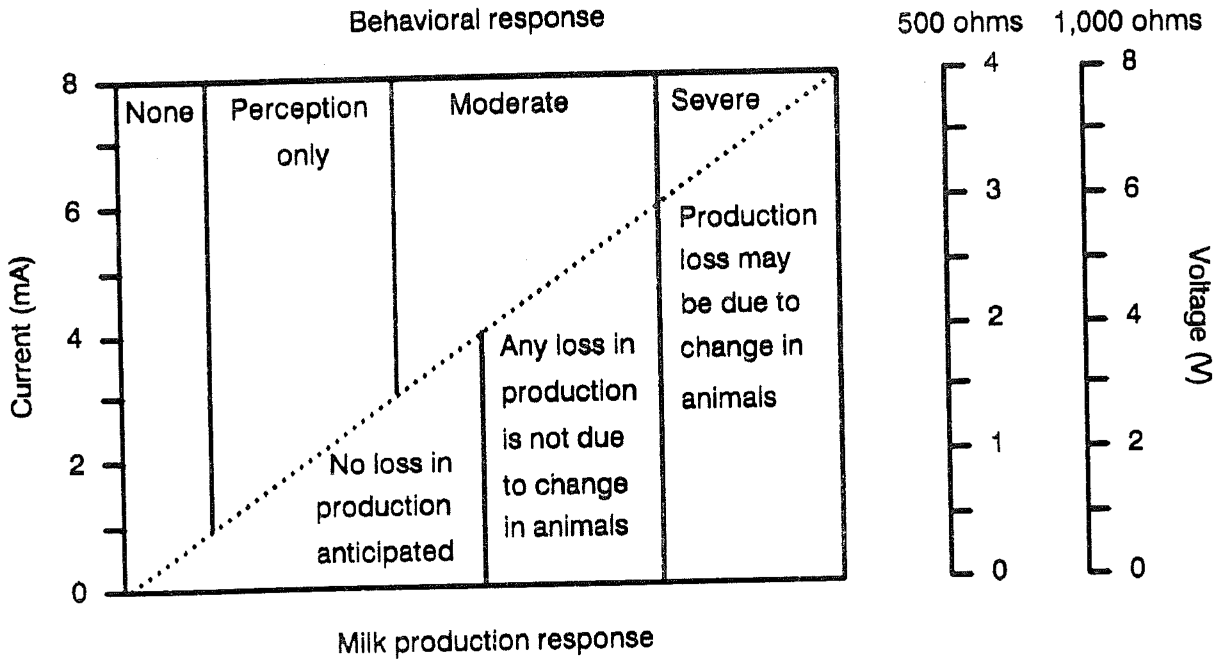


Figure 7-2. Behavioral and milk production responses to increasing current levels. Voltages, on the right, were estimated using a worst case circuit impedance and a more realistic impedance.

statistical distribution, the distribution will have extremes represented by a very small percentage of animals.

In the experiments, a small percentage of cows, less than 3 percent, showed behavioral changes at relatively low current levels. It is impossible to determine to what degree this variation is due to genetic heritage or to the cows' history. However, because the currents were administered under experimentally controlled conditions, we can rule out the possibility that the differences in responses were due to changes in the circumstances under which the currents were administered.

Prior experiences will most definitely influence how a cow responds to current. For example, the response to any novel stimulus will be exaggerated; thus, the initial response of cows to even a low-intensity electric current is often exaggerated and sometimes even appears theatrical. If the current is sustained, the cows will quickly adapt; and after a few minutes, behavior will appear normal. If, instead, currents of short duration are repeated, the greatest response will be at the onset of each application of current; and after a few episodes, even the onset will not elicit a response. A cow's life history will also influence how she responds to electrical current. For example, previous traumatic experiences will tend to diminish responses to current.

Although cows do not respond uniformly to electrical currents, 97 percent of cows tested showed a general uniformity in their behavioral responses to currents of different intensities (fig. 7-2).

Physiological Responses to Current

Researchers have measured physiological variables such as heart rate and endocrine variables such as levels of oxytocin, catecholamines, and prolactin in plasma in a number of stray voltage experiments on cows. In general, no meaningful change in any physiological or endocrine variable was detected. A few cows did show questionable responses, but only when current levels exceeded 8 mA.

Factors Influencing Responses to Stray Voltages

Predictability and Controllability of Stimuli

Predictability and controllability of stimuli are important concepts which help us to understand how cows perceive and interpret electrical currents. Predictability involves the ability of a cow to predict when it will receive a current flow. Controllability has to do with whether the cow can avoid the current. The extremes for controllability are absolute control at essentially no cost in effort and no control regardless of energy expended. One of the most distressing situations for an animal is to be able to readily predict but be unable to control (avoid) exposure to current flow. The distress is compounded if for some reason the animal believes the current could be avoided when in reality it is unavoidable.

For example, a cow may know that she has a good chance of receiving an electric shock if she enters the milking parlor, so she decides not to enter the milking parlor. The farmer, however, forces her into the parlor, thus thwarting her apparent ability to avoid exposure. Forcing the cow into the parlor under these circumstances could result in physiological and psychological responses that could be even more damaging than the response to the shock itself.

Genetic Selection

Evidence from stray voltage experiments suggest that the process of selecting animals for production has resulted in animals whose ability to respond to noxious stimuli has been reduced.

Lactation

In some species, such as humans and rats, physiological and behavioral responses to noxious stimuli are reduced during lactation.

Learned Behavior/Conditioning

The conditioning aspect of electric shock has important consequences for stray voltage/current problems on farms. Adverse behavior may be learned or, alternatively, cows may be conditioned to respond to some stimuli indirectly associated with shock. Even when the shock stimulus is removed by fixing the underlying electrical problem, the animals may continue to respond to the stimulus they had previously associated with shock.

Animal-Operator Interaction: Dairy cows must be trained to the milking routine. Key aspects during milking are that they stand quietly, allow the udder to be handled without kicking, and avoid defecating or urinating. They should have a good milk let-down response with minimal stimulation and milk out quickly. When currents passing through animals range from 3.0 to 6.0 mA, any loss in milk production appears to be primarily due to the way the operator handles the animals. As indicated by experiments under controlled conditions and by many field observations, animals affected by such currents may cause the operator to become frustrated and less patient and thus employ inconsistent, hurried, and less desirable milking practices.

Mastitis

Attempts have been made to link mastitis with stray voltage. Mastitis is a fact of life in the dairy industry. Mastitis is caused by infection of the udder and not electricity. Animal susceptibility and treatment as well as milking and hygiene practices are directly related to problems with mastitis. Electrical current can affect the incidence of mastitis only indirectly. For example, a milking machine kicked off by a cow in response to current exposure may be reattached without first being cleaned.

Caveat

It should be emphasized that factors such as mistreatment of cows, milking machine problems, disease, poor sanitation, and nutritional disorders may cause cows to manifest any of the symptoms that can be associated with stray voltage/current problems.

Conclusions

Older recommendations for tolerable levels of cow contact voltages (0.5 - 0.7 V) were based on the lowest values of perceived current and low values for body, contact, structure, and source impedances. These past recommendations need to be reviewed in light of recent research on the economic impact of electrical currents. Recent research indicates that there are no direct changes in production, reproduction, or animal health for currents below 6 mA. Furthermore, no evidence has been found that such currents adversely affect the levels of hormones naturally released during milking and stress. Currents between 3 and 6 mA do elicit some moderate behavioral changes that might require an additional investment of time from the dairy operator. Using the estimates for worst case and realistic impedances, these currents translate to voltages of 1.5 to 6 V. However, it also appears that the large majority of cows probably do not demonstrate problem behaviors until voltages are above 3.0 to 4.0 V. Direct economic effects, including reductions in milk yield, have been shown for a small percentage of cows (7 percent) at voltages of 4.0 V and above.

In addition, experiments involving long term (full lactation) exposures of cows have shown that cows quickly became acclimated both physiologically and behaviorally to constant and intermittent currents below 6 mA.

Mitigation

Mitigating existing stray voltage/current problems and preventing their future development demand careful consideration of the electrical sources and the characteristics of the corrective and preventetive procedures or devices that might be used, including their costs. Effects of any mitigation technique on the electrical power distribution system under normal and fault conditions must be considered. Approaches for controlling neutral-to-earth voltages are outlined below and discussed in detail in chapter 4 of this handbook.

Voltage Reduction

If analysis shows a troublesome level of neutral-to-earth voltage due to such conditions as 1) high-resistance neutral or grounding connections (either on or off the farm), 2) neutral imbalance currents on or off the farm, 3) undersized neutrals, and 4) fault currents to earth or to equipment grounding conductors, corrections can be made and the remaining voltage assessed.

Four-Wire System

If the farmstead system contains long secondary neutrals, an option of using a four-wire service to a building is allowed by the National Electrical Code. In a four-wire system, the grounding bus is not connected to the neutral bus at a building service; a fourth wire is used to carry the ground back to the primary service where the grounding and neutral buses *are* connected and grounded to earth. The four-wire system will reduce the contribution of the secondary neutral drop to the neutral-to-earth voltage at the building service.

Active Voltage Suppression

Since voltage is produced by current flow through a system impedance, a second source of current can be used to null or cancel the original source at a point in the system. One way to mitigate neutral-to-earth voltage is to deliver a controlled current to earth. Voltage between a point in the neutral/grounding system and an isolated reference ground or grounds is used as the input to a differential amplifier. Current delivered to a remote-grounding-electrode system is then adjusted to null out the measured neutral-to-earth voltage.

Gradient Control

Gradient control by equipotential planes will negate the effects of all neutral-to-earth voltages in livestock facilities if they reduce the potential differences at all possible animal contact points to an acceptable level. Gradient control is used by the electrical industry to minimize the risk of hazardous step (foot to foot) and touch (hand to foot) potentials under fault conditions at substations and around electrical equipment. In addition to protecting people, animals, and equipment under fault or lightning conditions, properly installed equipotential systems in livestock facilities can solve stray voltage/current problems.