UNIVERSITY OF MINNESOTA

Dairy Extension
Department of Animal Science
101 Haecker Hall
1364 Eckles Ave.
St. Paul, Minnesota 55108
(612) 373-1014

Dairy Update

November, 1984
Issue 70

SOURCE OF STRAY VOLTAGE AND EFFECT ON COW HEALTH AND PERFORMANCE[1]

R. D. Appleman, Department of Animal Science and
R. J. Gustafson, Department of Agricultural Engineering

ABSTRACT

In dairy cows, two distinct and important aspects of the interrelationship between stray voltage problems on the farm and dairy cow productivity can be identified. One is behavioral modification that increases in intensity when currents associated with neutral-to-earth voltages above .7 V find a pathway through the cow. The other is immediate endocrine response. Results of research are less clear on the current necessary for the latter to occur; it may require 8 mA or more. This implies, depending on the pathway and the cow's pathway resistance, that voltage difference between two cow contact points must exceed 3 V. Resistance of different cow pathways range from 350 to 1700 ohms. Milk production is more likely to be affected adversely when cows are subjected to shock patterns that are both intermittent and irregular. Less than 10% of the dairy cow population are thought to perceive any electrical currents upon contact with conductive grounding equipment provided voltages on the farm electrical neutral system remain below .35 V. This paper also identifies various sources of stray voltage problems and discusses appropriate procedures for correction.

Accepted for Publication in the Journal of Dairy Science, August 23, 1984.
[1] Minnesota Agricultural Experiment Station Scientific Journal Series No. 14,016.

Table of Contents

INTRODUCTION

Many different problems associated with management and milking of dairy cows occur when relatively small currents of electricity pass through cows' bodies. Producers are experiencing cow health problems and lowered milk production because of currents from "stray" voltages.

Stray voltage is known by several names: neutral-to-earth (NE) voltage, neutral-to-ground voltage, tingle voltage, extraneous voltage, transient voltage, and metal structures-to-earth voltage. The problem arises from a voltage at an undesirable intensity between two animal contact points.

The concept of stray voltage is relatively simple electrically although sources can be varied and complex. It is likely the number of stray voltage problems will increase as farm operations increase in size and sophistication, as farmstead electrical wiring systems deteriorate or become obsolete, and as electrical loads on rural distribution systems increase unless appropriate action is taken.

The purpose of this paper is to present problems reported, discuss briefly effective diagnostic and corrective procedures, identify what is known about effects of stray voltage on cattle, review briefly appropriate prevention and problem correction procedures, and discuss what still is unknown about its effect on livestock.

Location and Prevalence.

The national and worldwide nature of the problem has been recognized. An Australian researcher (4). implied in 1948 that current resulting from electrical equipment in the milking area may have affected cows negatively. Phillips (29), in New Zealand, published a similar statement in 1962. Craine et al. (9, 10) first reported stray voltages in the US (Washington) in 1969. Feistman and White (14) reported its presence in Canada in 1975.

About 1980, problems from stray voltages were being identified throughout much of the US and Canada (1, 7, 35). Cloud et al. (5) in 1980 and Williams (40) in 1981 estimated that 20% of all parlor operations probably were affected. Rodenburg (32) surveyed 131 Ontario dairy farms and concluded that 80% had voltages on the electrical neutral sufficiently high to be a potential problem. Based on current guidelines, from 29 to 36% of these farms had a voltage drop between cow contact surfaces sufficient to be of concern.

Field Observed Responses.

A variety of cow responses to stray voltages have been reported from farm case studies. A comprehensive list was developed by Williams (39). Other workers have verified the list through case farm studies (1, 12, 19, 24, 34, 37). Commonly cited cattle responses include: 1) intermittent periods of poor production; 2) unexplained poor production; 3) increased incidence of mastitis; 4) elevated somatic cell counts; 5) increased milking times; 6) incomplete milk letdown; 7) extreme nervousness while in the milking parlor; 8) reluctance to enter the milking parlor; 9) rapid exit from the parlor; 10) reluctance to use water bowls or metallic feeders; and 11) altered consummatory behavior ("lapping" of water from the watering device).

The observed effects of stray voltage can be classified into four general areas: effect on milking performance and behavior, effect on herd health, effect on nutritional intake, and effect on production. Pertinent research related to these four general areas is addressed later in this paper.

Other factors such as mistreatment, milking machine problems, disease, sanitation, and nutritional disorders can create problems which also manifest themselves in the above 11 symptoms. A careful analysis of all possible causes is necessary if the proper corrective procedure is to be found.

STRAY VOLTAGE SOURCES

Any electrical condition that sustains a potential difference of sufficient magnitude between any two animal contact points may create a stray voltage problem. Stray voltages associated with the electrical distribution network and the farmstead wiring system can be separated into several categories. In the field the contribution from all sources will be superimposed, and their interactions can make an accurate diagnosis difficult. If the contribution from each source can be identified clearly and measured, the diagnosis is easy, and the appropriate corrective measures can be determined readily. However, a good understanding of sources and their interactions is necessary.

Seven potential sources of stray voltage are listed herein (16), and discussed in detail by Gustafson and Cloud (17). The first two problems discussed result from forces originating off farm. The remaining five causes originate on farm. Depending on the region, off-farm problems may be involved in approximately two-thirds of all problem farms. Rodenburg (32), in Ontario, found the principal sources of stray voltage on 76% of the farms surveyed were attributable to neutral resistance of the distribution system and 5% to on-farm sources. Bodman et al. (3), on the other hand, found that most Nebraska problem herds were the result of on-farm problems.

Off-Farm Causes:

1. Primary neutral current external to the farm.

As the current in the distribution neutral increases, due either to increased load on the single phase tap or the imbalance current in three-phase feeder increases, the primary NE voltage will increase. This can be reflected to a varying degree on a specific farm through the primary-secondary neutral interconnection at the transformer. This contribution on the problem farm can be determined at any specific time by measuring NE voltages with the main farm disconnect open (neutral intact).

2. Primary neutral currents from 240-volt on-farm loads.

As the electrical load on the distribution transformer of the problem farm increases, the increase of primary neutral current will result in increased primary NE voltages which again will be reflected to the farmstead grounding system through the interconnection at the transformer. In the case of a farm near a three-phase feeder, it is possible for an increase in on-farm load to improve the balance on the feeder and thereby reduce the primary NE voltage. A common misconception is to relate an increase of NE voltage associated with operation of equipment on the farm to an on-farm problem. An increase of NE voltage with the operation of "clean" 240-volt loads is a primary NE voltage.

On-Farm Causes:

3. Secondary neutral current in the farmstead wiring system.

A current in any portion of the secondary neutral from imbalance in 120-volt loads is accompanied by a voltage drop. Because the secondary neutral current may be either in-phase or 180° out-of-phase with the primary neutral, the phase relationship between this voltage source and that due to the off-farm or primary neutral source must be considered. A voltage drop created by imbalance current in-phase with the primary will increase the NE voltage at the barn. On the other hand, if the imbalance current is out-of-phase with the primary, the NE voltage at the barn may decrease. If the primary NE voltage exists, an increase of out-of-phase secondary neutral current first will decrease the NE voltage at the barn. As this imbalance current continues to increase, the NE voltage at the barn may diminish to zero and then begin to increase but 180° out-of-phase with the primary. This means the NE voltage at the barn may be 180° out-of-phase with the primary.

4. Fault currents on equipment grounding conductors.

Any fault current flowing in equipment grounding conductors will create a voltage drop on the grounding conductor in addition to the effect of this current flowing in the secondary neutral serving the service entrance. If the fault current is not enough to open the branch circuit protection, it may go undetected for some time. The major effect of the fault current may create a potential difference between conductive objects in contact or adjacent to the faulty equipment and other objects on different equipment grounding circuits. A 10-ampere fault current in 15 m of #12 copper conductor results in a potential difference of .8 volts. This emphasizes the importance of maintaining low resistance equipment grounding. Corrosive environments in livestock facilities can deteriorate electrical connections and increase stray voltage problems as a result of fault currents.

5. Improper use of neutral conductor on 120-volt equipment as a grounding conductor or interconnection of the neutral and grounding conductor at the equipment location.

In agriculture wiring systems the neutral (grounded conductor) and the equipment grounding conductors are bonded together only at the building service entrance. These also are bonded to an acceptable grounding electrode. However, all feeders and branch circuits beyond the building main service must maintain the neutral and equipment grounding separately. This must be done to meet the code requirements of placing no nonfault load current on the grounding conductors.

Reportedly, the practice of neutral and equipment grounding conductor interconnection beyond the service entrance is a relatively common practice in some locations where electrical code requirements are not enforced. This is a violation of the code and may create an additional serious stray voltage problem even though no lethal hazard exists. In this situation the load current will be carried by the grounding conductor (where it is improperly used as the neutral), or by the grounding conductor in parallel with the neutral (where they are interconnected at the device). The additional stray voltage component then is added to equipment equal to the voltage drop for the neutral current between the service entrance neutral bar and the equipment. This is of particular importance in circuits with 120 V motor starting surges as currents may be large.

6. Ground fault currents to earth through faulty insulation on energized conductors or improperly grounded equipment.

Leakage currents to earth from an energized secondary conductor must return to the center tap of the distribution transformer. Significant fault currents to earth are due to insulation breakdown on a conductor or in ungrounded faulty equipment in contact with earth. If such a fault develops, the seriousness of the situation depends on the electrical resistance of the return path from the fault to the grounded neutral system. If this is a high resistance path, dangerous step and touch potentials can be in the area of the fault. These could be at a potential that creates a lethal hazard. They also will affect significantly the NE voltage on the farm and utility distribution system.

7. Induced voltages on electrically isolated conductive equipment.

It is possible for induced voltages to exist on isolated conductive equipment located in an electric field. In dairy facilities, electrically isolated water lines, milk pipelines, and vacuum lines may exhibit a potential difference to other animal contact points as measured with a very high impedence voltmeter. A common source of the electric field in stanchion barns are high voltage cow trainers running parallel to the lines. Any other isolated conductive equipment in close proximity to the electric field source can show a potential difference also.

Because of the high impedence of such a voltage source, the current producing capabilities are small. However, if the equipment is electrically well isolated and has sufficient electrical capacitance, it may provide a capacitive discharge of sufficient energy when an animal shorts it through a low resistance path to earth to cause stray voltage problems.

VOLTAGE PROBLEM VARIATION

Animals are not affected by voltage per se but by the electrical current produced by these voltages (27). The relation between voltage and current is the familiar Ohm's Law: $E = IR$,

where E is the voltage potential (volts)

I is the current flow (amperes)

R is the resistance of the total circuit (ohms).

Measuring the resistance of various pathways through the cow and calculating distributions is needed to discern variability of current flows from an applied voltage (26).

Resistance.

Resistance variability between cows and pathways is evident from the available data. Craine et al. (6, 10), Drenkard et al. (11), Lefcourt (21, 23), Norell et al. (27), Phillips and Parkinson (31), Whittlestone et al. (38), and Woolford (41) reported average resistances in the range of 300 to 1700 ohms for various pathways (Table 1). A combination of differences in methods of measurement, contact resistances, and actual pathway resistances likely explain the six-fold or more differences in resistances between specific pathways.

Norell et al. (27) determined the electrical resistance of eight defined cow pathways on 28 Holstein cows. Significant differences existed between pathways. Contrasts were used to compare pathway resistances including: two vs four hooves; front vs rear hooves; and mouth vs teat. Pathway resistances including four hooves were significantly less than those including two hooves. The resistance of pathways including front hooves only were greater than those including rear hooves only. Resistances of both pathways including mouth-hoof combinations were lower than those including teat-hoof combinations. The mouth-teat pathway was significantly lower in resistance than the teat-hoof pathway combinations. The front-rear hooves pathway resistance was larger than the mouth-hoof combinations but not as large as the teat-hoof combinations.

The lowest resistance for pathways (Table 1) was the front leg-rear leg pathway (21, 23). Metal electrodes plus conducting paste were applied to shaved front and rear hock. This pathway is unrealistic in comparison to on-farm situations because legs are shaved and hooves are not included in the circuit. Norell et al. (27) showed the front-to-rear leg pathway resistance is decreased by approximately 55% when the hooves are not included.

Considerable variation exists between cows for a given pathway (Table 1). Norell et al. (27) used selected percentile limits (10%, 25%, 50%, 75%, and 90%) for each pathway. These data are useful in illustrating differences in current flow between cows from an applied voltage. For example, for a mouth-all hooves pathway,

$$R_{10\%} = 244 \text{ ohms} \quad \text{and} \quad R_{90\%} = 525 \text{ ohms.}$$

In this case, 10% of the cattle exposed to a 1.0 V mouth-all hooves shock would receive a 4.0 mA or greater shock whereas 90% of the cattle would receive a 1.9 mA or greater shock. These data demonstrate a doubled difference in resistance and resulting current flow within the middle 80% of the population.

ANIMAL RESPONSE TO STRAY VOLTAGE

The effect of a specific voltage on dairy cattle is influenced by many factors which combined determine the distribution of current flow through the cow's body, namely: 1) voltage (what is measurable in the field); 2) the resistance of cow's body pathway (discussed previously) and the pathway current sensitivity; 3) condition of concrete, soil, and metallic conductors affecting resistance to "true earth"; 4) resistance of cow's contact points; 5) resistance of the electrical pathway to cow's contact points; and 6) impedance of the source (16).

Because these many factors can not be determined in the field, scientists have determined the current flow necessary to elicit a response, then applied the resistance estimates from research trials to calculate probable voltage necessary to cause an animal to respond.

Three criteria have been used in judging cow response to electric current, namely: behavioral responses, endocrine responses, and change of milking performance.

Behavioral Response.

Norell et al. (26, 27) reported that specific avoidance responses were exhibited 13.8% of the time at 1.0 mA of current. Significant increases (P < 4.0 vs 5.0 mA paired test, namely: 2.0 mA = 30.0% response; 3.0 mA = 69.2%; 4.0 mA = 92.3% response; and 5.0 mA = 98.4% response (Figure 1). No responses were observed during control (no shock) trials suggesting the mouth opening was a specific shock elicited response. Six cows were involved in this trial.

In a separate experiment involving a different group of six Holsteins, cows were trained to press a plate to earn a grain reward. The typical response was a "touch-withdrawal" from the "live" metal plate. Currents between 3.0 and 4.5 mA consistently suppressed touching of the plate. These results suggest that cattle should not be exposed to voltages on farms capable of delivering a 3.0 mA shock.

In a third trial involving four groups of five cows each, cows were subjected to currents of .00, 1.33, 2.66, and 4.0 mA as they crossed a grid prior to entering their milking stall in a side-opening parlor. Cows subjected to the 4.0 mA current took twice as long to cross the grid compared to that required when no currents were present.

Three types of inhibited grid crossing behavior was expressed by cows in the 4.0 mA group. The first type was a brief pause halfway across the two grids (testing). A second type was a "cautious" placement of a front hoof on the front grid. The cow then either proceeded forward or stepped back off the front grid (awareness). The third type of inhibited grid crossing behavior was stepping back as the stall door opened (painful shock).

Drenkard et al. (11) used an udder-all hooves pathway on four cows being milked to obtain behavioral responses at 0, 2, 4, and 6 mA of current. Treatments consisted of current administered during 1 min with alternate on and off times of 5 s each. Scores assigned to each measurement were: 0 = no observed response; 1 = slight response characterized by muscle contraction or foot movement; and 2 = a strong or continuous reaction, such as jumping and kicking. Mean scores for 0, 2, 4, and 6 mA treatment groups were .00, .38, 1.50, and 1.50. These results suggest that some cows can be expected to exhibit a behavioral response to 2 mA currents, and most cows will respond to a 4 mA current.

In another trial (11), six cows received the same current for 14 consecutive milkings. Current treatment of 0, 4, and 8 mA were begun 5 min before cows were prepared for milking and continued for 5 s every 30 s until removal of the milking unit. As expected, each cow responded at least part of the time to 4 and 8 mA treatments. One cow responded similarly to both treatments, and five of six cows displayed stronger responses to the 8 mA treatment.

Lefcourt (21) used a front leg-rear leg pathway, and subjected five cows to an applied incremented current for 30 s. A mild response (cow flinched, became vocal, or showed behavioral changes at least half of four or more repeated trials) occurred, on the average, at 2.47 mA. A distinct response (startle response or raised a leg consistently in repeated trials) occurred at 3.8 mA. One cow reacted mildly at .7 mA current and exhibited an even stronger reaction at 1.0 mA current.

Lefcourt et al. (23) subjected seven cows for 14 milkings to a 3.6 mA shock and six cows to 6.0 mA current (5 s on, 25 s off) from starting preparation to milk until 9 1/2 min after the start of milking. The mean number of behavioral events per cow at 3.6 mA during the preshock, shock, and postshock period were .66, 3.90, and .73. At 6.0 mA, the mean numbers of behavioral events per cow were .67, 5.50, and .69. A seventh cow in the 6.0 mA group had to be removed from the study because of a severe behavioral response that prevented her from being milked. Prior to the start of this trial three cows were subjected to 12.0 mA currents. They could not be approached.

Even though many of the observed cow behavior modifications are associated with the milking process, Gustafson et al. (18) demonstrated that under normal conditions the milking equipment itself is not a likely path of problem currents to the animal. The minimum resistance for this milk line-claw path under milking conditions, for a 9 kg/min flow rate, would be above 47 kohms for a typical stall-barn high line and above 26 kohms for a low line configuration. Resistance of the milk hose from the milk line (receiver) to the machine claw was inversely proportional to milk flow rate. Minimum resistance from the claw through the cow to the floor was 3 kohm. Estimated voltages across this system required to obtain perceptible currents through the cow would be in the range of 25 and 50 volts AC for the low and high line.

In summary, independent research at three stations showed that behavior functions vary in response rate. An indication of the required voltage drop across the animal pathway for a given response can be obtained by combining the current response and pathway resistance data.

For example, because voltage is the product of current X resistance (E = IR), voltages expected to elicit a response from dairy cattle in the mouth-all hooves pathway are: 360 ohms X 3 mA = 1.08 V. A plot of voltage vs response rate for mouth-all hooves shocks is shown in Figure 2. The family of voltage response curves was drawn based on the pathway resistance percentile distribution (27). As an example, this plot indicates that at 1.0 V across the mouth-all hooves pathway, 90% of the population would respond 28% of the time; 50% would respond 50% of the time; and 10% would respond 92% of the time.

The front-rear hooves pathway represents conditions sometimes found when cattle are shocked entering a milking parlor. Figure 3 provides a similar plot of voltage vs response rate. In this case, there is a base response rate of approximately 20%. Above the base rate, effects of the current can be seen. For example, at 2.0 V, 50% of the population can be expected to respond 37% of the time. This represents a 17% response rate above base (27).

Endocrine Response.

Discomforting electric current flows were hypothesized to elicit endocrine responses in cows. Milk secretion and removal are influenced by changes of specific blood hormones. Because hormone concentrations are sensitive to stimuli, electric currents high enough to cause a cow discomfort were assumed also to cause an endocrine response. Thus, research on the effect electrical current has on hormonal response of dairy cows was undertaken at two experiment stations, USDA's Milk Secretion Laboratory at Beltsville MD and at Cornell University (11, 22, 23).

Lefcourt and Akers (22) first measured change of peripheral concentrations of norepinephrine, epinephrine, dopamine, oxytocin, and prolactin while animals were subjected to a 5 mA front-rear leg shock during a single milking. The voltage either remained on for 20 min starting 10 min prior to milking (three cows) or was on intermittently 5 of every 30 s (three cows). Lefcourt et al. (23) submitted 13 cows to intermittent shock for 14 consecutive milkings at either 3.6 or 6.0 mA of current. In both cases, a front-rear leg pathway was utilized.

Drenkard et al. (11), used an udder-all hooves pathway to subject four cows to 0, 2, 4, and 6 mA current that was alternately on and off every 5 s during 1 min. In another trial, they used the same pathway to subject six cows to 0, 4, and 8 mA. Current treatments were begun 5 min before cows were prepared for milking. Treatments consisted of 5 s of current stimulus every 30 s until removal of the milking unit. In the first trial, each treatment was for 2 days; in the second trial, treatments were applied during three 1-wk periods. Results are summarized in Table 2 and discussed herein.

1. Oxytocin. The posterior pituitary gland secretes oxytocin into the blood stream where it is transported to the udder and causes contraction of the myo-epithelial cells and milk ejection (2).

In the New York trial, oxytocin release was delayed during 8 mA current treatments, and applications of 4 mA current had no effect (11). In the first Beltsville trial (22), neither continuous nor intermittent voltage stimulation lowered differential oxytocin responses. On the contrary, intermittent electrical stimulation appeared to amplify peak oxytocin response. In longer experiments (23), oxytocin responses were essentially normal throughout except in the 3.6 mA group where peak oxytocin was delayed slightly. Because milking characteristics remained unchanged, it is difficult to ascribe meaning to small changes of oxytocin responses.

2. Epinephrine and Norepinephrine. The adrenal medulla, which is an extension of the nervous system, produces epinephrine and norepinephrine. Their major function is to regulate metabolic balance and homeostasis. Their secretion can result from stressful stimuli. Epinephrine increases blood glucose, liberates fatty acids from the fat depots, and stimulates adrenocorticotropic hormone (ACTH) release which in turn activates the adrenal cortex to discharge glucocorticoids. Both hormones increase heart rate and blood pressure. Both hormones may constrict the arterioles of certain tissues. Restriction of blood flow may account, in part, for inhibition of the milk-ejection reflex by epinephrine (2).

According to Lefcourt and Akers (22), electrical stimulation had no effect on norepinephrine; and in their trials epinephrine concentrations were low, with only 5% of the samples showing concentrations sufficiently high to be assayed with the methods used. Furthermore, dopamine could not be detected.

3. Prolactin. The anterior pituitary secretes prolactin. Its major function is to promote mammary growth and initiate and maintain lactation. Milking causes prolactin to be released in the blood; this response probably lasts for less than 30 min; and its relationship to continuous occurring basal concentrations in the blood is unknown (2). It is hypothesized, however, that lowered blood concentrations might result in lowered production early in lactation.

Drenkard et al. (11) found no response of prolactin related to treatment in their short trials. In their longer trials, no significant treatment effects were discovered although there was a trend toward higher prolactin response during 8 mA treatment. Lefcourt and Akers (22) found lower prolactin in blood during milking of cows subjected to intermittent shocks. They suggested that milk loss might be intensified from chronic electrical stimulation on farms with stray voltage problems. Later, Lefcourt et al. (23) found opposite results in that prolactin concentration increased when cows were shocked. They concluded that prolactin in cows is not directly affected by electrical shock of the magnitude used.

4. Cortisol. Various stimuli such as fright, pain, or elevated temperature stimulate the outpouring of corticotropin-releasing factor (CRF) from the hypothalamus which, in turn, increases the anterior pituitary secretion of ACTH. High ACTH promotes increased cortisol production and also reduces milk production (2).

In the first New York trial (11), no significant effect on cortisol response was detected; and although there was variability in the data, it was suggested that currents as low as 2 mA may cause cortisol response. In the longer (1 wk) trial, there were significant treatment differences. Elevated cortisol may affect negatively milk production, especially when cows are exposed to 8 mA current for long times.

Milking Performance Response.

Results of milk yield, milking time, and peak milk flow rate for treatment groups in experiments at New York (11) and Beltsville (22, 23) are summarized in Table 3. Cows subjected to electrical currents produced significantly less milk in only one trial, that being the intermittent 5 mA current. Similar intermittent 6.0 or 8.0 mA currents failed to reproduce these results.

Changes of time required to milk cows followed trends expressed by milk yields. When milk yield decreased, milking times dropped; when milk yield increased, it required more time to milk cows. Peak milk flow rate increased in all experiments when milk yield increased.

Additional milking performance results indicated when cows were subjected to electrical currents, the time required to obtain maximum flow rate did not increase significantly (11, 23), and subclinical mastitis scores did not increase significantly (11, 23).

The New York workers (11) found no effect from increasing electrical current on the amount of residual milk remaining in the mammary gland. Furthermore, milk composition (percent fat and protein) was not altered in milk produced by cows receiving shocks.

Most research trials in the US have been designed to subject animals to electrical currents either continuously or on a prescribed intermittent schedule. Gorewit et al. (15) studied the effect of semirandomized AC current exposure on milk production, milk composition, feed and water intake, behavior and metabolic hormones of eight mid-lactation Holstein cows producing 15 kg milk/milking. Cows were assigned to groups receiving 0 or 4 mA current once every 4 h for 4 days in a semirandomized fashion with no individual cow receiving current at the same time every day. After 4 days groups were reversed. The trial was replicated so that all cows received the series of shocks twice. Current was applied for 30 s, then off for 30 s alternately for a total of 5 min. The pathway was two epidermal electrodes in the lumbar region, 15.2 cm from one another on either side of the spinal column. Cows never were milked during current exposure. Results are in Table 4. Milk production was lowered .16 kg/milking (-1.2%); somatic cell count increased (+7.3%), primarily because of one cow with clinical mastitis; water consumption increased 1.6%; and fat percentage, protein percentage, and feed intake were maintained while cows were subjected to 4 mA currents. There were no statistically significant changes in any of the variables.

Behavioral responses (cows arching their backs and moving side to side in the stanchion) occurred upon initial exposure to current. Cows became accustomed to the shock within 24 h of exposure, and behavioral responses were almost extinct by the fourth (96 h) period of exposure. No relationship between concentrations of cortisol and thyroid hormones and current exposure was discerned.

Overmier (28) suggested response to a constant shock may decay rapidly following shock onset. Thus, several short shocks may be more bothersome to the animal than a long shock of the same intensity.

Phillips (30), in New Zealand, discussed his unreported data showing that an irregular, as well as an intermittent, shocking pattern is more likely to be disruptive to normal cow behavior and to lower production. He subjected cows to five shocks during each of 14 milkings and found no difference in production compared to controls. On the other hand, five random shockings applied on only 3 of 14 random milkings resulted in a 6 to 15% drop of milk production. Cows appeared to be bothered as much, or more, by anticipation of the shock treatment as by the shock itself. In these trials, a 3 V shock was applied to a rump-rear hooves pathway.

Summary of Animal Response.

Lefcourt et al. (23) summarized their studies by concluding that "any negative effects of electrical shock on milk production or mammary gland health most likely are not directly related to shock, i.e., physiological responses to shock were minimal and milk yield was generally maintained at normal levels during the shock period. However, the severe behavioral responses to shock would almost assuredly result in management problems and the degree to which milk production would be affected would depend on how dairymen deal with the abnormal behavior." Similarly, Drenkard et al. (11) found little or no physiological response to electrical currents common in stray voltage problem herds. Thus, it appears the primary influence of stray voltage on dairy cow performance is one of behavior modification (11, 21, 23, 26, 27).

Stray voltage problems are minimal in herds where neutral-to-earth voltages during full load conditions (at milking time) remain below .7 V. A reasonable and attainable goal on farms needing correction would be to maintain neutral voltages on the farm grounding system below .35 V. Based on research results to date, less than 10% of the population would perceive the presence of any electrical currents upon contact with conductive grounding equipment at this potential.

PREVENTION AND CORRECTION OF STRAY VOLTAGE PROBLEMS

There are three basic solutions to stray voltage problems: 1) eliminate or minimize the voltage causing the problem; 2) isolate the voltage from any equipment in the vicinity of all potential animal contact points; and 3) install an equi-potential plane that will keep all possible animal contact points at the same potential. Numerous papers address these solutions (3, 5, 13, 16, 17, 24, 35, 37, 42).

The solution or solutions selected depends on: 1) the source or sources of the stray voltage; 2) the magnitude of the stray voltage; 3) the cost of alternative solutions; 4) the physical facilities involved; and 5) the policies of the power supplier.

1. Eliminate or minimize the voltage causing the problem.

If the diagnosis indicates load current on the primary neutral system is a major contributor due to either on-farm or off-farm loads, a careful survey of the distribution neutral by the power supplier is necessary. High resistance connections, breaks in the neutral conductor, inadequate grounding, or broken or high resistance grounding electrode connections will increase the resistance of the neutral system and can create excessive primary NE voltages. The power supplier also should check the imbalance in the three-phase feeder which serves the farm, either directly or through a single-phase distribution tap. It is not possible to balance a three-phase feeder perfectly, but it may be possible to correct a large imbalance enough to minimize a primary NE voltage problem.

If the diagnosis indicates that voltage drops on the secondary neutral system are a major contributor, several corrective procedures are possible. All neutral connections must be checked. Any loose, corroded, or other high resistance connections can cause excessive voltage drops. Decreasing the length or increasing the size of the neutral will reduce the voltage drop. Better balancing of 120-volt loads to reduce the current in the secondary neutral may reduce the voltage drop. If possible, convert all 120-volt motors to 240 volts, particularly the larger motors.

If the diagnosis indicates major contributions from fault currents on equipment grounding conductors, improper use of the neutral as a grounding conductor, or improper interconnection of neutral and grounding conductors or ground fault currents to earth, either on-farm or off-farm, they must be corrected. Strict adherence to requirements of the National Electrical Code on the secondary wiring systems will help to minimize on-farm sources of stray voltage.

If the diagnosis shows a major contribution from the voltage drop on the secondary neutral to the service entrance at the livestock facility, it is possible to isolate the neutral system from the grounding electrode system at the barn. This is done by separating the neutrals (grounded conductor) from the grounding conductors at the service entrance and running a separate grounding conductor to the main farm service entrance. This effectively will remove the contribution of the secondary neutral voltage drop in the barn service neutral.

2. Isolation of the voltage from any equipment in the vicinity of all animal contact points.

If the diagnosis shows a major contribution from the primary neutral, it is possible to isolate this voltage from electrically grounded equipment in the proximity of the livestock. One possibility is operation with noninterconnected primary and secondary neutrals. This is accomplished by removal of the electrical bond between the primary and secondary neutrals at the distribution transformer. It appears Section 97D of the National Electrical Safety Code can be interpreted to allow operation with noninterconnected neutrals if properly done. However, many power suppliers, because of safety and operational considerations (17), will not operate with noninterconnected neutrals.

Another means of primary neutral isolation is installation of a general purpose insulating transformer (240 volt to 240/120 volt) between the distribution transformer and the service entrance serving the livestock facility. The "isolation" transformer can be installed at the main farm service entrance or at the service entrance or entrances serving the livestock facility. If the isolation transformer is located at the barn service entrance, it also may be effective in minimizing a secondary neutral contribution due to imbalance currents. With either option the isolating transformer should have overcurrent protection and should have its case grounded to the source side. All load side conductors should be insulated from the transformer case.

When isolation is used to solve stray voltage problems, it is necessary to remove all conductive interconnections which effectively may bypass the isolation. Some common interconnections are telephone grounding conductors, metal water lines, and feeding equipment between buildings. Any conductive interconnection will reduce the effectiveness of isolation. If isolation is contemplated as a solution, tests should be conducted to substantiate the absence of all conductive interconnections.

Some stray voltage cases reportedly have been solved (primarily in stanchion barns) by isolation of all conductive equipment (pipes, stanchions, etc.) in the barn from the electrical grounding system at the barn service entrance. THIS CAN CREATE A POTENTIAL ELECTRICAL HAZARD. Any electrical fault to this isolated conductive equipment, because it is not electrically grounded, may create a lethal condition. In the interest of electrical safety, all conductive equipment should be grounded electrically through an equipment grounding conductor to the service entrance, particularly if there is electrical equipment involved.

3. Installation of equipotential planes.

The concept of equipotential planes or grounding mats as a solution to stray voltage problems is simple and practical. If all possible animal contact points are maintained at the same potential, there can be no current flow through its body. This may be accomplished by installing a continuous electrically conductive grounding mat in the floor, bonding it to all electrically conductive equipment in the area, and electrically grounding the complete system. Properly installed equipotential planes can be effective in solving stray voltage problems in milking parlors. Animal access to equipotential planes should be through a voltage ramp installed in the access areas.

The use of equipotential systems will solve stray voltage problems in the area they cover, regardless of the source, if they are successful in maintaining the same potential at all possible animal contact points. In addition, they improve electrical safety characteristics of the installation. Equipotential planes are an extension of good electrical wiring and grounding practices. They should be included in the design of all new milking facilities. They also should be considered for all areas where electrically grounded equipment is located in space occupied by livestock or exposed to livestock traffic.

RESEARCH NEEDS

Much has been learned in a relatively short time about the effect of stray voltage on animal behavior and productivity. Physiological responses to relatively small shocks are minimal, and milk yield generally may be maintained. Still, several unanswered questions remain. These include:

1. Is there a carry-over effect after cattle have been exposed to stray voltages for several months before the problem was corrected? Some producers feel that such cattle are stressed and that physiological functions are impaired. Based on results of short research trials with dairy cattle, one would not suspect this to be the case. Still, research with laboratory animals (20, 25, 36) suggests this is a distinct possibility. Long trials involving a full lactation are recommended.

2. To what extent do cattle habituate or become sensitized to electrical shock? Both adaptation processes may occur on farms. Response frequency may change as a result of either adaptation process. Research results thus far suggest that random, intermittent shock applications more nearly simulate field conditions and observations.

3. Do "sensitive" cows have conditions that predispose them to lower resistance and greater sensitivity to current? For example, do cracked or abscessed hooves, open sores on joints or other body surfaces, etc. provide entry points of low contact resistance resulting in current density problems? Perhaps cattle in well managed research herds are not typical of those on the average farm suffering from prolonged exposure to stray voltage.

4. How frequently and to what extent do stray voltages affect other species of farm animals? Are there differences in the pathway resistance and sensitivity among dairy and beef cattle, hogs, sheep, chickens, and turkeys?

Spencer (33) indicates there is a need for more research on the problem, but wonders if it might not be more cost effective and humane if research resources were spent on developing less costly methods of preventing the problem, rather than continuing research on the effect of stray voltage on animals. Animal research related to this problem is expensive. On the other hand, agricultural industries using electricity are faced with litigation establishing liability associated with lowered animal productivity (8). Undoubtedly, industry will determine if more research involving animals will be conducted by their continuing financial support of animal related stray voltage research.

REFERENCES

1. Appleman, R.D., and H.A. Cloud. 1978. Neutral-to-ground voltage problems with dairy cows. Dairy Fact Sheet 21. Agric. Ext. Ser., Univ. Minnesota, St. Paul MN.

2. Bath, D.L., F.N. Dickinson, H.A. Tucker, and R.D. Appleman. 1978. Dairy Cattle: Principles, Practices, Problems, Profits. Lea and Febiger, Philadelphia.

3. Bodman, G.R., L.E. Stetson, and H. Shull. 1981. Investigations of extraneous voltages in Nebraska dairies. ASAE Paper No. 81-3510. Am. Soc. Agric. Eng., St. Joseph MI.

4. Churchward, R.E. 1948. A note on the occurrence of electrical shocks from milking machines and their possible effects on mastitis. Aust. Vet. J. 24:150.

5. Cloud, H.A., R.D. Appleman, and R.J. Gustafson. 1980. Stray voltage problems with dairy cows. N. Central Reg. Publ. 125. Univ. Minnesota.

6. Craine, L.B. 1975. Effects on mammals of grounded neutral voltages from distribution power lines. Inst. Elec. Eng. 75-303-3-IA.

7. Craine, L.B. 1980. Nationwide occurrences of electrical neutral-to-earth voltages on dairy farms. ASAE Paper No. 80-3502. Am. Soc. Agric. Eng., St. Joseph MI.

8. Craine, L.B. 1982. Liability for neutral-to-earth voltage on farms. ASAE Paper No. 82-3510. Am. Soc. Agric. Eng., St. Joseph MI.

9. Craine, L.B., A.L. Betts, and E.W. Greenfield. 1969. Electrical ground currents in Clark County. Div. of Industrial Research, Washington State Univ. Res. Rep. No. 69/16-5.

10. Craine, L.B., M.H. Ehlers, and D.K. Nelson. 1970. Electric potentials and domestic water supplies. Agric. Eng. 51:415.

11. Drenkard, D.V. Henke, R.C. Gorewit, N.R. Scott, and R. Sagi. 1984. Milk production, health, and endocrine responses of cows' exposed to electrical currents during milking. J. Dairy Sci. (Submitted for publication).

12. Fairbank, W.C. 1977. Stray electrical currents can cut production. Hoard's Dairyman 122:1093.

13. Fairbank, W.C., and L.B. Craine. 1978. Milking parlor metal structure-to-earth voltages. Western Reg. Agric. Eng. Ser. Publ. H-2.

14. Feistman, G.J., and R.R. White. 1975. Tingle voltages in milking parlors. British Columbia Dept. Agric. Eng. Notes: 324:5.

15. Gorewit, R.C., N.R. Scott, and C.S. Czarniecki. 1984. Effects of semirandomized alternating electrical current exposure on dairy cows. J. Dairy Sci. (Submitted for publication).

16. Gustafson, R.J. 1983. Stray voltage: detection and diagnostic procedures guide for rural electric systems. NCREA Res. Proj. 80-1. Nat. Rural Elec. Coop. Assoc., Washington DC.

17. Gustafson, R.J., and H.A. Cloud. 1981. Circuit analysis of stray voltage sources and solutions. ASAE Paper No. 81-3511. Am. Soc. Agric. Eng., St. Joseph MI.

18. Gustafson, R.J., G.S. Christiansen, and R.D. Appleman. 1983. Electrical resistance of milking system components. Trans. of the ASAE 26:1218.

19. Jones, G.M. 1981. The impact of stray electrical voltages on dairy herds. Proc. Nat. Milking Center Design Conf., Rochester NY, p. 291.

20. Keller, S.E., J.M. Weiss, S.J. Schleifer, N.E. Miller, and M. Stern. 1981. Suppression of immunity by stress: effect of a graded series of stressors on lymphocyte stimulation in the rat. Science 213:1397.

21. Lefcourt, A.M. 1982. Behavioral responses of dairy cows subjected to controlled voltages. J. Dairy Sci. 65:672.

22. Lefcourt, A.M., and R.M. Akers. 1982. Endocrine responses of cows subjected to controlled voltages during milking. J. Dairy Sci. 65:2125.

23. Lefcourt, A.M., R.M. Akers, R.H. Miller, and B. Weinland. 1984. Effects of intermittent electrical shock on responses related to milk ejection. J. Dairy Sci. (Accepted for publication).

24. Lillemars, L.D., and T.C. Surbrook. 1980. Stray voltage problems and solutions in Michigan. ASAE Paper No. 80-3504. Am. Soc. Agric. Eng., St. Joseph MI.

25. Monjan, A.A. 1981. Stress and immunologic competence: studies in animals. Psychoneuroimmunology. Academic Press, Inc., p. 185.

26. Norell, R.J. 1983. Dairy cattle sensitivity to electrical shocks as determined with behavioral indices. Ph.D. Thesis. Univ. Minnesota.

27. Norell, R.J., R.J. Gustafson, R.D. Appleman, and J.B. Overmier. 1983. Behavioral studies of dairy cattle sensitivity to electrical currents. Trans. Am. Soc. Agric. Eng. 26:1506.

28. Overmier, J.B. 1968. Differential pavlovian fear conditioning as a function of the qualitative nature of the UCS: constant vs pulsating shock. Cond. Reflex 3:175.

29. Phillips, D.S.M. 1962. Production of cows may be affected by small electric shocks from milking plants. NZ J. Agric. 105:221.

30. Phillips, D.S.M. 1984. Personal communication.

31. Phillips, D.S.M., and R.D.J. Parkinson. 1963. The effects of small voltages on milking plants: their direction and elimination. Dairy Farming Ann., p. 79.

32. Rodenburg, J. 1984. Ontario Ministry of Agriculture and Food survey of neutral-to-earth voltage on dairy farms. Personal communication.

33. Spencer, S.B. 1983. Does stray voltage really cause mastitis? Hoard's Dairyman 128:1165.

34. Steevens, B.J. 1982. Stray voltages in dairy facilities: economic losses, symptoms and how it affects the cows. Paper presented at 26th Ann. Farm. Electrification Conf.

35. Surbrook, T.C., and N.D. Reese. 1981. Stray voltage on farms. ASAE Paper No. 81-3512. Am. Soc. Agric. Eng., St. Joseph MI.

36. Visintainer, M.A., J.R. Volpicelli, and M.E.P. Seligman. 1982. Tumor rejection in rats after inescapable or escapable shock. Science 216:437.

37. White, R.R. 1981. Voltage tolerance levels and installation of equipotential planes. Proc. 20th Ann. AMC Mtg. p. 31. Nat. Mastitis Council, Arlington VA.

38. Whittlestone, W.G., M.M. Mullord, R. Kilgour, and L.R. Cate. 1975. Electric shocks during machine milking. NZ Vet. J. 23:105.

39. Williams, G.F. 1976. Farms with the "juice". Mimeograph, Coop. Ext. Ser., Washington State Univ., Puyallup WA.

40. Williams, G.F. 1981. Stray electric currents: economic losses, symptoms, and how it affects the cows. Proc. 20th Ann. NMC Mtg. Nat. Mastitis Council, Arlington VA.

41. Woolford, M.W. 1972. Small voltages on milking plants. Proc. 2nd Sem. Farm Machinery and Eng., p. 41.

42. Woolford, M.W., and D.S.M. Phillips. 1981. Farm dairies electric shock problems: avoidance and correction. Aglink FPP 518. Ministry of Agric. and Fisheries, Wellington NZ.

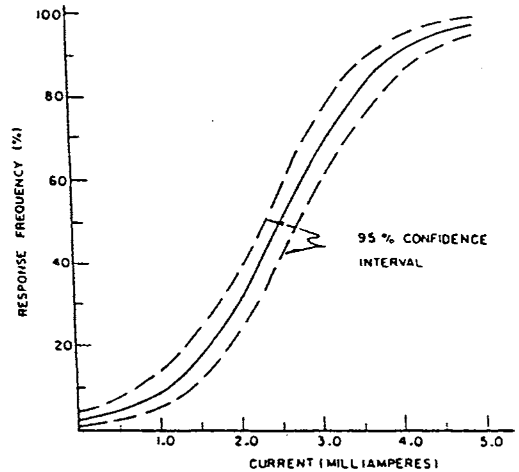

Figure 1. Response rate vs current flow for mouth-all hooves shock (27).

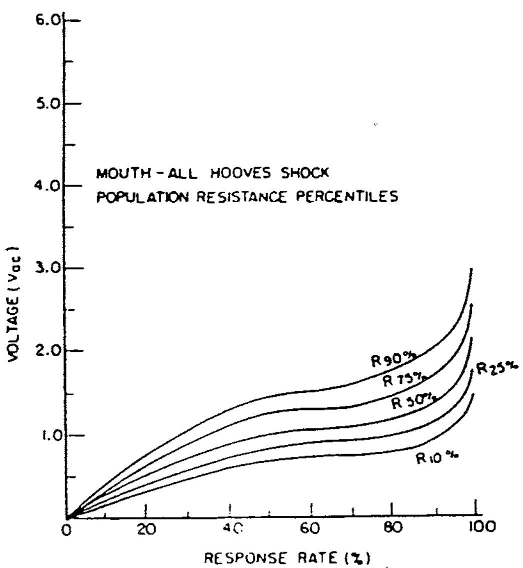

Figure 2. Voltage vs response rate for mouth-all hooves shock (27).

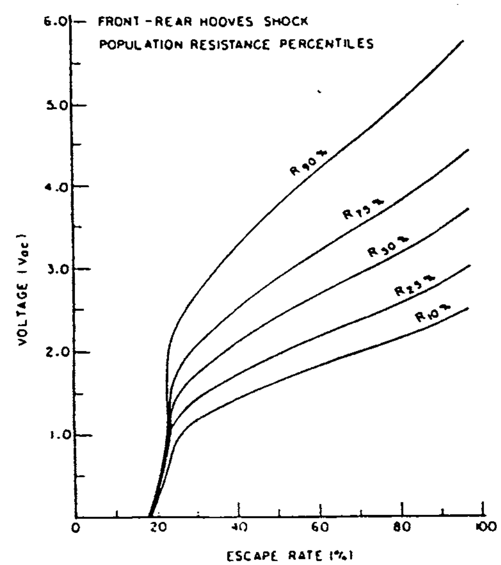

Figure 3. Voltage vs response rate for front-rear hooves shock (27).

Table 1. Summary of measured resistance of various electrical pathways through the cow.

Animal pathway	n	$\overline{x}$ (ohms)	Range (ohms)	Current Frequency (Hz)	Authors
Mouth-all hooves	70	350	324-393	60	Craine (6)
	28	361	244-525[a]	60	Norell et al. (27)
Mouth-rear hooves	28	475	345-776[a]	60	Norell et al. (27)
Mouth-front hooves	28	624	420-851[a]	60	Norell et al. (27)
Front leg-rear leg	5	300	250-405	60	Lefcourt (21)
	13	362	302-412	60	Lefcourt (23)
Front hooves-rear hooves	28	734	496-1152[a]	60	Norell et al. (27)
Rump-all hooves	7	680	420-1220	50	Whittlestone et al. (38)
Chest-all hooves	5	980	700-1230	50	Whittlestone et al. (38)
	NS[b]	1000[c]	NS[b]	50	Woolford (41)
Teat-mouth	28	433	294-713[a]	60	Norell et al. (27)
Teat-all hooves	28	594	402-953[a]	60	Norell et al. (27)
	4	880	640-1150	50	Whittlestone et al. (38)
Teat-rear hooves	28	710	503-1203[a]	60	Norell et al. (27)
Teat-front hooves	28	874	593-1508[a]	60	Norell et al. (27)
All teats-all hooves[d]	6	1320	860-1960	50	Whittlestone et al. (38)
	NS[b]	1000[c]	NS[b]	50	Phillips & Parkinson (31)
Udder-all hooves[d]	12	630	510-980	60	Drenkard et al. (11)

[a] Ranges given are for the 10% and 90% percentile, or percent of cows with measured resistance below the reported limit.

[b] NS = not specified.

[c] Approximate average stated by the author.

[d] Measured during milk flow.

Table 2. Summary of endocrine responses by cows subjected to various electrical currents.

Hormone	Major Functions (2)	Beltsville Trials (22, 23)		New York Trials (11)	
		1 Milking	14 Milkings	2 Days	7 Days
Oxytocin	Milk ejection	Increased concentrations	3.6 mA = delayed response 6.0 mA = no effect	---	4 mA = no effect 8 mA = delayed release
Epinephrine	Stress response	No response	---	---	---
Norepinephrine	Stress response	No response	---	---	---
Prolactin	Mammary growth; Initiation & maintenance of lactation	Trend toward lower levels during intermittent shock	Increased release	No response	4 mA = no effect 8 mA = trend toward increased production
Cortisol	Involved glucose, fat & protein metabolism	---	---	Non-significant trend toward increased concentrations	4 mA = no effect 8 mA = significant increase from baseline

Table 3. Comparison of change in milk yield, milking time, and peak milk flow rate in various stray voltage research trials (11, 22, 23).

	Change from .0 mA current control, %[a]					
	Beltsville				New York	
	Stimulation		mA			
Measurement	Continuous	Intermittent[b]	3.6	6.0	4.0	8.0
Milk yield, kg						
Shock	-2.4	-13.2[.1]	-0.1	+3.3	+2.5	+3.2
Postshock			+1.1	+1.7		
Milking time, min						
Shock	-5.2	-17.6[.01]	+1.1	+3.6	+3.0	+6.3
Postshock			+1.7	+5.5		
Peak flow rate (kg/min)						
Shock	---	---	+1.7	+6.3	+2.2	+3.0
Postshock	---	---	+1.0	-1.1		

[a] Data adapted from published kg measurements, and expressed as a percentage for comparison

[b] .1 and .01 indicates statistical significance. All other measurements are statistically not significantly different.

Table 4. Effects of randomized alternating current exposure on milk production, milk composition, and feed and water intake (11).

	Treatment		%
Measure	0 mA	4 mA	Change[a]
Milk production, kg/milking	13.74	13.58	-1.2
Fat, %	4.52	4.51	-0.2
Protein, %	3.27	3.28	0.3
Somatic cell count, 10^3	855.74	917.02	+7.3
Feed intake, kg	42.16	42.08	-0.2
Water intake, l	80.88	82.19	+1.6

[a] Differences between means statistically not significantly different.