Response of Dairy Cattle to Transient Voltages and Magnetic Fields

Douglas J. Reinemann, LaVerne E. Stetson, *Senior Member, IEEE*, and Nellie K. Laughlin

Abstract—**Stray voltages in dairy facilities have been studied since the 1970's. Previous research using steady-state ac and dc voltages has defined cow-contact voltage levels which may cause behavioral and associated production problems. This research was designed to address concerns over possible effects of transient voltages and magnetic fields on dairy cows. Dairy cow response to transient voltages and magnetic fields was measured. The waveforms of the transient voltages applied were: 5 cycles of 60-Hz ac with a total pulse time of 83 ms, 1 cycle of 60-Hz ac with a total pulse time of 16 ms, and 1 cycle of an ac square wave (spiking positive and negative) of 2-ms duration. Alternating magnetic fields were produced by passing 60-Hz ac fundamental frequency with 2nd and 3rd harmonic and random noise components in metal structures around the cows. The maximum magnetic field associated with this current flow was in excess of 4 G. A wide range of sensitivity to transient voltages was observed among cows. Response levels from 24 cows to each transient exposure were normally distributed. No responses to magnetic fields were observed.**

I. Introduction

Animal behavioral problems leading to potential production losses attributed to stray voltages have been observed [1]–[3]. Several research efforts to document the effects of stray voltage on dairy cows were initiated and investigative procedures developed to detect and correct stray voltage situations in dairies. These early efforts were summarized in a national workshop in 1983 [4] and a national symposium in 1984 [5]. Animal research and investigative methods were summarized in a USDA handbook [6]. One result presented in this publication was a general response curve for stray voltage showing both a behavioral response and a milk production response to current based on circuit impedance and voltage (see Fig. 1). This figure is the consensus opinion of animal scientists involved with several experiments. It depicts the average group response of animals and does not attempt to illustrate the variations found among experiments or within experiments.

In a comprehensive study of behavioral responses as to electrical currents by Gustafson *et al.* [7], frequency of escape responses were determined when an ac or dc voltage was applied on and off for 1/2 s through several body pathways.

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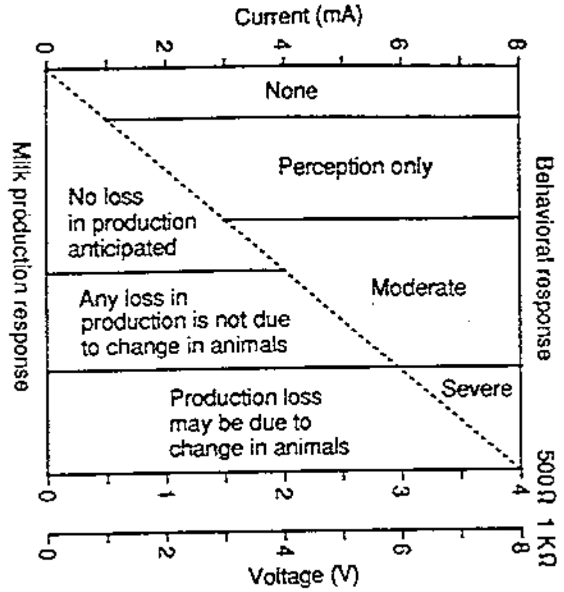

Fig. 1. Behavioral and milk production responses to current (from USDA Handbook 696).

The current level to elicit an escape response ranged from 1 to 5 mA among cows tested. Other studies have reported a similar range of sensitivity among cows as measured by avoidance of an electrical stimulus [8]–[13].

Research data on production and behavioral problems from stray voltage have led to the establishment of guidelines or rules for current levels, which if exceeded, suggest or require mitigative action. For example, the Public Service Commission of Wisconsin's (PSCW) investigation into the practices, policies, and procedures concerning stray voltage for electric distribution utilities in Wisconsin resulted in the 1989 issuance of a stray voltage order (PSCW Docket 05-EI-106). This order includes the Wisconsin legal definition of stray voltage:

> Stray voltages are low-level voltages present across points (for example, drinking cup to rear hooves) in which a current flow is produced when an animal simultaneously comes into contact with them.

As well as defining the maximum utility contribution to on-farm stray voltage:

> A level of concern above which corrective or mitigative action should be taken if production and behavioral problems exist is 1 milliampere steady state in the "cow-contact" areas (i.e. milking, feeding and watering areas).

This requirement is commonly interpreted as 1 mA through a 500-Ω resistor between two potential cow-contact points or a corresponding steady-state cow-contact voltage level of 0.5 V assuming an average cow and contact impedance of 500 Ω. To date, Wisconsin is the only state to adopt such a rule. However, at least two other states are considering adopting similar rules. Equipotential planes are widely used as a mitigative measure for stray voltage problems and are required by the Wisconsin Electric Code in all new animal confinement structures.

There has been considerable debate in the research and agricultural community over the definition and acceptable level of stray voltage defined in the 1989 PSCW stray voltage order. Farm groups and a manufacturer of a stray voltage mitigation device have claimed effects on dairy cows at cow-contact voltages lower than 0.5 V. Recommendations from the USDA Stray Voltage Handbook [6] state:

> "Older recommendations for tolerable levels of cow-contact voltages (0.5–0.7 V) . . . need to be reviewed in light of recent research. Based on current research, cow-contact voltages from low impedance sources should be kept less than 2 to 4 V."

Suggestions for further research [6] include studies of:

- how animals perceive and interpret current flow,
- the variability in sensitivity and response to current for a large number of dairy animals,
- evaluation of short and long term exposure to transients on animals, and
- the effects of dc on animals.

Concerns have been expressed in the farm community over the restrictions of the PSCW order to only steady-state voltages. It has also been noted that while equipotential planes are effective in reducing cow-contact voltages, they also act to improve farm grounding and thereby increase the primary current flow on the farm grounded neutral system. Concerns have also been expressed over current flow in the earth resulting from the operation of a multi-grounded electrical distribution system.

Some stray voltage investigators and dairy operators have claimed that in some cases in which continuously applied ac voltages have been reduced to below the PSCW acceptable level, cows still exhibit behavior suggestive of discomfort and stress. Short duration voltage spikes, and ac and dc current flow in metal structures surrounding animals have been suggested as sources of this irritation. The magnetic fields caused by this current flow is the presumed irritant. Observable behavioral changes have been claimed to occur upon the elimination of these phenomena. There is a lack of controlled research to address these concerns.

Concerns over the effects of electrical phenomena other than cow-contact voltages have resulted in a PSCW investigation into the potential adverse effects on dairy livestock from electric and magnetic fields, ground currents, and direct currents associated with electric utility service (PSCW Docket 05-EI-108). Farm concerns have also resulted in an effort to remove the requirement in the Wisconsin State Electrical Code that equipotential planes be installed in all new animal confinement buildings. Similar activities are occurring in Minnesota.

The research reported in this paper was initiated at the request of the Wisconsin Department of Agriculture Trade and Consumer Protection to provide additional data to address existing concerns and to use as a basis for future rule making in Wisconsin. This study was, therefore, designed to determine the level of electrical phenomena, other than steady-state 60-Hz ac voltage, which could produce a behavioral response in dairy cows.

II. Test Facilities and Equipment

Test facilities were constructed to investigate variability in sensitivity and response of a large number of individual cows to a range of electrical stimulus including:

- a variety of cow-contact voltage wave forms, and
- the alternating magnetic fields produced by current flow on metal structures surrounding cows.

Four test stalls were constructed that were electrically isolated from their surroundings. The test stalls were placed in a dairy barn similar to the barn in which the cows spend most of their time in an attempt to reduce stress from unfamiliar surroundings. The barn was a wooden structure. The only electrically operated equipment in the barn was two rows of fluorescent lights mounted 10 ft from the floor and two 18-in ventilation fans. Background magnetic fields in the barn were less than 0.4 mG.

The test stalls consisted of a wooden framework filled with two concrete pads (see Fig. 2(a) and (b)). A 6″ × 6″ welded grid of 3/8″ reinforcing bar was embedded in each pad. When a cow stood in the stall, the front hooves were on one concrete pad and the rear hooves on the other. The cows were secured with head locking stanchions supported on a wooden framework for electrical isolation of the head. Reinforcing steel in the concrete pads can be electrically connected to produce a uniform current flow in the reinforcing grid from front to rear or side to side without producing a hoof-to-hoof contact voltage. When appropriately connected, the pads served as one terminus of a nose-to-all-hooves current pathway.

Copper plates were attached to the surface of each pad to monitor potential between pads and between muzzle-and-hoof or hoof-to-hoof contact points (see Fig. 2(c)). The stalls were suspended off the floor by two load cells on the back corners and a single point PVC support in the center of the stall front (see Fig. 2(d)). This arrangement provided for electrical isolation of the stall from all grounding paths. Signals from the load cells are read and processed by computer-based multichannel input/output data acquisition systems. The load cells provided a sensitive measure of cow motion in the stall.

Visual observation records and backup video recording of all of the cow behavior trials were done in addition to the load-cell-cow-motion data. Behavioral and basic physiological signs have been shown in previous studies to be sensitive indicators of undesirable stimulus.

A computer based analog output board generated the waveform of the electrical stimuli to be applied. This signal was amplified to the appropriate level with a power amplifier. The electrical stimulus applied was monitored with a digital storage oscilloscope and the recorded stimuli saved to computer disk.

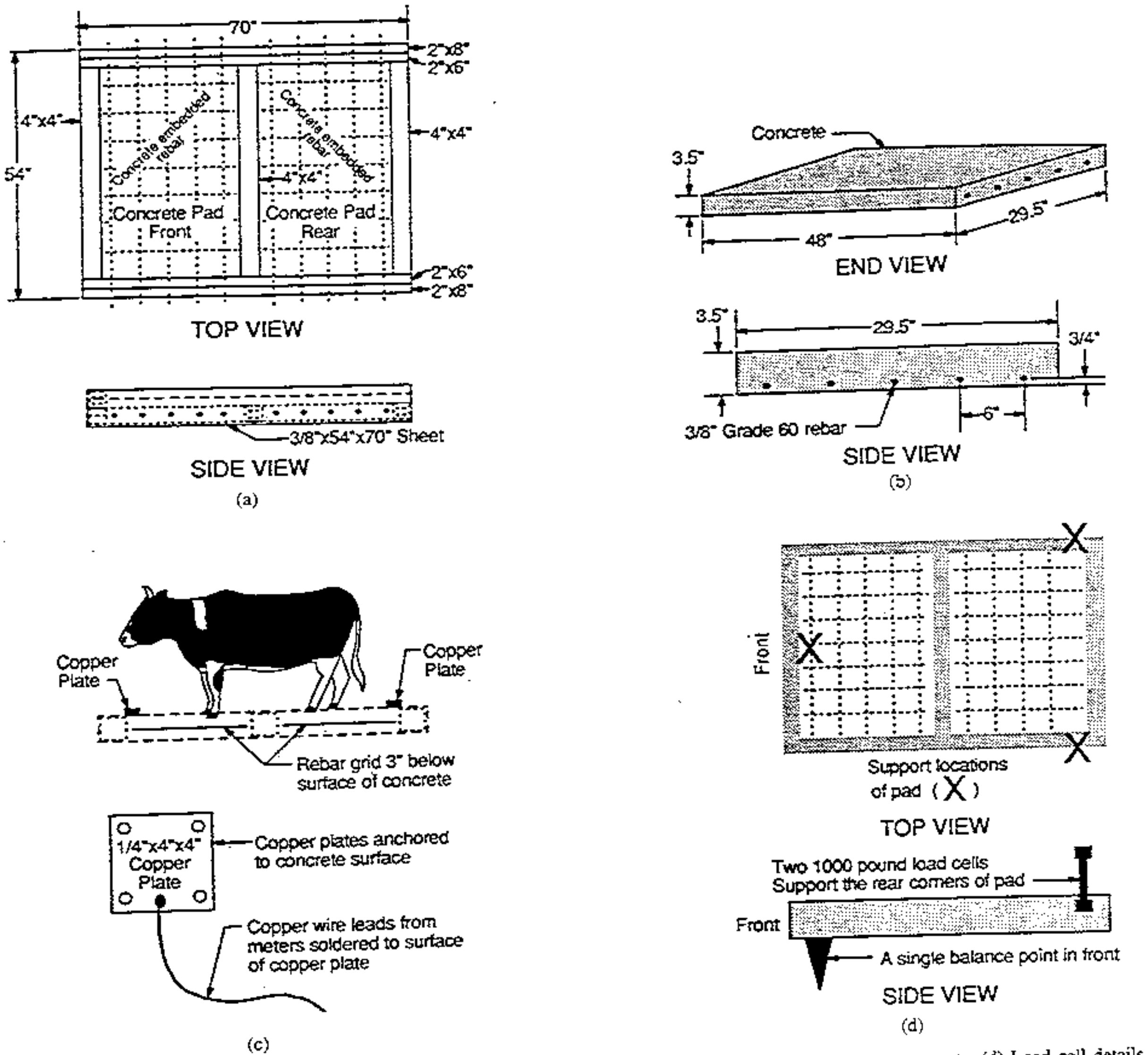

Fig. 2. Stall construction. (a) Framework. (b) Reinforced concrete pads. (c) Copper plates for surface voltage measurements. (d) Load cell details.

A. Electrical Stimuli

Two broad categories of electrical stimuli were produced. One category of stimuli were cow-contact voltages. The second category of electrical stimuli applied was current flow in the cow environment in the absence of a point-to-point cow-contact potential.

Transient Cow-Contact Voltage: The computer-based waveform generator allowed for infinite variation on the waveform, power level, and duration of exposure. These voltages were applied via nose-to-all-hooves pathway.

A diagram of the test setup for nose-to-all-hooves cow-contact voltage application is shown in Fig. 3. An oscilloscope was used to measure the voltage across a precision 1000-Ω resistor in series with the cow (Channel A) and the voltage across the 1000-Ω resistor alone (Channel B). The difference between these two voltages (Channel A–Channel B) was taken as the cow-contact voltage. The voltage through the 1000-W resistor (Channel B) is equivalent to the milliamperes that pass through the cow. Voltages and currents were measured and are reported as rms averages. The cow-contact voltage divided by the circuit current provides the impedance of each cow pathway including the contact resistance.

Transient cow-contact voltages were applied through the nose-to-all-hooves pathway. Each cow was fitted with a nose clip which assured a reliable electrical connection to the muzzle. The connected front and rear pads formed the other contact point. The waveforms of the transient voltages applied were:

5 cycles of 60-Hz ac with a duration of 83 ms,

1 cycle of 60-Hz ac with a duration of 16 ms, and

1 cycle of an ac square wave (spiking positive and negative) with a duration of 2 ms.

The 5-cycle, 83-ms transient was applied once at the beginning of the 30-s observation period. In later trials with the 1-cycle, 16-ms transient and the 1-cycle, 2-ms transient the cow-contact voltages were applied every 2 s over the 30-s observation period for a total of 15 shocks. This method of repeated shocks produced a more reliable and sensitive indicator of response.

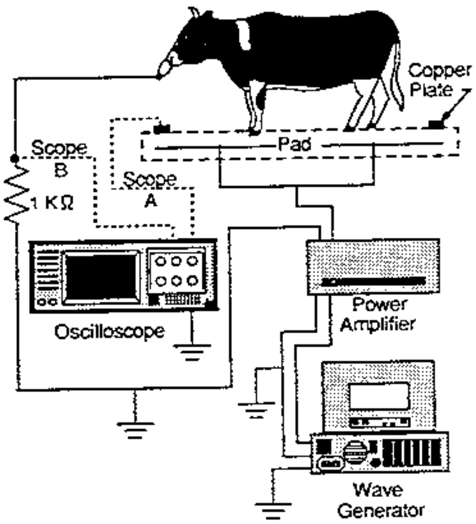

Fig. 3. Equipment and circuitry for supplying transient signals and measuring voltage and current applied to test animals.

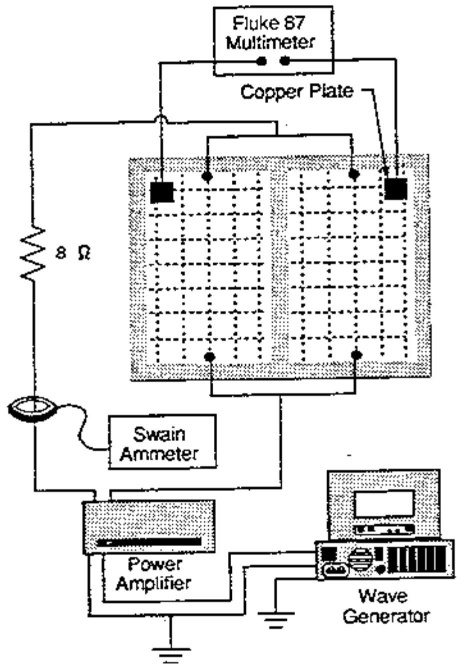

Fig. 4. Equipment and circuitry for applying current flow through stall floor for magnetic field.

Magnetic Fields: The magnetic fields produced by voltage and current flow present in the cow environment is the presumed mechanism of interaction. A diagram of the test setup for current flow in the cow environment is shown in Fig. 4. The total rms current flowing through the circuit was measured with a Swain[1] clamp-on Ammeter. Voltages between front and rear copper plates were monitored with a Fluke 87 to be certain there was no cow-contact potential for these tests. Magnetic fields were measured with a MEDA PLM 100 ELF magnetometer to determine the background field levels and monitor the maximum field levels produced during testing.

Electrical current was passed through the floor in the absence of cow-contact voltage. This is similar to the situation arising when current is found on equipotential planes and "ground currents." Current levels were varied from 0.6 to 9 A. The waveform of the current was 60-Hz ac fundamental frequency with 2nd and 3rd harmonics and random noise components. The maximum magnetic field associated with this configuration was about 40 mG measured at a distance of 25 mm from the stall surface. This magnetic field was imposed for 30 s continuously and also pulsed, 1 s on 1 s off, for a period of 30 s.

Currents were also passed through multiple turns of wire around the head-locking stanchion and cow's neck, simulating current flow on water lines, stalls, or other metal objects in the cow environment. The waveform of the current was 60 Hz with 2nd and 3rd harmonics and random noise components. The current for these tests were varied from 0.6 to 9 A. An additional test was done with a random "white" noise waveform ranging from 0.6 to 9 A. These currents were pulsed, 1 s on 1 s off, for a period of 30 s. The maximum magnetic fields associated with this configuration were approximately 4 G, measured in the center of the wire loop.

III. Test Procedures

A. Subjects

A group of 24 mid-lactation (100–200 days-in-milk) Holstein cows were used for each experiment. Animals were randomly selected from the available pool of mid-lactation cows from the research herd maintained at the University of Wisconsin's Arlington Agricultural Research Station.

B. Acclimation

Four cows were placed, one each, on each of four test stalls on the first day of testing. Nonpiercing, ball-end temporary nose clips were inserted into the cow's nose, access to food and water established, and a minimum period of 60 min was allowed for cow adjustment. Signs of adjustment to the new environment include prehension of food, mastication, rumination, laying down and drinking from water cups.

After the cows were properly adjusted to their environment, a wire test lead was attached to the nose clip. A period of adjustment to this new stimulus was again allowed (5 to 10 min). Signs of adjustment to this stimulus include indications showed previously and lack of attempt to remove the wire lead. The cows remained in the test stalls with the nose clips attached for the following two days and were tested once each day at approximately the same time of day.

C. Stimulus/Observation Protocol

The water cup was withdrawn immediately before the testing period, to prevent any electrical interference. Cows were tested one at a time. Two trained observers seated, one in front of the cow and one behind monitored movements during tests. The front observer recorded front leg motion (lifting leg from the pad) and any type of facial reaction including a twitch

[1]Mention of trade names is for identification purposes only and is not an endorsement by the University of Wisconsin or U.S. Department of Agriculture.

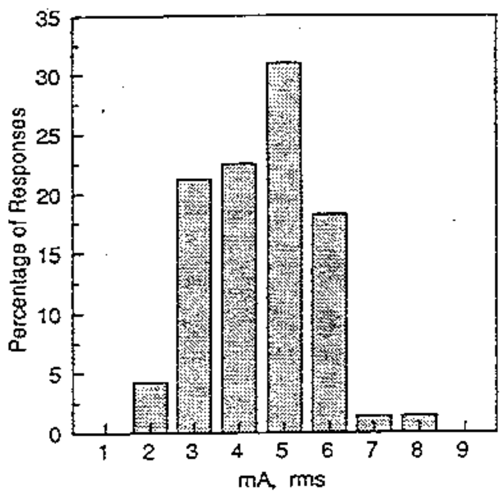

Fig. 5. Percentage of responses with current level for a 5-cycle, 83-ms, ac transient cow-contact voltage applied once in a 30-s period (a total of 71 observations from 24 cows).

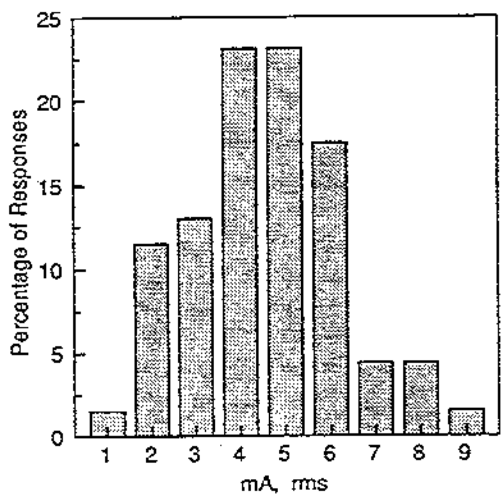

Fig. 6. Percentage of responses with current level for a 1-cycle, 16-ms, ac transient cow-contact voltage repeated every 2 s in a 30-s period (a total of 69 observations from 24 cows).

of the nose or ears or blink of the eyes. The rear observer recorded the number of rear leg lifts and tail switches. At the completion of each test, the observer also gave an overall impression of whether the cow perceived the stimulus or not, recorded as negative, marginal, or clear positive response.

Tests consisted of repeated trials, each divided into two time periods during which observations of cow movements were recorded. Each observer held a clipboard fitted with six manually actuated counters mounted along one side. The first 30 s of each trial provided an indication of the background response level for the animal. No electrical stimulus was applied during this period. In the second 30-s period of each trial, the cow was exposed to the electrical stimulus. The frequency of events in each of the two observation time periods was recorded using the counters. The beginning and end of each observation interval were signaled to the observers through headphones. These signals were not audible by the cows but were recorded on the video record of the trials.

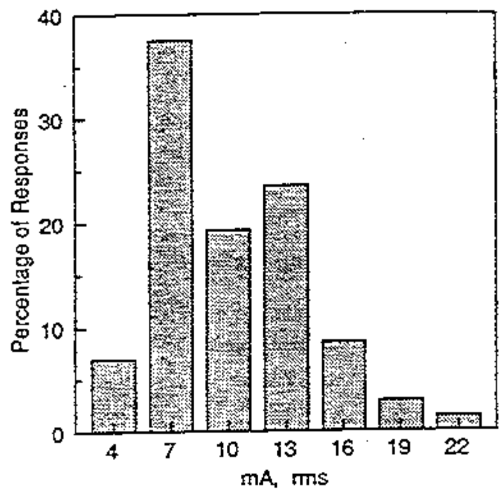

Fig. 7. Percentage of responses with current level for a 1-cycle, 2-ms, ac transient cow-contact voltage repeated every 2 s in a 30-s period (a total of 72 observations from 24 cows).

Tests were repeated on each cow with consecutively increasing voltages until a clear positive response was established or until the maximum level attainable with the test equipment was reached. Test stimuli were then reduced until a clear negative response was again obtained. This completed the testing on that cow on that day. Each cow was tested in this manner for three consecutive days. A total of 24 cows were tested for each type of stimulus. Equipment malfunction required testing fewer cows on some days.

D. Training Observers

Training was conducted with two people observing and recording the same response indicators during the same test. The observers independently observed and recorded responses. Paired observations were repeated until correlation of observed responses was in excess of 90% for several consecutive tests. The clear positive response noted by the observers was supported by analyses of the cow motion records from the load cells.

IV. Results

A. Transient Voltages

For each type of transient voltage signal applied a clear positive response, regarded as an indicator of perception, was noted in all cows when the current through the cow reached a sufficient level (see circuit diagram of Fig. 3). Current flow through the animal has been shown to be a more standardized measure of exposure than contact voltage as variability in body and contact resistance is eliminated. In general, facial response was the most sensitive response indicator followed by cow motion as measured by the number of leg lifts observed and the load cell motion measurement. Frequency of tail switching did not show any correlation to level of stimulus but did show a general day effect, increasing with increasing temperature in the barn.

The distributions of current flow through the cow required to elicit a response are shown in Figs. 5–7 for the 5-cycle 83-ms, 1-cycle 16-ms, and 1-cycle 2-ms duration transient voltages, respectively. These histograms include data for the response level for all 24 cows tested on each of the days (usually 3) that they were tested. Some trials were not conducted on all three days because of equipment malfunction of one test pad on the test day. The bin values indicate the bottom of the bin range (e.g., bin 1 in Fig. 5 = all responses greater than or equal to 1 and less than 2 mA).

The most sensitive cow responded to a current of 2.6 mA for the 5-cycle, 83-ms transient. The least sensitive cow did not respond until a current of 8.9 mA. Seventy-two percent of the responses occurred between 4 and 7 mA. The mean response threshold was 4.9 mA. This 5-cycle transient voltage was applied once during the observation period.

The most sensitive cow responded to a current of 1.4 mA for the 1 cycle, 16 ms transient. The least sensitive cow did not respond until a current of 9.9 mA. Sixty-four percent of the responses occurred between 4 and 7 mA. The mean response threshold was 5.0 mA. This 1-cycle transient voltage was applied 15 times during the observation period. The response was very similar to the 5-cycle treatment. More responses at current levels below 3 mA are probably a result of increased sensitivity to the test for the 1-cycle transient by repeating the transient 15 times.

The most sensitive cow responded to a current of 4.4 mA for the 1-cycle, 2-ms transient. The least sensitive cow did not respond until a current of 25 mA. Eighty-one percent of the responses occurred between 8 and 17 mA. The mean response threshold was 12 mA. This 1-cycle transient voltage was applied 15 times during the observation period. Cows appeared to be less sensitive to the 2-ms transient voltage than to either the 83- or 16-ms transient voltage.

B. Magnetic Fields

Of the three experiments conducted with electric and magnetic field exposure, no responses to any of the exposures were observed. In the test series in which animals were exposed to pulsed current in the floor, manure formed a contact between the test pad and the load cell. This resulted in false motion counts on the load cell measurements and an alternate electrical path to ground from the pad. After the problem was discovered, the test pad and load cell were thoroughly cleaned and the test was rerun on 12 additional cows and no response was observed in any of the response indicators.

V. Summary

Experiments were conducted to determine the response of dairy cows to short duration exposure to transient cow-contact voltages and alternating magnetic fields. The purpose was to address a gap in research data. The lowest level of current flow through an animal to elicit a response in these studies (1.4 mA for the 1-cycle, 16-ms ac transient) was of the same relative magnitude found for continuously applied ac voltages in previous studies. Current levels needed to elicit response increased for the shorter duration 2 ms ac transient voltage. No response was observed for dairy cows exposed to short duration but very high levels of magnetic fields.

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