A REVIEW OF STRAY VOLTAGE RESEARCH

EFFECTS ON LIVESTOCK

By

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Michigan Agricultural Electric Council Membership

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Introduction

The Michigan Agricultural Electric Council (MAEC) has completed this review in the interest of informing the electric power, agricultural and university communities about the results of the total body of research on the effects of stray voltage on livestock. Stray voltage was not widely recognized as a phenomenon in the United States until the early 1980s and the majority of the research on stray voltage has been performed since that time.

In 1991, a group of agricultural scientists published the *USDA Agricultural Handbook, 696, Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems* (USDA, 1991). The purpose of the USDA handbook was: a) to prevent research results from being misinterpreted and misconstrued, and b) to improve the understanding of causes and effects of stray voltage on farms.

For this review, all available research on the effects of stray voltage on animals, including that completed since 1991, was collected and reviewed. This document provides summaries of the studies where variables other than the treatment were controlled (repeatable research), and presents the results to address the following:

a. Provide a summary of conclusions of research findings.

b. Explain how the different research trials were conducted.

c. Explain the different methods used by researchers to determine if animals were being affected.

Stray Voltage Definition

Electrical systems on farms and electrical supply systems delivering power to farms, homes, and businesses are grounded to the earth to help assure safety and reliability. The grounding of these electrical systems results in some current flow through the earth. Associated with this current is a small voltage which develops at each point where the electrical system is grounded. That voltage is called neutral-to-earth voltage (NEV). When the NEV is found at animal contact points, it is frequently referred to as stray voltage.

Stray voltage is this small voltage (usually less than 10 volts) that is measured between two points a livestock animal can simultaneously touch. If these points are simultaneously contacted by a livestock animal, a current will flow. The amount of current depends on the voltage and the circuit impedance,[1] which includes the source, contact, and body impedances. Livestock respond to the resulting current flow and not the applied voltage.

Types of Electrical Exposure

Most exposure an animal may have to electricity in its environment is **alternating current** (ac) with a frequency of 60 cycles per

[1]For most situations, impedance and resistance are equal in animal circuits.

second (Hertz or Hz). The 60 Hz ac flows first in one direction and then in the other, 60 times each second. The majority of the stray voltage research has been conducted at 60 Hz.

Direct current (dc) on the other hand flows only in one direction. A chemical battery, as found in a tractor or car, typically produces dc. Different metals making contact with damp earth sometimes will act as a weak battery producing a voltage between two points.

An animal may also be exposed to an ac frequency that is higher than 60 Hz. Some of the research was conducted with the ac frequency as high as 50,000 Hz. Frequencies of ac less than 60 Hz are not known to be observed in the animal environment.

Animals may also be exposed to current that lasts for only a fraction of a second. Currents that last less than 1/2 of a 60 Hz cycle (about 1/100 of a second), are usually called **transient currents.** Some research was conducted to test for effects on animals with transient currents. The operations of contactors or switches are examples of transient sources. The currents from fencers are regular intermittent dc transients.

Currents that are greater than 1/100 of a second in duration but are less than one or two seconds are sometimes called momentary currents. The inrush current during an on-farm motor start is a common source of a momentary current.

An animal can be exposed to many different types of electrical current and voltage in its environment. Researchers used varying techniques and tried to duplicate any exposure an animal could receive. They also used differing methods to determine animal effects. Therefore, careful consideration should be given to the specific variables when comparing individual research trials. This document tries to categorize the different research trials to help the reader understand how an animal may be affected in an actual farm situation.

The threshold level for an animal's perception and response to an electrical current is widely variable between animals. The threshold for even one animal can change over time. Research was concerned with the determination of the lower threshold for a livestock population.

The pathway for current through an animal with the least resistance is from the mouth to all hooves. Due to this pathway being the most sensitive for the animal, much of the research has focused on current or voltages at feeders and waterers. This is especially true for long term studies.

Evaluation of Results

This evaluation of research results was started by grouping the findings of research trials as perception, behavior changes, and production losses (Table 1). **Perception** involves an animal's initial awareness of current. Animals cannot tell us when they first perceive current, therefore, researchers can only look for initial changes in normal behavior. Indications of perception that have been used by researchers include: the lifting of a leg, training animals to perform a specific task in response to stimulus, flinches, shifting of weight, blinking of eyes and other minor observable actions.

Behavior change will normally involve some type of avoidance by the animal. When exposed to the electrical current, an animal may position or move itself so that it is no longer a part of the electrical circuit. Behavior change may be identified when the animal: avoids an object or area, changes its manner of drinking, flinches, or exhibits other behavioral modification. All of these changes can also be associated with normal animal behavior, making the interpretation of behavior difficult at times.

A **production loss** occurs if water or feed consumption is reduced for a sustained period of

time. In some trials, it was noted that an animal acclimated after a period of time to the presence of a current or voltage between animal contact points by resuming normal water and feed consumption patterns. This was not considered a production loss if weight gain or milk production was not affected.

SUMMARY OF RESEARCH

Voltage[2] is required between animal contact points before current can flow through an animal, but **current**[2] must flow through the animal before it can be affected. The electrical quantity that an animal or a person feels or reacts to is electrical current. The levels of electrical current that can be perceived by an animal or a person is in the range of a few milliamperes (mA). One milliampere is 1/1000 of an ampere (A). An electrical pressure or voltage is required for electrical current to flow through the body of an animal or a person. If an animal simultaneously makes contact with two conducting points with a voltage between them, a current can flow through the animal's body. Electrical current must flow through an animal before the animal can be affected.

The relationship between voltage (V), current (C) and resistance (R) is described using Ohm's Law: $V = C \times R$. Current flow through an animal's body is equal to the voltage between body points divided by the animal circuit resistance: $C = V \div R$.

Voltage is normally measured between two points that an animal can simultaneously contact. By estimating the total circuit resistance, which includes the resistance of the animal, the amount of current that could flow through the animal's body can be determined using Ohm's law. This research review presents the results in current except in cases where only voltage between animal contact points was measured.

Currents

Animals may perceive currents through the body below 3.0 milliamperes (mA) at 60 Hz without any resulting behavior problems. Under unusual circumstances, an animal may be able to perceive currents below 1.0 mA. The perception level for an animal will vary greatly depending on the animal circuit pathway and points of application. Lefcourt (1982a) had an individual cow that responded to 0.7 mA where the current was applied intrusively between two points on the legs that had been shaved and sanded. Gustafson et al. (1986) found that pigs could detect a difference between a water nipple with no voltage present and one where the pigs were exposed to 0.25 mA.

Behavior changes that were found by researchers in the 3.0 to 6.0 mA range (60 Hz) caused only short term effects and did not affect overall production. Management or handling concerns may occur when an animal's body current exceeds 4 mA.

None of the research showed changes in production or feed or water consumption for currents at or below the 4 mA level. Lefcourt (1982a) measured a production decrease in one study at 5.0 mA, but a subsequent study measured no decrease in milk production at 6.0 mA. Currents of 5 and 6 mA had no effects on long term production in any other study.

As frequency is increased above 60 Hz, the response threshold rises (Reinemann et al., 1995a and Aneshansley et al., 1995). The average

[2]All values of current and voltage are root mean square (rms) unless otherwise noted.

threshold for animal response when exposed to a 0.017 second pulse every two seconds for thirty seconds was 5 mA at 60 Hz, 26 mA at 6000 Hz, and 132 mA at 50,000 Hz (Reinemann et al., 1994).

Based on the research conducted, it is improbable that currents can be sustained through an animal during milking at a level that will decrease milk production, without behavioral problems first becoming prevalent.

Physiological effects on animals can be determined by observing changes in hormone levels due to an electrical stimulus. No hormone level changes were observed at 5 mA or below. Changes in cortisol levels were observed by Henke-Drenkard et al. (1985) and Aneshansley et al. (1992) at 8 mA.

Limited research has been done with direct current (dc). Based on two sets of experiments for perception and behavior by Gustafson et al. (1985 and 1988), the threshold values for dc are 20 to 30 percent higher than those for ac.

Voltages

Current flow measurement through an animal's body on an actual farm is not practical. As a result, research was conducted where a specific open circuit voltage was applied across animal contact points. Current flow through any particular animal will vary as a function of the animal circuit resistance. The resistance of an animal's body is only a part of the total circuit resistance that includes the animal.

No water or feed consumption reduction was observed for any livestock below a threshold of 4 volts (V) applied continuously between animal contact points (60 Hz). However, two out of 30 animals in one test by Gorewit et al. (1989) refused to drink at 4 V for 36 hours and were given an alternate water source. No other research found any statistical effect on overall consumption or production at 4 V and below.

Voltage applied randomly between contact points has less effect than voltage of the same level applied continuously. No losses in water or feed consumption or production were found by Godcharles et al. (1993) where pigs were exposed to a continuous baseline level of 5 V with intermittently applied three-second pulses up to 8 V between feeders or waterers and a metallic floor. Aneshansley et al. (1988) applied one-second pulses of 8 V both randomly and intermittently at waterers for twenty-one days with no effect on feed or water consumption or milk production.

Reproductive parameters including days to first estrus, conception rates, calving interval and number of calves born dead were evaluated in full lactation studies by Gorewit et al. (1990) and Gumprich (1994). No change in any breeding parameter was found for any treatment, (the highest treatment levels were 4 V and 5 V respectively). Twelve and 13-week studies of voltage effects on fattening pigs by Robert et al. (1992) and Godcharles et al. (1993) examined blood samples every two weeks and meat and stomach conditions after slaughter. No statistically significant change in blood or tissue samples occurred for voltage treatments (highest treatment was 8 V).

RESEARCH CONCLUSIONS

Review of all research publications on effects of electrical current on animals indicates that the findings of *USDA Agricultural Handbook, 696, Effects of Electrical Voltage/Current on Farm Animals* were accurate. Figure 3–4 from USDA 696 (included as Figure 1) is a realistic representation of the responses of animals to currents. The diagonal line in Figure 1 (on the following page) represents the biological variability that exists in animals.

To eliminate the possibility of production loss, the amount of current that can flow through the body of an animal should be kept below 4 mA (60 Hz). None of the research showed a decrease in feed or water consumption or milk production at a level of current through the animal below 4 mA (60 Hz).

No overall decreases in feed and water consumption or milk production will occur below 4 V. A practical value for animal circuit resistance is 1000 ohms based upon research that shows no feed, water, or production loss below 4 V across an animal body or a body current of 4 mA (4 V ÷ 4 mA = 1000 ohms).

Voltage should be monitored as an indicator of potential stray voltage problems. It is not appropriate to monitor only animal behavior because there are many other animal environment factors beside stray voltage that could cause these changes.

While no research has found production losses for 60 Hz animal body currents below 4 mA or for voltages between animal contact points below 4 V, a conservative practice of keeping animal currents at or below 2 mA and voltages between animal contact points at or below 2 V will provide a margin that will prevent stray voltage from causing a problem.

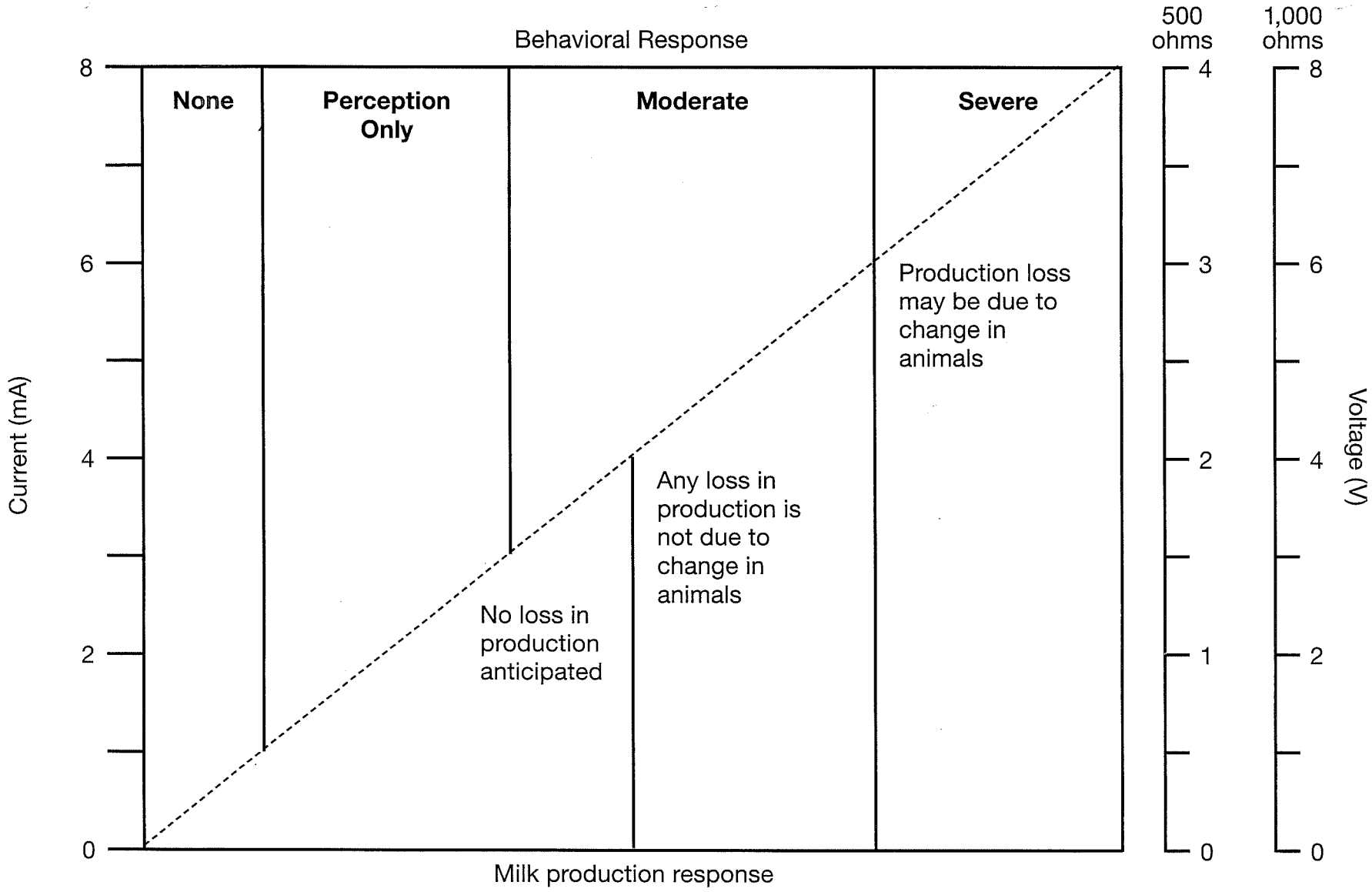


FIGURE 1.

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). From USDA 696.

TABLE 1. RESEARCH ARTICLE REVIEW

The repeatable research studies dealing with effects of electrical current on livestock were reviewed and are presented in the following table to facilitate comparison. A review of research articles and summary of research results are categorized according to threshold values for 1)perception, 2)behavioral response, and 3)production loss. The papers and articles reviewed are listed in the bibliography.

Electrical currents and voltages presented in the tables are 60 Hz alternating current (ac), unless otherwise noted, and are given as rms values for comparison purposes. If peak voltage is desired, multiply the rms value by 1.414. For the studies where voltages are presented, the values in the tables are open circuit voltages.

Statistical significance was normally determined using a 95% confidence interval and *t* test ($P<0.05$) with exceptions noted.

TABLE 1A. RESEARCH ARTICLE REVIEW: Electrical Current Effects on Livestock

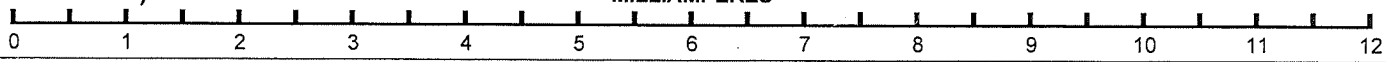
- The articles are arranged by: 1. Location of research, earliest to latest work, 2. First author, and 3. Year of published article (These are listed on the left hand side of the table).
- The number of animals, method of application of electricity and pathway, and a brief description are in the first few lines for each research experiment.
- The letter **T** indicates the specific level of current at which the treatment was conducted, experiment is abbreviated EXP.
- Refer to definitions section for meaning of abbreviations or explanation of some terms.

MD, USDA
Lefcourt
1982a

EXPERIMENT DESCRIPTION

- 5 Holstein cows were subjected to ac voltages (with known resistance so current is known) applied between ECG electrodes attached with bands to shaved areas on the right front knee and right rear hock (roughed skin and electrode jell) to determine mild and distinct behavioral response levels.
- Responses are the average of 4 or more repeated tests at the same trial voltage.
- Voltage was applied for a 30 s period in increments of 0.25 V up to 1 V, and increments of 1 V between 1 and 5 V.
- Mild response: if a cow flinched, became vocal, or showed any behavioral changes for at least half of the tests at that level.
- Distinct response: if a cow showed a startled response or raised a leg consistently in repeated trials.

TREATMENTS (TEST LEVELS)



T current was increased until a mild response and distinct response were attained.

RESULTS

	Perception	Response current	
	Behavior Response	Perception (mild)	Behavior Response (distinct)
Cow 1		2.75 mA	3.94 mA
Cow 2		2.76 mA	4.07 mA
Cow 3		2.32 mA	3.40 mA
Cow 4		3.81 mA	5.07 mA
Cow 5		0.70 mA	0.96 mA

MD, USDA

Lefcourt and Akers 1982b

EXPERIMENT DESCRIPTION

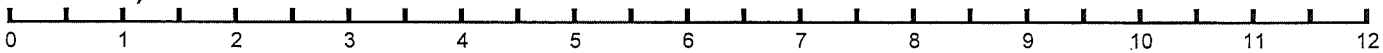
- 6 Holstein cows were subjected to continuous and intermittent ac current treatments to study treatment effect on norepinephrine, epinephrine, dopamine, oxytocin and prolactin. Milk yield and milking time were also measured.
- Currents were applied between ECG electrodes attached to shaved areas on the right front knee and right rear hock (roughed skin and electrode jell).
- The first 2 days were control with no treatment; 3rd day, 3 cows treated with Exp. 1 and 3 cows as controls; 4th day same as 3rd day only cows reversed; 5th day, 3 cows treated with Exp. 2 and 3 cows as controls; and 6th day all 6 cows treated with Exp. 2.

EXP. 1 • Continuous current of 5 mA for 20 minutes starting 10 minutes before milking.

EXP. 2 • Intermittent 5 mA current, 5 out of every 30 seconds for 20 minutes starting 10 minutes before milking.

TREATMENTS (TEST LEVELS)

MILLIAMPERES



EXP. 1	T T	continuous
EXP. 2	T	intermittent

RESULTS

EXP. 1

Behavior Response • 5 mA: The cows seemed distressed following the initiation of shock, but within minutes most of the cows showed no abnormal behavior and some cows actually seemed to enjoy the stimulation.

Production Loss • 5 mA: No significant effect on milk yield, milking time or any other measured variables. There was an increased oxytocin response to milking stimuli.

EXP. 2

Production Loss • 5 mA: The cows showed distinct responses such as lifting the leg throughout the stimulation period.

• 5 mA: Significant decrease in milk yield and milking time. Oxytocin response to milking stimuli was increased and the normal prolactin response to milking inhibited.

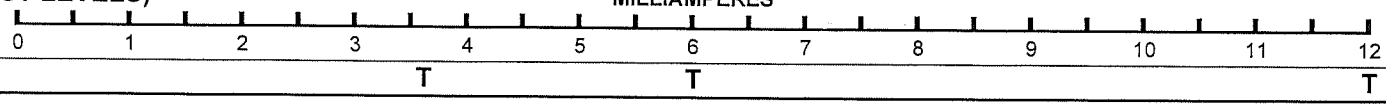
Note: The author questioned whether the loss of milk was actually due to the intermittent current, due to the lack of any other sign of stress and the small number of cows in the test.

MD, USDA Lefcourt et al. 1985

EXPERIMENT DESCRIPTION

- 15 cows were subjected to intermittent ac currents for 14 milkings (7 days) to monitor the effect on milk yield, milking time, SCC and oxytocin release.
- Cows were divided into 3 groups based on milk yield, and subjected to intermittent shocks (5 out of every 30 seconds) starting 1 minute before milking and continuing for 10 minutes after the start of milking.
- Results were compared to 5-day pretreatment period.
- Currents were applied between ECG electrodes attached to shaved areas on the right front knee and right rear hock (roughed skin and electrode jell).
- Treatments were at 3.6, 6.0 and 12 mA, but the 12 mA treatment was discontinued due to severe behavioral responses.

TREATMENTS (TEST LEVELS)



RESULTS

Behavior Response
- 3.6 and 6 mA: Both treatments had responses that could lead to milking problems.
- 1 cow was removed from the 6.0 mA treatment due to severe behavioral response and another in the 3.6 mA group would remove electrodes; therefore, the test was completed with 7 cows at 3.6 mA and 6 cows at 6.0 mA.

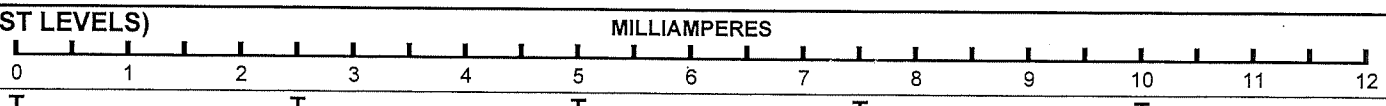
Production Loss
- 3.6 mA: Significant delay in the oxytocin peak, this did not occur at 6 mA.
- No significant effect on milk yield, milking time or SCC for either treatment.

MD, USDA Lefcourt et al. 1986

EXPERIMENT DESCRIPTION

- 7 cows were subjected to ac current biweekly for 10 seconds at least 1 hour before milking to study effects on milk yield and hormone levels.
- Currents were applied between ECG electrodes attached to shaved areas on the right front knee and right rear hock (roughed skin and electrode jell).
- Experiment design called for increasing the current level (0.0, 2.5, 5.0, 7.5, 10.0 and 12.5 mA) until a change occurred in hormone or neurotransmitter levels. Behavior responses discouraged using currents above 12.5 mA.

TREATMENTS (TEST LEVELS)



RESULTS

Behavior Response
- 10 and 12.5 mA: Heart rates were significantly different from controls after being shocked. Some animals had violent behavior reactions.

Production Loss
- No effect on milk yield, prolactin levels, or any hormone changes at any level.

MN, U of
Norell et al.
1983

EXPERIMENT DESCRIPTION

- 3 experiments assessing animal sensitivity to ac current based on behavioral indicators were performed.
- Electrical contact was from front-to-rear hooves and mouth-to-all hooves.

EXP. 1
- 6 holstein cows were taught to suppress a plate for grain rewards (30 presses and the cow was rewarded with grain).
- The grain interval was defined as the mean time between initiation of plate pressing and ending at the start of plate pressing for the next reward (at the control current level of 0 mA). A 95% confidence interval (C.I.) was then determined for the grain interval time.
- Treatments started with a current of 0.5 mA and were increased in 0.5 mA intervals until the grain interval was greater than the 95% C.I.
- When the grain interval was greater than the 95% C.I., the learned response was considered suppressed.
- The experiment was repeated for decreasing currents.

EXP. 2
- 7 cows were exposed to 50 training shocks during 1 session. A learned escape response - lifting front foot stopped current.
- For training, a 5.0 mA front-to-rear hooves pulsating (repeated on and off at approximately 60 cycles per minute) shock was used.
- Maximum training shock duration was 30 seconds.
- 24 hours later cows were exposed to 20, 5 mA warm-ups and a session of 60 treatment shocks was applied over the range of currents.

EXP. 3
- 7 cows were exposed to 10, 5.0 mA warm-up shocks, followed by 60 treatments as in Exp. 2, but with learned escape response - opening mouth stopped current.

TREATMENTS (TEST LEVELS)

	MILLIAMPERES 0	1	2	3	4	5	6	7	8	9	10	11	12
EXP. 1	T T	T T	T T	T T	T	T	T						
EXP. 2	T	T	T	T	T								
EXP. 3	T	T	T	T	T								

RESULTS

EXP. 1	Behavior Response	• 6 mA: Front-to-rear hooves currents did not suppress plate pressing behavior. • 1 to 2 mA: Mouth-to-all hooves current initially suppressed plate pressing behavior in 4 of the 6 cows, but later sessions required currents of 3 to 4.5 mA to suppress behavior response in all of the cows.
EXP. 2	Behavior Response	• 3 mA: Learned escape response, lifting front foot to stop current, above normal activity level (first significant level).
EXP. 3	Behavior Response	• Significant increases in response rate occurred between each 1.0 mA increment comparison up to 4 mA. Cow response averaged 13% at 1 mA, 92% at 4 mA and 98% at 5 mA.

MN, U of
Gustafson et al.
1985

EXPERIMENT DESCRIPTION

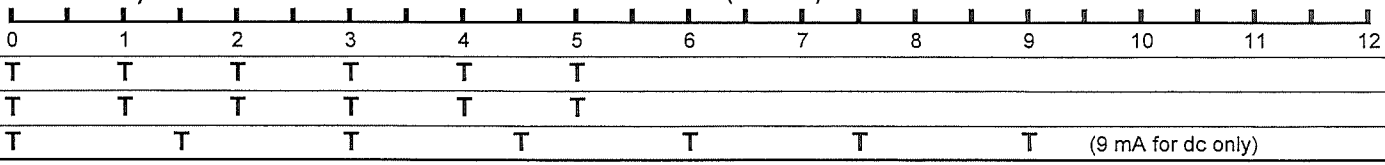
- 6 Holstein cows were tested for behavioral response to ac and dc current for 3+C461 pathways.
- Current treatment was repeated 0.5 seconds on, then 0.5 seconds off for a maximum of 30 seconds or until cow responded correctly.

EXP. 1
- Cows were taught that opening mouth stopped current.
- Cows subjected to 50 trainings sessions at 5 mA ac and 6 mA dc for mouth (metal bit)-to-all-legs pathways. The interval between exposures was 30 to 90 s. A cow was considered trained when she gave the proper response 90% of the time over the last 20 trials.
- 24 to 48 hours later the cows were given 10 "warm-ups", followed by randomly assigned treatments in blocks of 10.

EXP. 2
- Cows were taught that lifting hoof stopped current and training was the same as Exp. 1 except for current through front-to-rear hooves.

EXP. 3
- Additional training sessions were required for body-to-all-legs pathway and trained response was poorer than with other pathways.
- Current applied to brass metallic patch (5 cm x 12 cm) attached to shoulder area of front leg with straps and ECG conductor paste. Placement of brass plate critical in terms of how cow reacted.

TREATMENTS (TEST LEVELS)



RESULTS

EXP. 1	Behavior Response	• 3 mA: ac response frequencies significantly different from 0 mA ($P<0.005$). • 2 mA: dc response frequencies significantly different from 0 mA ($P<0.008$).
EXP. 2	Behavior Response	• 3 mA: ac response frequencies significantly different from 0 mA ($P<0.005$). • 5 mA: dc response frequencies significantly different from 0 mA ($P<0.005$).
EXP. 3	Behavior Response	• 6 mA: ac response frequencies significantly different from 0 mA ($P<0.005$). • 6 mA: dc response frequencies significantly different from 0 mA ($P<0.008$).

MN, U of

Gustafson et al.

1986

EXPERIMENT DESCRIPTION

• 8, 3-month old (40.5 kg) pigs were used for both experiments. Currents (ac) were applied between nipple waters and all hooves (metal grate).

EXP. 1

• Pigs were exposed to 3 water nipples each of which had a different current producing capability to assess at what current level the pigs could sense the electrical current and would move to a different water source if given an alternative.

• 4 different current combinations were examined with 1 combination replicated (1B, 1C) at a different time. Combinations are as follow:
1A) 0.0, 0.25, 0.5; 1B) 0.0, 0.5, 1.0; 1C) 0.0, 0.5, 1.0; 1D) 0.0, 1.0, 2.0; 1E) 0.0, 2.0, 4.0

• Current levels were randomized among nipples and recordings were manually made for each of the following:
number of unsuccessful attempts at drinking, number of successful drinks, length of each drink, and total water consumption.

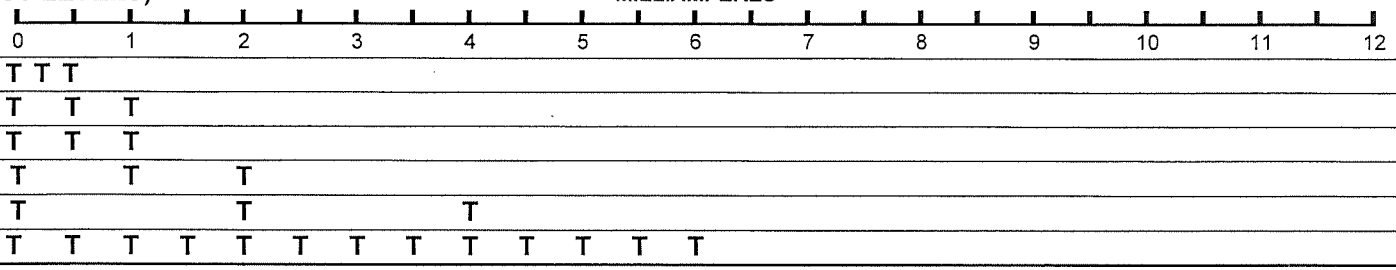
EXP. 2

• Pigs were given only 1 nipple to drink from. On day-1, 4 of the 8 pigs were exposed to a current level and the other 4 received no current. The next day the roles were reversed (pigs served as their own control).

• Current levels ranged from 0 to 5.0 mA in 0.5 mA increments. Experiments were done in an increasing current sequence.

• Recordings were made of number of unsuccessful attempts at drinking, number of successful drinks, length of each drink, and total water consumption.

TREATMENTS (TEST LEVELS)



RESULTS

EXP. 1

Perception

• For currents of 0.25 mA and above the pigs could perceive the current and knowing an alternative source existed, would seek out that source.

EXP. 2

Behavior Response

• 3.5 mA: Total drinking time per day was significantly less than controls for currents at 3.5, 4.5, and 5.0 mA ($P<0.05$). Consumption per drink showed a significant difference only at the 3.5 mA level ($P<0.05$). Time per drink showed the most variability in comparing the controls to current treatments.

• Significant differences in the number of unsuccessful attempts to drink were observed between the control and exposed groups at each current level. At the 5.0 mA level and above, there were very few attempts to drink.

Production Loss

• 4.5 mA: Total consumption per day was significantly less than controls for currents at or above 4.5 mA ($P<0.05$).

MN, U of
Brennan and Gustafson 1988

EXPERIMENT DESCRIPTION

- 6 Holstein first-calf heifers were exposed to 60 Hz ac current at the 5 mA level for durations of 0, 1, 3, 8, 15 and 30 cycles, repeated every second for a maximum of 30 s.
- Response of opening mouth stopped current applied between a metal bit in mouth and all hooves on a metal grate.

TREATMENTS (TEST LEVELS)

MILLIAMPERES

0	1	2	3	4	5	6	7	8	9	10	11	12
					T							

Current durations of 0, 1, 3, 8, 15 and 30 cycles, once/s up to 30 s.

RESULTS

Perception

- All treatments were different from 0 with the longest duration having the highest response.

MN, U of
Gustafson et al. 1988

EXPERIMENT DESCRIPTION

- A direct current (dc) level was applied to 6 Holstein cows across a metal bit-to-all-hooves (metal grate) pathway and the duration was increased until a reaction was achieved.
- Reaction was observed as opening mouth, rubbing bit, lifting feet or muscle contractions.

TREATMENTS (TEST LEVELS)

MILLIAMPERES (dc)

0	1	2	3	4	5	6	7	8	9	10	11	12
			T	T		T		T			T	(13.3 mA) T

RESULTS

Perception

Mean Stimulation Current level (mA dc)		Mean Time to Obtain Reaction Duration (ms)	
3.39	[0.06]	265.85	[46.85]
4.70	[0.05]	189.95	[80.40]
6.06	[0.08]	97.04	[64.44]
7.88	[0.09]	34.44	[25.05]
10.64	[0.08]	2.01	[1.99]
13.30	[0.11]	0.52	[0.56]

Note: Values in [ ] are standard deviations

MO, U of
Currence et al.
1987

EXPERIMENT DESCRIPTION

- The electrical sensitivity of 21 Holstein cows to a 60 Hz current was observed for 1, 10 or 100 cycles.
- Increasing current was applied through a left-front hoof to left-rear hoof pathway (salt saturated sponge between metal grate and hoof) until a reaction was observed.
- To test for the residual effect of previous shock the 3 durations were tested with 6 groups of 3 cows to allow the 6 possible sequences.

TREATMENTS (TEST LEVELS)

MILLIAMPERES

0 1 2 3 4 5 6 7 8 9 10 11 12

Increasing current was applied until a reaction was observed

RESULTS

Perception

Mean magnitude of 60 Hz current (mA)

	Direct effect	Residual effect*
1cycle	5.46	-0.192
10 cycles	3.51	-0.013
100 cycles	3.66	0.205
	Standard Error = 0.1164	Standard Error = 0.1561

*Residual effect of prior current: negative residual would indicate that cow responded at lower level of current on 2nd test, positive residual would indicate a higher current on 2nd test.

NY, Cornell
Gorewit et al.
1984

EXPERIMENT DESCRIPTION

- 4 cows were exposed to ac current treatments in 2-day blocks over 8 days to study behavioral changes.
- Treatment was once a day for 1 minute with 5 second alternating on and off.
- Current was applied between a stimulating electrode attached to the rear of the udder and a metal plate on the floor.

TREATMENTS (TEST LEVELS)

MILLIAMPERES

0 1 2 3 4 5 6 7 8 9 10 11 12

T T T T

RESULTS

Perception: 2 mA: 2 cows showed slight response, 2 cows showed no response.
4 mA and 6 mA: All 4 cows showed response.

Behavior Response: 4 mA: 1 cow showed strong response
6 mA: 2 cows showed strong response

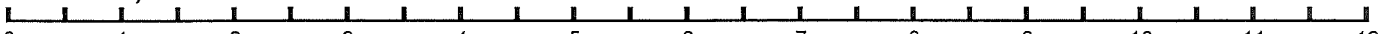
NY, Cornell **EXPERIMENT DESCRIPTION**

Gorewit et al. 1985

- 8 cows were randomly subjected to ac currents throughout the day to determine behavior, production, and water and feed consumption responses.
- A 4 mA treatment was randomly applied once every 4 hours for 5 minutes (30 seconds on, then 30 seconds off, repeated) for 4 days through electrodes in spine .

TREATMENTS (TEST LEVELS)

MILLIAMPERES



RESULTS

Behavior Response
- 4 mA: Cows became accustomed to the current within 24 hours. By the end of the experiment behavioral response was almost extinct.

Production Loss
- 4 mA: No significant difference in milk production, % fat in milk, feed and water consumption were noted.

NY, Cornell **EXPERIMENT DESCRIPTION**

Henke-Drenkard et al. 1985

- 6 cows were exposed during milking to electrical currents to assess its effects on behavior, health, milking performance and hormone response.
- Treatments were during 3, 1-week periods; a cow received the same treatment during 14 consecutive milkings. Treatments began 5 minutes before milking and continued until the milking unit was removed.
- Treatments consisted of a 60 Hz square wave current of 5 seconds duration applied every 30 seconds between the udder and the hooves. Currents of 0, 4 and 8 mA were used.
- Current was applied between a metal plate under all the hooves and a stimulating electrode on the posterior of the udder. The stimulation area was shaved, washed, swabbed with acetone, and sanded before attachment with ECG jell and rubber cement.

TREATMENTS (TEST LEVELS)

MILLIAMPERES

RESULTS

Behavior Response
- 4 mA and 8 mA: Behavioral changes occurred compared to 0 mA.

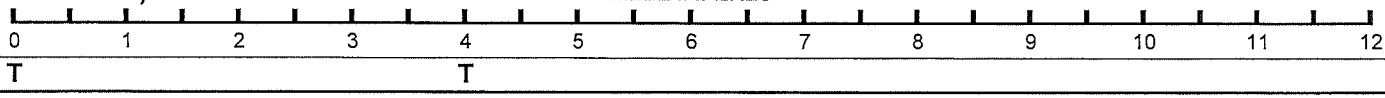
Production Loss
- 4 mA: No significant changes in cortisol and oxytocin levels as compared to 0 mA.
- 4 mA and 8 mA: No significant differences in milk yield or residual milk. No significant effect on protein or fat composition, or SCC.
- 8 mA: Oxytocin release significantly slower. Cortisol level significantly greater.

NY, Cornell
Gorewit and
Scott
1986

EXPERIMENT DESCRIPTION

- 6 Holstein cows in late lactation were used to determine the effects of a 4 mA square wave ac current on mammary gland blood flow rate, heart rate and blood pressure.
- Current was applied through electrodes placed in the lumbar-sacral region (base of the tail) of the back and were applied 10 seconds prior to udder massage and throughout milking.
- Cows received treatment every other morning milking for 6 days.

TREATMENTS (TEST LEVELS)



RESULTS

Production Loss

- 4 mA: Start of treatment caused increased blood flow, but flow remained the same for milking. Increased heart rate and blood pressure but no effect on milk production or physiological concentrations of epinephrine.

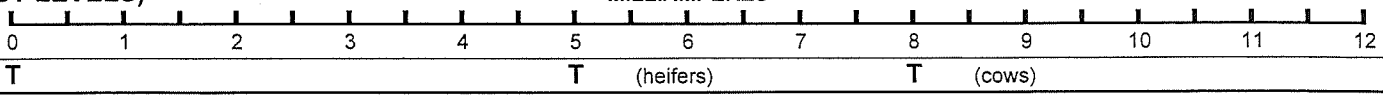
NY, Cornell

Aneshansley et al. 1992

EXPERIMENT DESCRIPTION

- Currents (ac) were delivered to lactating cattle in their declining phases of yield through the milk during milking.
- Currents were applied between top of the short milk tubes and the rear hooves.
- Milking duration, milk yield, milk composition for primary and residual milk, and blood cortisol levels were monitored.
- *t* test ($P<0.05$) was used to determine significant differences between 6 treatment and 6 control milkings.
- Currents selected were just below those that caused cows to kick milking machines in trial 1 (see voltage table, Aneshansley 1992).
- Treatments for heifers and cows were 5 mA and 8 mA respectively, and were delivered only during the open or milk phase of liner operation. and when the flow of milk allowed voltages 20 V or less to deliver the current.

TREATMENTS (TEST LEVELS)



RESULTS

Production Loss

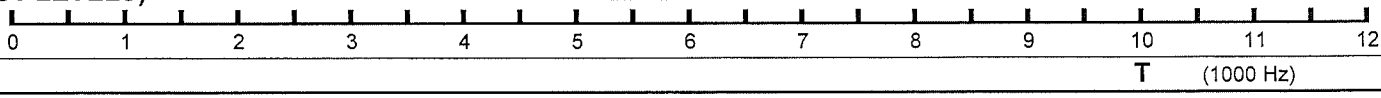
- 5 mA (heifers): No significant change in milk yield, there was a slight increase during current treatment.
  - Milking duration was significantly shorter for heifers.
  - No significant change in milk fat, was lower when currents were applied.
  - No significant difference in milk protein.
  - SCC was higher during current treatment, but not significantly.
- 8 mA (cows): No significant change in milk yield, there was a slight increase during current treatment.
  - Milking duration was shorter when currents were applied, but not significantly.
  - Milk fat was significantly lower for cows.
  - No significant difference in milk protein.
  - SCC was lower during current treatment, but not significantly.
  - Significant reductions in serum cortisol were found only at 2 and 6 minutes after the start of milking. Sampling every 2 minutes from before milking, throughout milking, and after milking found no other differences.

NY, Cornell
Aneshansley et al.
1995

EXPERIMENT DESCRIPTION

- The impedance from muzzle to front, rear and all hooves was studied as a function of frequency.
- Current (ac) levels were kept below levels for any response from the Holstein cow studied.

TREATMENTS (TEST LEVELS)



RESULTS

Perception

- 10 mA (1000 Hz): No perception response for current of 10 mA for frequencies at or above 1000 Hz.

N.Z.

Whittlestone et al.
1975

EXPERIMENT DESCRIPTION

- Mature, non-pregnant, dry Jersey cows were tested to determine the current level at which the cows would stop pressing the plate delivering feed and depress the plate that stopped current flow.
- The cows were familiarized with an automatic feeder which had a left and right plate that when pushed, would provide feed (crushed barley) on a variable schedule of around 25 pushes per feed allowance.
- During training, the cows were taught to respond to the left-hand plate by manually switching off the right-hand plate until approximately 90% of the responses were directed to the left hand plate.
- For the experiment, a 50 Hz current source was switched in such a way that the 1st press of the left-hand plate turned the current on. Continued pressing of the left-hand plate delivered feed in increments, but with each feed delivery the current was increased by 0.5 mA. The right-hand plate turned the current off, and continued pressing of the right-hand plate would deliver more feed in increments without current being applied.
- The current level was increased in steps of 0.5 mA within the range of 0-10 mA, with increases occurring after at least 20 responses had been made to the left plate at the previous current level.
- Responses to the two plates were automatically recorded and the threshold at which the cow quit using the plate that maintained the current and resorted to the other for feed was determined.

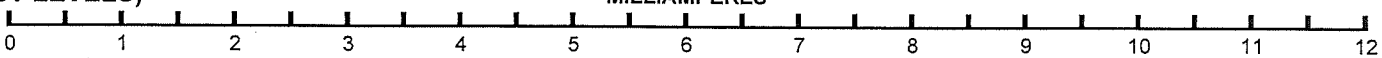
EXP. 1 • Current applied to the **left front teat** of 4 cows through a plastic cup filled with conducting gel and a grid that the cow was standing on.

EXP. 2 • Current applied to **all four teats** of 6 cows through plastic cups filled with conducting gel and a grid that the cow was standing on.

EXP. 3 • Current applied to the **rump** of 7 cows via an aluminum electrode (4.5 x 1 cm) taped to the skin covered with conducting gel and a grid that the cow was standing on.

EXP. 4 • Current applied to the **chest** of 6 cows via an aluminum electrode (4.5 x 1 cm) taped to the skin covered with conducting gel and a grid that the cow was standing on.

TREATMENTS (TEST LEVELS)



ALL EXP T T T . . . (Current was increased in steps of 0.5 mA within the range of 0 to 10 mA) . . . T

RESULTS

Behavior Response: Threshold sensitivity of Jersey cows to 50 Hz alternating current.

		Current (mA) mean	Current (mA) range
EXP. 1	Right Front Teat to Floor	7.12	6.0-9.0
EXP. 2	All Four Teats to Floor	5.58	2.5-9.0
EXP. 3	Rump to Floor	6.14	4.0-9.0
EXP. 4	Chest to Floor	4.00	3.0-8.0

N.Z. Woolford 1972

EXPERIMENT DESCRIPTION

• The following values were based on observations of currents applied between the front and rear hooves and a wet flank and the floor.

RESULTS	
	Perception • 3 to 8 mA: Observed range of perception threshold currents. Behavior Response • 4.5 to 12 mA: Range of uncomfortable currents, 50% greater than threshold. Note: Values were based on observation without description of any experiment.

WA State Crane 1975

EXPERIMENT DESCRIPTION

• A single Jersey cow was subjected to increasing ac voltages applied between a copper and rope woven bridle and ground.

RESULTS	
	Behavior Response • 4 to 6 mA: Cow exhibited some discomfort.

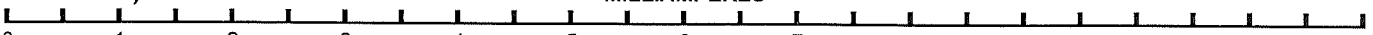
WI, U of
Reinemann et al.
1994

EXPERIMENT DESCRIPTION

- The sensitivity of cows to a wide frequency range of sinusoidal transient voltages and the variability of cows perception levels were tested.
- 24 cows were tested at 60 HZ and 500 Hz. 12 cows were tested at 6000 Hz and 50,000 Hz. 15 applications per animal.
- Cows were tested once each day at the same time over 3 days. Current path through a non-piercing ball-end clip in nose to all hooves.
- 2 observers looked for indications of behavioral change due to current application; leg motion, twitching of nose or ears, blinking of eyes, and switches of the tail. Cow movement was also monitored with load cells under the stall automatically recorded on a computer.
- Tests repeated on each cow with increasing stimulus level until a clear positive response was established.

TREATMENTS (TEST LEVELS)

MILLIAMPERES



T current was increased until a reaction was observed.

RESULTS

		Average* (mA)	Standard* Deviation	Minimum* (mA)	Maximum* (mA)
Perception	• 60 Hz findings reported in Reinemann 1995a.				
	• 1 cycle of 500 Hz applied every 2 seconds for 30 seconds.	10	3.4	4.5	19
	• 100 cycles of 6000 Hz applied every 2 seconds for 30 seconds.	26	3.9	20	34
	• 1 cycle of 50,000 Hz applied every 2 seconds for 30 seconds.	129	26	91	182
	• 833 cycles of 50,000 Hz applied every 2 seconds for 30 seconds.	132	26	88	174

*Values are given here as rms for comparison. The author reported values as peak currents in the paper as the waveforms were distorted sinusoidals.

WI, U of Reinemann et al. 1995a

EXPERIMENT DESCRIPTION

EXP. 1

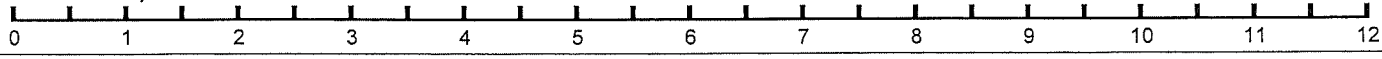
- 24 cows were exposed to currents applied between a non-piercing ball-end nose ring and all hooves, once per day for 3 days, with a series of ascending and descending exposures to determine a response level.
- 2 observers looked for indications of behavioral change due to current application; leg motion, twitching of nose or ears, blinking of eyes, and switches of the tail.

EXP. 2

- Experiments were also performed with electric and magnetic field exposure.
- Current levels in the floor and surrounding metal work were varied from 0.6 to 9 A. The waveform of the current was 60-Hz ac with 2nd and 3rd harmonics and random noise components.
- The magnetic field was imposed for 30 s continuously and also pulsed, 1 s on 1 s off for a period of 30 s.
- Part 1: A magnetic field of up to 40 milligauss was produced at a distance of 25 mm above the floor for a period of 30 seconds by passing current through the floor.
- Part 2: Currents were 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's environment. A maximum magnetic field of 4 Gauss at the cows head was produced.

TREATMENTS (TEST LEVELS)

MILLIAMPERES



EXP. 1, 2 Increasing current was applied until a reaction was observed

RESULTS

			Average* (mA)	Minimum* (mA)	Maximum* (mA)
EXP. 1	Perception	• 5 cycles of 60 Hz at the beginning of a 30 seconds test period. (72% of the responses occurred between 4 and 7 mA)	4.9	2.6	8.9
		• 1 cycle of 60 Hz applied every 2 seconds for 30 seconds. (64% of the responses occurred between 4 and 7 mA)	5	1.4	9.9
		• An ac square wave, 1 cycle of 2 ms duration every 2 seconds for 30 seconds. (81% of the responses occurred between 8 and 17 mA)	12	4.4	25
		*Values are given here as rms for comparison. The author reported values as peak currents in the paper as the waveforms were distorted sinusoidals.			
EXP. 2	Perception	• No responses to any of the electric and magnetic field exposures was observed.			

WI, U of
Reinemann et al.
1995b

EXPERIMENT DESCRIPTION

- This study was conducted to determine the level of 60 Hz transient current, relative to the short-term reaction threshold, required to affect feed and water intake, milk production and cow behavior.
- A 1 cycle 60 Hz transient current was applied between the water bowls and the floor once every second over a 21-day treatment period (14-day pre-treatment and 14-day post-treatment periods were monitored for comparison).
- The reaction threshold was determined for each cow prior to the treatment period and after the treatment period.
- 3 trials using the 8 stalls had 2 cows as controls (no current), 2 cows at the reaction threshold, 2 cows at the reaction threshold plus 1.0 mA*, and 2 cows at the reaction threshold plus 2.1 mA*. (*Values are reported here as rms, author reported as peak values in paper).
- The other trial had 2 cows as controls (no current) and 6 cows at 1.5 times the reaction threshold.
- The same cows were not used for each treatment.

TREATMENTS (TEST LEVELS)*

	MILLIAMPERES (0 1 2 3 4 5 6 7 8 9 10 11 12)
Controls	T
Reaction threshold	T 5 mA up to . . . . . 9.5 mA T
Reaction threshold + 1.0 mA	T 6 mA up to . . . . . 9.5 mA T
Reaction threshold + 2.1 mA	T 6.5 mA up to . . . . . 12 mA T
Reaction threshold x 1.5	T 8 mA up to . . . . . 14 mA (T)

RESULTS

Electrical Parameters	Thresholds used as treatments	n	Range of currents
	Controls	8	0 mA
	Reaction threshold	6	5 to 9.5 mA*
	Reaction threshold + 1 mA*	6	6 to 9.5 mA*
	Reaction threshold + 2.1 mA*	6	6.5 to 12 mA*
	Reaction threshold x 1.5	6	8 to 14 mA*

*Values are given here as rms for comparison. The author reported values as peak currents in the paper as the waveforms were distorted sinusoidals.

Behavior Response
- Behavioral responses were observed for cows exposed to electrical current at levels below those required to cause a reduction in water consumption, feed intake, and milk production.

Production Loss
- Reaction threshold + 2.1 (or 1.0) mA: No significant reduction in water consumption, feed intake, or milk production.
- Reaction threshold x 1.5: For the first 3 days of the treatment period, there was a statistically significant reduction in water consumption, feed intake, and milk production for the cows exposed at this level (adapted by 21 days).
- For the entire 21 day treatment period, no adverse effects were found (statistically significant) for any current treatment group with respect to water consumption, feed intake, or milk production.

TABLE 1B. RESEARCH ARTICLE REVIEW: Voltage Effects on Livestock

- The articles are arranged by: 1. Location of research, earliest to latest work, 2. First author, and 3. Year of published article (These are listed on the left hand side of the table).
- The number of animals, method of application of electricity and pathway, and a brief description are in the first few lines for each research experiment.
- The letter T indicates the specific level of current at which the treatment was conducted, experiment is abbreviated EXP.
- Refer to definitions section for meaning of abbreviations or explanation of some terms.

NY, Cornell Aneshansley et al. 1988

EXPERIMENT DESCRIPTION

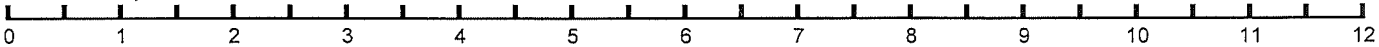
- Investigated the effects of discontinuous ac voltages on water intake, milk production, milk quality and SCC.
- 24 cows, 8 in each of 3 experiments, had voltages applied between water bowl and a metal plate under the rear hooves.

EXP. 1
- Examined the effects of 5 volts on the water bowls for 50% of the day timed so that voltages were on during and after milking. Voltages were cycled on and off in intervals of 2, 3, 4 or 6 hours (2 of the 8 cows were exposed to 1 of the intervals for the whole experiment).
- 6-day pre-control period, 12-day experiment, and 6-day post-control period.

EXP. 2
- Examined the effects of having 8 volt pulses, 1 second in duration and 20 seconds apart during 50% of the day.
- Pulses were present between 6 AM - noon and 6 PM - midnight. 7-day control period, 21-day experiment, and 7-day control period.

EXP. 3
- Examined the effects of having random 8 volt pulses, 1 second in duration throughout the day. Pulses approximately 2.5% of the time.
- 7-day pre-control period, 21-day experiment, and 7-day post control period.

TREATMENTS (TEST LEVELS)



EXP. 1	T	50% of day
EXP. 2	T	One s pulse every 20 s, 50% of day
EXP. 3	T	One s pulse randomly 2.5% of time

RESULTS

EXP. 1	Production Loss	• No significant difference in water consumption for voltage on or off times. • No significant difference in milk production.
EXP. 2	Production Loss	• No significant change in total water consumption. • Significant difference in average water consumption when the voltage was on (more water drank with the voltage off and less drank with the voltage on), when compared to the control period. • No significant difference in milk production. • No significant difference in milk protein or milk fat, or SCC (data not available for experiment 1).
EXP. 3	Production Loss	• Total water consumption the same for control and treatment periods. • No significant difference in milk production. • No significant difference in milk protein or milk fat, or SCC (data not available for experiment 1).

NY, Cornell

Gorewit et al.

1989

EXPERIMENT DESCRIPTION

• Voltages were applied to the water bowls for 15 cows and 15 heifers. Water intake, feed consumption, milk yield and milk composition were monitored.

EXP. 1

• There were 8 sessions with 4 animals and 2 replacements. Animals were exposed to 1+E220 of 5 treatments (0, 0.5, 1, 2 or 4 volts).

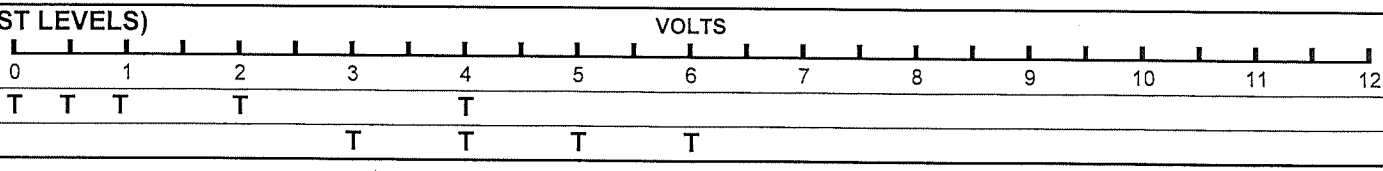
• Voltages were applied between water bowl and a metal grate under the rear feet in concrete stall with no bedding.

• Cows monitored for 10.5 days before, 21 days during and 10.5 days after treatment.

EXP. 2

• 40 cows and 44 heifers were observed when exposed to voltages of 3, 4, 5 and 6 volts (0.5 day control and 2 days treatment).

TREATMENTS (TEST LEVELS)



RESULTS

EXP. 1

Production Loss

• 4 volts: 1 cow and 1 heifer refused to drink for 36 hours and were given an alternate water source.

• Of the 28 remaining cows and heifers (3 cows and 3 heifers at each voltage level):

No significant change in water intake, milk yield and milk composition (protein and fat).

27 of the cows had no significant change in feed consumption, 1 cow at 4 volts had a decrease of 7.5% in feed consumption.

EXP. 2

Production Loss

• 5 and 6 volts: 2 heifers at 5 volts and 2 heifers at 6 volts did not drink for 36 hours and were given an alternate source of water.

• 3, 4, 5 and 6 volts: The remaining 80 animal that did drink (20 at each level) had no significant change in water consumption in the 48 hours that voltages were applied to the water bowls.

NY, Cornell

Gorewit et al.

1990

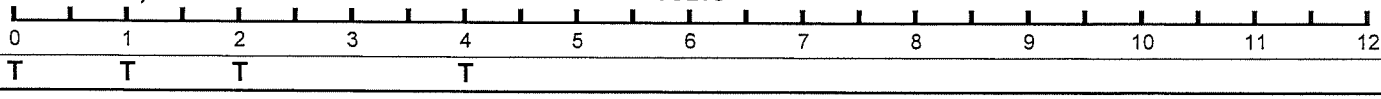
EXPERIMENT DESCRIPTION

- 0, 1, 2 or 4 V was applied continuously between a stainless steel grid under cows front hooves and waterer for an entire lactation for 40 cows (10 cows per treatment group).
- Monitored animal health, reproductive and calving parameters, and milk production.

  Animal Health: somatic cell, mastitis, hoof problems and body weight.

  Reproductive and Calving Parameters: days to 1st breeding, days open, services/conception, PGF2/month (to induce heat), calving interval, visible abortions and calves born dead.

TREATMENTS (TEST LEVELS)



RESULTS

Electrical Parameters
- The averages (and ranges) of currents for 2 randomly selected days were 3.1 (4.5-1.5), 6.5 (8.6-4.6), and 11.2 (14.1-7.5) mA for the 1, 2, and 4 V pens.

Production Loss
- No significant effect on milk production, animal health or reproduction for any of the treatments.

NY, Cornell

Aneshansley et al.

1992

EXPERIMENT DESCRIPTION

- Currents were delivered to lactating cattle in their declining phases of yield through the milk during milking. 7 days of acclimation were allowed.
- Milking duration, milk yield, milk composition for primary and residual milk, and blood cortisol levels were monitored
- *t* test was used to determine significant differences between treatments ($P<0.05$).

EXP. 1 • 7 heifers: Voltages were applied continuously between top of the short milk tubes and the rear hooves (0, 2, 4, and 8 V).

EXP. 2 • 8 cows: Voltages were applied continuously between top of the short milk tubes and the rear hooves (0, 4, 8, and 16 V).

TREATMENTS (TEST LEVELS)

	VOLTS												
	0	1	2	3	4	5	6	7	8	9	10	11	12
EXP. 1	T		T		T				T				
EXP. 2	T				T				T				(T at 16 volts)

RESULTS

EXP. 1

Behavior Response
- 4 volts: Behavioral changes were noticeable for treatments at/or greater than 4 volts.
- 8 volts: Some heifers kicked milkers off (currents ranged from 5 to 12.5 mA). Voltages were discontinued after the milker was kicked off 3 times.

Production Loss
- Milking duration increased at 4 and 8 V, but not significantly.
- There were no significant differences in milking duration, milk yields, or composition (fat, protein, or SCC) of primary and residual milk for any of the voltage levels.

EXP. 2

Behavior Response
- 8 volts: Behavioral changes were noticeable for treatments at/or greater than 8 volts.
- 16 volts: Some cows kicked milkers off (currents ranged from 8 to 18 mA). Voltages were discontinued after the milker was kicked off 3 times

Production Loss
- Milking duration increased at 8 and 16 V, but not significantly.
- There were no significant differences in milking duration, milk yields, or composition (fat, protein, or SCC) of primary and residual milk for any of the voltage levels.
- Residual milk protein was higher for all voltage treatments with multiple lactation cows with significant differences at 4 and 8 V treatments.

EXP. 1,2

- 4 volts: Average currents of 4.1 mA, range (2 to 7 mA).
- 8 volts: Average currents of 9.1 mA (range 4 to 14 mA)

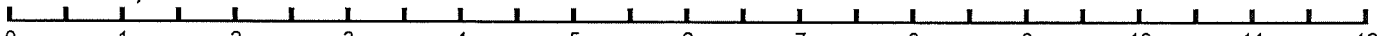
Ontario
Gumprich
1992

EXPERIMENT DESCRIPTION

- The effect of stray voltage on milk production and composition (fat, protein), incidence of mastitis, feed and water consumption, fertility (days to estrus, breeding dates) and behavior, were monitored.
- Experiment was a switchback design consisting of 4, 4-week periods. 6 groups of 5 cows, with each cow starting 10-14 days postpartum.
- Treatment effects can be tested against within-cow, within-lactation variability (separation of residual effects from direct effects).
- Voltage was applied continuously between the metal platform the cow was on (with reduced bedding and moistened with solution for good contact), and the water bowl, pipeline and all metal stabling components including the headset and tie chains.

TREATMENTS (TEST LEVELS)

VOLTS



T	0 volts (control).
T	1.0 volts 5-8 am and 5-8 pm, 0.3 volts other times.
T	2.5 volts 5-8 am and 5-8 pm, 0.75 volts other times.
T	5 volts 5-8 am and 5-8 pm, 0.75 volts other times.

RESULTS

Behavior Response

- No behavior changes noted for any of the treatments, behavior patterns of feeding, watering, defecating and urinating changed very little.

Production Loss

- 1 and 2.5 volts: There were no statistically significant differences in the production or consumption parameters measured, when compared to the control group.
- 5 volts: There were statistically significant differences in milk production, the amount of water, hay, protein and mineral topdress consumed during the first week of treatment. After 1 week the cows acclimated and no significant differences were found.

Quebec
Robert et al.
1991

EXPERIMENT DESCRIPTION

- Experiments were conducted to test the sensitivity of fattening pigs (8 to 21 week of age) to stray voltage on waters and feeders (72 pigs in experiment).
- Voltages were created as a difference of potential between the feeder or waterer and the metallic floor.
- Half the pigs were fed free choice and the other half were restricted to 90% free choice.
- Treatments of 0, 2, and 5 volts were continuously applied to feeders and waters.
- Feed and water intake were recorded every day, while animal weights were taken every 2 weeks.
- Behavior of each pig was recorded during 24 hours once every 2 weeks with an instantaneous scan every 10 minutes.
- Samples were taken every 2 weeks for analysis of blood chemistry (red blood cell concentration, hemoglobin, electrolytes, sugars, proteins).
- After slaughter, stomachs of individual animals were examined and scored according to the degree of ulceration.

TREATMENTS (TEST LEVELS)	VOLTS												
	0	1	2	3	4	5	6	7	8	9	10	11	12
EXP. 1	T		T			T							

RESULTS

Behavior Response

- 2 volts: No significant differences from the control group.
- 5 volts: Significantly decreased the observed eating time by 1.8% for both the full and 90% fed groups.
  Significantly decreased the duration of drinking bouts and total drinking time.

Production Loss

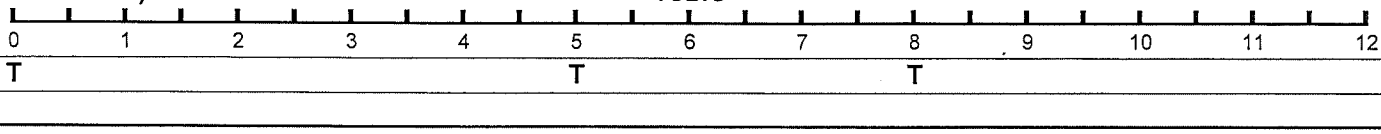
- 2 volts: No significant differences from the control group.
- 5 volts: Significant decrease in daily feed intake as compared to the 2 V and control groups from 17 to 21 weeks of age.
  Average daily gain was significantly lower than in the 2 V and control groups from 17 to 21 weeks of age.
  The mean daily feed intake for the whole fattening period was affected in the 5 V group.
  No significant difference in mean water intake, daily gain and feed conversion.
- No significant difference in frequency and severity of gastric lesions for any of the treatments.
- No significant effect on the concentrations of the blood chemistry variables measured for any of the treatments.

Quebec
Robert et al.
1992

EXPERIMENT DESCRIPTION

- Experiments were conducted to test the sensitivity of fattening pigs (10 to 22 week of age) to stray voltage on waters and feeders (72 pigs in experiment).
- Voltages were created as a difference of potential between the feeder or drinker and the metallic floor.
- Treatments of 0, 5, 8 volts were continuously applied to feeders and waters.
- Half the pigs were fed free choice and the other half were restricted to 90% free choice.
- Feed and water intake were recorded every day, while animal weights were taken every 2 weeks.
- Samples were taken every 2 weeks for analysis of blood chemistry (red blood cell concentration, hemoglobin, electrolytes, sugars, proteins).
- Behavior of each pig was recorded during 24 hours once every 2 weeks with an instantaneous scan every 10 minutes.
- After slaughter, stomachs of individual animals were examined and scored according to the degree of ulceration.
- 1 slice of the longissimus muscle was also collected from each carcass at the 13th rib level for measurement of meat color.

TREATMENTS (TEST LEVELS)



RESULTS

Behavior Response
- 5 and 8 volts: Induced some changes in behavior but had no effects on production and health parameters.
- Observed aggressive behavior remained below 0.1% of observation time for all groups.
- 8 volts for restricted-fed pigs: The number of drinking bouts were significantly lower during the hour following feed distribution. The total drinking time was lower (not significantly) during the hour following feed distribution.

Production Loss
- 5 and 8 volts: Significant reduction in drinking time occurred only at 18 and 20 weeks of age.
  Significant reduction in water intake occurred only between 14 and 16 weeks of age.
- No significant impact on mean daily feed intake and average daily gain over the fattening period.
- The frequency and severity of gastric lesions and the color of the meat were similar among treatments.

Quebec
Godcharles et al.
1993

EXPERIMENT DESCRIPTION

- Experiments were conducted to test the sensitivity of fattening pigs (9 to 22 weeks of age) to stray voltage on waters and feeders (72 pigs in experiment).
- Voltages were created as a difference of potential between the feeder or drinker and the metallic floor.
- Pulses (P) superimposed to baseline voltage(B); 0B-0P, 0B-2P, 2B-5P or 5B-8P volts. (Example: 5 V baseline with pulses to 8 V)
- Pulses of 3 seconds duration were in the form of an increase in the amplitude of the constant 60 Hz signal, mimicking transient voltages due to switching of loads.
- 1 pulse appeared every 20, 40 and 100 seconds during the hour following feed distribution and every 60, 120 and 300 seconds during the rest of the day.
- Feed and water intake were recorded every day, while animal weights were taken every 2 weeks.
- Samples were taken every 2 weeks for analysis of blood chemistry (red blood cell concentration, hemoglobin, electrolytes, sugars, proteins).
- Behavior was recorded during the hour following the 2 daily feed distributions at 9-10, 13-14, 17-18, and 21-22 weeks of age.
- After slaughter, stomachs of individual animals were examined and scored according to the degree of ulceration.

TREATMENTS (TEST LEVELS)

VOLTS

0 1 2 3 4 5 6 7 8 9 10 11 12

T 0 V baseline, 0 pulse.

T 0 V baseline, 2 V pulses of 3 s duration.

T 2 V baseline, 5 V pulses of 3 s duration.

T 5 V baseline, 8 V pulses of 3 s duration.

RESULTS

Behavior Response

- No significant effect for the feeding, drinking, sitting or laying activities was found for any of the treatments.
- 5 volt base - 8 volt pulse: At 9-10 weeks of age, the number of routing bouts and number of events of butting the penmate was significantly higher.

Production Loss

- 0 volt: The average daily gain was significantly lower between 9-10 weeks of age.
- 2 volt base - 5 volt pulse: At 17 and 18 weeks of age had a significantly higher rate of gain than the other treatments.
- No significant impact on feed or water intake over the fattening period for any of the treatments.
- No significant effect was found for frequency and the severity of gastric ulcerative lesions and the blood chemistry profiles for any of the treatments.

WA State
Crane
1975

EXPERIMENT DESCRIPTION

- Waterers were electrified and instrumented so that currents and water consumption could be measured.

EXP. 1
- 70, 12 to 24-month old heifers (mixed Holstein, Guernsey and Jersey) were provided water at 3 fountains with varying patterns of voltages.
- The heifers had access to all 3 waterers at all times.
- Current and water consumption were monitored and heifers were observed for 2, 4-hour periods per day (0, 3, 6, and 8 V).

EXP. 2
- 30 holstein heifers were placed in 2 groups, a control with a water at 0 volts and a treatment with an adjustable voltage water.
- Treatment was 5 days on and 2 days off, then next higher voltage (0, 1.85, 4, 6, 7, and 8 V).

TREATMENTS (TEST LEVELS)

	VOLTS												
	0	1	2	3	4	5	6	7	8	9	10	11	12
EXP. 1	T			T			T		T				
EXP. 2	T		T		T		T	T	T				

RESULTS

EXP. 1

Behavior Response
- Animals preferred the lower voltage waterer.
- 3 and 6 volts: Some animals exhibit some discomfort drinking.
- 3 volts: Water consumption from this tank was reduced about 20% from the waterer at 0 volts.
- 6 volts: Water consumption from this tank was reduced about 66% from the waterer at 0 volts.
- The most water was drank at the closest tank regardless of voltage.

EXP. 2

Electrical Parameters
- Currents measured up to 19 mA, resistances 324 to 393 ohms.

Production Loss
- Daily total water consumption for treatments showed a decrease in test consumption toward the end of the week at 4, 6, and 7 volts, with recovery during the 2 day rest period.
- Gallons/drink were higher at all voltage levels different from 0 (except 8 volts, this treatment was discontinued after 1 day).
- 4 volts: Some animals would drink from an electrified fountain until this level was reached.
- 8 volts: Herd refused to drink for 8 hours on a hot day

NOTE: No statistics were provided.

ABBREVIATIONS

A	Ampere
ac	alternating current
dc	direct current
ECG	electrocardiogram
EXP.	experiment
mA	milliampere (1/1000 A)
ms	millisecond (1/1000 s)
V	volt

DEFINITIONS

Alternating Current (ac): Flows first in one direction and then in the other to complete one cycle. Electrical power serving homes and farms are at 60 Hz.

Behavioral change: Changes in behavior that can be associated with novel or objectionable stimuli or events. Changes range from mild or moderate (i.e., flinching or becoming vocal) to distinct (i.e., raising a leg or kicking).

Circuit: An electrical pathway, consisting of conductors, loads, and source, through which electric current flows.

Cortisol: A hormone sometimes released in response to a stressful stimulus.

Current (A): The flow of electrons through a pathway, due to a difference in electric potential (voltage).

Direct Current (dc): Current or voltage, either positive or negative, (monophasic) applied continuously for a given period of time, or applied intermittently with a period of zero level between stimulus applications.

Dopamine: An inhibitor of prolactin secretion.

Electrocardiograms (ECG): A tracing of the changes of electrical potential occurring during the heartbeat used in diagnosing abnormalities of heart action. ECG electrodes and paste are designed as conductors used in applying and measuring currents and voltages.

Epinephrine: Also known as adrenalin (inhibits milk letdown).

Impedance (Z): Combination of electrical resistance, inductance, and capacitance that impede the flow of current in an electrical pathway (approximately equal to the resistance for animal circuits).

Hertz (Hz): A unit of frequency. One hertz equals one cycle per second.

mA: Electrical current in milliamperes. One milliampere = 1/1000 ampere.

Momentary: A current or voltage event that is between about 1/100 of a second, and one or two seconds (usually a damped waveform).

ms: Time in milliseconds. One millisecond = 1/1000 of a second. The time required for one cycle of 60 Hz voltage or current is 16.7 milliseconds (0.017 seconds).

Norepinephrine: A hormone that is similar to epinephrine with slightly different receptors and effects.

Oxytocin: A hormone involved in milk letdown.

Perception: An awareness of. It is impossible to determine when animals first become aware of an object or event; therefore, visible signs of perception are measured by looking at changes in behavior, e.g., leg lifting, or training animals to perform a specific task, such as pressing a lever, in response to stimulus.

PGF_2: Used to induce heat in cattle.

Physiological effects: Measurable changes in the normal body functions of an animal. Measured variables commonly include levels of hormones in blood, heart rate, and other indices of normal functioning.

Postpartum: After calving and coming into milk.

Prolactin: This hormone is necessary for mammary growth in cows.

Resistance (R): The properties of a material that impedes the flow of current in an electric circuit.

rms: This is the root mean square value of an alternating current or voltage. It is the value generally displayed by an analog or digital electrical meter. For a sinusoidal current or voltage the rms value is 0.707 times the zero to peak value of the sine wave. For a square wave current, the rms value is the same as the peak value.

SCC: Somatic cell count.

Transient: A voltage or current impulse of short duration, usually less than 1/2 of a 60 Hz cycle (approximately 1/100 of a second).

Voltage (V): A difference in electrical potential between two points.

BIBLIOGRAPHY

Aneshansley, D. J., R. A. Pellerin, J. A. Throop and D. C. Ludington. 1995. Holstein cow impedance from muzzle to front, rear and all hooves. ASAE Paper 95-3621. ASAE, St. Joseph, MI.

Aneshansley, D. J., R. C. Gorewit and L. R. Price. 1992. Cow sensitivity to electricity during milking. *J. of Dairy Sci.* 75 (10): 2733–2741.

Aneshansley, D. J., R. C. Gorewit, L. R. Price and C. S Czarniecki. 1988. Effects of discontinuous voltages applied to waterers. ASAE Paper 88-3523. ASAE, St. Joseph, MI.

Brennan, T. M. and R. J. Gustafson. Behavioral study of dairy cow sensitivity to short ac currents. Technical Paper No. NCR-86-202, ASAE, St. Joseph, MI.

Crane, L. B. 1975. Effects on mammals of grounded neutral voltage from distribution power lines. *Inst. Elec. Eng.* 75-303-3-IA.

Currence, H. C., B. J. Steevens, D. F. Winter, W. K. Dick and G. F. Krause. 1990. Dairy cow and human sensitivity to 60 hertz currents. *Appl. Engin. in Agric.* vol. 6(3) ASAE, St. Joseph, MI.

Godcharles, S. Robert, J. J. Matte, J. Bertin-Mahieux and G. P. Martineau. 1993. Transient stray voltage: is it detrimental to growth performance, health status and welfare of market pigs? *Vet. Res. Com.* 17(1), 41–53.

Gorewit, R. C., D. J. Aneshansley, D.C. Ludington, R.A. Pellerin and X. Zhao. 1989. ac voltages on water bowls: effects on lactating Holsteins. *J. of Dairy Sci.* V. 72 (8): 2184–2192.

Gorewit, R. C., D. J. Aneshansley and L. R. Price. 1992. Effects of voltages on cows over a complete lactation. 1. Milk yield and composition. *J. of Dairy Sci.* V. 75 (10): 2719–2725.

Gorewit, R. C., D. J. Aneshansley and L. R. Price. 1992. Effects of voltages on cows over a complete lactation. 2. Health and reproduction. *J. of Dairy Sci.* V. 75 (10): 2726–2732.

Gorewit, R. C., L. R. Price, D. J. Aneshansley and C. S. Czarniecki. 1990. Holsteins' reproductive performance during long-term voltage exposure. ASAE Paper 90-3503. ASAE, St. Joseph, MI.

Gorewit, R. C. and N. R. Scott. 1986. Cardiovascular responses of cows given electrical current during milking. *J. of Dairy Sci.* V. 69 (4): 1122–1127.

Gorewit, R. C., N. R. Scott and C. S. Czarniecki. 1985. Responses of dairy cows to alternating electrical current administered semirandomly in a nonavoidance environment. *J. of Dairy Sci.* V. 68 (3): 718–725.

Gorewit, R. C., N. R. Scott, and D.V. Henke Drenkard. 1984. Effects of electrical current on milk production and animal health. ASAE Paper 84-3502. ASAE, St. Joseph, MI.

Gumprich, P. S. Stray voltage effects on dairy cattle. 1992. Report for the: Canadian Electrical Association. Montreal, Quebec. CEA 178 D 477.

Gustafson, R. J., R. D. Appleman and T. M. Brennan. 1986. Electrical current sensitivity of growing/fishing swine for drinking. Tran. of the ASAE V. 29 (2) 592–596, 600.

Gustafson, R. J., T. M. Brennan and R. D. Appleman. 1985. Behavioral studies of dairy cow sensitivity to ac and dc electric currents. Trans. of the ASAE V. 28 (5): 1680–1685.

Gustafson, R. J., Z. Sun and T. D. Brennan. 1988. Dairy cow sensitivity to short duration electrical currents. ASAE Paper 88-3522. ASAE, St. Joseph, MI.

Henke Drenkard, D. V., R. C. Gorewit, N. R. Scott and R. Sagi. 1985. Milk production, health, behavior, and endocrine responses of cows exposed to electrical current during milking. *J. of Dairy Sci.* V. 68 (10) p. 2694–2702.

Lefcourt, A. 1982. Behavioral responses of dairy cows subjected to controlled voltages. *J. of Dairy Sci.* V. 65 (4) 672–674.

Lefcourt, A. M. and R. M. Akers. 1982. Endocrine responses of cows subjected to controlled voltages during milking. *J. of Dairy Sci.* V. 65 (11): 2125–2130.

Lefcourt, A. M., R. M. Akers, R. H. Miller and B. Weinland. 1985. Effects of intermittent electrical shock on responses related to milk ejection. *J. of Dairy Sci.* V. 68 (2): 391–401.

Lefcourt, A. M., S. Kahl and R. M. Akers. 1986. Correlation of indices of stress with intensity of electrical shock for cows. *J. of Dairy Sci.* V 69 (3): 833–842.

Norell, R. J., R. J. Gustafson, R. D. Appleman and J. B. Overmier. 1983. Behavioral studies of dairy cattle sensitivity to electrical currents. Tran. of the ASAE V. 26 (5): 1506–1511.

Reinemann, D. J., L. E. Stetson and N. K. Laughlin. 1994. Effects of frequency and duration on the sensitivity of dairy cows to transient voltages. ASAE paper no. 943597. ASAE, St. Joseph, MI.

Reinemann, D. J., L. E. Stetson and N. K. Laughlin. 1995. Response of dairy cattle to transient voltages and magnetic fields. IEEE Transactions on Industry Applications, vol. 31, no. 4, pp. 708–714.

Reinemann, D. J., L. E. Stetson and N. K. Laughlin. 1995. Water, feed and milk production response of dairy cattle exposed to transient currents. ASAE paper no. 953276. ASAE, St. Joseph, MI.

Robert, S., J. J. Matte, J. Bertin-Mahieux and G.P. Martineau. 1991. Effects of continuous voltage on health, growth and welfare of fattening pigs. *Can J. Vet. Res.* 55: 371–376.

Robert, S., J. J. Matte, J. Bertin-Mahieux and G.P. Martineau. 1992. Stray voltage: its influence on swine production during the fattening period. *Can. J. Anim. Sci.* 72: 467–475.

USDA. 1991. *USDA Agricultural Handbook, 696, Effects of Electrical Voltage/Current on Farm Animals.* Alan M. Lefcourt—Editor in chief. U.S. Government Printing Office: 1992-617-013/46592.

Whittlestone, W. G., M. M. Mullord, R. Kigour and L. R. Cate. 1975. Electric shocks during machine milking. *N.Z. Vet. J.* 23:105.

Woolford, M. W. 1972. Small voltage in milking plants. In Proceedings of the 2nd Seminar on Farm Machinery and Equipment. Publication 645, New Zealand Department of Agriculture, Hampton, N.Z. pp. 41–47.

New 6:96-2M-KMF, File 18.34 (Electrical Wiring), Extension Bulletin E-2606.