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Tests of a high stimulation unit on a commercial beef slaughter floor

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INTRODUCTION

In early 1978, discussions between officers of the CSIRO Meat Research Laboratory and management of Kilcoy Pastoral Co. Pty. Ltd., led to an agreement to install a prototype high voltage electrical stimulation unit on the beef slaughter floor at the Kilcoy Abattoir, some 100 km North West of Brisbane. Broadly, CSIRO were to design and supply the equipment necessary to effect stimulation, and the abattoir undertook to install and enclose the equipment in a suitable safety enclosure. CSIRO would assist in commissioning and modifying the equipment as necessary to bring it up to reliable production standard and would then have access to the stimulation facility for experimental work aimed at establishing factors of importance in effectiveness of stimulation. Kilcoy management were enthusiastic to participate in this project because they could foresee economic advantage in being able to supply their local trade markets with consistently tender beef. The results of the experimental work are reported here. Technical appendices, giving detailed results associated with the experiments are in a companion report by Herbert et al. (1981).

LOCATION OF STIMULATION UNIT

Kilcoy beef floor can process up to 45 cattle/hour on a rail dressing system with gravity-aided manual transport of carcasses along the rail. The cattle are knocked, hoisted onto the bleeding rail and stuck. At the end of the bleeding rail, the head and hocks are removed, and knife work is completed prior to hide pulling on an upward hide puller. Carcasses are then eviscerated, split into sides, washed and weighed before being pushed into chillers. After about 24 hours chilling, sides are quartered and moved into the boning room, or sent out to local trade. About half Kilcoy's production is sent to local trade, either as bone-in quarters or as chilled, vacuum-wrapped cuts.

Space on the beef slaughter floor is restricted, and there are only three locations where stimulation equipment could be installed; on the bleeding rail; on an approximately 15 m length of rail between hide pulling and evisceration; and on rails in chiller corridors or in chillers. Previous work had indicated that carcasses should be stimulated

- as soon after sticking as possible
- before splitting, to simplify electrode application
- with hide-off, to permit good contact between electrodes and body.

The decision was made to install the stimulation unit between hide pulling and evisceration corresponding to a point on the rail normally reached by carcasses about 13 minutes after stunning. However, for the 10 or so bodies on the rail between sticking and the stimulation unit, this time could be extended to 23 min as a result of 10 min "smokos" and to 43 mins for 30 min "smokos".

The Kilcoy beef floor is unusual in having manual transport along the rail and for this reason fairly complex automatic equipment was required to capture, locate, stimulate, and eject bodies one at a time. The Kilcoy unit is considerably more complex than would be required for beef floors with powered-rail systems, as would be the case in most abattoirs killing 350 cattle/day. A further complication arises because of the type of trolleys used on the Kilcoy rail, which incorporate nylon bushes as bearings for the wheel axles and for the hook swivel. This construction could not be relied on either to isolate the trolley from the rail or to give a good electrical connection, so that special provision had to be made to ensure positive electrical contact with the Achilles tendons of each carcass.

DESCRIPTION OF STIMULATION UNIT

General: Stimulation takes place inside a safety enclosure which incorporates several features designed to ensure safe operation in the slaughter-floor environment. Operation of the unit is fully automatic, controlled by a relay logic control unit with appropriate safety interlocks. The unit is diagramatically represented in Fig. 1. A carcass is pushed along the rail, and when the cabinet is empty, the up-line stop retracts, allowing the carcass to run on to the cabinet stop. The leading trolley is now resting on an electrically isolated section of rail and the trailing trolley is positioned on an earthed section of rail. The doors close automatically and two electrodes are moved into contact with the hooks of the leading and trailing trolleys. A bar electrode is also moved into contact with the neck end of the spine (not shown on Fig 1, but seen clearly in Fig. 2). Stimulation power is then automatically applied for the required length of time. The power is then turned off, the doors open and a pneumatic ram pushes the carcass out of the cabinet. Two hinged footplates and the doors are interconnected with the safety circuit, such that all must be in the 'safe' position before stimulation power can be applied.

Stimulation Configuration: Leg-to-leg: As originally designed, stimulation current flow is directed from the active electrode contacting the leading trolley down one hind leg, through the hindquarters, and up the other hind leg to the earthed electrode contacting the trailing trolley. The neck electrode is not used in this configuration.

Neck-to-legs: The neck bar is connected as the active electrode and both electrodes contacting the trolleys are connected to earth. Current flow is from neck, through the body and to earth via both legs. The retracted neck bar is sprayed with hot water to sterilise it before it contacts the next carcass, the stimulation power being turned off when the bar is retracted.

Leg-to-leg and neck: Operation with an active neck bar gave rise to some spectacular flashes and bangs when high voltages short circuited to earth across wet solids build-up on neck electrode insulators. Drip of blood and body fluids onto the neck electrode was unavoidable, and the use of water for sterilization compounded the problem. For normal works production, therefore, the neck electrode is connected to earth.

The trolley electrodes, (as in leg-to-leg configuration) become active (leading) and earth (trailing). Connection of the trailing electrode to active is not considered satisfactory, as there is no certainty that the nylon bushes insulate the trolley from the earthed rail on which it is positioned. Current flow is from leading hook, down one leg, and then along parallel paths to earth, up the other leg to earth at the trailing hook, and down the body to earth at the neck bar.

Experimental Features in Electrical System: Specially-constructed equipment is incorporated into the Kilcoy unit, as befits its prototype and experimental nature. The power unit can be quickly and simply reset to give a range of electrical outputs from a 240V 50Hz input. Voltages are variable in 100V steps from 100 to 1200 VRMS and pulse frequences can be set at 9.1, 11.1, 14.3, 20.0, and 33.3 pulses per second (corresponding to 11, 9, 7, 5 or 3 half sinusoidal wave forms per second when derived from a 50Hz supply). Pulse widths can be set at either ½ wave (10 millisecs) to ¼ wave (5 millisecs). The duration of stimulation can be set to give any desired number of seconds between 10 and 120.

OBJECTIVE & DEFINITIONS

The objective of the test work was to determine optimum conditions for effective stimulation of beef carcasses under production conditions at Kilcoy. For the purposes of this report, the terms 'effective stimulation' and 'optimum conditions' have been defined as follows:

'Effective Stimulation' is the electrical stimulation required to accelerate the rate of fall of muscle pH such that, one hour after stimulation, the pH of stimulated muscle is 0.9 or more pH units lower than the pH of unstimulated muscle. This definition of effective stimulation was chosen in preference to others, e.g. that pH of stimulated muscle is 6.0 or lower at one hour after stimulation, because of problems in pH measurement experienced in some earlier tests (see section 'Test Procedures'). For example, in Test 3, values of pH as low as 6.25 were obtained in the striploin of unstimulated carcasses and as low as 5.26 in the cube roll of stimulated carcasses. A pH of 6.0 or lower for stimulated muscle would not be a reasonable definition of effective stimulation when pH values of 6.25 were obtained for unstimulated muscle. However, the accuracy of pH measurement was suspect, apparently resulting in pH values that were 0.6 or 0.7 units too low for both stimulated and unstimulated muscles. Rather than make an arbitrary correction to observed pH values, we have chosen to adopt a definition for effective stimulation which takes account of such consistent errors.

'Optimum Conditions': As results from tests were analysed, it became clear that effective stimulation could be obtained using various combinations of electrode configuration, duration of stimulation, voltage, pulse frequency and pulse width. However, in any given practical stituation, there are constraints on these variable e.g. at Kilcoy the rate of carcass flow (one every 75 to 80 seconds) sets an upper limit of about 60 seconds on duration of stimulation. Thus the selection of 'optimum conditions' involves the selection of pulse frequency and width, electrode configuration and lowest voltage (for safety reasons) that result in effective stimulation when applied for 60 seconds (or shorter) duration of stimulation.

TEST PROCEDURE

Nine tests (see Table 1) were completed between June 1980 and February 1981, each involving measurements on up to 40 carcasses out of a single day's production.

Table 1 Experimental Conditions.

Test No.	Voltage Peak	Pulse* Frequency pulses/sec	Stimulation Duration (sec)	Configuration
1	1700	14.3	90	Leg to Leg
2	1700	14.3	90,45	Leg to Leg & Neck
3	850	14.3	120,90,45	Neck to Legs
4	1700,850	14.3	90,60,30,15	Neck to Legs
5	850,420	14.3	90,60,45,30,15	Neck to Legs
6	140	14.3	90,60,45,30	Neck to Legs
7	420,140	14.3	45	Neck to Legs
8	420,140	100	45	Neck to Legs
9	420	9.1,14.3,14.3(½) 33.3	45	Neck to Legs

* All full pulse (10 ms) except for part of Test 9

Because works production was of paramount importance, test work had to be carefully planned to ensure objectives could be achieved without interrupting normal production. At the end of slaughtering on the day before the test, two Laboratory staff set up the required stimulation configuration, set electrical variables and checked the stimulation unit in readiness for the test. Up to six staff were involved from the start of slaughtering on the day of the test, labelling carcasses, controlling variables, taking measurements and recording information. On the day after the test three or four staff were involved in collecting meat samples and resetting stimulation conditions for normal production. In most tests, values of meat pH were measured at 3 locations in the longissimus dorsi (LD) muscle which contains the striploin and cube roll. A spear-type combination pH electrode, Ionode Type G101F, was used with a digital pH meter. In Tests 1, 2 and 3, a mains powered TPS meter Model 3852/R was used but it was not reliable when operated at the cool, humid conditions of the tests. For tests 4 to 9, the meter was changed to TPS model LC80, similar in appearance to the model 3852/R, but battery operated and completely self-contained. This meter proved to be completely satisfactory.

The technique of Shaw et al. (1977) was used for pH measurements. A scalpel was used to make a cut about 50 mm long, completely through the fat cover and about 10 mm deep into the meat at the point of measurement. The electrode was inserted into the cut in the wet meat and a steady reading was obtained after 15 to 20 seconds. After taking about 10 readings, the electrode tip was immersed in alcohol and wiped with a tissue, to clean off accumulations of fat which would otherwise adversely

affect electrode accuracy. The technique outlined above is time-consuming and needs considerable practice to be sure of accurate readings, in addition it leaves unsightly cuts in the meat. Developments are in hand which should lead to a more satisfactory technique for measurements of pH on hot carcasses on the slaughter floor or in the chiller (Anderson et al., 1981).

Instantaneous values of stimulation voltage and current were displayed on a dual-beam oscilloscope, Tektronix Type 335, and peak values measured by scaling the displayed values. Other information such as dentition, sex, fat cover and side weights were recorded from grading tickets attached to the sides. In some early tests, deep butt and deep LD temperatures were recorded continuously on several sides in the chiller, and adjacent air temperatures were also measured. Copper-constantan thermocouples were used, with outputs of up to 30 thermocouples recorded on a 2 pen Riken Denshi chart recorder Model SPH6P, in conjunction with 3 Keithley Scanners, Type 702. Reference thermocouples were immersed in an Ice Point Reference unit (Kaye Industries).

RESULTS & DISCUSSION

Effects of Stimulation

Visual: Carcasses were observed to have a violent initial reaction to stimulation. With all three configurations and at all voltages, the carcass stiffened and the back bone arched immediately voltage was applied. The forelegs moved upwards to horizontal or higher, and in some of the bigger carcasses the forelegs touched earthed portions of the cabinet, giving rise to another path for current to flow to earth (Tests 4 and 5). Stiffening gave problems particularly on smaller carcasses when the neck bar was in use. If the carcass was swinging at the start of stimulation or if the neck bar contacted the carcass near the cut end of the neck, initial stiffening could cause the carcass to move away from the neck bar. The carcass then relaxed allowing it to recontact the neck bar, and causing immediate stiffening. In several cases, the carcasses jumped so violently that it was necessary to turn off the stimulation voltage. Burst paunches were noted on carcasses so affected, and in one or two cases, the bung was thrown out. showering the cabinet and its contents with faeces.

In most carcasses, the initial stiffening and arching was maintained for the first 20 to 30 seconds of the stimulation cycle, and the carcass was observed to be trembling at about pulse frequency of the applied voltage. After about 30 seconds, the stiffening slowly moderated and at about 45 seconds, there was a marked drooping of the forelegs. After 90 seconds, particularly at higher voltages, the forelegs had drooped almost back to the unstimulated position.

Twitching of the neck and shoulder muscles of beef sides is a well-known phenomenon, which persists for an hour or more after slaughter, even when sides are moved into a chiller. Little or no twitching was observed in stimulated sides, at 30 minutes or so after slaughter. Twitching of unstimulated sides is a manifestation of residual muscular energy, which is dissipated by electrical stimulation.

Temperature: Acceleration of rigor mortis reactions by electrical stimulation may be expected to result in an increase in carcass temperature. In Tests 1, 2 and 3, deep butt temperatures were about 1.3°C higher in stimulated carcasses than in unstimulated carcasses, 1 hour after stimulation. This temperatures difference has been used as the basis of a simple device for determining whether a carcass has been stimulated or not (Anderson and Larnach 1980).

pH: During the nine tests, pH measurements were taken on several hundred sides of beef, generally at 3 locations in the LD at 1 hour after the carcass passed through the stimulation cabinet. From the results of early tests, it became clear that for LD samples cut from rapidly chilled beef sides, this value of pH was correlated with toughness, as measured by WB shear force. The greater the difference between pH of unstimulated meat and the pH of stimulated meat, the greater the difference in toughness between the unstimulated and the stimulated meat, i.e. the better the stimulation effectiveness. Conversely the smaller the pH difference the smaller the difference in toughness, i.e. the worse the stimulation effectiveness. This correlation is clearly shown in Table 2.

Table 2 pH differences and WB shear force values for LD samples.

Test No.	Dentition	pH difference		WB Shear Force (kg)			
		Striploin	Cube Roll	Striploin		Cube Roll	
				Unstim.	Stim.	Unstim.	Stim
1	0 and 2	0.99	0.06	13.7	5.6	10.1	14.5
(Leg-to-Leg)	6 and 8	1.23	0.01	21.4	6.6	14.7	17.0
2	0 and 2	1.11	0.99	19.9	6.0	19.6	7.6
(Leg-to-Leg and Neck)	8	0.93	0.97	13.6	7.9	11.2	10.8
3	0 and 2	1.14	1.01	20.4	7.3	12.2	8.6
(Neck-to-Legs)	8	0.96	1.12	14.4	6.8	9.2	7.0
7	0	1.12	-	18.7	6.4	-	-
(Neck-to-Legs)	6	1.06	-	17.7	7.7	-	-
	8	0.70	-	16.3	9.0	-	-
8	4 and 6	0.79	-	18.9	13.0	-	-
(Neck-to-Legs)	4 and 6	0.55	-	18.9	15.8	-	-
9	4 and 6	0.81	-	13.9	6.4	-	-
(Neck to Legs)	4 and 6	0.72	-	13.9	7.0	-	-
	4 and 6	0.96	-	13.9	5.9	-	-
	4 and 6	0.83	-	13.9	6.0	-	-

It is not possible and, for the purposes of this report, probably not necessary, to quantify the relationship between pH difference and change in toughness due to stimulation. Stimulation conditions which produce a pH difference of 0.9 units or greater can be regarded as providing effective stimulation.

The use of pH measurement to gauge effectiveness of stimulation has several advantages over other methods for use in abattoirs. Firstly, the difference between pH values for stimulated and unstimulated meat, taken 1 hour after stimulation, is a direct measure of the degree of acceleration of the rigor mortis reactions. The difference between shear force values on chilled meat samples is not, because it depends on rates of chilling. Thus, it is quite possible for a sample from a carcass which has been effectively stimulated to have the same shear force value as a sample obtained from a slowly-cooled, unstimulated carcass. Secondly, pH measurement is non-destructive, can be done by works personnel using standard equipment, and takes only a few seconds for each reading. Thirdly, and perhaps most important for abattoir use, results are obtained within an hour or so of stimulation, allowing reasonable control of the stimulation process. The usefulness of the pH measurement technique is shown in the following sections.

Effectiveness Related to Animal Characteristics

For given stimulation conditions, the pH-difference measure of effectiveness appeared to be unaffected by carcass breed, sex, age or weight. However, there was clear evidence that shear force values were affected by age and weight (to some extent age and weight and directly related, with older cattle being heavier and fatter than younger animals). In general, LD samples from unstimulated 6 and 8 tooth animals gave lower shear force values than samples from unstimulated yearlings. The probable explanation is that older, heavier carcasses cooled more slowly than the lighter yearlings, and therefore suffered less cold shortening, and toughening. Samples from stimulated 6 and 8 tooth animals gave slightly higher shear force values than samples from stimulated yearlings. Higher shear force values for stimulated 6 and 8 tooth animals reflect the greater toughness of meat from older animals.

It was also noted that, in each test, one stimulated carcass and sometimes two, out of the 40 or so test carcasses, gave much lower pH differences than the rest, although stimulation conditions were the same for all carcasses. In some cases, these anomalous carcasses were identified as 'dark-cutters'. It is well known that pre-slaughter stress causes glycogen depletion in muscles, and meat from cattle killed in this condition will be 'dark-cutting' or 'high-pH'. Stimulation cannot produce a low pH in such meat, and by our definition, stimulation effectiveness will be poor. At Kilcoy, it appears that up to 5% of cattle are affected, but this figure may be much higher, depending on the condition of stock being slaughtered. At another abattoir, it was reported that a run of cows in poor condition gave little or no visual response (stiffening, arching of back) to stimulation, presumably due to glycogen depletion. Clearly stimulation effectiveness would have been very poor in virtually 100% of these animals.

Effectiveness Related to Time After Stunning

From pH readings, poor stimulation effectiveness was obtained in the striploins of two yearlings and four 8 tooth cattle stimulated in Test 1 whereas satisfactory effectiveness was noted for 50 other cattle stimulated under similar conditions. The only obvious difference was that these six cattle had been stunned before 'smoko' breaks, spending up to 30 minutes longer between stunning and stimulation than the other cattle. With the leg-to-leg configuration used in Test 1, the LD muscle was not in the current flow path and the striploin may be assumed to have received its stimulation indirectly through the nervous system. As stimulation conditions that were effective at 13 minutes after stunning were not effective at 23 or 43 minutes, it appears that the nervous system had ceased to function for stimulation purposes in the intervening period. In Test 2, six older cattle were stimulated at 40 minutes after stunning. Satisfactory stimulation effectiveness was noted at all locations in the LD of these animals, presumably because the LD muscle is in the current flow path when the leg-to-leg and neck configuration is used and stimulation does not rely on the nervous system for its effect. In Tests 3 to 9, readings were taken only on cattle that had been stimulated 12 to 13 minutes after stunning, avoiding those affected by 'smoko' breaks.

Effectiveness Related to Stimulation Conditions

Configuration: The results of Test 1 showed that the leg-to-leg configuration did not stimulate the cube-roll end of the LD and sometimes not even the striploin end (see previous section). In Test 2, with leg-to-leg and neck configuration, all 3 locations in the LD were effectively stimulated. It appears that in the Kilcoy unit, where carcasses are stimulated about 13 minutes after stunning, that only those muscles in, or close to, the current flow path will be effectively stimulated. With either leg-to-leg and neck, or neck-to-legs configurations, all the LD is effectively stimulated and from the small amount of data on other muscles (topside, rump and foreleg) taken in these tests, other muscles in both hind and forequarters also benefit. At Kilcoy, we would advise the leg-to-leg and neck configuration as satisfactory from the viewpoint of effective stimulation. With the neck bar at earth potential, safety is improved and the problem of short circuiting of the stimulation voltage across wet neck bar insulators is eliminated.

Duration: Points representing average values of pH difference at 15, 30, 45, 60, 90 and 120 sec. duration of stimulation have been plotted in Fig. 3 for all cattle breed, sex and age; values of voltage between 140 and 1700 V peak; leg-to-leg and neck, and neck-to-legs configurations; and pulsing rate of 14.3 pulses/sec. The average value of pH differences at a given duration is marked as an inverted triangle. At 45 sec. duration and higher, the triangles are all above the effective stimulation value of 0.9. Only 3 points (two at 45 sec. and one at 90 sec.) are just below 0.9, and two of these points are associated with tests at 140V peak stimulation voltage. At Kilcoy we would advise 45 seconds duration as a minimum value for effective stimulation.

Voltage: Points representing average values of pH differences at 140, 425, 850 and 1700 V peak have been plotted in Fig. 4 for all cattle breed, sex and age; stimulation durations of 45, 60, 90 and 120 sec.; neck-to-legs and leg-to-leg and neck configurations; and pulsing rate 14.3 pulses/sec. The average value of pH differences at a given voltage is marked as a triangle. All the triangles are at values above 0.9 pH difference, indicating effective stimulation at all voltages. Three points (the same 3 points as in Fig. 3) are below the 0.9 value, two of them are included in the 140V peak voltage points. There appears to be no benefit to stimulation effectiveness in the use of voltages higher than 425V peak, and we would advise Kilcoy to use 425V peak, which is less dangerous and more economical in energy than higher voltages.

Pulse Frequency: Points representing average values of pH differences at pulsing rates of 9.1, 14.3, 33.2 and 100 pulses per second have been plotted in Fig. 5 for all cattle breed, sex and age; stimulation duration 45 seconds; 425V peak; and neck-to-legs and leg-to-leg and neck configurations. The only pulsing rate which gave effective stimulation was 14.3 pulses/sec. Pulsing rates of 9.1 and 33.2 pulses/sec were almost satisfactory, but the 100 pulses/sec. frequency (unmodified 50 Hz power) did not give effective stimulation at the stimulation parameters which were satisfactory at lower pulsing rates. We would advise Kilcoy to use 14.3 pulses/sec.

Electrical Resistance of Carcasses and Power Requirements: Instantaneous values of current and voltage were measured on most carcasses during the tests. The electrical resistance of the carcasses (voltage divided by current) averaged 293 ohms for leg-to-leg, 200 ohms for leg-to-leg and neck, and 167 ohms (105 to 283 ohms for individual carcasses) for neck-to-legs. As previously noted, the forelegs of several carcasses contacted earthed parts of the cabinet, providing another current flow path and thereby increasing current flow for all or part of the stimulation cycle. Taking carcass resistance to be 200 ohms, the energy required at 425V peak, 14.3 pulses/sec and 45 second duration will be 0.001 kWh for each carcass.

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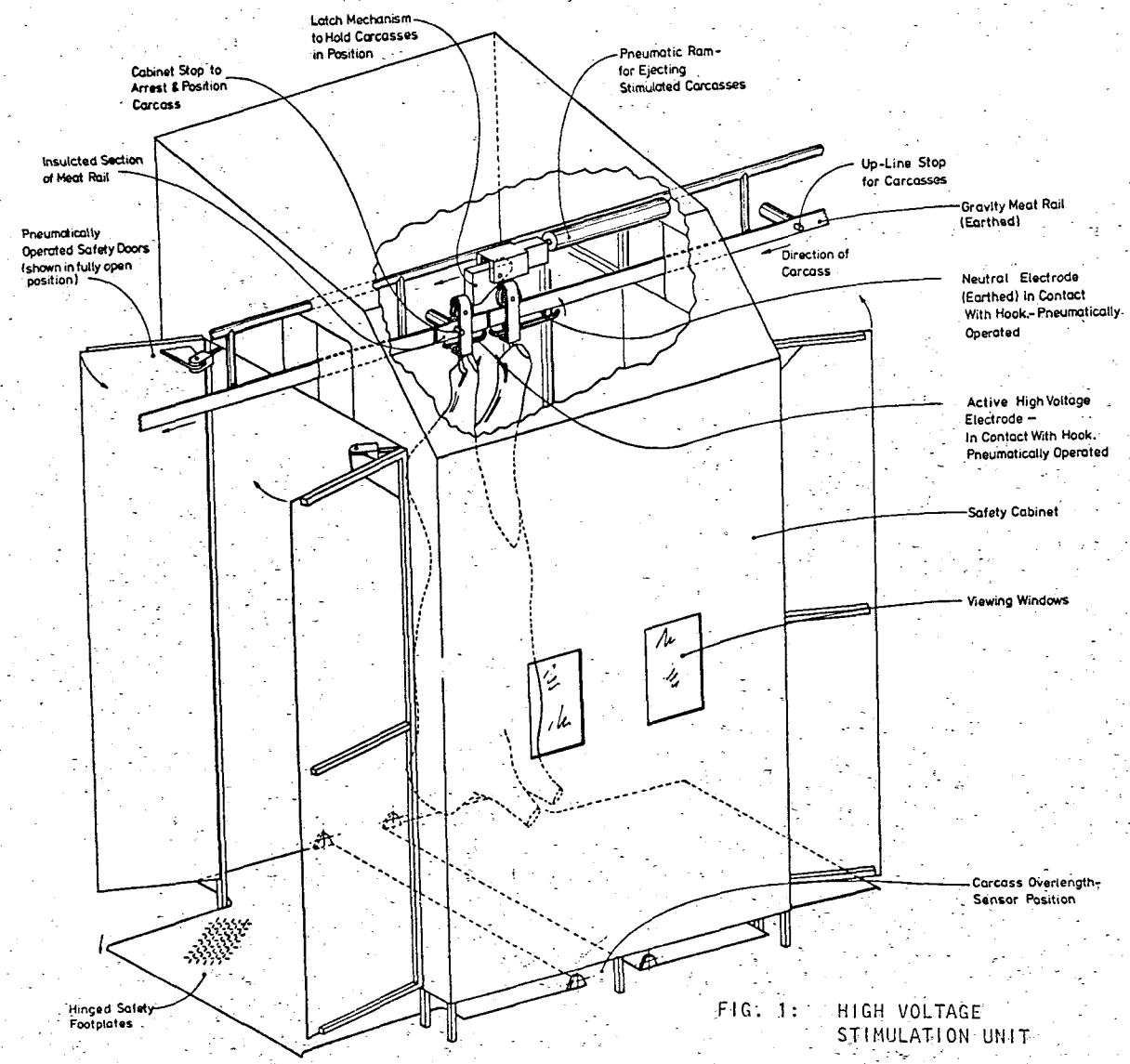
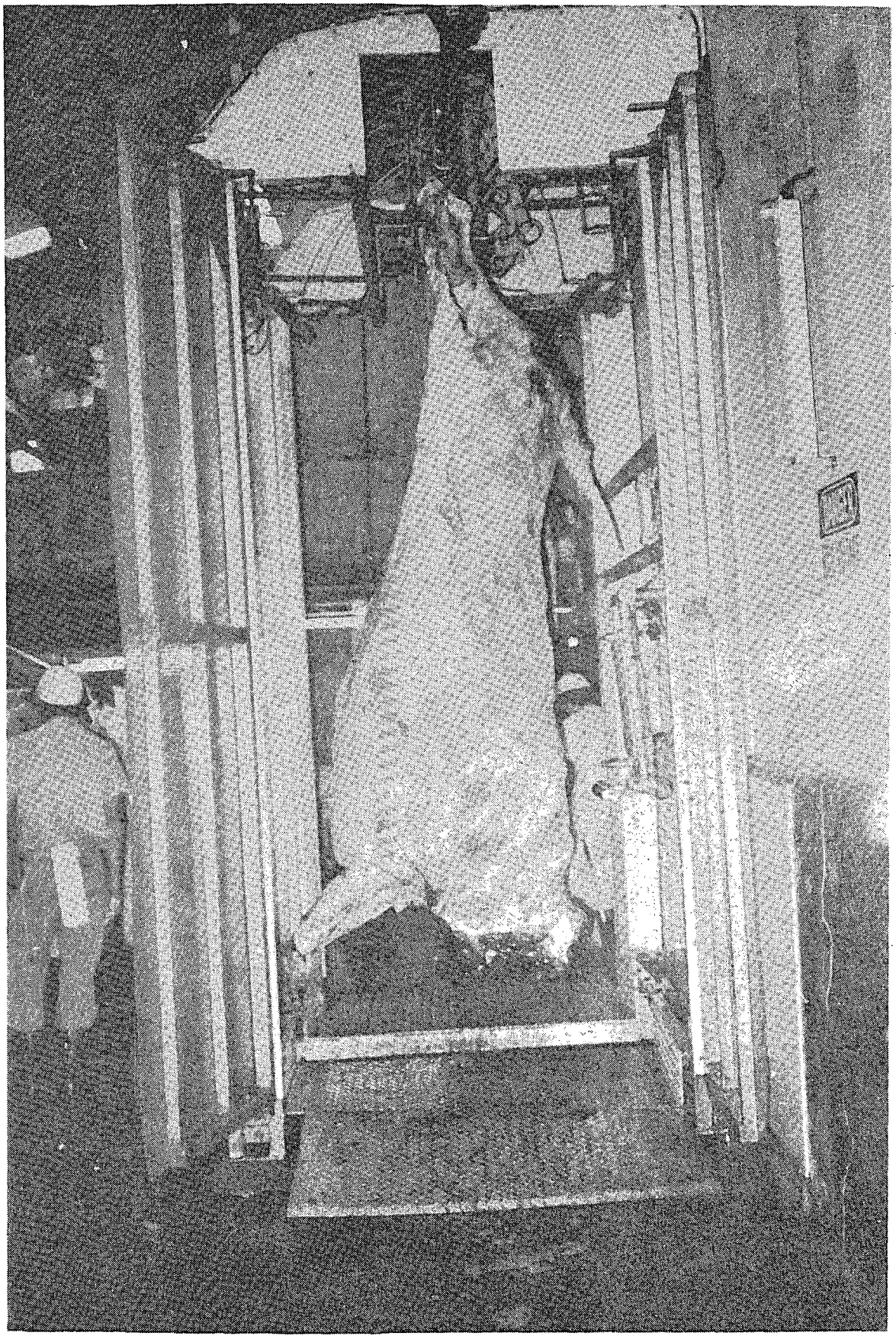


FIG. 1: HIGH VOLTAGE STIMULATION UNIT



HIGH VOLTAGE STIMULATION UNIT.

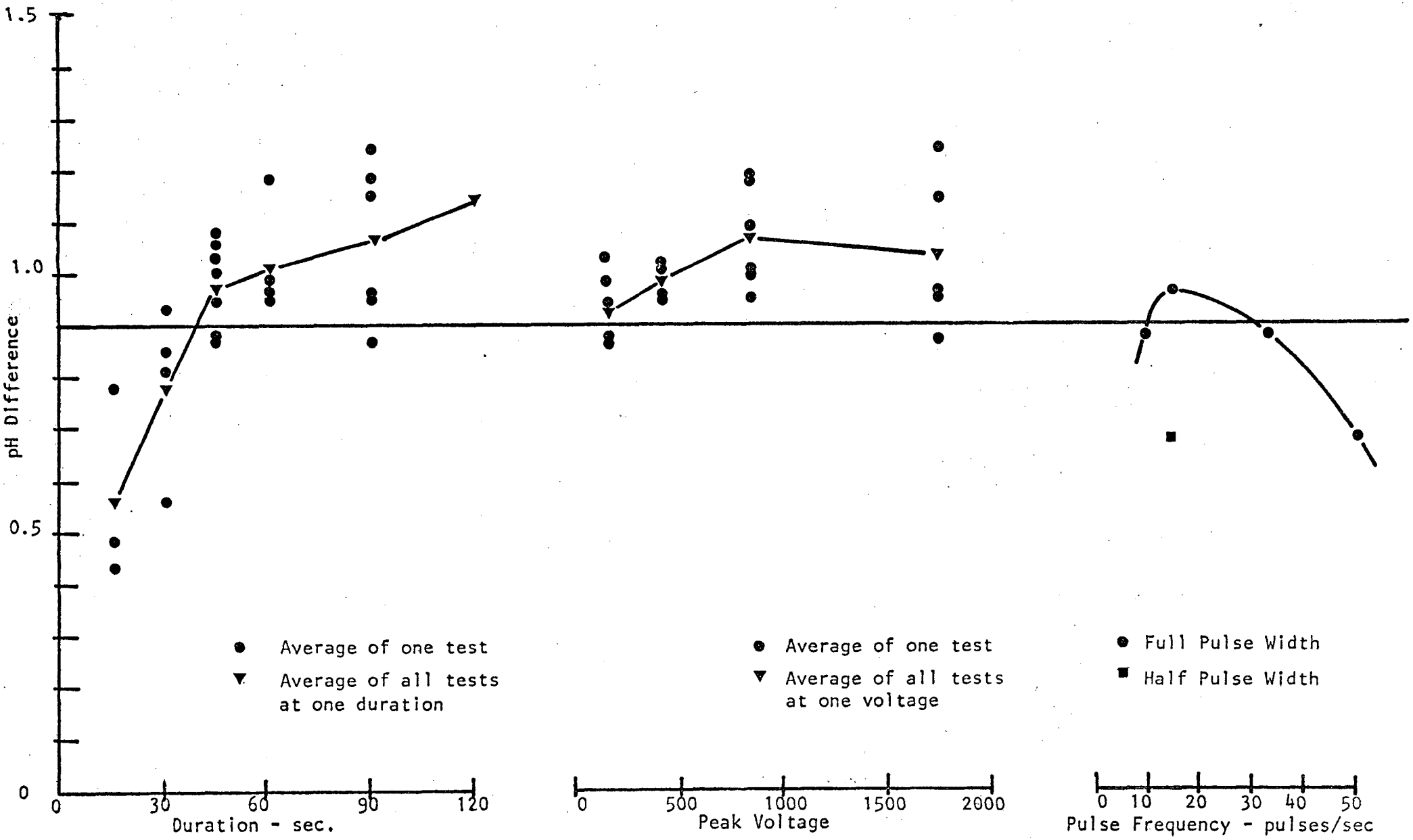


FIG. 3: Effect of Duration

FIG. 4: Effect of Voltage

FIG. 5: Effect of Pulse Frequency