

Title	A study of the milking performance of eight milking machines
Authors	Cowhig, Michael Joseph
Publication date	1968
Original Citation	Cowhig, M. J. 1968. A study of the milking performance of eight milking machines. MSc Thesis, University College Cork.
Type of publication	Masters thesis (Research)
Rights	© 1968, Michael Joseph Cowhig. - https://creativecommons.org/licenses/by-nc-nd/4.0/
Download date	2026-09-21 14:56:52
Item downloaded from	https://hdl.handle.net/10468/16381



UCC

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

*A Study
of
The Milking Performance
of
Eight Milking Machines*

BY

MICHAEL JOSEPH COWHIG, B.Agr.Sc.

[A Thesis submitted for the Degree of M.Sc. (Agriculture)]

A STUDY OF THE MILKING PERFORMANCE OF EIGHT MILKING
MACHINES

BY

MICHAEL JOSEPH COWHIG B.Agr.Sc.,

A thesis submitted for the degree of M.Sc. (Agriculture) in
the National University of Ireland

February 1968

Dairy Research Centre,
An Foras Taluntais,
Moorepark,
Fermoy,
Co. Cork.

CONTENTS

	Page
INTRODUCTION	1
OBJECTIVE	12
EXPERIMENTAL PROCEDURE	14
DEFINITIONS	24
RESULTS	25
DISCUSSION	63
COMMENTS ON EASE OF OPERATION AND MAINTENANCE	69
CONCLUSIONS	73
SUMMARY	75
REFERENCES	76
ACKNOWLEDGMENTS	85

INTRODUCTION

There are twenty makes of milking machine available to the Irish farmer at present. Most of these are available in bucket and pipeline plants but two are available in pipeline plants only. However, 90% of the 30,000 milking machines in the Republic of Ireland are bucket type. All the machines available are the two-chamber type and normally work at a vacuum of 13" to 15" Hg. No two machines have exactly the same properties in pulsation characteristic or design of cluster assembly.

Vacuum level

There is a large volume of evidence in the literature to show that milking rate of cows increases with increase in milking vacuum, Smith and Petersen (1946), Baxter et al (1950), Gregoire et al (1954), Caruolo et al (1955), Dodd and Clough (1955), Mochrie et al (1955), Porter et al (1955), Stewart and Schultz (1956, 1958), Bratlie (1958), Clough and Dodd (1958), Lightbody and Murray (1960), Brandsma (1963a), Rusev (1963), Smith et al (1963b, 1964),

and Tilliole (1964). In all the experiments reported above with the exception of ^{those of} Porter et al (1955) and Brandsma (1963a) one type of cluster assembly was used with different levels of vacuum. Furthermore the milking clusters used with the exception of ^{those used by} Brandsma (1963a) were designed to milk cows at a vacuum of 10" to 15" Hg and when they were used in experiments with vacuum levels greater than 16" Hg teat cup crawl occurred early in milking and this gave rise to excess machine strippings with the result that there was only a small gain in total milking time. Consequently, all the milking machines available to farmers milk at a vacuum of 15" Hg or less. Increases in milk yield with increase in vacuum level have been reported by Dodd and Clough (1955) and Brandsma (1963a). This increase was in the region of 5% for Dodd and Clough (1955), using a half udder technique. However when the same experiment was carried out using twins there was no difference in yield. In a lactation experiment Gregoire et al (1954) found that cows milked with high vacuum had a longer lactation but there was no significant difference in milk yield. The effect of high vacuum on udder damage and number of new infections is not clear. Some teat damage was reported by Bratlie (1958), Rusev (1963), Dodd and Clough (1955) and

Walsh and Nyhan (1966); also an increase in new infections was reported by Bratlie (1958) and Walsh and Nyhan (1966). The latter two research workers used vacuum levels greater than 20" Hg in their experiments. In the experiments of Dodd and Clough (1955), Mochrie et al (1953 , 1955), Rusev (1963), and Schmidt et al (1963b), vacuum levels up to 20" Hg did not increase the number of new infections in cows compared to vacuum levels from 10" to 15" Hg. However, these experiments were carried out when fewer facts were available concerning the importance of hygiene in the control of new infections. Consequently, it is not possible to attach much significance to the new infection data in these experiments with the exception of ^{those of} Dodd and Clough (1955), & Nyhan Mochrie et al (1963 , 1965) and Walsh (1966) where the hygienic control systems used in the experimental methods are described.

Pulsator Characteristics

All two-chamber teat-cups have a pulsation chamber where pressure alternates between atmospheric pressure and milking vacuum during milking. When the pulsation chamber

is under vacuum, the teat cup liner is in its normal open position and milk flows. When the pulsation chamber is under atmospheric pressure, the liner is collapsed, stopping milk flow and massaging the cow's teat. Naturally, the number of times the liner opens and closes during one minute (pulsation rate) and the percentage of the cycle time that the liner remains open will influence milking rate and milking time.

Changes in pulsator rate and ratio influence the rate of milking to a lesser extent than changes in vacuum level and the literature on these aspects of machine milking has been reviewed by Labussiere and Richard (1965). Experiments by Smith and Petersen (1946), Clough and Dodd (1956 , 1958), Aigner and Hobbiger (1957), Allison (1959), Kaveshnikova (1960), Bratlie et al (1962), Gedde-Dahl (1962), Phillips (1963), Schmidt et al (1963a), Jorgensen and Caruolo (1963) & Moore (1965) show that machines with wide ratio pulsation milk faster than machines with narrow ratio pulsation. In one experiment, Bratlie et al (1962) found some petechiae in the mucous membrane of the teat cistern of cows milked with a pulsation ratio of 4 : 1. On the other hand, Schmidt et al (1963), in

their experiments, found that pulsation ratio did not affect the amount of udder infection or the degree of udder irritation when ~~they were~~ comparing pulsation ratios of 1 : 1, 2 : 1 and 3 : 1. Most of the experiments with the exception of ^{that of} Bratlie ~~et al~~ (1962) are short-term experiments and, it is not possible to predict the effect pulsation ratio may have on udder health without doing more specific investigations. None of the experiments reported above used a standard technique for challenging the cows with pathogenic bacteria.

Phillips (1963) has shown that the rate of change of pressure in the pulsation chamber to and from milking vacuum will influence the rate of milking. When the delay in air to vacuum phase was increased from 8 to 18 per cent of the cycle time the milking time increased and the yield of machine stripping increased by 18 per cent which indicates that teat cup crawling takes place earlier in milking when a delayed vacuum stroke is used. When the delay in vacuum to air phase was increased from 7 to 23 per cent the average milking time was decreased by five seconds

and the average and maximum milking rates were reduced by 2 and 10 per cent. Phillips also attaches importance to a slow vacuum to air phase for cow comfort and minimising the chances of the introduction of bacteria to the teat sinus with milk jetting back through the streak canal during milking. Thiel et al (1964 , 1966) have studied in detail, pressures in the teat-cup assembly and liner wall movement as well as the flow rate pattern within single-pulsation cycles. From these studies and the studies of Adran et al (1958) it is reasonable to define pulsation ratio as the ratio of the time the pressure is $< 5''$ Hg below maximum milking vacuum, to the time the pressure is $> 5''$ Hg from maximum milking vacuum during one pulsation cycle in the pulsation chamber - e.g. the ratio A : B in fig. 1.

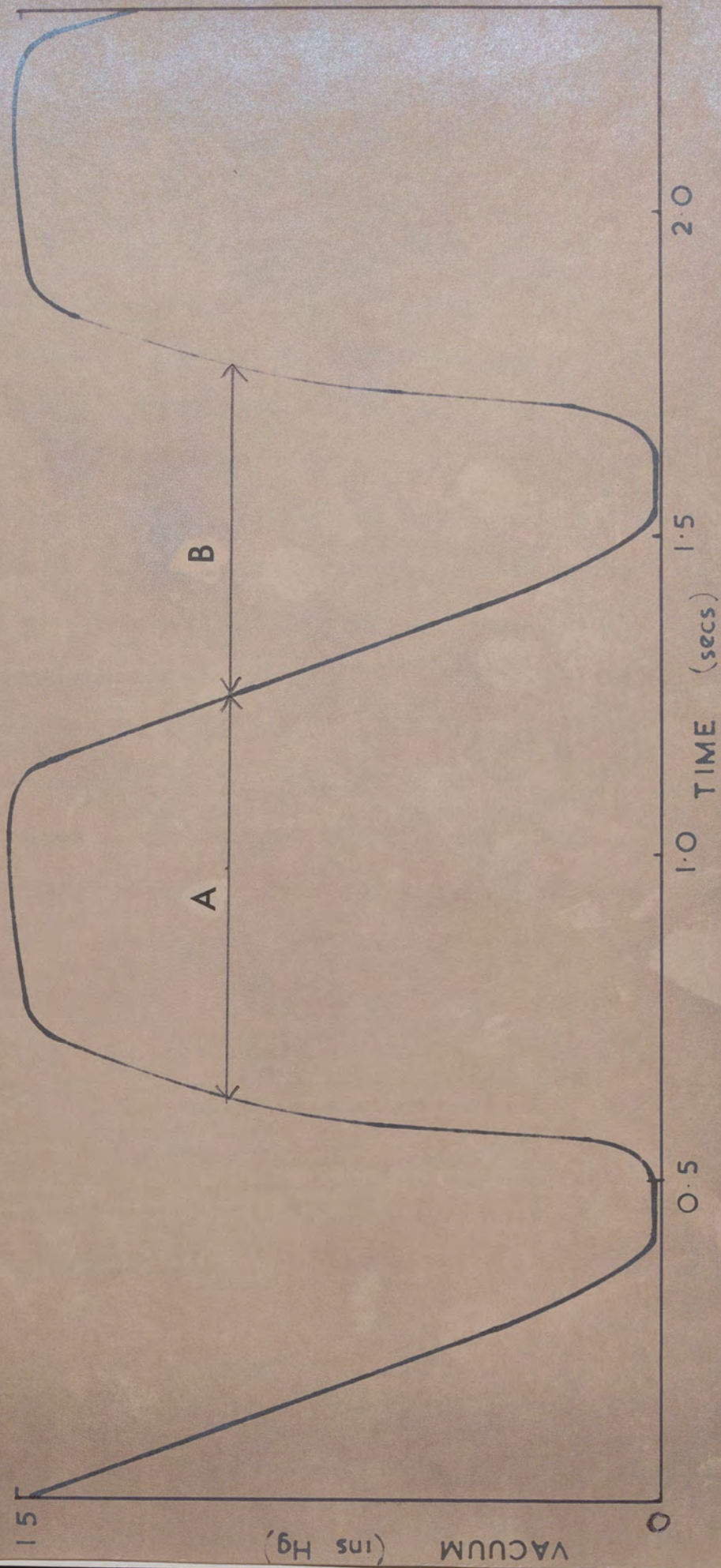


FIG. 1 PULSATION RATIO A:B MEASURED 5" Hg BELOW MAXIMUM VACUUM ATTAINED IN THE PULSATION CHAMBER.

Several experiments have been carried out to determine the effect of changing pulsation rate on milking rate. Increases in pulsation rate increased milking rate for Clough et al (1953), Steward and Schultz (1956), Andreae (1957), Valdmann (1959), Kaveshnikova (1960), Jorgensen and Caruolo (1963), Smith et al (1963a) and Langeluddeke and Kloth (1964). However, in some short experiments by Stewart and Schultz (1956 , 1958), Valdmann (1959) and Schmidt et al (1963a), the milking rate results were not conclusively in favour of increasing pulsation rate. Bratlie et al (1959) and Kaveshnikova (1960) in one experiment found that increases in pulsation rate reduced milking rate. Some of the conflicting results in these experiments are possibly due to the fact that, when the pulsation rate was changed in some pulsators, there was a corresponding change in pulsation ratio and this was not taken into account. The size of the vacuum and air ports of a pulsator can influence the pulsation ratio when the rate is changed, and it would, in fact, be possible to get a reverse ratio at a high pulsation rate if the vacuum port of the pulsator is small. This may have occurred in the experiments of Bratlie et al (1959) and Kaveshnikova (1960). Some research workers found increased machine

stripping times with increase in pulsation rate - Stewart and Schultz (1956 , 1958), Schmidt et al (1963a), and this increase influenced total milking time. The increase in machine stripping time associated with increases in pulsation rate may possibly be explained by the findings of Phillips (1963). However there was no information given on the rate of change of pressure in the pulsation chamber for the above studies. There is no evidence in the literature, from short-term experiments, to suggest that increasing the pulsation rate increases the rate of new infections. However, in a long-term experiment, Bratlie et al (1959) found the characteristic signs of poor blood circulation, eroded streak canal and serum exudate at the orifice, more frequently in cows milked at 75 pulsations per minute than in cows milked at 40 pulsations per minute. Walsh and Nyhan (1966) found that a pulsation rate of 140 led to a marked increase in the incidence of new infections compared to a pulsation rate of 50 in a lactation experiment with 16 first-lactation cows.

Cluster Assemblies

The weight of the cluster assembly and the design of liner has received attention from research workers for many years. Dodd and Henriques (1949) showed that increasing the weight of a cluster assembly from 7 to 11 lb. gave an insignificant increase in milk yield and a highly significant reduction in machine stripping yield with one type of liner. The reduction of machine stripping time by increase of cluster weight was offset by the rate at which clusters fell off at the heavier weights. Smith (1951) found that the addition of 1, 2, 3 and 4 lb. weights to the teat-cup assembly had little effect on rate of milking but the amount of machine stripping was reduced for some cows, particularly those on which teat-cups "crawl" early in the milking process. Adding 2 lb. weights to the teat-cup assembly caused a slight decrease in machine stripping time for Schmidt et al (1963b). However the addition of a 4 lb. weight caused a significant increase in the maximum rate of flow. Adding 2 and 4 lb. weights significantly increased the average rates of flow as well as the number of times the units fell off the cows. Similar results were obtained by Abbasov (1965). Brandsma

(1963b), Rabolt (1963) and Langeluddeke and Kloth (1964) showed that milking rate was affected by different cluster assemblies. Clough (1964 a, b) found that cluster assembly weight was significantly and inversely related to quantity of machine stripping with eighteen commercial sets of cluster assemblies weighing between 6.2 and 7.8 lb. He also found a highly significant difference between peak flow rates with different liners. Under the conditions of Schmidt's (1963) experiment, the narrow-bore moulded liner ($\frac{7}{8}$ inch internal diameter) had no advantage for milking cows over the medium or wide-bore liners ($1\frac{1}{4}$ inch internal diameter). Tilliolle (1962) found that liner size had no effect on milking rate and Gedde-Dahl's (1962) results showed that the effect of pulsation ratio on maximum milking rate was four times as great as that of cluster assembly. Dodd (1953), found that increasing the tension of the walls of extruded teat-cup liners resulted in an increase in the maximum milking rate of cows.

Liner Design and Mastitis

In experiments with moulded and extruded liners Dodd et al (1957), Murphy (1961) and Dillon et al (1957), found that more mastitis was associated with moulded liners. However Oliver et al (1957), found that a slightly higher incidence of infected quarters and clinical mastitis occurred in quarters milked with extruded liners in comparison to quarters milked with moulded liners. Cows with infected quarters responded more favourably to stretched liners for Murphy (1960), and there was no difference in the mastitogenic effect of moulded and extruded liners. The number of cows badly infected with mastitis was greatly reduced when the liners were changed from a slack wide-bore liner to a narrow-bore stretched liner, by Wilson (1958). However the bore diameter and type of mouthpiece did not influence the degree of udder irritation or new infection rate of cows milked with the various types of liners in experiments of Schmidt et al (1963a).

OBJECTIVE

The objective of this experiment was to measure the effect of eight different milking machines differing in some or all of the following characteristics, vacuum level, pulsator rate, pulsation ratio, cluster assembly weight and liner design on production, milking rate, stripping yield and udder irritation. Most of the experiments carried out on the effect of changes in milking machine characteristics, have been carried out with one or two different types of machine with the exception of ^{those of} Clough (1964a,b) and his experiments were of very short duration. It is reasonable to assume that an increase in milking rate will occur with increases in vacuum level with different types of machine. However, it is important to measure the magnitude of this increase and find out how changes in pulsator and cluster assembly characteristics influence it.

The machines included are available on the Irish market and the experiment should show up any differences in ease of operation that may arise in the 6 month experimental period. All the machines with the exception of Machine H milk at

15" Mercury Vacuum so that the difference in performance between seven machines will be due to differences in pulsator and cluster characteristics at a standard vacuum.

This experiment does not measure the effect of the different milking machines on the rate of new infections. It was felt that it would not be possible to carry out a meaningful investigation on infection within treatment periods of 17 days duration. However, stringent precautions were observed to keep the cows free from mastitis pathogens during the experiment. Thus it was postulated that it would be possible to measure any direct irritational effects the milking machines had on the teats and secretory tissue by recording cell count and teat apex abnormalities.

EXPERIMENTAL PROCEDURE

The experiment was carried out using an eight by eight Latin Square design with sixteen cows, eight cows in each replicate. The variables are replicates, cows within replicates, periods and machines. Fifteen of the cows were in their second or later lactations and one cow was in her first lactation. Details of the cows are shown in Table 1.

TABLE 1. Data on Cows Used in Experiment

Cow No.	Milk Yield lb Previous Lactation	Days in Lactation before Exp. Started	Breed
82	6,795	65	Sh
104	5,655	88	Sh
115	6,797	102	Sh
116	5,863	71	Fr
121	8,775	90	Fr
335	10,181	88	Fr
402	8,474	110	Fr
403	6,549	30	Fr
480	8,515	103	Fr
500	4,446	105	Fr
607	5,275	12	Fr
651	Nil	61	Sh
927	7,682	115	Fr
929	7,859	105	Fr
930	6,634	116	Fr
931	6,038	40	Fr

At the beginning of the experiment the cows were assigned to two groups of eight on milk yield and date of calving. These groups were randomly assigned to both replicates and the layout of the experiment is shown in Table 2.

TABLE 2. Layout of Experiment, Replicate I

Period								
	C	F	D	E	G	A	B	H
I	480	927	651	121	82	335	116	402
II	651	82	121	116	335	927	402	480
III	335	116	480	402	651	82	927	121
IV	121	402	927	335	480	116	82	651
V	927	651	402	82	116	480	121	335
VI	402	335	116	480	927	121	651	82
VII	116	480	82	651	121	402	335	927
VIII	82	121	335	927	402	651	480	116

Replicate II

	C	F	D	E	G	A	B	H
I	930	104	115	403	931	929	607	500
II	500	115	929	607	104	931	930	403
III	931	930	104	500	115	403	929	607
IV	115	403	931	930	929	607	500	104
V	929	607	403	931	930	500	104	115
VI	607	931	930	104	500	115	403	929
VII	104	500	607	929	403	930	115	931
VIII	403	929	500	115	607	104	931	930

All the cows were free from infection before the experiment started and they were maintained free until the experiment was completed.

Cow management

The cows were run as a herd and grazed pasture night and day. They did not receive any supplementary feeding during the experiment. Milking was carried out in a 16 stall cowbyre. There was one milker and a helper. The milking was begun at 6.30 a.m. and 4.30 p.m.

The cows were prepared for milking by drawing fore milk into a strip cup. Then the udder and teats were washed with a cloth from a disinfectant solution (100 ppm Iodine) and dried with the same cloth. The teat-cup assembly was put on within one minute of the end of preparation. When the sight glass cleared the milker 'machine stripped' and the clusters were removed when the sight glass cleared again. A three and a half pound weight was added to the clawpiece of Machine F after seventy five per cent of machine yield was milked and the milker 'machine stripped' when the sight glass cleared. The teats were dipped in an Iodophor solution (5000 ppm available Iodine) immediately after milking.

Description of cluster assembly and pulsators

All teat-cup shells used in the experiment were made of stainless material. Three cluster assemblies used semi-moulded liners incorporating a sight glass between the liner and short milk tube and five machines had moulded liners. Details of the cluster assemblies are given in Table 3.

TABLE 3. Description of Clusters

Machine	Weight of cluster (lb)	Type of liner	Identification no. of liner	Air Admission in clawpiece cubic feet per min. free air	Clawpiece
A	6.6	Moulded	96000-1 (Alfa-Laval)	0.11	952766-1
B	6.3	Semi-moulded	Universal S (Fullwood)	0.15	Fullflow
C	5.3	Moulded	Type 40 (Gascoigne)	0.25	Gascoigne bowl type 273/51/52
D	4.5	Moulded	Monokura (G.V.B) Universal no. 6	0.30	Flynn H. type
E	5.5	Semi-moulded	Manus 11	0.25	Tip Top
F	5.2*	Moulded	N.Z. reg. no. 6554 (Ruakura)	0.15	Fullflow
G	Not recorded**	Moulded	T47-13 (Surge)	0	None
H	6.4	Semi-moulded	4974-18 (Westfalia)	0	Westfalia

* A $3\frac{1}{2}$ lb. stripping weight was added to the clawpiece after 75% of machine yield was milked.

** Not possible to record weight of suspended pail type cluster.

All the machines except D and F had individual pneumatic pulsators, fitted to the lids of the milking pails, as they are normally supplied for a pail type plant. Machines D and F had mechanical master pulsators driven from the shaft of the vacuum pump, and relay pulsators operated pneumatically by the pulses from the master pulsator. The pulsation rate of machines D and F was determined by the speed of the pump. All the pneumatic pulsators except A permitted adjustment of the pulsation rate, while the master pulsator of Machine D permitted adjustment of the pulsation ratio. Details of the pulsation and type of machine are given in Table 4 and Plates 1 - 13.

TABLE 4. Description of Milking Machines and Pulsation Characteristics

Machine	Type	Pulsation rate (pulsation/min)	Pulsation ratio	Vacuum Level
A	Pail	61	73 : 27	15
B	Pail	50	56 : 44	15
C	Pail	45	(*54 : 46) (46 : 54)	15
D	Pipeline	48	60 : 40	15
E	Pail	44	49 : 51	15
F	Pipeline	42	51 : 49	15
G	Suspended pail	60	40 : 60	15
H	Pail	60	70 : 30	13

* The two sides of the pulsator in Machine C had different ratios; i.e. the teat cups on one side of the cow were pulsed with a 54 : 46 ratio, and the cups on the other side with a 46 : 54 ratio.

Procedure and apparatus for recording pulsation characteristics
and vacuum.

The four teat-cup liners were sealed with mouthpiece bungs and operated in the milking position. A pressure transducer was connected to the short pulse tube by means of a T-piece inserted in the pulse tube as close as possible to the pulsation chamber of the teat-cup. The pressure transducer provides an electrical output proportional to the pressure at the inlet to the pulsation chamber, and by recording this during a complete pulsation cycle the pulsation characteristic is obtained. Plate 14.

The pulsation characteristics were recorded with the pulsator working at milking vacuum. For the twin pulsators in machines A, C, E and H, the pulsation characteristic was recorded for the two sides of the pulsator.

The pressure transducer¹ used was of the variable-reluctance, half-bridge type, and measured differential pressures in the range 0-20 p.s.i. It was energised at 3 kc/sec and worked with a carrier-amplifier/demodulator², the output from which was fed to a galvanometer³ of an ultra-violet oscillograph recorder⁴.

¹SE 150, SE Laboratories (Engineering) Ltd., Feltham, Middlesex, England

²SE 449/2, SE Laboratories (Engineering) Ltd.,

³SMI/A, S.M.I. Ltd., 128/130 Hamilton Road, West Norwood, London S.E. 27.

⁴ABEM Ultralette 5651 (Svenska Diamant Bergborrnings AB, Stockholm, 1, Sweden).

The pulsation characteristics shown in Fig. 2 to Fig. 9 inclusive illustrate the rate of change of pressure of the various pulsators. The pulsation ratio was measured from each characteristic as the ratio of the vacuum phase to the atmospheric pressure phase along a horizontal line drawn at a vacuum level of 5 inches of mercury below the steady vacuum level of the vacuum phase, i.e. the ratio A : B in Fig. 1. The pulsator rate was calculated by counting the number of pulsation cycles in three minutes and dividing this number by 3. The milking vacuum was measured with a mercury manometer. The manual vacuum reserve was 5 C.F.M. free air.

The two pipeline machines milked into a pail, consequently there was no difference in the vertical distance the milk was lifted between any of the eight machines.

Each cow was milked by one machine for 17 days and then transferred to another machine. The milk was recorded at each milking, using a spring balance scales graduated in 0.25 lb divisions. Composite milk samples for fat and total solids analysis were taken on three successive days each week. The milk samples were pipetted from the pail after the milk had been poured twice. Fat was estimated by the Gerber method and

total solids by Claesson Total Solids Milk Analyser. The solids-non-fat was got by subtraction.

Milk flow rate and machine stripping were measured at the morning milking during the final 3 days of each period by milking into a pail suspended from a spring balance graduated in 0.1 lb. The weight of milk in the pail was recorded at 15 second intervals. Timing of machine milking started when the last teat-cup shell was attached to the cow and machine stripping was started when the rate of milk flow dropped to 0.3 lb per 15 second interval. The cluster was removed when milk flow rate dropped to less than 0.1 lb per 15 second interval. Particular attention was paid to the pre-milking preparation on milk flow rate recording days. It was not possible to record the weight of milk in the suspended pail at 15 second intervals. The technique of Schmidt et al (1963b) was tried in a pre-experimental run and repeatability was so poor that the system was rejected. Total milk yield and total milking time were recorded for the suspended pail machine.

Milk samples for cell count were taken four times during the final 14 days of each period from a composite sample of mornings' and evenings' milk. The cell count was estimated, using

the method of Klasttrup (1960) and a microscopic factor of 10,000.

Teat apex erosion was assessed at the end of each 17 day period. The teat apex was examined visually and classified into categories negative, 1, 2, 3, 4, 5 with the aid of photography depending on the severity of the erosion.

Quarter milk samples were taken at monthly intervals with the usual precautions and a loopful (0.025 ml) was streaked on aesculin blood agar plates. The plates were incubated for 48 hours at 37°C and examined for mastitis pathogens. Fore-milk samples were examined with the California Mastitis Test at each evening milking and classified into neg, $\pm$, +, ++ and +++. Any quarter giving a reaction greater than or equal to one plus was sampled and plated for the isolation of mastitis pathogens.

Statistical analysis

Where values for the suspended pail machine were missing in machine milking time and yield, maximum milking rate, machine stripping time and yield and machine milking rate, the method of Yates (1936) for analysis of incomplete latin squares was used.

When the F-test showed significant differences at the 5%, 1% or 0.1% level between machine means Duncans (1955) Multiple Range Test was applied to select differences between the means of the eight machines at the 5% level of significance only.

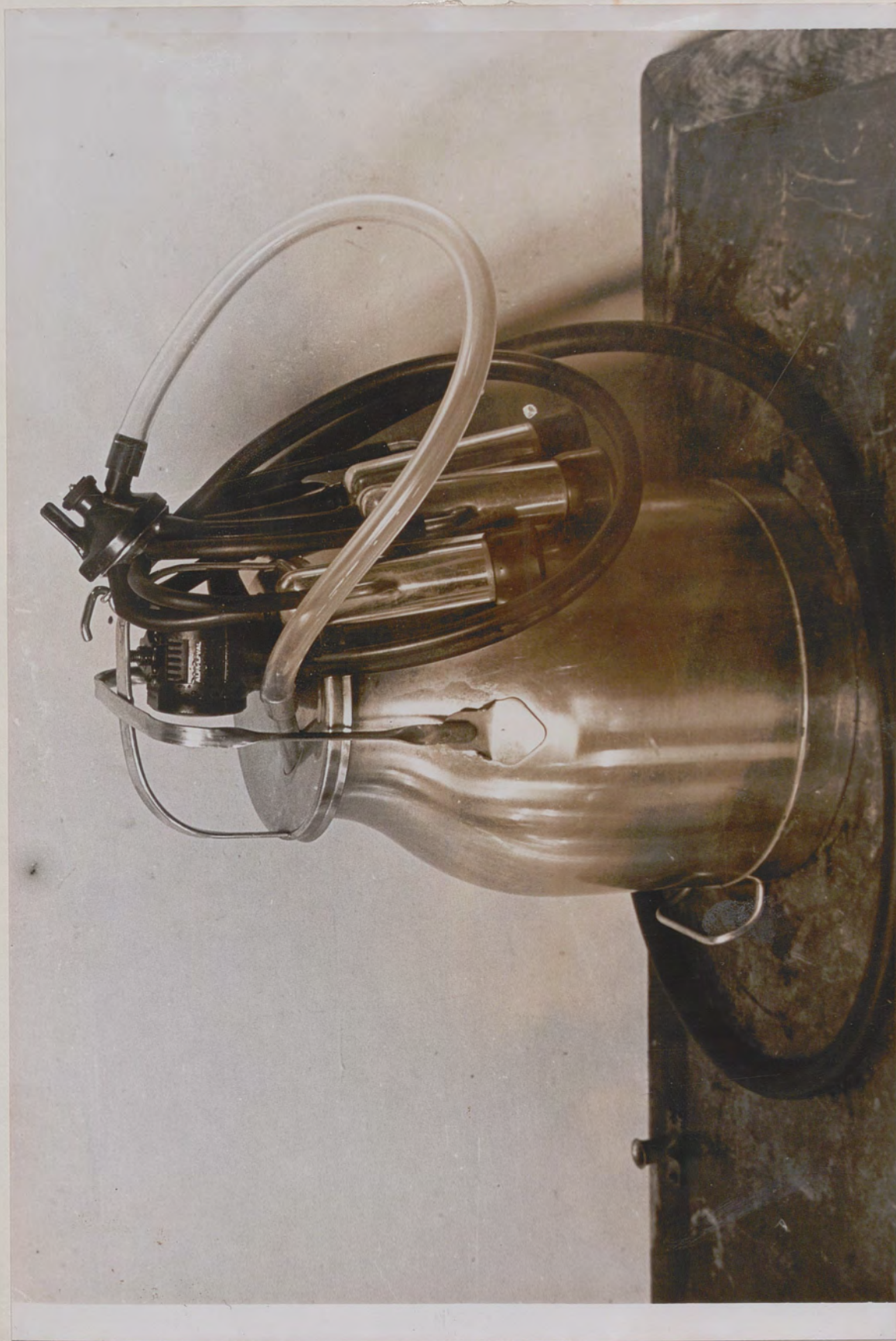


Plate 1. Machine A

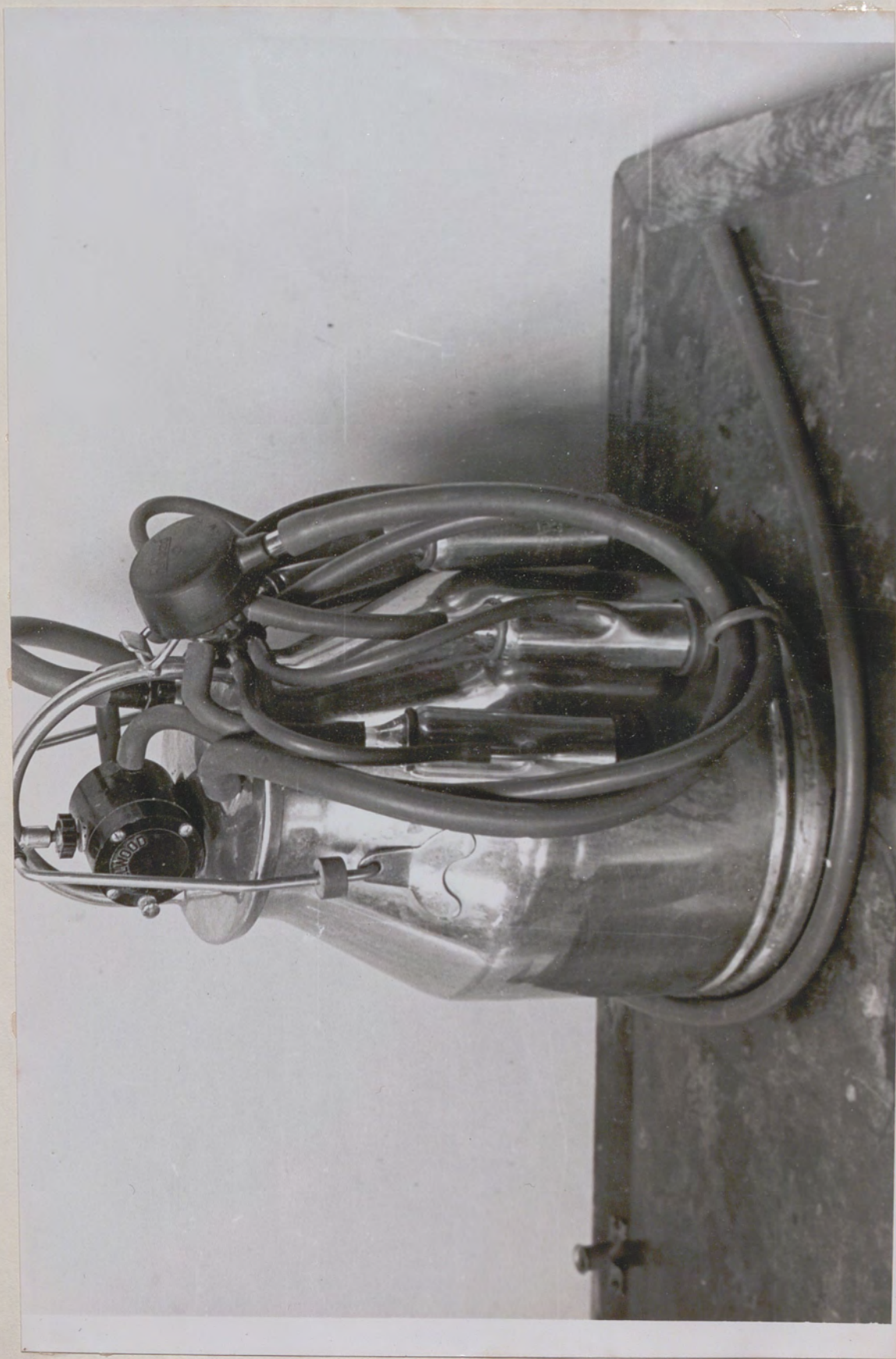


Plate 2. Machine B.

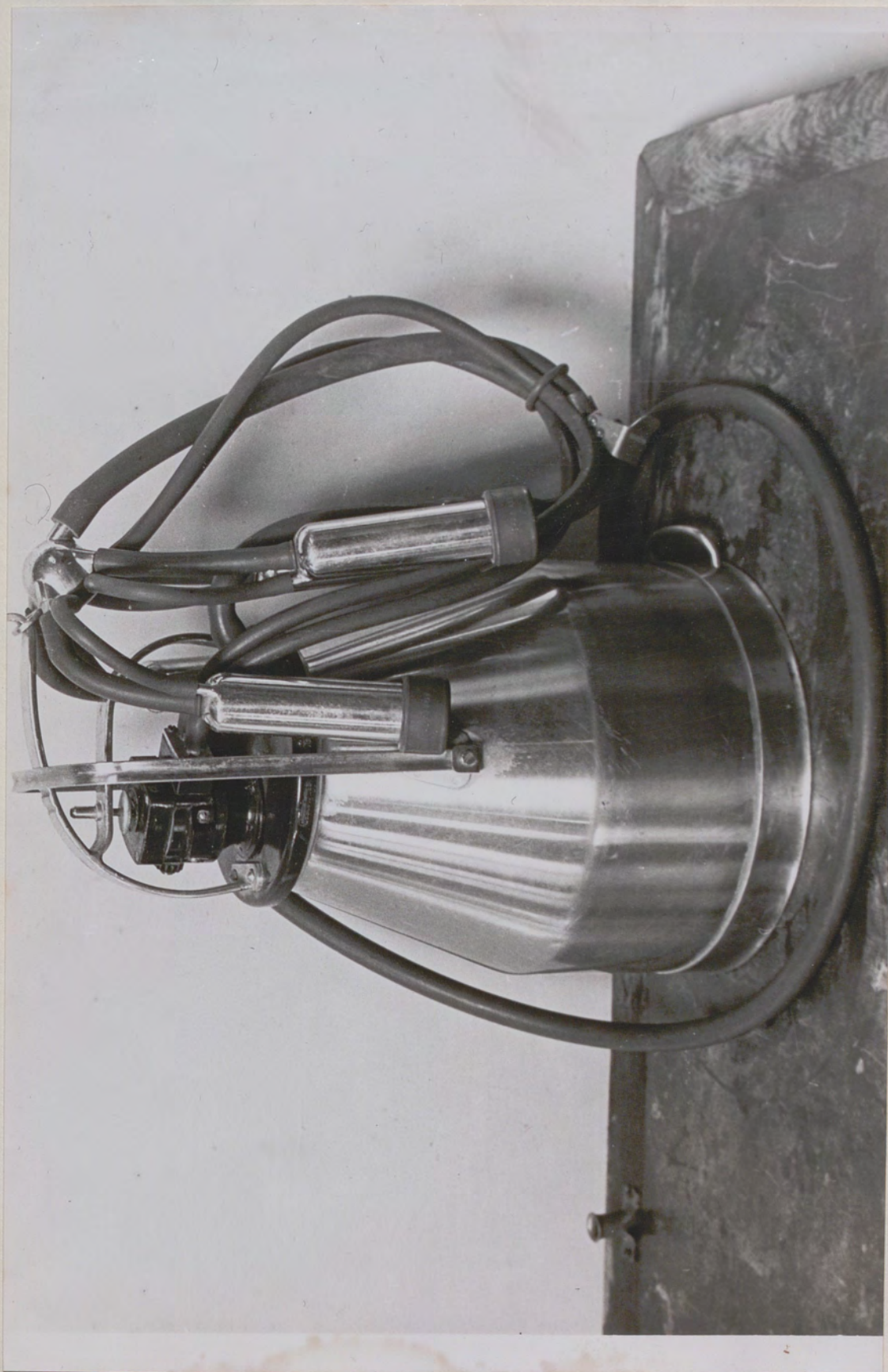


Plate 3. Machine C

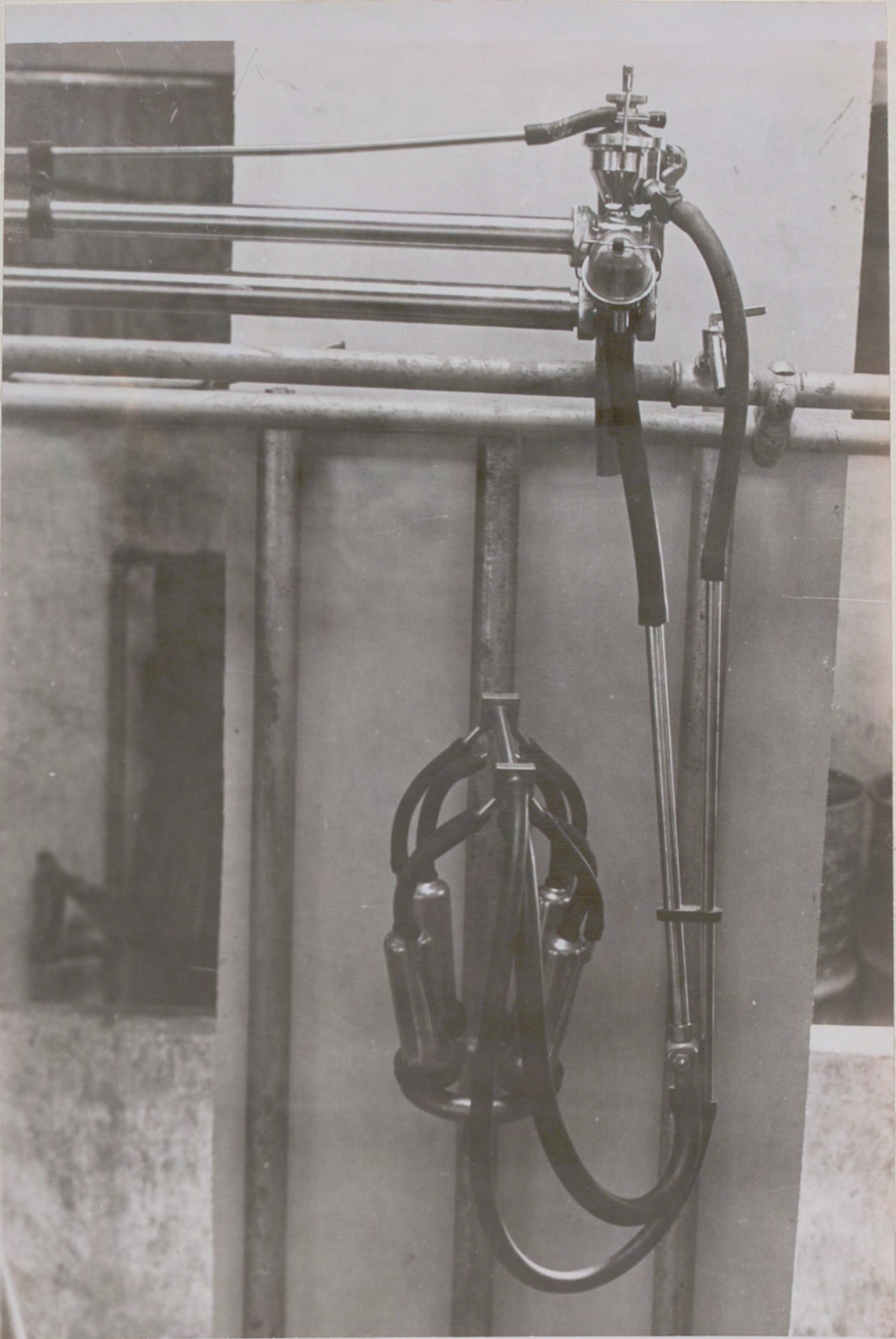


Plate 4. Machine D.

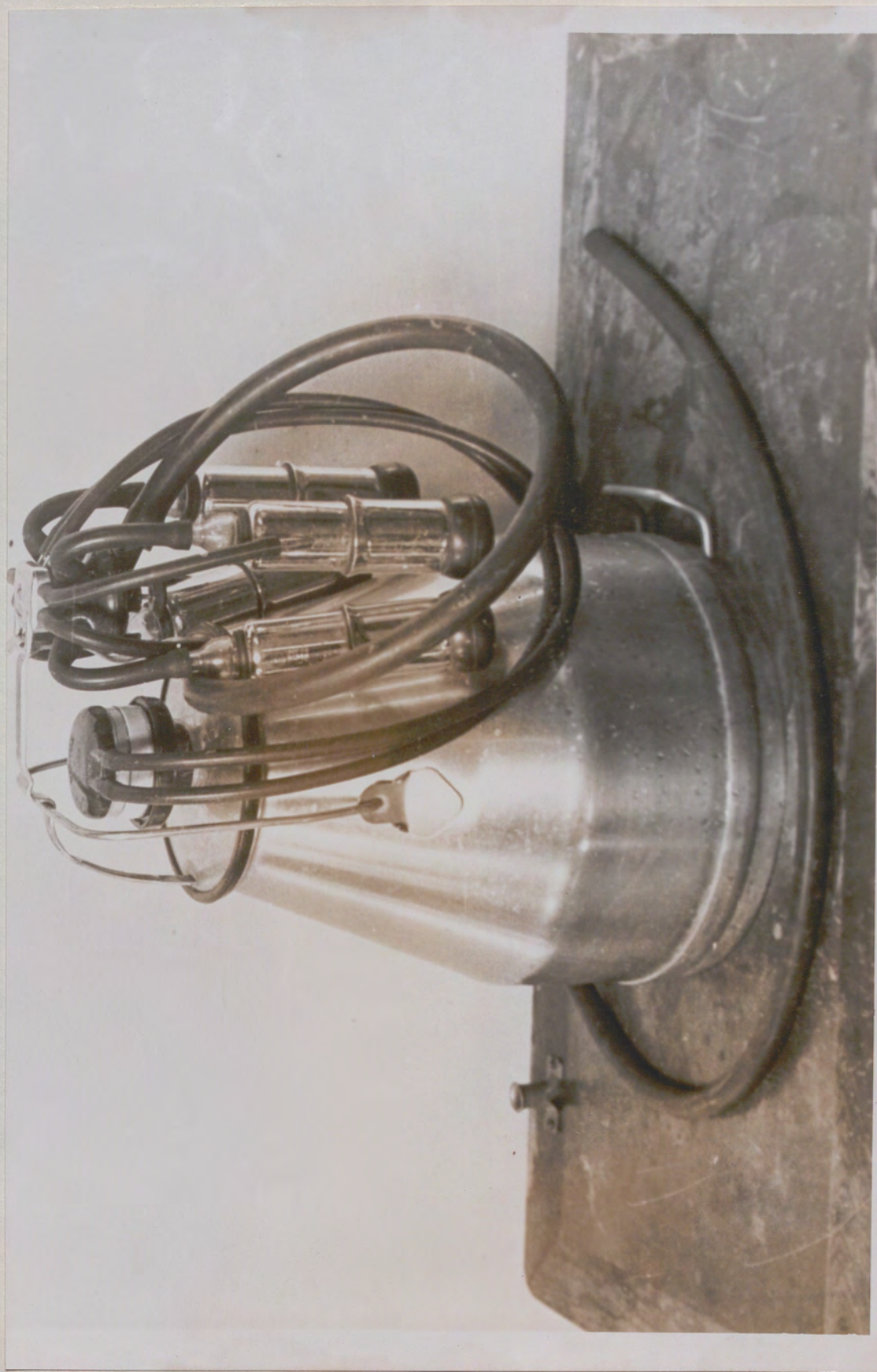


Plate 5. Machine F.

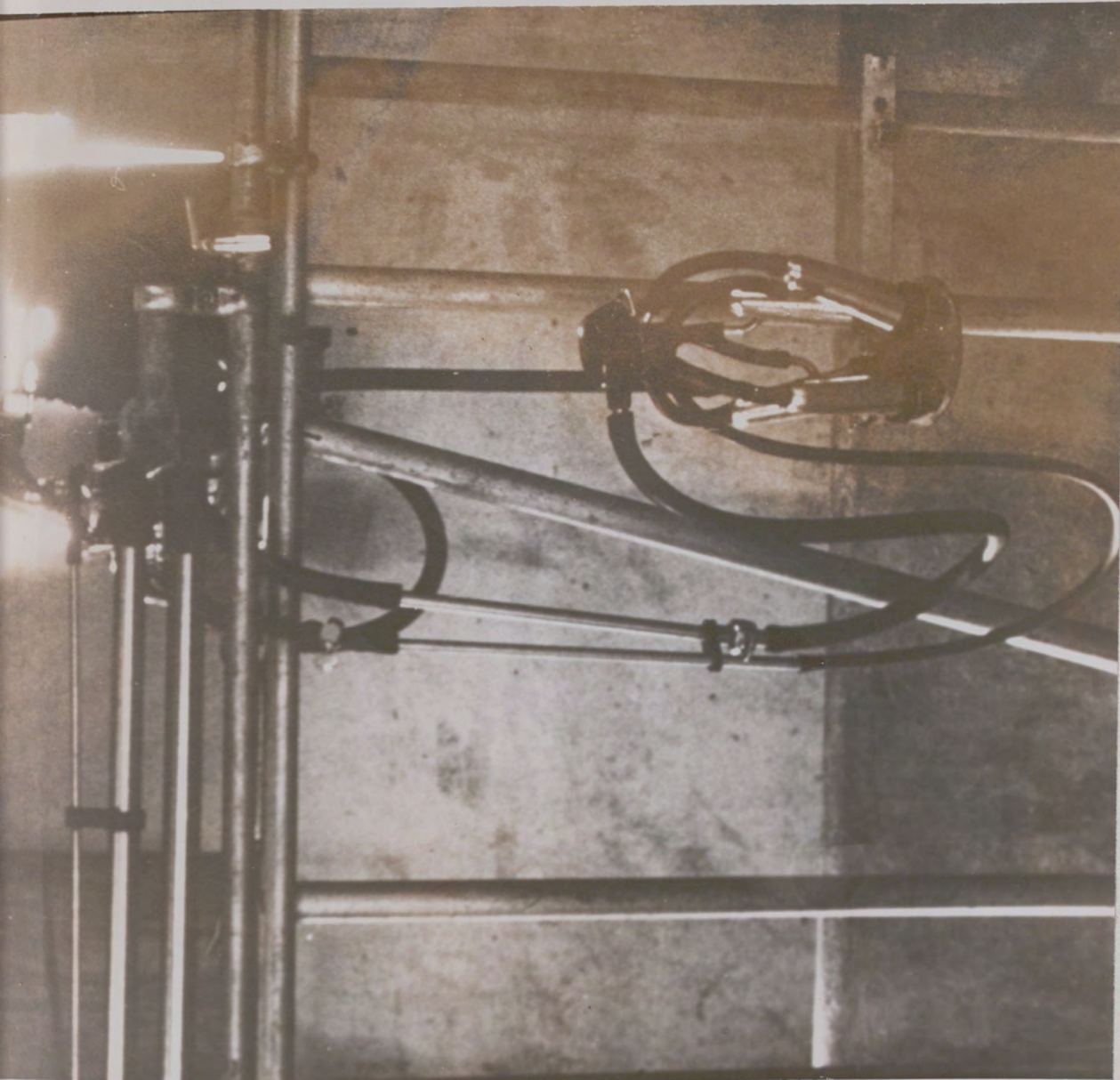


Plate 6. Machine F.

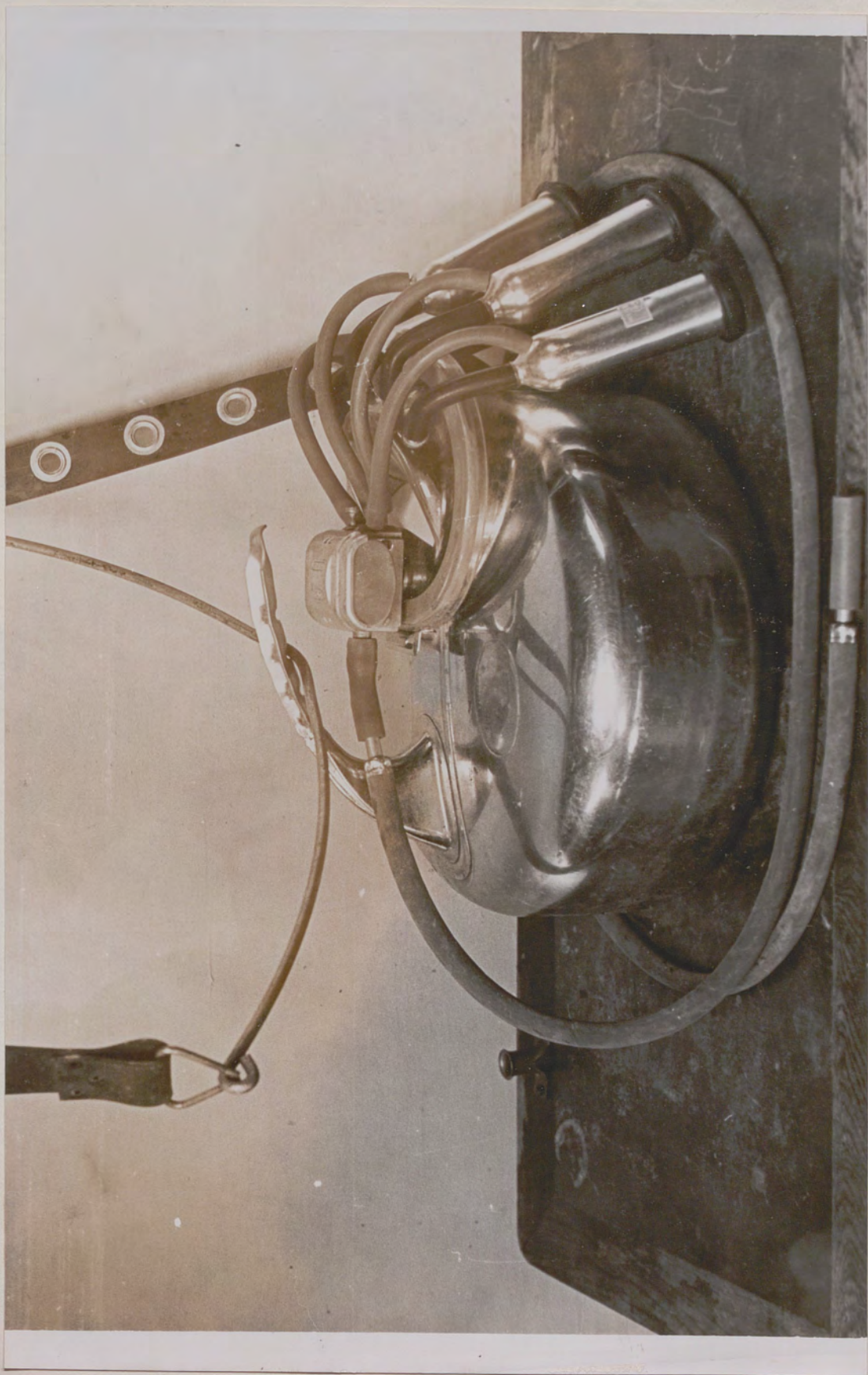


Plate 7. Machine G.



Plate 8. Machine H.

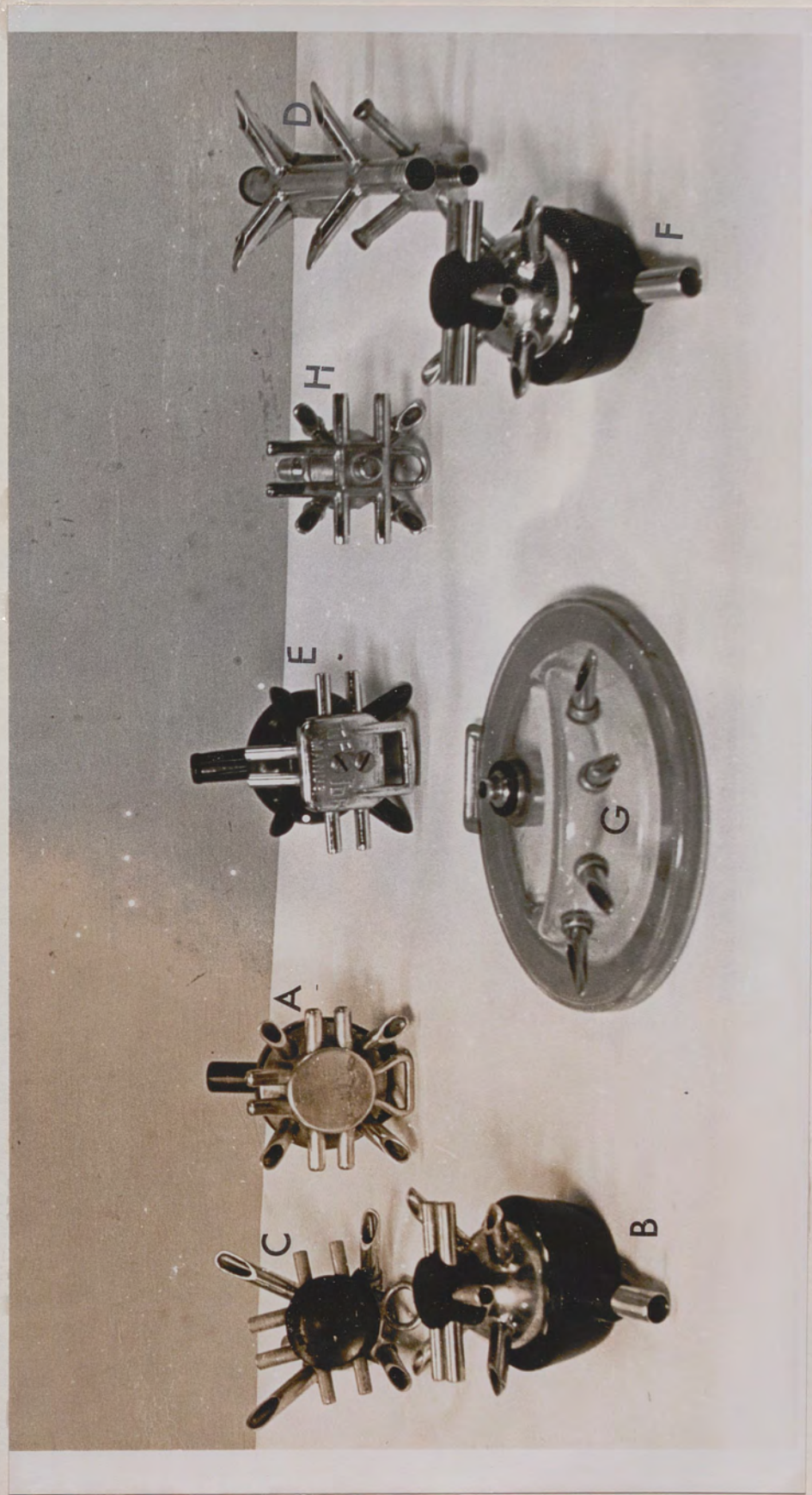


Plate 9. Clawpieces assembled.

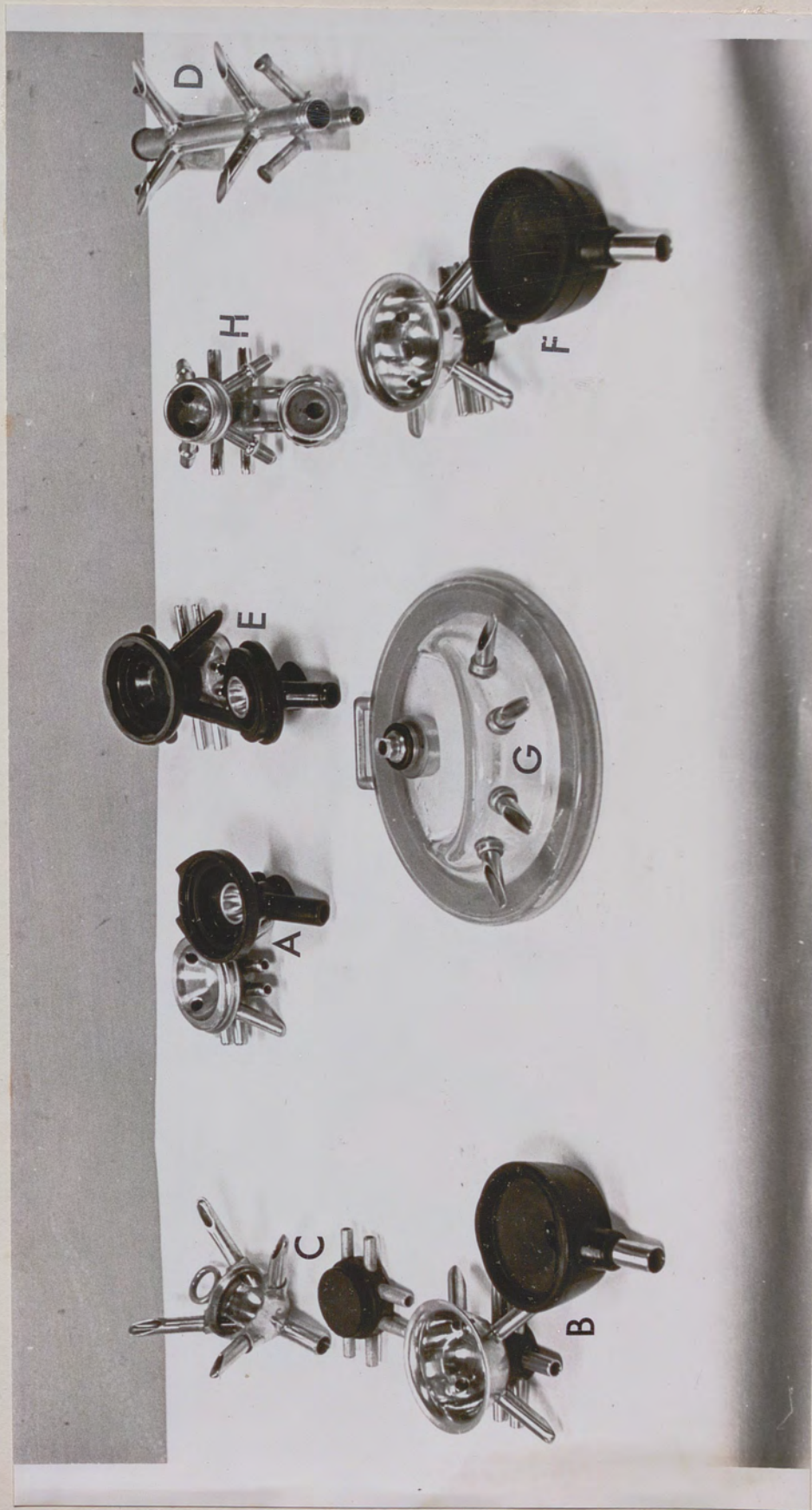


Plate 10. Clawpieces dismantled.

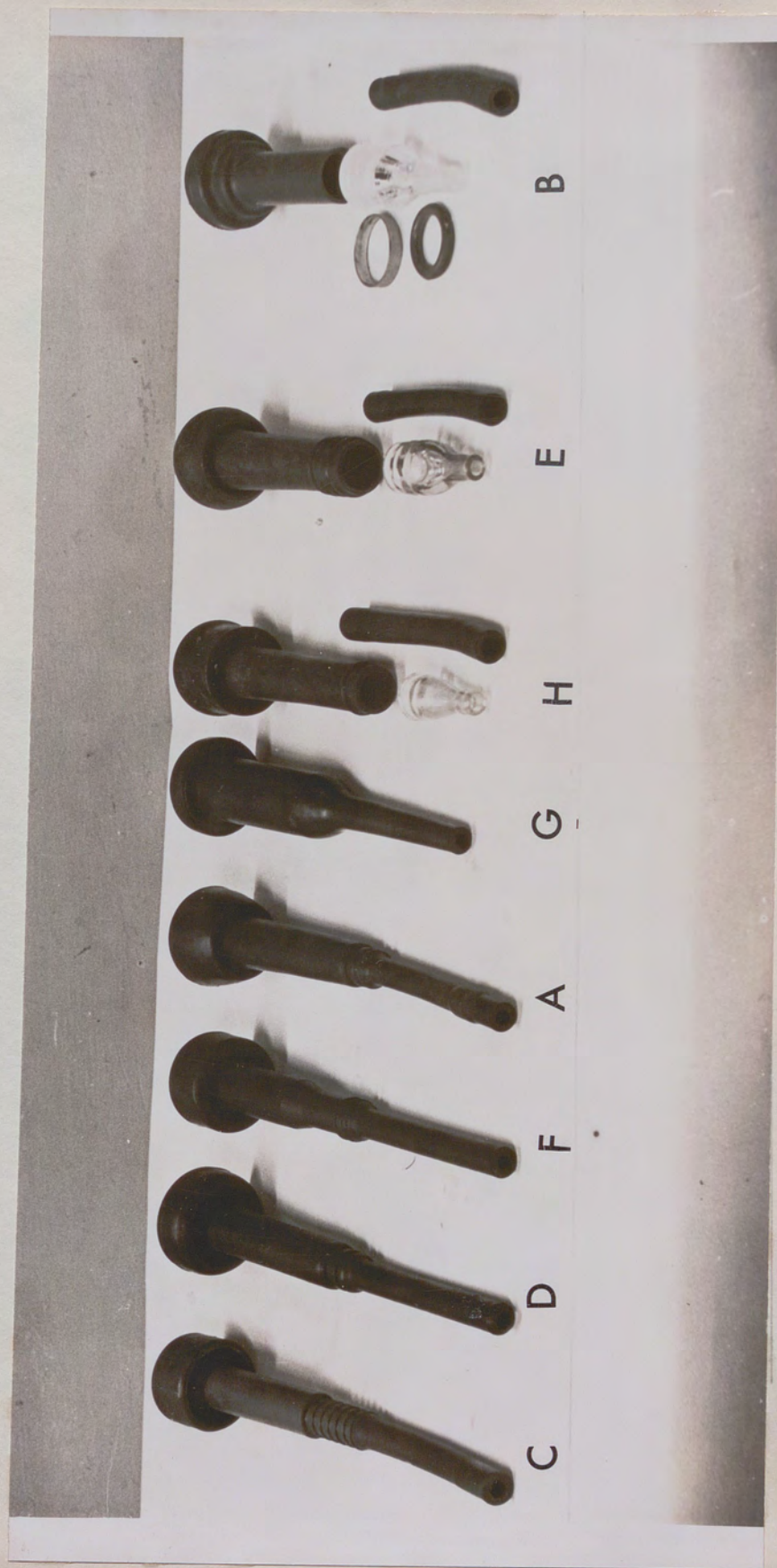


Plate 11. Teat-cup liners from machines.

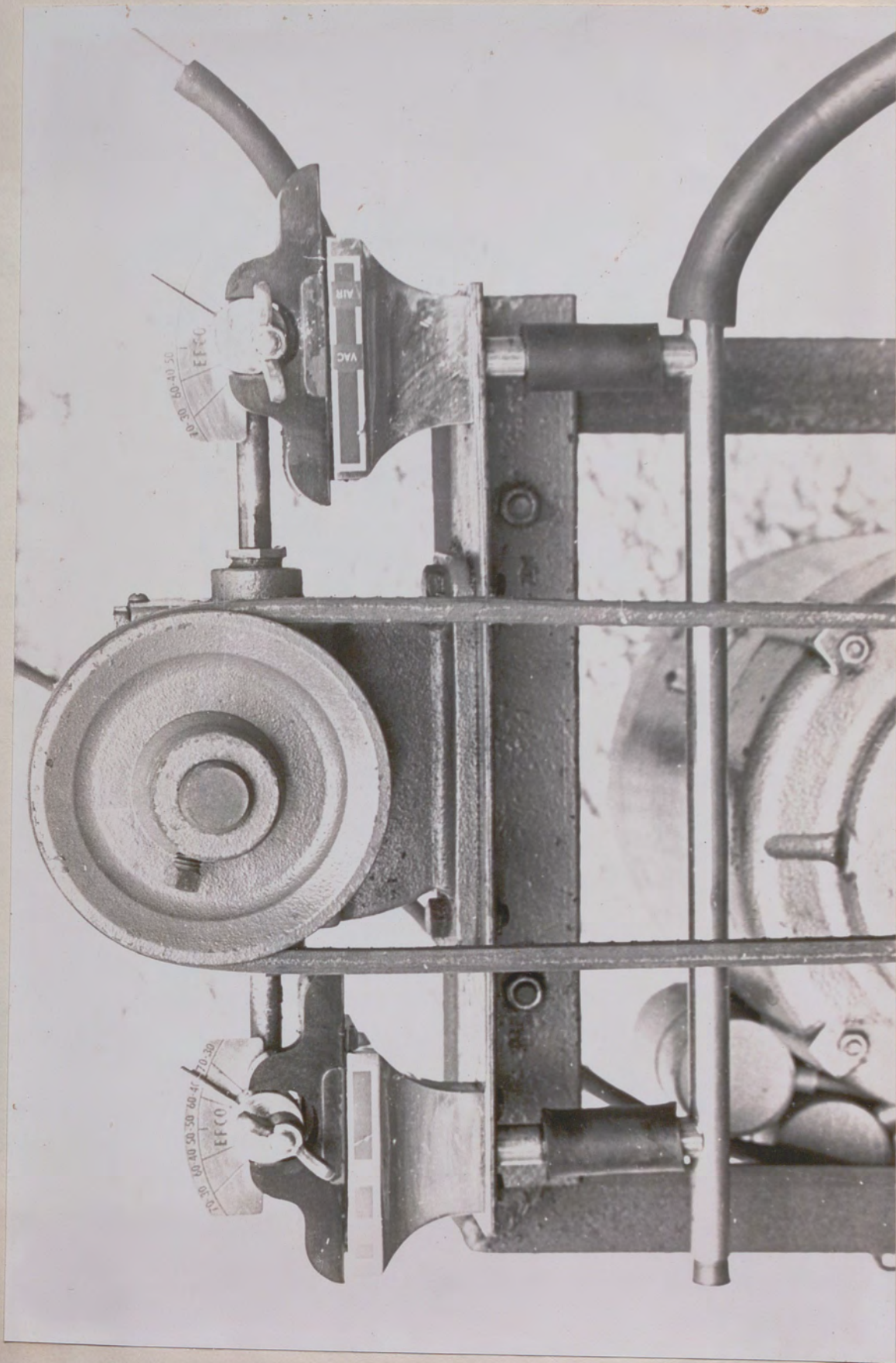


Plate 12. Master pulsator mechanism, machine D.

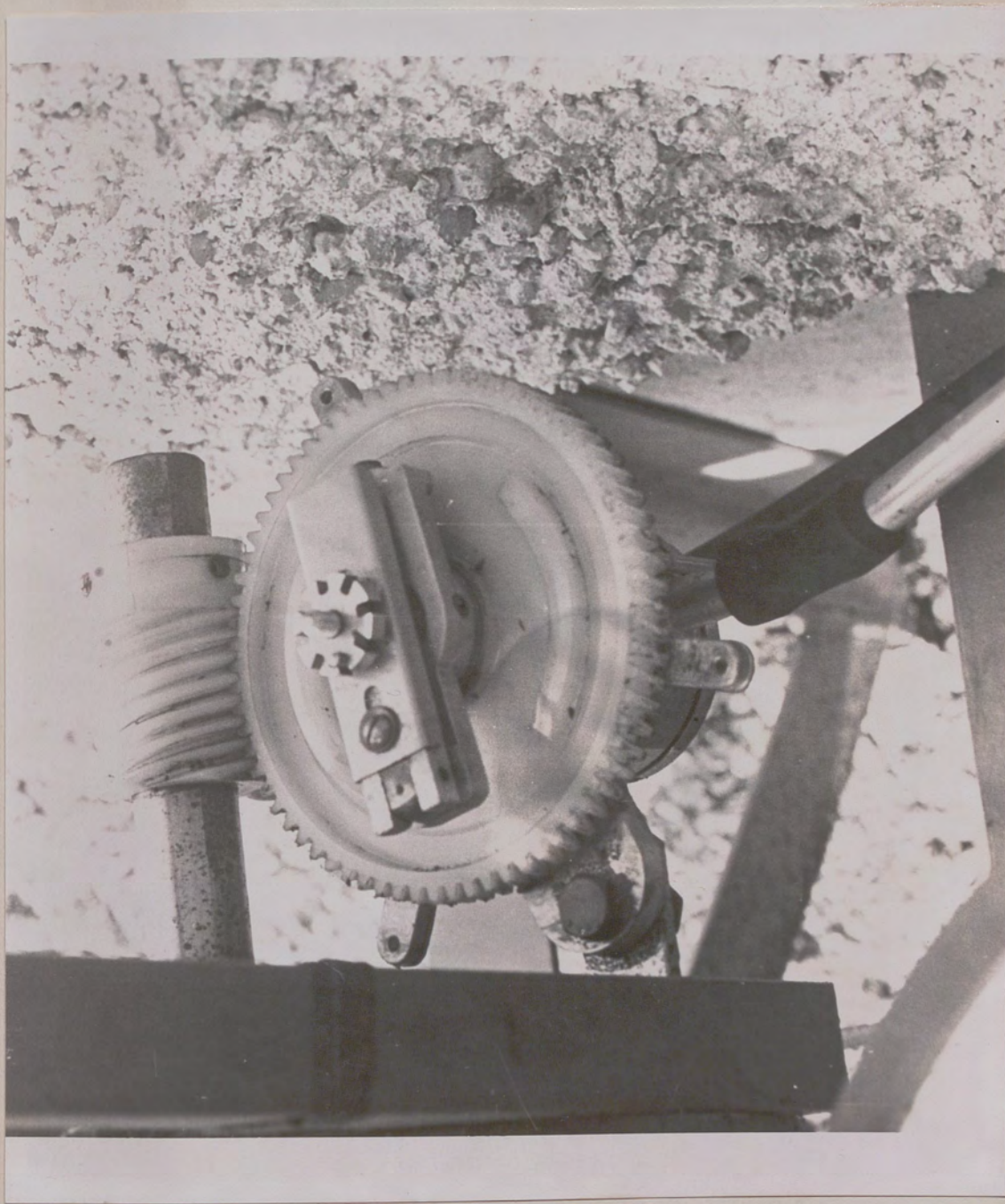


Plate 13. Master pulser mechanism, machine T.

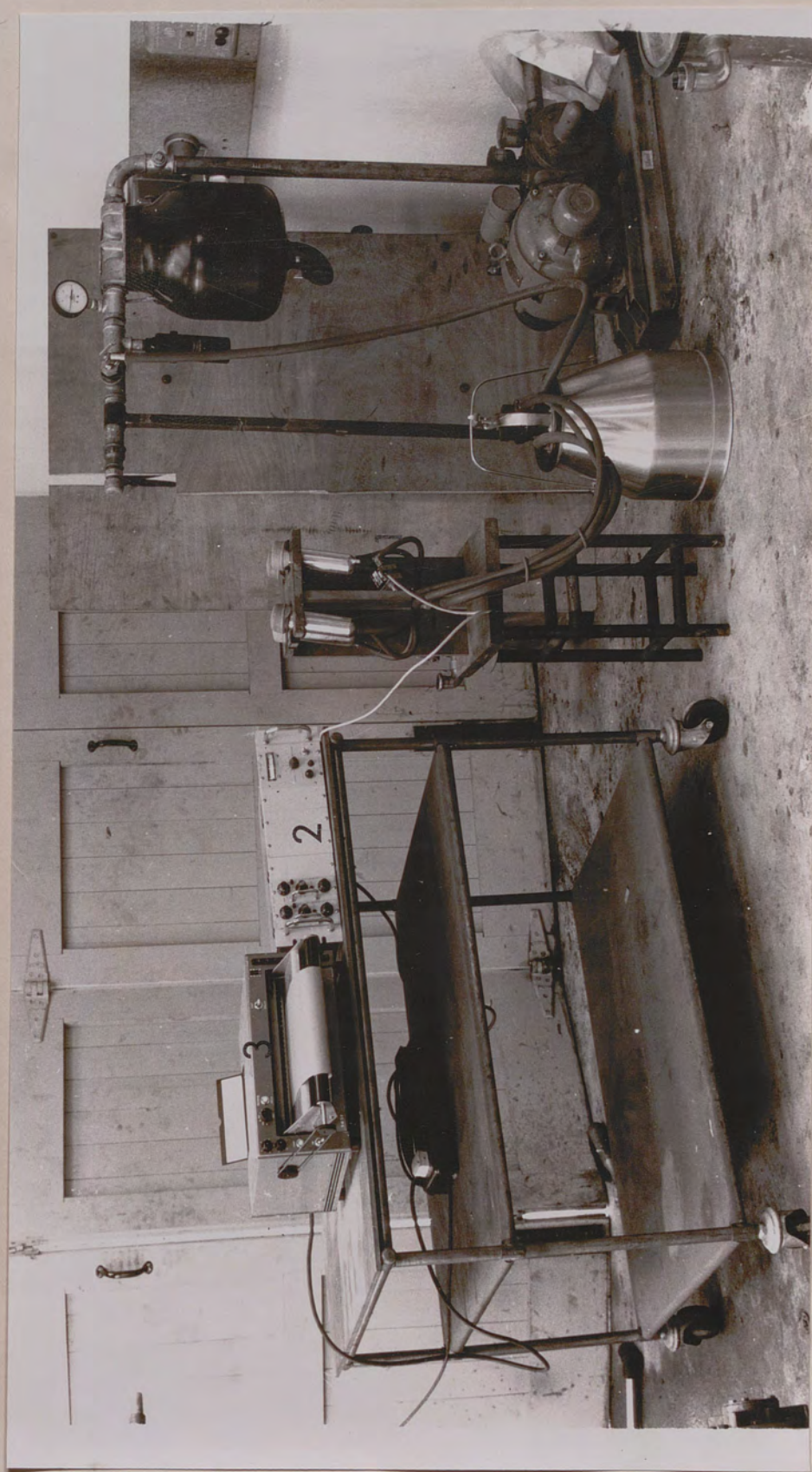


Plate 14. Apparatus for recording pulsation characteristic
(1) pressure transducer (2) galvanometer (3) recorder.

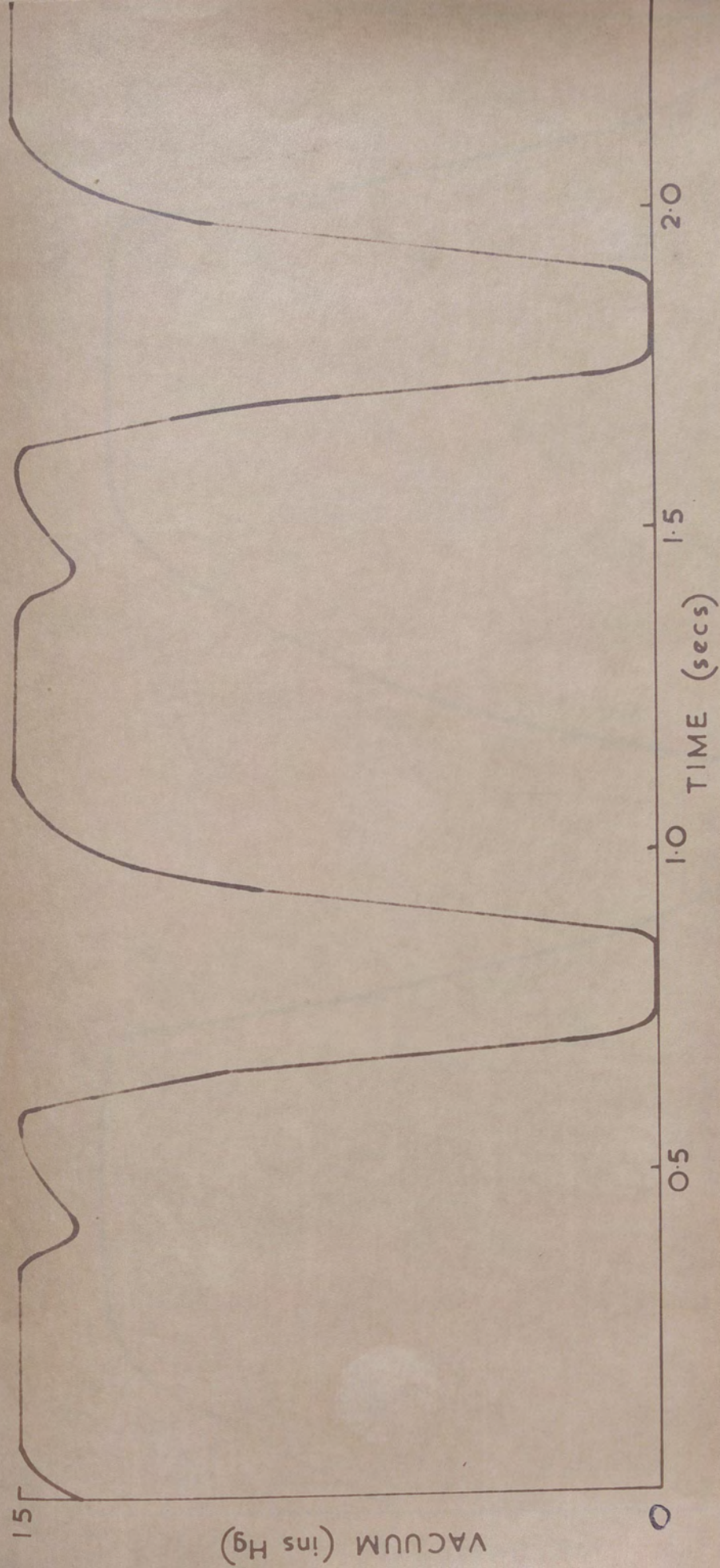


FIG. 2 PULSATOR CHARACTERISTIC OF MACHINE A.

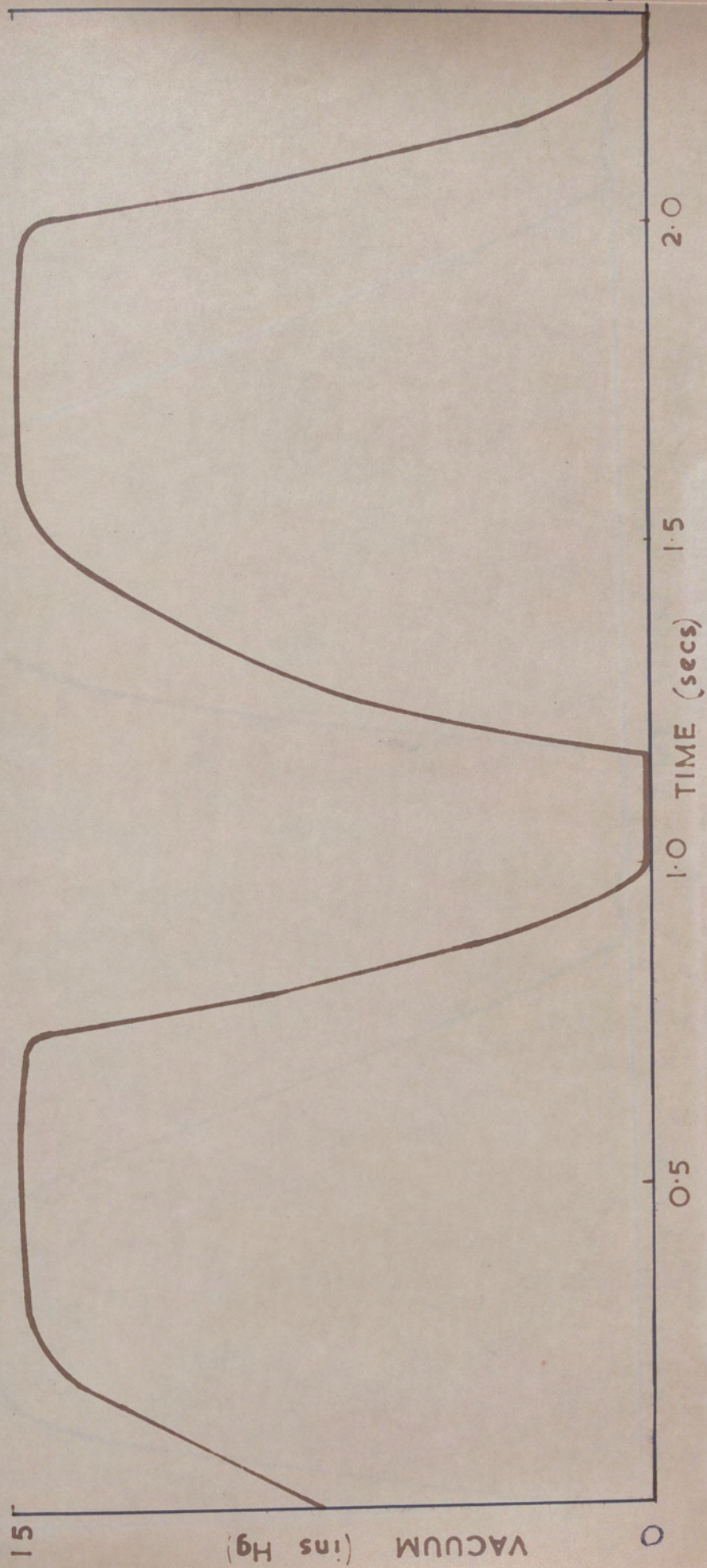


FIG. 3 PULSATOR CHARACTERISTIC OF MACHINE B.

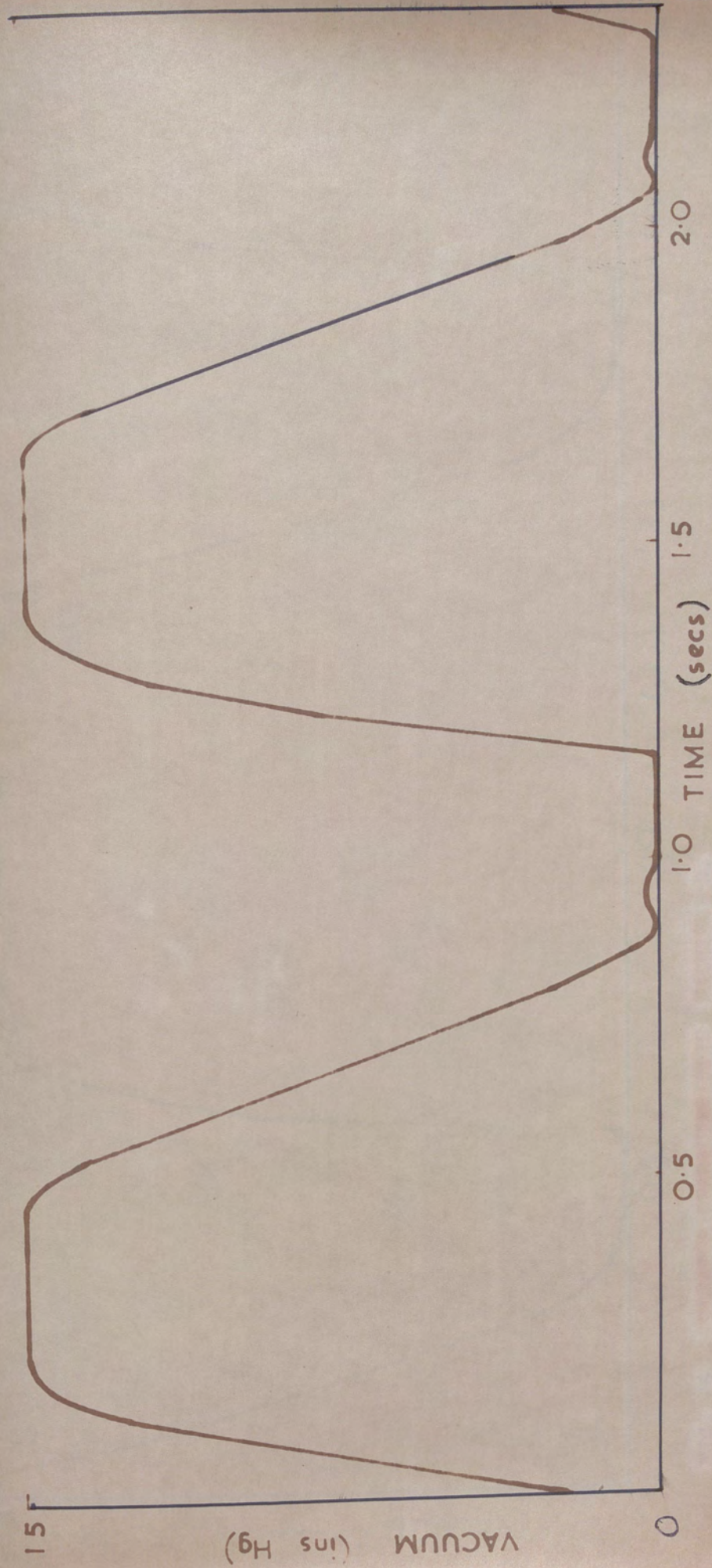


FIG. 4. PULSATOR CHARACTERISTIC OF ONE SIDE OF TWIN PULSATOR IN MACHINE C.

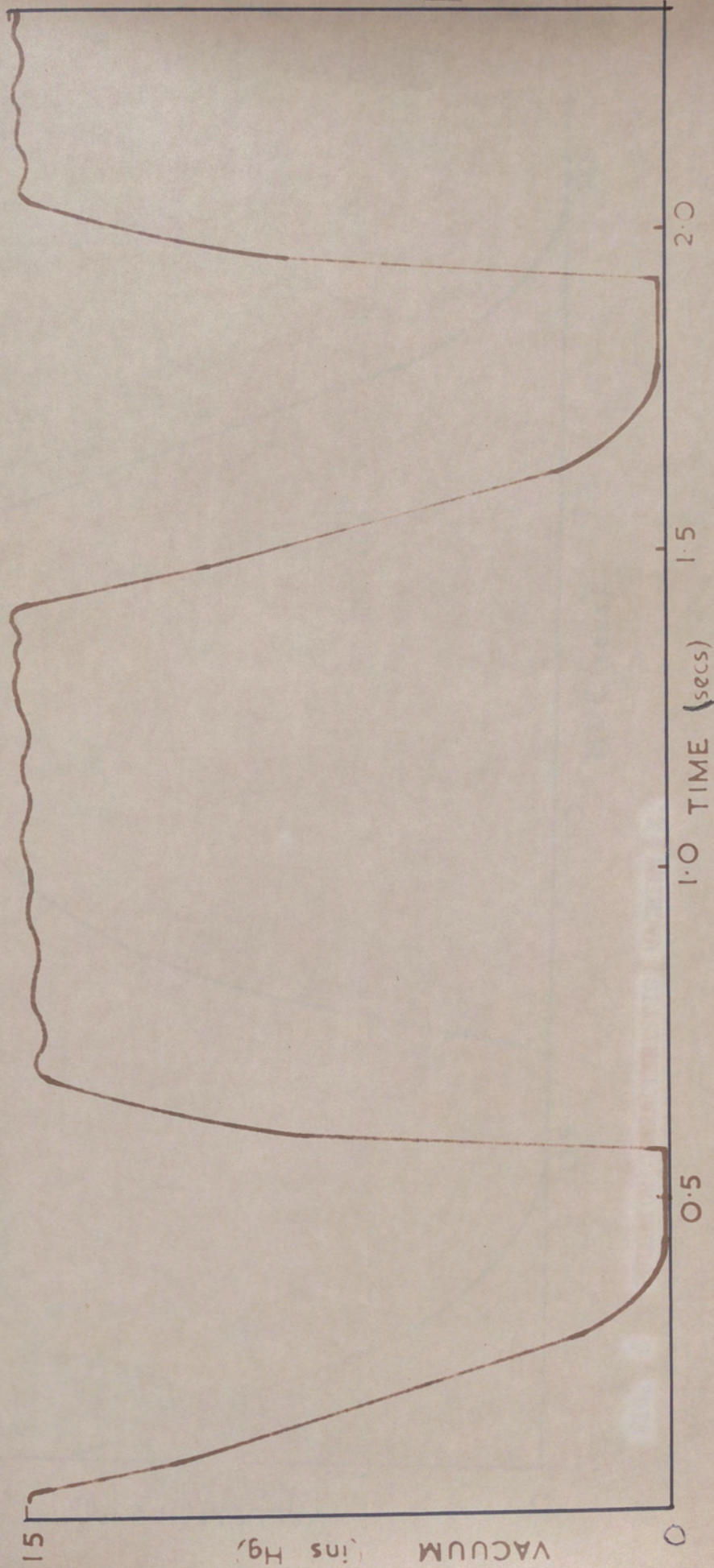


FIG. 5 PULSATOR CHARACTERISTIC MACHINE D.

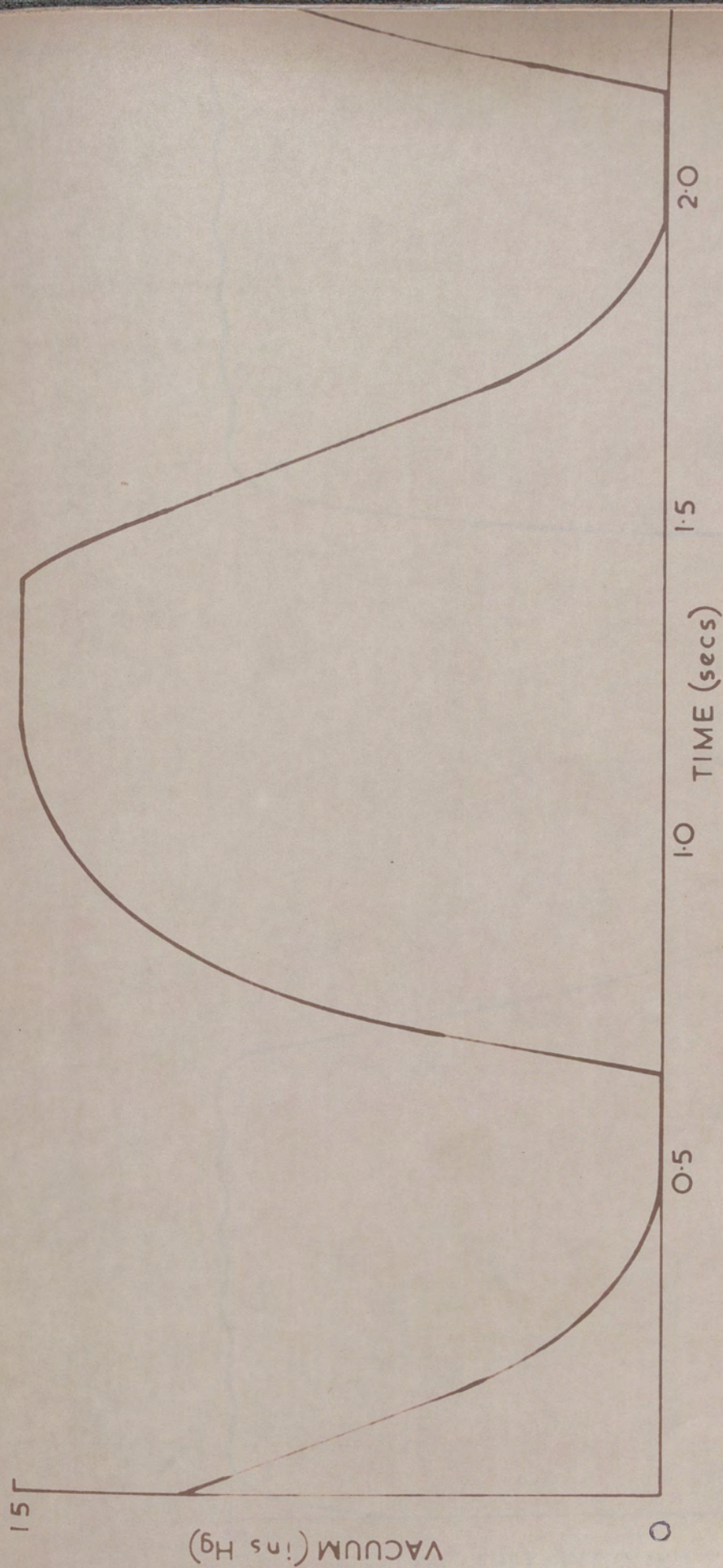


FIG. 6 PULSATOR CHARACTERISTIC MACHINE E.

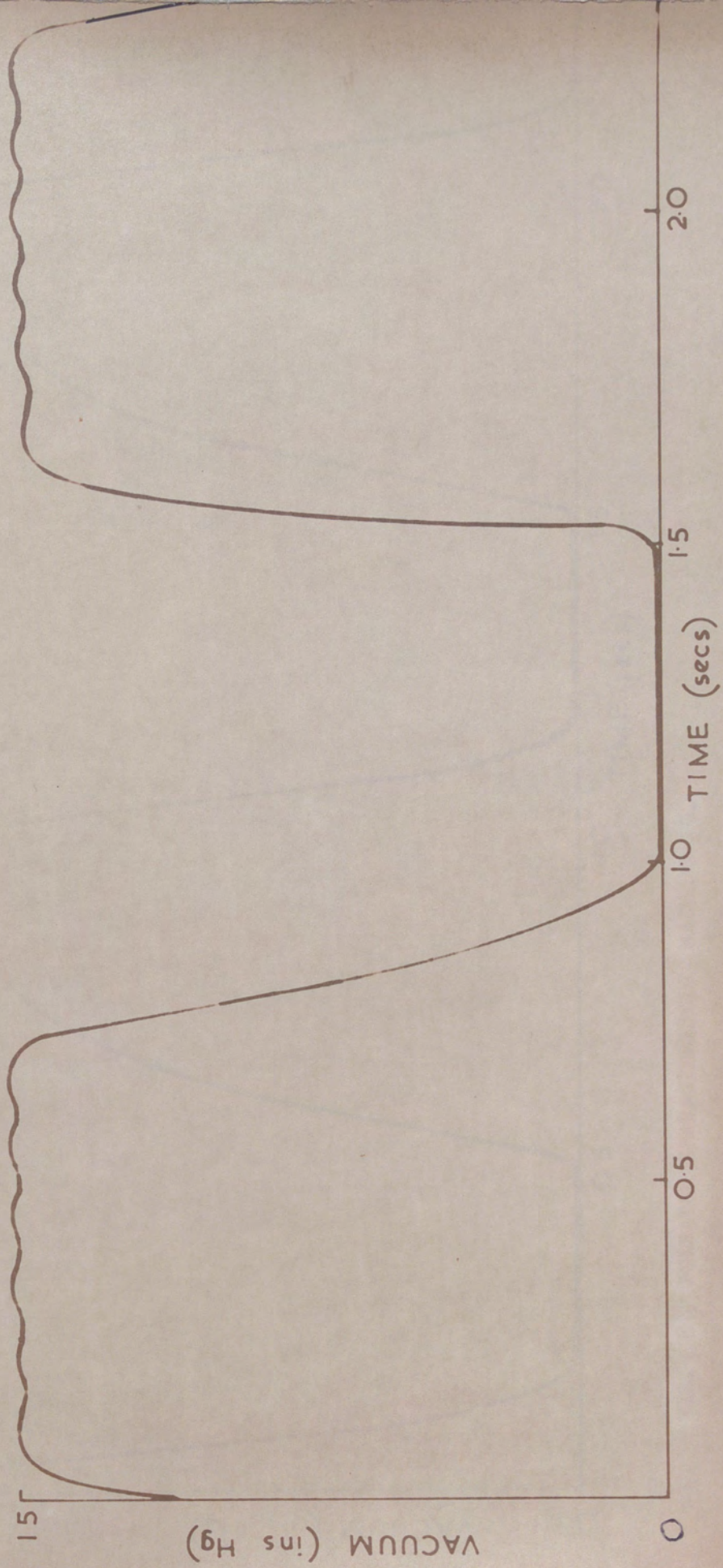


FIG. 7 PULSATOR CHARACTERISTIC MACHINE F.

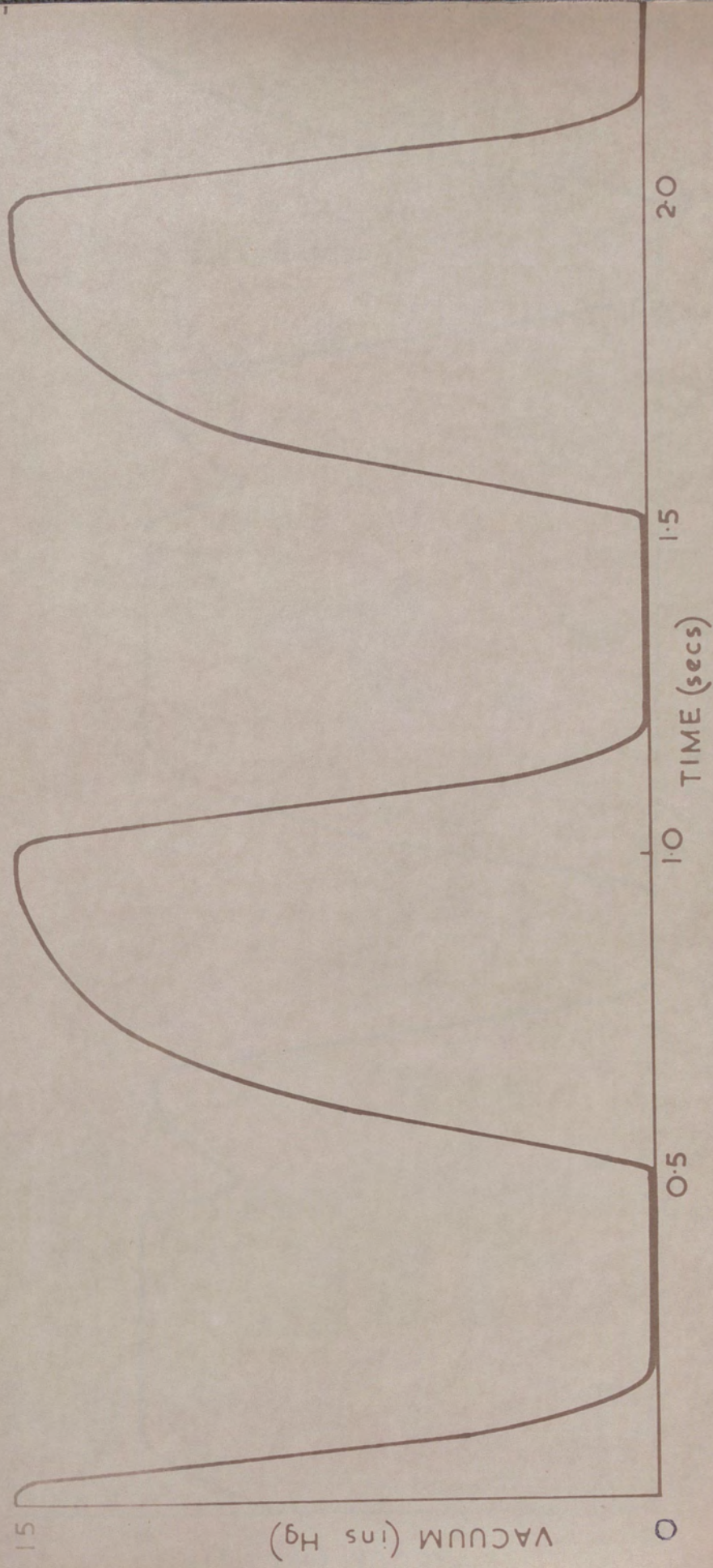


FIG. 8 PULSATOR CHARACTERISTIC MACHINE G.

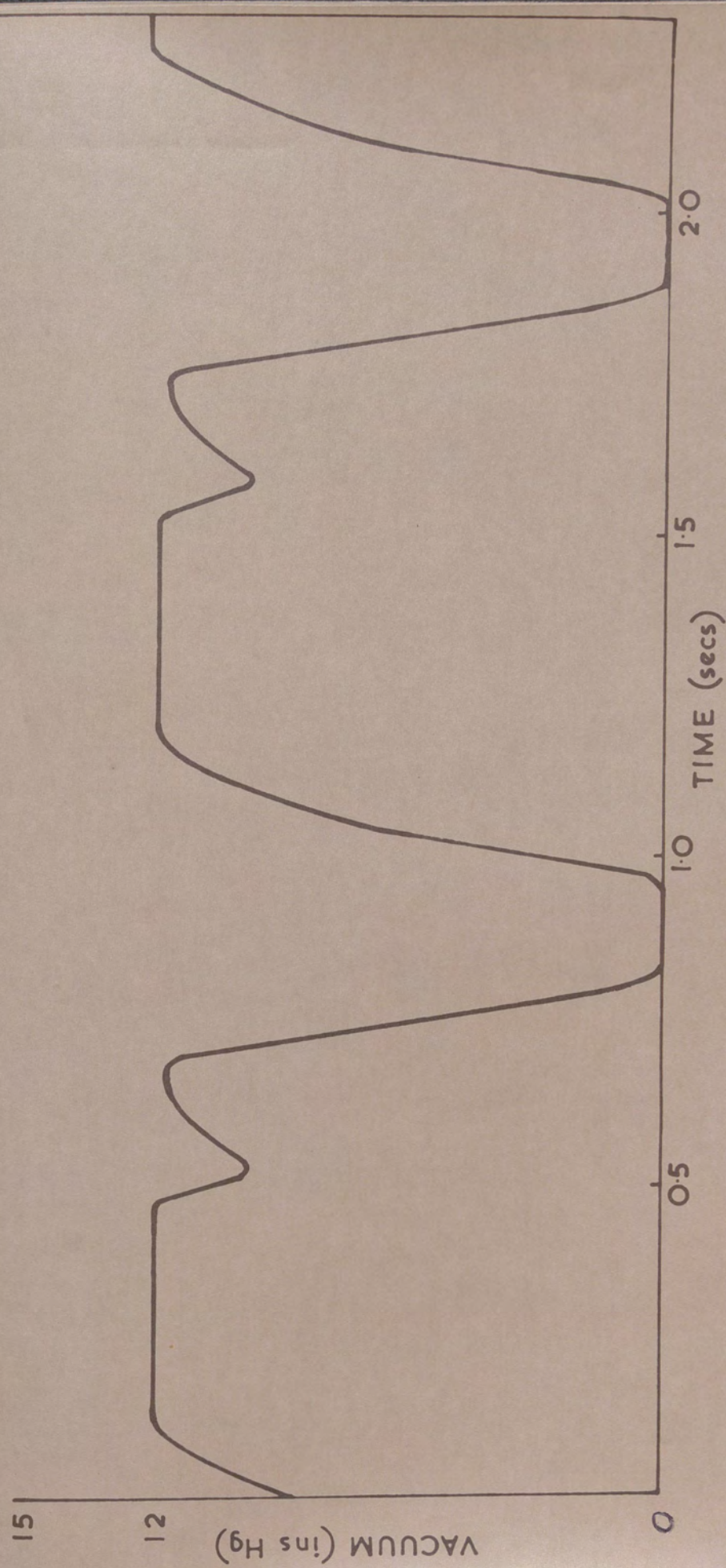


FIG. 9 PULSATOR CHARACTERISTIC MACHINE H.

DEFINITIONS

- Total milking time (min): is from the attachment of the fourth teat-cup to the cow until the milk flow rate drops below 0.1 lb in 15 seconds.
- Machine milking time (min): is from the attachment of the fourth teat-cup to the cow until the milk flow rate drops below 0.3 lb per 15 seconds.
- Machine stripping time (min): is from the start of machine stripping until the milk flow rate drops below 0.1 lb per 15 seconds.
- Total milk yield (lb): is the quantity of milk obtained during total milking time.
- Machine yield (lb): is the quantity of milk obtained during machine milking time.
- Machine stripping yield (lb): is the quantity of milk obtained during machine stripping time.
- Mean milking rate (lb/min): is total milk yield (lb) divided by total milking time (min).
- Mean machine milking rate (lb/min): is machine yield (lb) divided by machine milking time (min).
- Maximum milking rate (lb/min): is the maximum amount of milk obtained in any one minute during milking.

RESULTS

The results are presented in five sections:

Production,

Milking Rate,

Machine Milking Rate,

Machine Stripping

&

Udder Irritation.

PRODUCTION

The mean daily milk yield in lb for the 16 individual cows on their respective machines during each 17-day period for Replicates I and II are shown in Tables 5 and 5a respectively. The mean daily milk yield from the combined replicates for the eight machines is given in Table 5c. The F-test (Table 5b) shows that the difference between the mean daily milk yields of the eight machines is not significant. However, the seven percent difference between the greatest and least mean is approaching significance at the 5% level (Table 5c). The mean daily milk yield was adjusted for lactation stage and this had no effect on the error component of variation. The difference between any two adjacent means should be 1.48 lb to reach significance at 5% level.

The results for milkfat and solids-non-fat yield and percentage are given in Table 5d.

TABLE 5 Mean Daily Milk Yield for 8 Cows on their Respective Machines
(Replicate I)

Mean Daily Milk Yield (lb)									
Period	C	F	D	E	G	A	B	H	Total
I	47.77	44.03	27.57	48.56	40.42	53.66	39.50	41.10	342.61
II	26.21	38.63	47.44	37.85	51.74	40.78	40.07	46.00	328.72
III	47.44	33.41	41.06	35.99	22.57	32.16	34.75	42.03	289.41
IV	42.81	35.90	34.19	47.50	40.12	32.32	31.24	21.78	285.86
V	36.16	21.27	36.82	29.43	30.81	40.40	43.27	45.99	284.15
VI	37.43	45.79	28.91	37.72	36.40	40.25	21.35	26.27	274.12
VII	24.07	35.29	21.41	19.04	34.71	36.22	44.15	30.53	245.42
VIII	17.53	27.50	40.21	27.50	34.06	15.46	32.62	20.79	215.67
Total	279.42	281.82	277.61	283.59	290.83	291.25	286.95	274.49	2265.96
Mean (Machine)	34.928	35.228	34.701	35.449	36.354	36.406	35.865	34.311	
Cow No.	480	927	651	121	82	335	116	402	
Mean daily yield lb/cow	40.122	35.542	21.906	40.821	29.636	47.06	30.957	37.198	

TABLE 5a Mean Daily Milk Yield for 8 Cows on their Respective Machines
(Replicate II)

	Mean Daily Milk Yield (lb)								
Period	G	F	D	E	G	A	B	H	Total
I	40.50	33.16	31.16	47.56	50.14	39.82	39.92	29.14	311.40
II	28.16	29.02	38.41	41.60	30.25	40.82	39.07	46.25	293.58
III	35.78	35.17	26.96	25.59	22.70	43.35	35.95	35.48	260.98
IV	23.91	42.10	33.81	34.35	38.03	36.59	25.71	25.47	259.97
V	36.90	39.27	40.37	33.59	35.72	24.84	25.03	22.88	258.60
VI	36.97	30.38	32.96	22.59	21.06	19.66	37.71	34.75	236.08
VII	19.04	17.15	33.46	31.57	34.65	31.43	15.85	24.43	207.58
VIII	27.13	26.15	14.24	14.24	33.07	16.63	19.89	27.43	178.78
Total	248.39	252.40	251.37	251.09	265.62	253.14	239.13	245.83	2006.97
Mean (Machine)	31.049	31.550	31.421	31.386	33.203	31.643	29.891	30.729	
Cow No.	930	104	115	403	931	929	607	500	
Mean (Cow)	34.578	24.891	22.427	39.89	33.601	35.197	37.045	23.236	

29.

The Grand Total is 4272.93, The correction factor (C) =

$$\frac{(4272.93)^2}{128} = 142,640.08$$

The number of values is 128

Total Sums of Squares (SS) $152,729.2873 - 142,640.08 = 10,089.21$

$$\text{Replicates SS } \left\{ \frac{(2,265.96)^2}{64} + \frac{(2,006.97)^2}{64} \right\} - 142,640.08$$

$$= 143,164.1100 - 142,640.08 = 524.03$$

Cows within

$$\text{Replicates SS } 2,582.7060 + 3,407.5282 = 5,990.23$$

$$\text{Machines SS } \frac{2,283,167.0907}{16} - C$$

$$= 142,697.9400 - 142,640.08 = 57.86$$

$$\text{Periods SS } \frac{2,331,527.3161}{16} - 142,640.08$$

$$= 145,720.45 - 142,640.08 = 3,080.37$$

$$\text{Error} \quad \quad \quad \text{is } 436.72$$

TABLE 5b. Analysis of Variance for Mean Daily Milk Yield

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	524.03	1	524.03	117.49	***
Cows within Replicates	5990.23	14	427.87	95.93	***
Periods	3080.37	7	440.05	98.67	***
Machines	57.86	7	8.27	1.85	N.S.
Error	436.72	98	4.46		
Total	10,089.21	127			

TABLE 5c: Mean Daily Milk Yield from Combined Replicates for 8 Machines

Machine	Mean Daily Milk Yield (lb)
G	34.8
A	34.0
E	33.4
F	33.4
D	33.1
C	33.0
B	32.9
H	32.5
Standard Error	± 0.528

Fat

TABLE 5d The Mean Daily/Yield (lb) the Mean Percentage Fat,
the Mean Daily Solids-non-Fat and Mean Solids-non-Fat
Percentage for 8 Milking Machines from Combined
Replicates.

Machine	Mean Daily Fat Yield (lb)	Mean Fat Percentage	Mean Daily Solids-non-fat Yield (lb)	Mean Solids-non-fat Percentage
G	1.25	3.58	3.09	8.87
A	1.18	3.56	3.03	8.91
E	1.16	3.52	2.95	8.93
F	1.16	3.53	2.97	8.89
D	1.18	3.60	2.98	9.00
C	1.16	3.57	2.93	8.87
B	1.17	3.58	2.92	8.90
H	1.13	3.52	2.89	8.86
Standard Error	± 0.03	± 0.06	± 0.06	± 0.09

The production data indicate that the different characteristics of the eight milking machines had no significant effect on production of milk, milk fat and solids-non-fat in this experiment when seventeen-day periods were used.

There was a significant difference in the mean morning milk yield between machines during the 3-day milking rate recording period.

The analysis of variance for the mean milk yield for the three morning milkings during milking rate recordings are given in Table 6.

TABLE 6: Analysis of Variance for Mean Morning Milk Yield during
Milking Rate Recordings

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	310.0650	1	310.0650	89.75	***
Cows within Replicates	2,029.3012	14	144.9501	41.95	***
Periods	768.2220	7	109.7460	31.76	***
Machines	97.5700	7	13.9386	4.03	***
Error	338.5800	98	3.4549		
Total	3,543.7382	127			

The mean morning milk yields from the combined replicates during milking rate recording are given in Table 7.

TABLE 7: Mean Morning Milk Yield (lb) from the Eight Machines
from Combined Replicates

Machine	Mean Morning Milk Yield (lb)
G	21.1
D	19.8
F	19.7
A	19.6
C	18.9
E	18.9
B	18.6
H	18.1

Standard Error is ± 0.465

There is a significant difference between the machines. On application of Duncan's (1955) test, a significant difference shows up between G and all other machines. Machine H yielded significantly less than the other machines with the exception of C, E and B. Any two means not covered by the same vertical line in Table 7 are significantly different at the 5% level.

MILKING RATE

The three measurements given are (1) Mean milking rate,
 (2) Total milking time,
 (3) Adjusted total milking time.

The mean milking rate results are given in Table 8 and Table 8a.

TABLE 8: Analysis of Variance for Combined Mean Milking Rate
 (lb/min) for Eight Machines.

Analysis of Variance for Mean Milking Rate					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	0.5565	1	0.5565	2.63	N.S.
Cows within Replicates	131.8226	14	9.4159	44.48	***
Machines	5.3489	7	0.7641	3.61	**
Periods	5.8376	7	0.8339	3.94	***
Error	20.7507	98	0.2117		
Total	164.3163	127			

TABLE 8a Mean Milking Rate (lb/min) for Eight Machines
from Combined Replicates

Machine	Mean Milking Rate (lb/min)
A	3.84
B	3.69
D	3.59
E	3.45
F	3.44
G	3.39
C	3.38
H	3.12
S.E.	* 0.115

The difference in mean milking rate between the eight machines is significant at the 1% level. Applying Duncan's (1955) test, there is no significant difference ($P < 0.05$) between the mean milking rate of A, D and B. These three machines milk significantly faster than Machine H but Duncan's (1955) test suggests that the difference between B, D, E, F, G, C and C are not significant.

The mean total milking time data for each machine and cow in both replicates is presented in Table 9.

TABLE 9: Total Milking Time (min) for Each Machine and Cow in Both Replicates

Machine	Total Milking Time (min)					
	RI	RII	Cow No.		RI	RII
			RI	RII		
C	6.319	5.593	480	930	4.684	4.112
F	6.323	6.156	927	104	5.097	5.426
D	6.290	5.576	651	115	2.886	3.113
F	6.501	5.553	121	403	10.726	7.432
G	7.225	7.038	82	931	4.827	8.013
A	6.055	5.023	335	929	8.612	4.477
B	5.853	4.780	116	607	6.625	5.178
H	7.046	5.913	402	500	8.155	7.877

The Grand Total is 777.99 and the number of values 128

Correction factor is $\frac{(777.99)^2}{128} = 4728.6596$

Total Sums of Squares (SS) 5,451.9033 - 4,728.6596 = 728.2437

Replicates SS $\frac{303,777.1181}{64} - 4728.6596$

4,746.5170 - 4728.6596 = 17.8574

37.

Cows within Replicates SS $369.3760 + 193.2410$ = 562.6170

Machines SS $\frac{76,223.6097}{16} - 4728.6596$

= $4,763.9755 - 4728.6596$ = 35.3159

Periods SS $\frac{76,334.2251}{16} - 4728.6596$

= $4770.8890 - 4728.6596$ = 42.2294

Error SS = 70.2240

Analysis of Variance for Total
Milking Time

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	17.8574	1	17.8574	24.92	***
Cows within Replicates	562.6170	14	40.1869	56.08	***
Periods	42.2294	7	6.0328	8.42	***
Machines	35.3157	7	5.0451	7.04	***
Error	70.2240	98	0.7166		
Total	728.2437	127			

The difference in total milking time between the 8 machines is significant at the 0.1% level, and the combined means from both replicates are shown in Table 10.

TABLE 10: Mean Total Milking Time (min) from Combined Replicates

Machine	Mean Total Milking Time (min)
B	5.32
A	5.54
D	5.93
C	5.96
E	6.03
F	6.24
H	6.48
G	7.13

Total milking time will be influenced by milk yield and it is necessary to calculate the regression coefficient of milking time on yield and adjust total milking time means accordingly.

$$\text{Correction factor (C)} \frac{(2477.2 \times 777.99)}{128} = 15,056.537$$

$$\text{Total Sums of Products (SP)} 15,862.2392 - 15,056.537 = 805.702$$

$$\text{Replicates SP} \frac{1338.22 \times 412.90 + 1,139.00 \times 365.09}{64} - 15,056.537 = 74.534$$

$$\text{Machines SP} \quad \frac{241,381.9199}{16} - 15056.537 = 29.833$$

$$\text{Periods SP} \quad \frac{243,689.6187}{16} - 15,056.537 = 174.064$$

$$\text{Error SP} = 51.438$$

Sums of Squares of Deviations from Regression

$$\begin{aligned} \text{Error} \quad 70.2240 & - \frac{(51.438)^2}{338.5800} \\ & = 70.2240 - 7.8146 = 62.4094 \end{aligned}$$

Machines + Error

$$\begin{aligned} & = 105.5399 - \frac{(81.271)^2}{436.1500} \\ & = 105.5399 - 15.1438 = 90.3961 \end{aligned}$$

Analysis of Covariance

Source of Variation	f	$\sum x^2$	$\sum xy$	$\sum y^2$	Deviations from Reg.		
					f	SS	MS
Replicates	1	310.0650	74.534	17.8574			
Cows within replicates	14	2029.3012	475.833	562.6170			
Periods	7	768.2220	174.064	42.2294			
Machines	7	97.5700	29.833	35.3159			
Error	98	338.5800	51.438	70.2240	97	62.4094	0.6434
Machines + Error	105	436.1500	81.271	105.5399	104	90.3961	
					7	27.9867	3.9981

$$F = 6.21_{***}$$

y is total milking time

x is total milk yield

$$\text{The regression coefficient (b) of y on x} = \frac{51.438}{338.58}$$

$$= 0.15192$$

$$\bar{x} = 19.35$$

The adjusted means are calculated by getting the product of the regression coefficient(b) and the difference in milk yield from the average ($\bar{x}_1 - \bar{x}$) and subtracting this from the total milking time ($\bar{y}$).

Machine	$\bar{x}$	$\bar{x}_1 - \bar{x}$	$b(\bar{x}_1 - \bar{x})$	$\bar{y}$	$y - b(\bar{x}_1 - \bar{x})$
G	21.14	1.79	0.2719	7.1319	6.8600
D	19.84	0.49	0.0744	5.9331	5.8587
F	19.70	0.35	0.0532	6.2400	6.1868
A	19.62	0.27	0.0410	5.5394	5.4984
C	18.90	-0.45	-0.0684	5.9562	6.0246
E	18.88	-0.47	-0.0714	6.0275	6.0989
B	18.64	-0.71	-0.1079	5.3162	5.4241
H	18.11	-1.24	-0.1884	6.4800	6.6684

These adjusted means are shown in Table 11. The difference between the machines is highly significant and any two means not covered by the same vertical line are significant at the 5% level when Duncan's (1955) range test is applied.

TABLE 11: Mean Total Milking Time (min) Adjusted for Milk Yield from Combined Replicates

Machine	Total Milking Time (min)
B	5.42
A	5.50
D	5.86
C	6.02
E	6.10
F	6.19
H	6.67
G	6.86

The results of the milking rate and adjusted total milking time show that machines with wider ratio pulsation (A, B and D)

milk faster than machines with narrow ratio pulsation (E and F) at a constant level of vacuum. Machine H was working at a vacuum of 13" Hg. In this particular experiment increasing the milking vacuum from 13" Hg to 15" Hg reduced adjusted mean total milking time by 1.17 minutes per cow. This comparison is made between Machine A and Machine H because both had a pulsator ratio of approximately 3 : 1 and a pulsation rate of 60.

MACHINE MILKING RATE

The three measurements given in machine milking rate are:

- (1) Mean machine milking rate,
- (2) Maximum milking rate
- (3) Mean machine milking time.

The mean machine milking rate for machines and cows for each replicate, its analysis of variance and the significant difference between machine milking rate means are shown in Tables 12, 13 and 14.

TABLE 12: Mean Machine Milking Rate (lb/min) Data for Machines and Cows in both Replicates (R)

Mean Machine Milking Rate (lb/min)						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	4.103	3.805	480	930	5.957	5.932
F	3.791	3.747	927	104	4.663	2.852
D	4.270	4.372	651	115	5.374	5.121
E	3.971	4.074	121	403	2.455	3.367
G			82	931	4.232	3.042
A	4.603	4.426	335	929	3.781	4.948
B	4.431	4.272	116	607	3.104	4.917
H	3.504	3.433	402	500	3.202	1.955

44.

The values for Machine G are missing and the variation due to the different components are analysed using the technique of Yates (1936).

$$\text{Correction factor } \frac{(454.35)^2}{112} = 1843.1600$$

$$\text{Total Sums of Squares (SS)} = 2045.3537 - 1843.1600 = 202.1937$$

$$\text{Replicates SS } \frac{(229.40)^2}{56} + \frac{(224.95)^2}{56} - 1843.16 = 0.1760$$

$$\text{Cows within Replicates SS } 69.3414 + 94.1519 = 163.4933$$

$$\text{Machines SS } \frac{29,695.7047}{16} - 1843.16$$

$$= 1855.9815 - 1843.16 = 12.8215$$

$$\text{Periods SS } \frac{25,830}{14} - 1843.16$$

$$= 1845.0188 - 1843.16 = 1.8588$$

$$\text{Error SS} = 23.8441$$

TABLE 13: Analysis of Variance for Mean Machine Milking Rate

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	0.1760	1	0.1760	0.61	N.S.
Cows within Replicates	163.4933	14	11.6781	40.65	***
Periods	1.8588	7	0.2655	0.92	N.S.
Machines	12.8215	6	2.1369	7.44	***
Error	23.8441	83	0.2873		
Total	202.1937	111			

TABLE 14: Mean Machine Milking Rate (lb/min) for Seven Machines from Combined Replicates

Machine	Mean Machine Milking Rate (lb/min)
A	4.51
B	4.35
D	4.32
E	4.02
C	3.95
F	3.77
H	3.47
SE	± 0.134

Any two means not covered by the same vertical line are significantly different at the 5% level.

The mean maximum milking rate for machines and cows for each replicate, its analysis of variance and the significance of the differences between maximum milking rate means are given in Tables 15, 16 and 17.

TABLE 15: Mean Maximum Milking Rate (lb/min) Data for Machines and Cows in both Replicates (R)

Mean Maximum Milking Rate						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	5.54	5.25	480	930	7.71	8.16
F	5.08	5.36	927	104	6.54	3.93
D	5.75	5.90	651	115	7.19	7.21
E	5.37	5.25	121	403	3.24	4.53
G			82	931	6.34	4.16
A	6.33	5.90	335	929	4.69	6.56
B	6.13	5.59	116	607	4.72	6.46
H	4.78	4.67	402	500	4.11	2.30

TABLE 16: Analysis of Variance for Mean Maximum Milking Rate
for Seven Machines

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	0.6660	1	0.6660	1.12	N.S.
Cows within Replicates	304.1613	14	21.7258	36.39	***
Periods	2.2194	7	0.3171	0.53	N.S.
Machines	21.3716	6	3.5619	5.97	***
Error	49.5573	83	0.5971		
Total	377.9756	111			

TABLE 17: Mean Maximum Milking Rate (lb/min) for Seven Machines
from Combined Replicates

Machine	Mean Maximum Milking Rate
A	6.11
B	5.86
D	5.82
C	5.39
E	5.31
F	5.22
H	4.73

SE = ± 0.193

Any two means not covered by the same vertical line are significantly different at the 5% level. When maximum milking rate was adjusted for total milk yield, there was no change in the significance or order of the means.

The mean machine milking time for machines and cows for each replicate, its analysis of variance and the significance of the differences between machine milking time means are given in Tables 18, 19 and 20.

TABLE 18: Mean Machine Milking Time (min) for Cows and Replicates (R)

Mean Machine Milking Time (min)						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	4.750	4.500	480	930	3.880	3.107
F	5.696	4.947	927	104	4.188	4.452
D	6.687	4.243	651	115	2.274	2.434
E	5.343	4.661	121	403	8.705	6.357
G			82	931	3.511	5.047
A	4.876	4.190	335	929	7.022	3.892
B	5.031	3.478	116	607	5.308	4.368
H	6.031	4.885	402	500	6.712	5.656

TABLE 19: Analysis of Variance for Mean Machine Milking Time (min) for Seven Machines

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	17.3480	1	17.3480	34.84	***
Cows within Replicates	285.4149	14	20.3868	41.00	***
Periods	62.9584	7	8.9941	18.09	***
Machines	20.1061	6	3.3510	6.74	***
Error	41.2653	83	0.4972		
Total	427.0927	111			

TABLE 20: Mean Machine Milking Time (min) for Seven Machines
from Combined Replicates

Machine	Mean Machine Milking Time (min)
B	4.26
D	4.47
A	4.53
C	4.63
E	5.00
F	5.32
H	5.46

SE: = ± 0.176

When mean machine milking time was adjusted for machine yield, the standard error and the order of the means changed. The analysis of covariance and mean milking times adjusted for yield for seven machines are shown in Tables 21 and 22 where x is machine yield (lb) and y is machine time (min).

TABLE 21: Analysis of Covariance for Mean Machine Milking Time (mins)

Adjusted for Machine Yield

Source of Variation					Deviations from Reg.		
	f	$\sum x^2$	$\sum xy$	$\sum y^2$	f	SS	MS
Replicates	1	233.160	63.601	17.3480			
Cows within Replicates	14	1676.095	291.920	285.4149			
Periods	7	881.025	231.943	62.9584			
Machines	6	44.821	-4.423	20.1061			
Error	83	299.752	44.596	41.2653	82	34.6305	0.4223
Machines + Error	89	344.573	40.173	61.3714	88	56.6877	
					6	22.0572	3.6762

$$F = 8.71 ***$$

The regression coefficient (b) estimated from the error sums of squares and products is $\frac{44.596}{299.752} = 0.1488$. For every pound of milk above or below the grand average, it is necessary to add or subtract the product of the deviation and the coefficient from the original unadjusted means. This gives adjusted means - Table 22.

TABLE 22: Mean Machine Milking Time (min) Adjusted to Machine Yield for Seven Machines from Combined Replicates

Machines	Adjusted Mean Machine Milking Time (min)
B	4.28
A	4.43
D	4.46
C	4.71
E	4.98
F	5.19
H	5.62

Standard Error:= ± 0.162

Any two means not covered by the same vertical line are significantly different at the 5% level.

There was a 10% difference between the seven machines in machine yield. Nevertheless, these differences were not significant at 5% level. Details of the Analysis of Variance and Mean Machine Yield for the seven machines is shown in Tables 23 and 24.

TABLE 23: Analysis of Variance of Machine Yield (lb)

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	233.160	1	233.160	64.56	***
Cows within Replicates	1676.095	14	119.721	33.15	***
Periods	881.025	7	125.861	34.85	***
Machines	44.821	6	7.470	2.07	N.S.
Error	299.752	83	3.611		
Total	3134.853	111			

TABLE 24: Mean Machine Yield (lb) for Seven Machines from Combined Replicates

Machines	Mean Machine Yield (lb)
F	18.76
A	18.57
E	18.03
D	17.95
B	17.74
C	17.35
H	16.77

Standard Error: = 0.475

Any two means not covered by the same vertical line are significantly different at the 5% level.

MACHINE STRIPPING

The mean machine stripping yield from seven milking machines varied from 0.91 lb to 1.89 lb. This difference was significant at the 5% level. The mean machine stripping yield for cows and machines in both replicates is shown in Table 25. The analysis of variance and mean machine stripping yield appear in Tables 26 and 27.

TABLE 25: Mean Machine Stripping Yield (lb) for Seven Machines and Sixteen Cows in both Replicates (R)

Mean Machine Stripping Yield (lb)						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	1.878	1.157	480	930	0.650	1.014
F	0.636	1.283	927	104	0.787	0.644
D	2.174	1.601	651	115	0.521	0.648
E	1.053	1.083	121	403	2.474	1.132
G			82	931	1.057	2.392
A	1.173	0.857	335	929	1.648	0.514
B	0.810	1.005	116	607	1.511	0.798
H	1.077	1.194	402	500	1.431	2.224

TABLE 26: Analysis of Variance for the Machine Stripping Yield (lb)
of Seven Machines

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	0.2206	1	0.2206	0.34	N.S.
Cows within Replicates	43.9927	14	3.1423	4.91	***
Periods	3.7575	7	0.5368	0.84	N.S.
Machines	12.3383	6	2.0564	3.22	**
Error	53.0798	83	0.6395		
Total	113.3889	111			

TABLE 27: Mean Machine Stripping Yield (lb) for Seven Machines
from Combined Replicates

Machine	Mean Machine Stripping Yield (lb)
B	0.91
F	0.96
A	1.02
E	1.07
H	1.14
C	1.52
D	1.89

Standard Error ± 0.200

Any two means not covered by the same vertical line are significantly different at the 5% level.

The mean machine stripping time in minutes for seven machines and sixteen cows is presented in Table 28 and the analysis of variance and the combined mean machine stripping times are presented in Tables 29 and 30.

TABLE 28: Mean Machine Stripping Time (min) for Seven Machines and Cows in both Replicates (R)

Mean Machine Stripping Time (min)						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	1.571	1.208	480	930	0.631	0.987
F	0.635	1.186	927	104	0.807	0.688
D	1.553	1.339	651	115	0.595	0.673
E	1.031	0.881	121	403	1.961	1.082
G			82	931	1.200	2.237
A	1.178	0.823	335	929	1.403	0.475
B	0.852	1.030	116	607	1.114	0.774
H	1.0621	1.115	402	500	1.261	1.741

TABLE 29: Analysis of Variance for Machine Stripping Time (min)

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	0.0514	1	0.0514	0.19	N.S.
Cows within Replicates	27.0072	14	1.9291	7.22	***
Periods	1.6928	7	0.2418	0.90	N.S.
Machines	4.7614	6	0.7861	2.94	*
Error	22.1788	83	0.2672		
Total	55.6466	111			

TABLE 30: Mean Machine Stripping Time (min) for Seven Machines from Combined Replicates

Machine	Mean Machine Stripping Time (min)
F	0.91
B	0.94
E	0.96
A	1.00
H	1.09
C	1.39
D	1.45

Standard Error ± 0.129

Any two means not covered by the same vertical line are significantly different at the 5% level.

When machine stripping time was adjusted for machine stripping yield and re-analysed, there was no significant difference between the machines. The analysis of covariance and mean stripping time for seven machines adjusted for machine stripping yield are given in Tables 31 and 32 where x is machine stripping yield in lbs and y is machine stripping time in minutes. There is no significant difference between the machines in mean machine stripping rate.

TABLE 31: Analysis of Covariance for Machine Stripping Time (min)
Adjusted to Machine Stripping Yield for Seven Machines.

Source of Variation	Degrees of Freedom	$\sum x^2$	$\sum xy$	$\sum y^2$	Deviations from Reg		
					f	SS	MS
Replicates	1	0.2206	0.1065	0.0514			
Cows within Replicates	14	43.9927	33.5549	27.0072			
Periods	7	3.7575	2.3439	1.6928			
Machines	6	12.3383	7.3447	4.7164			
Error	83	53.0798	29.7607	22.1788	82	5.4926	0.0670
Machines + Error	89	65.4181	37.1054	26.8952	88	5.8489	
					6	0.3563	0.0594

$$F = 0.89 \text{ NS.}$$

TABLE 32: Mean Machine Stripping Time for Seven Machines
Adjusted for Machine Stripping Yield

Machine	Adjusted Mean Machine Stripping time (min)
E	1.04
F	1.05
D	1.07
A	1.11
B	1.11
H	1.13
C	1.22
Standard Error ± 0.065	

UDDER IRRITATION

The effect of the machines on udder irritation is presented in cell count ($\log_{10}$). The cell count ($\log_{10}$) per ml of milk from eight machines and sixteen cows is presented in Table 33 and the analysis of variance and mean cell count ($\log_{10}$) ml is presented in Tables 34 and 35 respectively.

TABLE 33: Mean Cell Count ($\log_{10}$) per ml Milk for Machines and Cows in Both Replicates (R)

Mean Cell Count ($\log_{10}$)						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	4.767185	4.844388	480	930	4.413471	4.820095
F	4.632016	4.784421	927	104	4.485430	4.946751
D	4.580032	4.983125	651	115	4.531560	5.163894
E	4.487836	5.062896	121	403	4.326489	4.491542
G	4.354835	4.839463	82	931	4.670898	5.360209
A	4.545745	4.834553	335	929	4.498067	4.753599
B	4.502310	4.946617	116	607	4.575171	4.850617
H	4.525923	4.846795	402	500	4.533813	4.755490

TABLE 34: Analysis of Variance for Cell Count ($\log_{10}$)
per ml Milk

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F	Significance
Replicates	4.8287	1	4.8287	21.0	***
Cows within Replicates	4.6033	14	0.3288	1.4	N.S.
Periods	10.7712	7	1.5387	6.7	***
Machines	0.9720	7	0.1389	0.6	N.S.
Error	22.5358	98	0.2300		
Total	43.7110	127			

TABLE 35 : Mean Cell Count ($\log_{10}$) per ml Milk for Eight
Machines from Combined Replicates

Machine	Mean Cell Count ($\log_{10}$) per ml	Mean Cell Count (Transformed) per ml
E	4.495	31,260
H	4.686	48,530
A	4.690	48,980
G	4.697	49,770
F	4.708	51,050
B	4.724	52,960
D	4.782	60,540
C	4.806	63,900

Standard Error ± 0.120

There is no significant difference between the means for the eight machines at the 5% level.

The mean teat apex erosion score for eight machines and sixteen cows for both replicates is shown in Table 36.

Table 37 shows the mean teat apex erosion score for the eight machines. There is no significant difference between the machines.

TABLE 36: Mean Teat Apex Erosion Score* for Machines and Cows in Both Replicates

Mean Teat Apex Erosion Score						
Machine	RI	RII	Cow No.		RI	RII
			RI	RII		
C	1.8	1.8	480	930	2.1	1.7
F	1.6	1.6	927	104	1.7	2.0
D	1.9	1.8	651	115	1.4	1.6
E	1.6	1.5	121	403	1.6	1.6
G	1.6	1.6	82	931	2.4	1.9
A	1.8	1.8	335	929	1.5	1.2
B	1.8	1.7	116	607	2.0	1.5
H	1.8	1.6	402	500	1.0	1.4

*The teat apex erosion was classed as 0,1,2,3,4,5 depending on severity.

TABLE 37: Mean Teat Apex Erosion Score for Eight Milking
Machines from Combined Replicates

Machine	Mean Teat Apex Erosion Score
C	1.8
F	1.6
D	1.9
E	1.6
G	1.6
A	1.8
B	1.8
H	1.7

Air Admission Holes

It was not possible to detect the effect of different size air admission holes in the clawpieces (Table 3) on milking rate. Machine H was the only floor type pail without an air admission hole and it was possible to see the milk tube and clawpiece flooding during peak flow with most cows. The effect this flooding had on milking rate was not measured. Flooded milk tubes would be very serious in pipeline machines where the milk may be lifted up to six feet to the milk pipeline.

DISCUSSION

I Production

The seven milking machines working at 15" Hg vacuum yielded more milk, milkfat and solids-non-fat than the machine working at 13" Hg vacuum. This agrees with the findings of Gregoire et al (1964) Dodd and Clough (1955) and Brandsma (1963a). This difference in production though nonsignificant is important. These results lend some support to the view that a relationship exists between milk yield and milking rate and that milk yield is dependant to some degree on the rate of removal of milk from the udder, (Clough and Dodd 1957).

II Vacuum Levels

There is no logical reason for recommending that bucket milking machines should work at 13" Hg vacuum if they milk cows less efficiently than machines working at 15" Hg vacuum. There is no indication from the results of the mean cell count in Table 35 and mean teat apex erosion score in Table 38 that the machine working at 13" Hg vacuum caused any less irritation to the cows udder than the machines working at 15" Hg vacuum.

Comparing Machine H milking at 13" Hg vacuum and Machine A milking at 15" Hg vacuum both machines used a pulsation rate of 60, a pulsation ratio of approximately 3 : 1 yet the cell counts from both machines were 48,000 per ml of milk. Their teat apex erosion values are not significantly different at 1.7 and 1.8 respectively. There were no known pathogenic bacteria to challenge the cows during milking or between milkings because of the hygienic methods practised in the experiments. Consequently it is not possible to comment on the effect these two vacuum levels may have on the incidence of new infection. There is evidence from the experiments of Dodd and Clough (1955), Mochrie et al (1953, 1955), Porter et al (1955) and Schmidt et al (1963b) that vacuum levels in the range of 13" to 15" Hg do not effect the rate of new infections.

Pulsator Characteristics

It is not possible to draw any conclusions on the effect of pulsation rate on mean milking rate because the three machines with a pulsation ratio of approximately 50 : 50 milking at 15" Hg vacuum had only a pulsator rate range of from 42 to 45 pulsations per minute. There is evidence from the literature of Clough et al (1963), Stewart and Schultz (1956), Andrae (1957),

Valdmann (1959) & Smith et al (1963) that pulsator rate increases milking rate. The explanation for this increase postulated by Clough et al (1963) has been confirmed by Thiel et al (1966). They concluded from a series of flow rate curves at the different pulsation rates that flow rate from the teat increased in about 0.05 seconds to a steady value which continued for 0.5 seconds, and then declined over a period of about 1.5 sec. to a new constant value. Their results suggest that once the pressure difference across the streak canal during milking forces the teat sphincter open a considerable time elapses before the muscle control system responds, and that a further much longer period elapses before the full closing force of the sphincter is exerted. Thus it would appear that at pulsation rates of 50 cycles per min and above, the streak canal is closed by pressure exerted on the teat by the closing liner, the sphincter muscle playing no active part because its response rate is slow compared with the pulsation rate. At lower pulsation rates the flow rate declines during each cycle because the sphincter muscle has time to exert a closing force to a greater or lessor extent depending on the duration of the milk flow period. This slow reaction of the sphincter muscle relative to liner wall movement at high pulsation rates could be an important mechanism

whereby bacteria may be jetted through the streak canal especially when milk is trapped at the base of the teat by a fast squeezing liner. The dynamics of the fast liner movement associated with a fast vacuum to air phase in the pulsation chamber has been propounded by Phillips (1963), and this merits further research.

It is well established that machines with wide ratio pulsation milk faster than machines with narrow ratio pulsation (Labussiere and Richards 1965). This experiment confirms this fact and in both mean milking rate and mean machine milking rate Tables 8 and 14, Machine A with a pulsation ratio of 73 : 27 milked significantly faster than the other machines working at approximately 50 : 50 pulsation ratio, with the exception of Machines D and B. These two latter machines had pulsation ratios of 60 : 40 and 56 : 44 respectively. When discussing experiments on pulsator ratio it is essential to know how ratio is defined.

Machine Stripping

The cluster of Machine D had significantly higher machine stripping yield than any of the other six machines and the clusters of Machines C and D had significantly longer machine

stripping times. These two clusters weighed 4.5 and 5.3 lb. respectively and they were the **lightest** clusters in the experiment. These results confirm the findings of Clough (1964 a.b.) that cluster assembly weight is significantly and inversely related to quantity of machine stripping. There was no evidence from this experiment that a machine working at 13" Hg vacuum gave less machine stripping yield than machines working at 15" Hg vacuum; indeed Machine H with a cluster assembly weight of 6.4 lb had a higher stripping yield than four of the machines working at 15" Hg. - Tables 27 and 30. Increase in vacuum levels from 13" - 15" Hg may give rise to increased machine stripping if the weight of the cluster assembly is less than 5.5 lb. Normally a $3\frac{1}{2}$ lb weight is added to the cluster assembly of Machine F when the cow is three-quarters milked bringing the weight of the cluster up to 8.7 lb. This practice is recommended in New Zealand where a cluster weight in excess of 5.3 lb would fall off the teats of Jersey cows in early lactation. There was no indication from this experiment that cluster assemblies weighing up to 6.6 lb had any disadvantage milking Shorthorn or Friesian cows. There was no significant difference between the machines in mean machine stripping rate and the range was from 0.97 lb. per

minute for Machine B up to 1.30 lb per minute for Machine D. The other five machines had mean machine stripping rates varying from 1.02 to 1.12.

Udder Irritation

The two measures of udder irritation in this experiment, namely, cell count and teat apex erosion did not pick up any significant differences in udder irritation between the machines. However Table 35 suggests that Machines C and D gave somewhat higher readings than the other machines in mean cell count. It is not possible to say whether this is associated with machine stripping time. Studying cow reaction to the different machines was not very conclusive. Most cows were uneasy when a new machine was introduced for the first milking and settled in for the second milking. However cows 335, 500 and 927 were uneasy with the Machines A, E and G for two milkings.

COMMENTS ON EASE OF OPERATION AND MAINTENANCE

There was no appreciable difference in ease of operation between the eight machines. All units with the exception of unit G had vacuum cut-off taps in the milk system other than the stall tap. Unit G had an automatic vacuum cut-off when milk tubes kinked. Machines A and E had the cut-off valve on the clawpiece, four other makes had the vacuum cut-off on the long milk tube and Machine H had the vacuum cut-off tap at the entrance to the bucket. It is convenient for the operator to have the vacuum cut-off at or near the clawpiece. On six (6) occasions during the test, unit G had the vacuum cut off automatically from one teat during milking by the milk tube kinking. This is undesirable and gives uneven milking. However, it only happened with one cow that had a large uneven udder. Special care should be exercised with the suspended-type pail milking cows with uneven udders.

The $3\frac{1}{2}$ lb stripping weight supplied with Machine F was easily knocked from the clawpiece if the cow moved during machine stripping. This could be rectified by increasing the size of

the retaining cavity in the stripping weight.

The two pipeline milkers had master pulsators and the 6-bucket machines had pneumatic pulsators. The frequency with which pulsation rate could change in the pneumatic pulsators varied considerably and Table 38 shows the number of changes in pulsation rate of six makes during a period of twenty nine consecutive days.

TABLE 38: Number of Changes in Pulsation Rate Greater than ± 2 Pulsations Per Minute During 29 Consecutive Days

Machine	No. of Changes in Pulsation Rate
A	0
E	2
H	6
C	10
B	42
G	42

End-of-Milking Indicators

The ease with which the operator can see the end-of-milk flow is important and the eight machines had seven different methods of indicating this point. The systems used were as follows;

- A - Plastic tube
- B - Sight Glass at end of teat cup shell
- C - Sight glass in long milk tube
- D - Jelly jar sight glass on milk pipe
- E - Sight glass at end of teat cup shell
- F - Dairymaster milk flow indicator
- G - Plastic pail lid
- H - Sight glass and plastic tube.

The difference in time between the point when the milk flow drops to $\frac{1}{2}$ lb per minute and the point when the indicator shows that milking has ended is taken as a measure of the efficiency of the indicator. This time difference is given for each indicator in Table 39 (from Dwane 1967).

TABLE 39: Time Difference in Minutes Between True End-of-Milking and Actual End-of-Milking for Seven Milking Machines.

Machine	Time Difference (min)
F	0.16
D	0.32
A	0.56
H	0.56
B	0.61
E	0.61
C	0.72

CLEANING OF MACHINES

With the exception of the two pipeline milking machines which are normally washed by circulation cleaning, all the other makes were brushed and dismantled occasionally. All machines were cleaned satisfactorily by carrying out the manufacturers' recommendations, but there was a considerable difference between machines in the time taken to dismantle, wash and assemble units (Table 40).

Machines B, E and H used semi-moulded liners, while Machines A and C had moulded liners and Machine G had no clawpiece or long milk tube.

TABLE 40: Mean Dismantling, Washing and Assembling Time for Six-Bucket Units.

Make of Unit	Time (min)
G	4
A	6
C	7
H	10
E	11
B	12

Any two means not covered by the same vertical line are significantly different at the 5% level.

CONCLUSIONS

Milking machines milking at 15" Hg vacuum had higher mean milking rates than ^{the} machine milking at 13" Hg vacuum. There was no significant difference in mean milking rate between machines working at 15" Hg vacuum and a 1 : 1 pulsation ratio, and ^{the} machine working at 13" Hg vacuum and 3 : 1 pulsation ratio. Machines with a 3 : 1 pulsation ratio milked significantly faster than machines with a 1 : 1 pulsation ratio at the same level of vacuum.

Cluster assembly weight was inversely associated with the quantity and duration of machine stripping and cluster assemblies weighing 4.5 - 5.3 lb had significantly longer machine stripping times than cluster assemblies weighing between 5.5 - 6.6 lb. The milking machine characteristics of the eight machines had no significant effect on mean cell count per ml of milk or teat apex erosion score.

It was not possible to measure any differences due to air admission holes in clawpieces or liner design on milking rate and teat damage.

There was a big difference between the machines in ease of keeping pulsation rate constant and two pulsators needed very frequent adjustment to keep pulsator rate constant.

Increases in milking rate cannot be availed of at farm level unless the machine is fitted with an efficient end-of-milking indicator. The two pipeline machines were fitted with satisfactory milk flow indicators.

All clusters were adequately cleaned visibly using manufacturers instructions, but clusters with semi-moulded liners took significantly longer to dismantle, wash and assemble.

SUMMARY

Eight makes of milking machine with different milking characteristics, i.e. vacuum level, pulsator rate and ratio, cluster assembly weight and design and liner design, were compared.

Increasing milking vacuum level from 13" Hg to 15" Hg and widening pulsator ratio from 50 : 50 to 73 : 27 significantly increased ($P < 0.05$) mean milking rates.

Cluster assembly weight was inversely and significantly related to yield and duration of machine stripping. There was no relationship between vacuum level and machine stripping. In the absence of pathogenic bacteria there was no significant difference between the effect of the eight makes of milking machine on teat or udder damage as measured by cell count and teat apex erosion.

The relative ease of operating and maintaining the eight milking machines in satisfactory milking condition is reported.

REFERENCES

- ABBASOV, S. G., 1965, (Effect of additional loading of the clawpiece on the speed of milking and stripping by hand) Zhivotnovodstvo, Mosk, 27(6), 78-80.
- ADRAN, G. M., KEMP, F. H., CLOUGH, P. A., DODD, F. H., 1958. Cineradiographic observations on machine milking. J. Dairy Res., 25, 154-158.
- AIGNER, M., HOBBIER, A., 1957. Vergleichende Untersuchungen an Melkmaschinen mit elektrisch und vakuumgesteuerten Pulsatoren. Milchwiss. Ber. Woljpassing, 7, 139-148 (in Dairy Sci. Abstr., 19, 898).
- ALLISON, C., 1959. The effect of pulsation ratio on machine milking. A comparison of milking rates using a control and a wide ratio pulsator. J. Soc. Dairy Technol., 12, 153-156.
- ANDREAE, U., 1957. Melkversuche mit dem Schneltpulsverfahren. Tech. U. Landev., 7, 57.
- BAXTER, E. S., CLARKE, P. M., DODD, F. H., FOOT, A. S., 1950. Factors affecting the rate of machine milking. J. Dairy Res., 17, 117-127.

BRANDSMA, S., 1963a. Results of some experiments with a high vacuum milking machine (Bejema). Alfa-Laval Symposium No. 1, Stockholm.

BRANDSMA, S., 1963b. Preliminary results of some experiments with the teat-cups assembly of different milking machines. Alfa-Laval Symposium No. 1, Stockholm.

BRATLIE, O., 1958, (The importance of vacuum level in machine milking on milking technique and udder hygiene). Nord. Vet. Med., 10, 128 - 142.

BRATLIE, O., SLAGSVOLD, P., and TOLLERSRUD S., 1959. (Significance of pulsation rate in machine milking). Nord. Vet. Med., 11, 759-779.

BRATLIE, O., SLAGSVOLD, P., TOLLERSRUD, S., 1961. (Comparison of 1 : 1 and 4 : 1 Pulsation Ratio). Tidsska. Norske. Landbr. 68(4-5), 110-132.

BRATLIE, O., GEDDE-DAHL, T., SLAGSVOLD, P., TOLLERSRUD, S., 1962. (Experiments on the pulsation ratio of the milking machine and its effects on udder health). IXth Nordic Veter. Congr., Copenhagen, 4-7 juillet, Section G, No. 1.

- CARUOLO, E. V., DEMBICZAK, C. M., MOCHRIE, R. O., JOHNSON, R. E., EATON, H. D., SPIELMAN, A. A., 1955. Effects of vacuum level and milking duration on Guernseys and Holsteins differing with respect to lactation number and status of udder health. II. Milk yield, milking time and rate of milk flow. J. Dairy Sci., 38, 1283-1292.
- CLOUGH, P. A., DODD, F. H., HUGHES, E. W., 1953. Pulsation and milking rate, J. Dairy Res., 20, 375-380.
- CLOUGH, P.A., DODD, F. H. 1956. Effect of pulsation rate and ratio on milking rate. Agriculture, London, 63, 334-335.
- CLOUGH, P. A., and DODD, F. H., 1957, The relationship between milk secretion and the rate of milking by machine. J. Dairy Res. 24, 152-156.
- CLOUGH, P. A., DODD, F. H. 1958. Vacuum level and pulsation ratio. Report, National Institute for Research in Dairying, Shinfield, Reading, p. 26.
- CLOUGH, P., 1964a. Design of milking machine clusters. Report, National Institute for Research in Dairying, Shinfield, Reading, p. 26
- CLOUGH, P. 1964b. Machine Stripping, Agriculture, London 361-363.

DILLON, W. M., BROWN, C. M., ALBRIGHT, J. L., CALLAHAN, C. J., and WEINLAND, K. M., 1967. The influence of wide and narrow milking machine inflations on udder health. J. Dairy Sci. 50, 992-993.

DODD, F. H., HENRIQUES, E., 1949. The effect of teat-cup assembly weight on rate of machine milking. Agriculture, 56, 212-26.

DODD, F. H., 1953, Milking Research, Annual Report, National Institute for Research in Dairying, Shinfield, Reading, p.26.

DODD, F. H., and CLOUGH, P. A., 1955. Vacuum level and milking rate. Annual Report, National Institute for Research in Dairying, Shinfield, Reading.

DODD, F. H., OLIVER, J. and NEAVE, F. K. 1957. The effect of Design of Teat-Cup Liners on Mastitis Incidence. J. Dairy Res. 24 : 20.

DUNCAN, D. B., 1955. Multiple Range and Multiple F-Tests, Biometrics 11, 142.

DWANE, T., 1967, An Foras Taluntais - Private communication.

- GEDDE-DAHL, T., 1962. (Effect of pulsation ratio and type of cluster assembly on maximum milking rate). Tidsskr. Norske Landbr. 68(7) 191-97 (D.S.A. Vol. 24 (1250)).
- GREGOIRE, A. T., MOCHRIE, R. D., ELLIOTT, F. I., EATON, M. C., SPIELMAN, A. A., 1954. Effect of vacuum level and milking duration on milk production, milking time and rate of milk flow in mastitis-free first-calf heifers. J. Dairy Sci., 37, 276-283.
- JORGENSEN, K. E., CARUOLO, E. V., 1963. Milking rate and time, amount of complementary milk and amount of milk obtained by milking machines as affected by pulsation rates of 30, 50, 70 and 90 applied to separate mammary gland quarter. J. Dairy Sci., 46, 624 (Abstr).
- KAVESHNIKOVA, K., 1960. Rendement laitier de vaches avec differents parametre de la machine a traire (en russe). Zhivotnovodstvo, 22, 83-87.
- KLASTRUP, O., (1960). Cell counts on can milks, Nord, Vet-Med. 12, 621-638.
- LABUSSIÈRE, J., RICHARD, P., 1965. La traite mecanique. Aspects anatomique, physiologiques et technologique. Mise an point bibliographique. Ann. Zootech., 14, 63-126.

- LANGELUDDEKE, H., & KLOTH, H., 1964. (Effects of high pulsation rate on the rate of milk flow). Tierzucht 18(4) 190-92.
- LIGHTBODY, L. G., MURRAY, A. J. W., 1960. Effect of variation of vacuum level on milking rate of Australian Illawara Shorthorn cows. Queensland Journal Agr. Sc. 17 : 155.
- MOCHRIE, R. D., HALE, H. H., EATON, H. D., ELLIOTT, F. I., PLASTRIDGE, W. N., BEALL, G., 1953. Effects of vacuum level and milking duration on udder health in mastitis-free first-calf heifers. J. Dairy Sci., 36, 504-515.
- MOCHRIE, R. D., HALE, H. H., DEMBICZAK, C. M., EATON, H. D., PLASTRIDGE, W. N., JOHNSON, R. E., 1955. Effect of vacuum level and milking duration on Guernseys and Holsteins differing with respect to lactation number and status of udder health. I. Udder health. J. Dairy Sci., 38, 1272-1282.
- OLIVER, J., and DODD, F. H. 1957. Milking machine and technique investigations. Annual Report, National Institute for Research in Dairying, p. 27.
- MOORE, C. L., 1965, Effects of pulsation rates of 44, 55 and 66 pulsation ratios of 50 : 50 on milking rate and milking time. J. Dairy Sci., 48, 1612-1614

- MURPHY, J. M., 1960. A comparison of the mastitogenic effect of two types of milking machine liners, one moulded and one stretched. J. Dairy Sci., 43, 1890.
- MURPHY, J. M. 1961. An attempt to measure experimentally the possible mastitogenic effect of several milking machine factors. J. Dairy Sci., 44 : 1201.
- PHILLIPS, D. S. M., 1963. The effect of pulsator ratio on milking rate. Proc. Ruakura Farm. Conf. Week, 219-234.
- PORTER, R., MILLER, D. D., SKAGGS, S. R., 1955. Effect of high and low vacuum milking machines on udder health and milk removal. J. Dairy Sci., 38 A. 101 (abstr).
- RABOLD, K. 1963. Investigations on different types of teat cups and their influence on the ease of milking cows. Alfa-Laval Symposium No. 1 Stockholm, 78.
- RUSEV, G., 1963 (Effect of different vacuum levels on the milking of cows with a DA-3 machine) Izv. Int. Zhivotn "Georgi Dimitrov" Kostinbrod 18, 123-127. (D.S.A. Vol. 26 (1217)).
- SCHMIDT, G. H., GUTHRIE, R. S., GUEST, R. W., 1963a. Effect of teat-cup liner diameter and mouth piece on the milking rate, machine stripping and mastitis in dairy cows. J. Dairy Sci., 46, 1064-1068.

- SCHMIDT, G. H., GUTHRIE, R. S., GUEST, R. W., HUNDTOLT, E. G., KUMAR, A., HENDERSON, C. R., 1963(b). Effect of changes in milking machine design on milking rate, machine stripping and mastitis. Cornell Agric. Expl. Sta. Bull. 983.
- SCHMIDT, G. H., MERRILL, W. G., GUTHRIE, R. S., 1964. Relationship of milking times, procedures, and installations to level of milk production and incidence of mastitis. Bull 996 Cornell University Ag. Ext. Station.
- SMITH, V. R., PETERSEN, W. E., 1946. The effect of increasing the negative pressure and widening of the vacuum release ratio on the rate of removal of milk from the udder. J. Dairy Sci., 29, 45-53.
- SMITH, V. R., 1951. Art of Good Milking. Hoard's Dairyman 96: 763.
- STEWART, W. E., SCHULTZ, L. H., 1956. Effect of vacuum and pulsation rate on rate of milking. J. Dairy Sci., 39, 926-927.
- STEWART, W. E., SCHULTZ, L. H., 1958. The rate of machine milking of dairy cows. Effect of vacuum and pulsation rate. J. Dairy Sci., 41, 849-856.

THIEL, C. C., CLOUGH, R. A. & AKAM, D. N. 1964.

Mechanics of machine milking I. Pressures in the teat cup assembly and liner wall movement. J. Dairy Res. 31, 303-313.

TILLIOLE, P., 1964 (Milking machine duration of milking: experimental study) Ecole nationale Veterinaire d'Alfort: These No. 56.

THIEL, C. C., CLOUGH, P. A., WESTGARTH, D. R., and AKAM, D. N. (1966) Mechanics of machine milking II The flow rate pattern within single-pulsation cycles. J. Dairy Res. 33(2) 177-192.

VAIDMANN, E., 1959. Effet du rythme de pulsation sur la rapidite de traite. Sborn. nauch. Trud. Estonsk nauch issled Inst. Zhivotn. vet., 3, 28-38 (in Dairy Sci., Abstr., 25, 187).

WALSH, J. P., and NYHAN, J. F., 1966. Research Report, An Foras Taluntais, Eire. Animal Production.

YATES, F., 1936. Incomplete Latin Squares, J. Agric. Sci. 26, 301-315.

WILSON, C. D., 1958. Factors that predispose to mastitis with special reference to milking technique. Vet. Record, 70; 159.

ACKNOWLEDGMENTS

I wish to acknowledge the assistance of Professor T. Raftery, Dairy Husbandry Department, University College, Cork for his encouragement and helpful criticism during the preparation of the manuscript. The co-operation of Mr. M. J. Walshe, Officer in Charge at Moorepark for providing facilities for this work and his guidance during the project is acknowledged. I also wish to express my thanks to Mr. J. O'Mahony, Mr. M. Griffin and Mr. M. Talbot for expert technical assistance, and to the staff of the Physiology and Chemistry Departments at Moorepark; the Agricultural Engineering Department, Oakpark, Carlow and the Statistics Department, Sandymount Avenue for services in the planning and analysis of the project.