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The Construction of an Improved
Milk Flow Meter

presented by

Preston Miller Givens, Jr.

has been accepted towards fulfillment
of the requirements for

MS degree in Agricultural Engineering Technology

[signature]

Major professor

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# THE CONSTRUCTION OF AN IMPROVED MILK FLOW METER

By

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# ABSTRACT

## THE CONSTRUCTION OF AN IMPROVED MILK FLOW METER

By

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A flow meter was constructed to measure the milk production of an individual cow. This unit was designed to be inserted in the milk hose between the milking unit and the pipeline. The flow meter used a floating needle valve to determine flow rate. The float was displaced over a distance proportional to the milk flow rate. A modified LVDT circuit was used to sense the position of the float and give a corresponding electronic indication of the flow rate. Digital circuits were used to totalize the cow's production.

Experimental results from the unit were not encouraging. The flow meter performed reasonably well in the laboratory but failed to give usable results in the milking parlor.


Approved William [signature]
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To "Ginny Lou"

ACKNOWLEDGMENTS

I would like to take this opportunity to thank all of those people who have given me support and counsel during my trip through the halls of academia. Special appreciation goes to Dr. Bill Bickert and to my wife, Jane, as these individuals have patiently endured the frequent delays and setbacks that have characterized my program.

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# INTRODUCTION

The history of mechanized milking has always been one of incremental improvements. Generally, no one individual has been responsible for more than a few of these improvements. Instead, those people involved with the dairy industry have contributed a concept here, a device there, until today it is possible to equip a milking parlor so that the operator only needs to wipe the cow's udder, inspect it, attach the milking machine, and disinfect the teats after milking. Automatic machinery does the rest: it opens and closes the parlor gates, sprays the udders with warm water, and removes the milking machine from each cow when her milk flow ceases. A parlor with this degree of mechanization was called a "semi-automatic milking parlor" by Bickert et al (1972).

There is one process, however, that is difficult to reliably automate at the present: weighing and recording the amount of milk that each cow produces. Under the present system of mechanized milking, each cow's milk production can be measured with either an accumulating weigh jar or an in-line milk-measuring meter. None of the devices that are available in either of these categories are capable of being completely automated and giving reliable results.

An improved instrument is needed that will automatically and reliably determine the amount of milk a cow has produced and present this information in a form that is compatible with electronic recording equipment. The construction of such an instrument was the goal of this research.

# OBJECTIVES

The overall objective of this research was to develop an instrument that would determine the individual milk output of a cow at each milking.

Criteria for the instrument were:

1. To meet DHIA standards for milk weight determination
2. To be compatible with the operation of currently-used milking systems
3. To be adaptable to clean-in-place operations
4. To be compatible with electronic data systems.

## LITERATURE REVIEW

Man's use of milk goes far back into our recorded history. References can be found in the Bible and in Egyptian hieroglyphics concerning the use of sheep and goats' milk. Man has also been keeping account of the amount of milk these animals produced and with the process of measurement in general. Leviticus 19:36 says: "just balances, just weights, . . . shall ye have." We can infer from this reference that the first method of measuring the milk production of an animal was probably a balance beam with established weights balancing a bucket or skin of milk. Irvin (1977) says that the balance beam was used as far back as 3000 B.C. in Egypt.

The balance beam continued to be the common method for weighing milk production until about A.D. 1700 when the spring scale was invented. Although the balance beam was theoretically capable of greater accuracy, the spring scale was easier and faster for the farmer to use than the balance beam. The less-accurate spring scale usually provided greater accuracy than the farmer needed.

The advent of machine milking initially brought few changes to this picture. Most of the first machines collected milk in a metal container over which a vacuum was drawn during milking. It was a simple matter to weigh the container both before and after the cow was milked. The introduction of the milk-conveying pipeline, however, complicated this procedure. Because the pipeline carried the milk directly to the bulk tank, it eliminated the metal container for accumulating the milk from each cow. Thus, there was no way to measure each individual cow's production.

This inherent limitation of pipeline systems led to the development of two basic types of accessories for pipeline systems to measure the milk production of each cow. The first type was called a weigh jar. Conceptually, this was the metal container of pre-pipeline systems in that it accumulated all of the milk that a cow produced during a milking in a large glass jar. A new twist, however, was that the scale on the side of the jar was calibrated in pounds rather than a volumetric unit. This feature enabled the immediate readout of the cow's milk production by the milker. A system of valves on the weigh jar was used to control the flow of milk and air into and out of the jar, enabling the milker to collect the milk from a cow, measure it, and then dump it into the pipeline and bulk tank with the rest of the milk.

The second type of accessory developed to measure milk production was the milk-measuring meter. These units were essentially continuous-flow devices that measured the flow of milk directly as it came from the cow without a significant amount of accumulation. They were either a count-incremental unit, such as a Te Sa Milk-O-Meter,* which counted the number of times a known volume was filled with milk, or a proportional-flow device, which divided the flow of milk by a large fixed ratio and accumulated the smaller portion in a calibrated container, as in the Babson Bros. Tru-Test Meter.

Both of these types of units had their drawbacks. The count-incremental units were well-suited to remove and/or digital readout techniques. It was only necessary to count the movements of the mechanical linkages inside the unit. These same mechanisms inside the unit, however, gave rise to reliability and cleaning problems. The damp, corrosive environment of the milking parlor has always created trouble with moving parts, seals, and electrical contacts. There were also some problems with flooding of the Milk-O-Meter under heavy milk-flow conditions. Nonetheless, these problems did not prevent three manufacturers from marketing count-incremental-type units with remote readout capabilities. One of these units, the Bou-Matic Milk Master, was part of a complete

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*Mention of commercial product names is intended only for purposes of illustration and clarification and does not constitute endorsement by the author or Michigan State University.

milk-production recording system that recently came onto the market.

The proportional-flow devices, on the other hand, had very few moving parts, mostly consisting of one or two valves that controlled milk flow. The internal structure of these units made them easier to clean than the count-incremental type, but the high temperature of the cleaning solutions sometimes caused distortion. Another drawback was the difficulty in adapting meters which used this principle of operation to remote and/or digital readout. There was no reliable method on the market of doing this. Even so, proportional-flow meters have been popular with many farmers.

The primary goal of both types of milk-measuring meters described above was the accurate measurement of a cow's milk production. The need for this accurate measurement stems, for the most part, from the existence of the Dairy Herd Improvement Association (DHIA). This group is responsible for fostering the improvement of dairy herds through the maintenance of production and breeding records on all cows in a herd involved in the program. To insure some degree of control over the production data going into these records, DHIA established standards governing the accuracy and repeatability of all devices that were to be used to measure milk production. These standards were found in a document by

DHIA (1974) containing the regulations and specifications for all facets of the record-keeping process.

The above standards established by DHIA for milk-production measurement break down into specifications for random errors in milk weight, bias in sampling, and average accuracy. The random error standard says that the errors in individual weighings must be normally distributed and that 95% of them must be within ±4.1% of the true mean. The percentage magnitude of the allowable error is controlled to some extent by the specifications for the amount of bias which is consistently overweighing on some cows and underweighing on others. The ±4.1% maximum allowable error is for a bias of 25%, but the error can be as high as ±10% when the bias is 0%. The maximum allowable bias is 25% and it is defined as the square of the correlation between errors, expressed as percentages of the true weight, in two milkings of the same cow (DHIA, 1974). DHIA also specifies that 95% of the test-group averages must differ from the true mean by no more than 1.4% where a test-group average is the mean performance of a single device at one milking on a single milking system. When the above specifications for random error, bias, and accuracy are considered together, they clearly define the performance level required from all DHIA-approved milk-production measuring meters.

During the course of this research, one meter has become available that meets all of the criteria for the approval of DHIA; this approval is pending. One would suppose that competing manufacturers are engaged in research on similar meters, but accessibility to such research tends to be very limited. This, combined with the fact that the author knows of no one else in the public sector engaged in similar research, makes ascertaining the current state of the art difficult.

## DESCRIPTION OF OPERATION

In describing the operation of the improved milk flow meter, an examination of the problems involved is in order.

The milk leaving a milking claw generally flows in an irregular fashion that can be characterized as a pulsating two-phase flow. The pulsations arise from the fact that the milk is propelled through the hoses by vacuum, but only when enough milk collects in a low spot in the milk hose to fill the cross-sectional area of the hose completely, thereby creating a "slug" for the vacuum pumps to work against. This slug is accelerated rapidly until it reaches an area where the pressure differential which has been created across it can be released. This can be in a pipeline, a weigh jar, or a milk meter. As a result, a given point in a milk hose can be full, partially full, or empty at any given time. This pulsating two-phase flow makes it difficult to apply any of the industrial flowmeters on the market, as almost all of them require a single-phase flow for proper operation.

In addition to the problem of the two-phase flow, the physical properties of milk make it quite susceptible to foaming. Foaming will generally occur anywhere that fluid milk is agitated, either by air or by more milk. Unfortunately, situations where milk foaming occurs are hard to avoid. First of all, almost all milking claws are designed with an air bleed hole to allow the moving of the milk towards the vacuum pumps by air pressure. Under heavy milk flow conditions, this air bleed is covered by fluid milk, thus creating foam as air enters the hole and bubbles through the milk. The second problem occurs a little further down the line, whenever the milk line enters a weigh jar or milk meter. If the connection is made perpendicular to the side of the vessel, the entering milk stream will impact either the vessel walls or the milk collected inside. This turbulence will create large amounts of foam that has a long persistence time. The remedy for this is to introduce the milk hose connection in such a manner that the connection is tangential to the vessel's inner diameter. If this is done, the stream will adhere to the walls of the vessel and be conducted to the surface of the milk below with less foaming.

Accumulating the milk in a container having such a tangential milk inlet reduces somewhat the problems of two-phase flow and foaming. This means the milk can be collected for measuring without causing any interference to the flow of air through the system, as the air can pass out of the vessel without bubbling through the milk.

The question that immediately arises, however, is how much to accumulate? The accumulation could conceivably range from a few ounces to a cow's entire production at that milking. It was felt that a better milk-measuring meter would result if the accumulation were kept as small as feasible, reducing the bulkiness and related fragileness that have been drawbacks of the weighjar. With this in mind, it was decided to try to restrict the size of the meter to about 2 liters of internal volume, with a maximum milk accumulation of about 1/3 liter. This size was arrived at in an arbitrary manner and was subject to change.

Once the milk was accumulated, however, it was necessary to get it out and to somehow measure the amount of milk that left the vessel. In the early part of this research, ideas were considered whereby some sort of valve would be used to control the flow out of the vessel, with the valve being controlled by conductive probes or a float switch sensing the milk level. Due to problems with valve sealing and cleaning, this approach was abandoned.

The next idea was to try to adapt some sort of continuous flow device to measure the output from the accumulation vessel. An obvious candidate for this device was a rotameter. This unit gives a continuous visual output that varies with flowrate, and it was felt that it would be possible to sense the position of the float in the rotameter by some electronic means of transduction.

One serious drawback to the rotameter existed, however; that was the fact that a rotameter must be oriented so that the flow being measured travels vertically upward. No way could be found to conveniently direct the flow of milk in that direction and still maintain compatibility with present milking systems. It was felt that severe problems would be encountered with milk flow reversal in the rotameter under certain conditions. Since a rotameter cannot handle flow in a reverse direction, errors of multiple-counting and high total readings could result. There also would have been problems with maintaining a single-phase flow up through the rotameter during periods of fluctuating low output. These problems made the rotameter unusable.

The idea, however, of some sort of float which would change position with increasing or decreasing flow was felt to be worthy of further investigation. It was hoped that the fewer moving parts offered by such a device would result in improved reliability and easier cleaning. To achieve this goal would require that the basic upward-flowing rotameter be transformed into a device which operated in a downward-flowing mode. Further examination of the rotameter revealed that the constant factors on which the device could be calibrated were the weight of the indicator ball and the specific gravity of the fluid under measure. If an empirical calibration was satisfactory for an application, the weight of the indicator ball could be the determining factor.

Therefore, to turn a rotameter-like device around to operate in a downward-flowing mode, it would be necessary to make some function other than the weight of the indicator ball dependent on gravity. In other words, a new constant had to be introduced into the rotameter. It was felt that this would possibly be an application for the electrodeless conductivity cell used by Gerrish (1970). This cell was used to determine whether the milk flow rate of a cow was over .05 pounds/minute or not. It accomplished this by use of an orifice in the milk line which would pass 0.5 pounds/minute under gravity flow conditions and a bypass line around the orifice which relieved any differential air pressure and any milk in excess of 0.5 pounds per minute. The critical concept gleaned from the electrodeless conductivity cell was that a gravity-based, constant flow across an orifice in a milking system could be achieved by use of a vacuum bypass line around that orifice. Equally important was the realization that the bypass in the milk-measuring meter under consideration must pass only air and not milk. Any milk which did not pass through the orifice could not be measured and would therefore affect the accuracy of the meter. These two concepts established gravity-induced liquid flow as the standard phenomenon around which the meter would operate. This phenomenon would not predict the flow through the orifice, but would ensure that vacuum fluctuations within the meter or within the entire milking system would not disturb the flow across the orifice.

Once the concepts were established concerning the flow of milk through the orifice, all that remained was to measure that flow. The main thrust of the research at this point was to find a simple method of producing an analog electrical signal that varied proportionally with the flow rate through the orifice. Many ideas were tried, some of which attempted to generate an electrical signal without an intermediate mechanical step, and some of which used the motion of a mechanical part of the meter to generate a signal when the milk flow affected the mechanical part.

At some point during this process, the idea came about to use a tapered float which rested in the orifice under no-flow conditions, thereby closing off the orifice. It was hoped that the float would rise out of the orifice as sufficient milk accumulated around it to float it. It was also hoped that as the flow rate increased, the float would rise higher out of the orifice. If in fact these things did prove true, it would seem possible to measure the flow rate through the orifice by the vertical displacement of the float.

Some preliminary test models were made, and a configuration was found which worked satisfactorily. The larger diameter of the tapered portion of the float rested in the orifice under no-flow conditions, and the float would rise up with increasing flow, so that increasingly smaller diameters of the float were in the orifice. This had the effect of making the orifice larger. A point would soon be reached where the flow coming into the milk-measuring meter was equaled by the flow going out of the orifice. The position of the float would then stabilize until the flow rate into the milk-measuring meter changed, upsetting the equilibrium established by the float and causing the float to move to a new position of equilibrium.

These preliminary tests of the unit raised some important questions. First of all, did this unit have a unique position of the float for every incremental change in flow rate? If so, how small an increment of flow could the milk-measuring meter resolve? Another important question was whether the displacement of the float varied linearily with respect to the change in flow rate. Put another way, were the flow rate and float displacement related by a function such that a=bx, where a is the change in flow rate and b is the change in displacement?

The preliminary answer to the first question was arrived at qualitatively. Observation of the milk-measuring meter in the laboratory under varying flow rates indicated that a unique displacement of the float did exist for any given flow rate as long as the flow rate did not exceed the maximum capacity of the meter. The final answer to this question would be obtained when rigorous calibrations were undertaken. Calibration was also the only method by which to answer the question of whether the milk-measuring meter would act in a linear fashion. An attempt was made to find a group of equations which would predict the performance of this valve, but the attempt met with little success. Most of the available work on flow prediction in control valves is very theoretical and requires many assumptions. Even the manufacturer's published predictions are sometimes very inaccurate. Moore (1971), in speaking about this deviation, states that "this deviation can be as much as 40%. Thus the precise mathematical formulation of the optimum characteristics is not only prohibitive in terms of complexity, but is also futile unless the actual characteristic is known." With this advice in mind, it was felt that the time necessary to select and evaluate a predictive equation would be better spent by actually calibrating the unit.

Before the milk-measuring meter could be built, however, some method had to be found to transform the mechanical motion of the float into an analog electronic signal. The first criterion for this electronic interface was sufficient resolution. Since it would eventually be desirable to digitize the output of the meter, common sense decreed that the analog electronics should be able to resolve a change in flow rate ten times smaller than the smallest digitizing increment. The second criterion, while not absolutely essential, was certainly quite desirable: non-contact sensing. This would function without any electrical contact with the milk being measured. Non-contact sensing would eliminate problems with changing calibration due to a build-up of contaminants and milk film on the conducting surfaces.

The criteria just summarized would seem to point to some sort of electro-magnetic coupling. Several types of circuits were tested, all of which employed a passive element in the float which changed the inductance of a stationary concentric coil as the float traveled up and down within the coil. The circuit finally decided upon was a Linear Variable Displacement Transformer (LVDT). Herceg (1972) defines the LVDT:

> Two identical secondaries, symmetrically spaced from the primary, are connected externally in a series-opposing circuit. Motion of the non-contacting magnetic core varies the mutual inductance of each secondary to the primary, which determines the voltage induced from the primary to each secondary.

It was felt that this circuit would offer the best results and would be the least troublesome to implement. Also, as Herceg reports (1972), the LVDT has a linear transfer function, meaning that the output of the circuit is proportional to the movement of the passive element. Finally, the LVDT can be conditioned to produce as its output a varying DC voltage, highly suited to digitization if desired.

Once all of the foregoing concepts were established, a working model was constructed. Several iterations incorporating minor changes were gone through before a configuration was arrived at which was felt to work reasonably well. The mechanical layout of this meter, shown in Figure 1, consists of basically three parts. These are the vacuum vessel, the receiver compartment-float cup assembly, and the float itself. The vacuum vessel is large enough to contain the receiver compartment-float cup assembly and still allow free air circulation around the assembly. It, like almost all other parts in the prototype model, is made of an acrylic plastic. Two hose connections are made to the vacuum vessel, milk inlet and milk outlet.

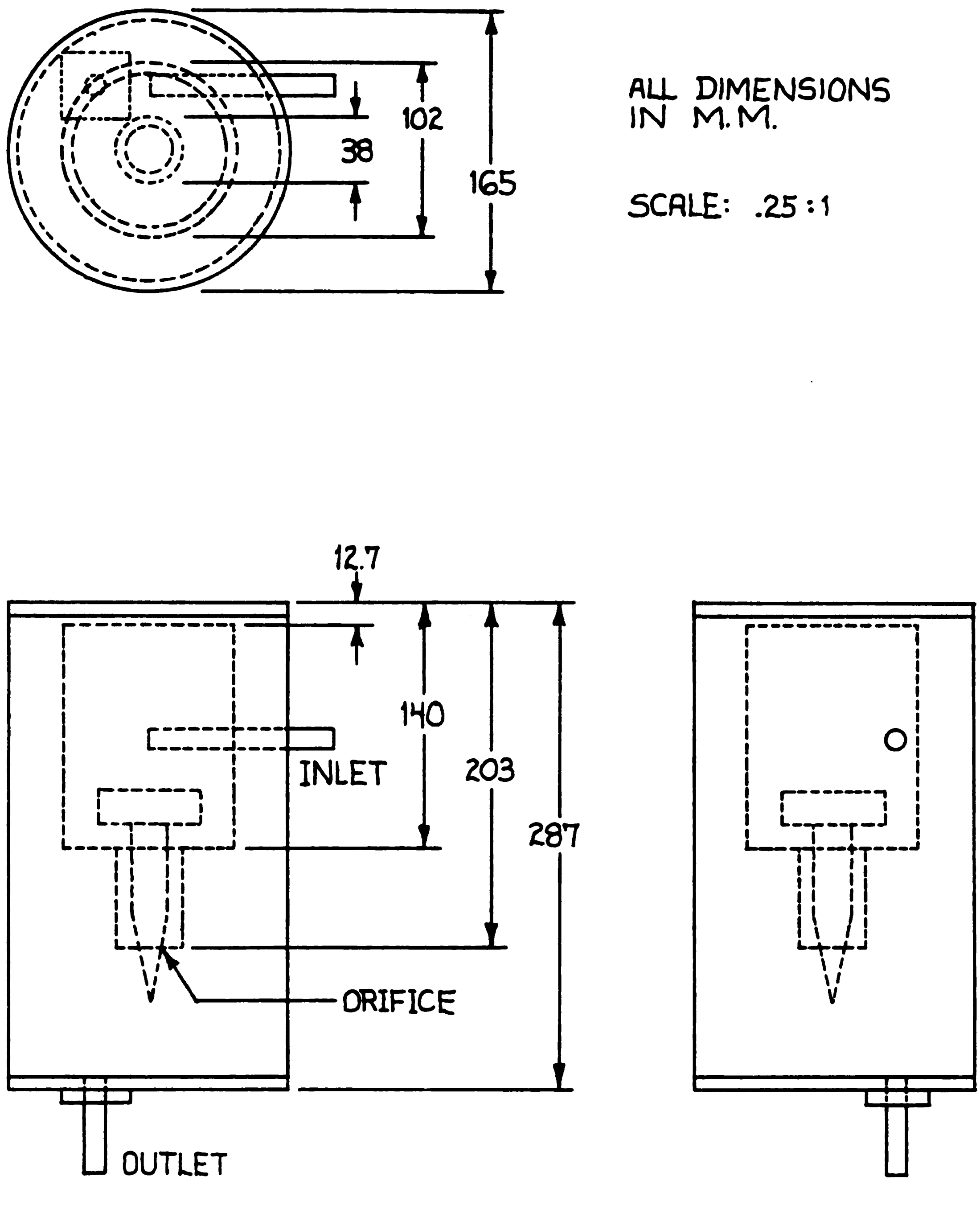


Figure 1.--Overall Mechanical Layout.

The receiver compartment-float cup assembly is supported in the center of the vacuum vessel to insure that the pressure differential across the receiver compartment-float cup assembly, which contains the orifice, is as close to zero as possible. This zero pressure differential will give gravity flow across the orifice, as was discussed earlier. The receiver compartment uses the tangential inlet that has been shown necessary to minimize the amount of milk foam created in the vessel. The top part of the float rides in this compartment. The float cup is attached to the bottom of the receiver compartment and is the supporting structure for the LVDT coils and the orifice plate. The orifice is machined with a 90° contour and a diameter of 22 mm. The LVDT coils are three coils of copper wire wound on the outside of the float cup to facilitate electro-magnetic coupling to the float. The coils are wound with AWG 36 copper wire and are 35 mm apart center-to-center. Each of the coils are wound with 200 turns in a multi-layer random pattern.

The float is constructed of machined acrylic plastic. Detailed dimensions are given in Figure 2. An early version attempted to use a float which had a total diameter equal to the largest diameter of the tapered section. This version had insufficient bouyancy to lift itself properly, hence the development of the "mushroom"

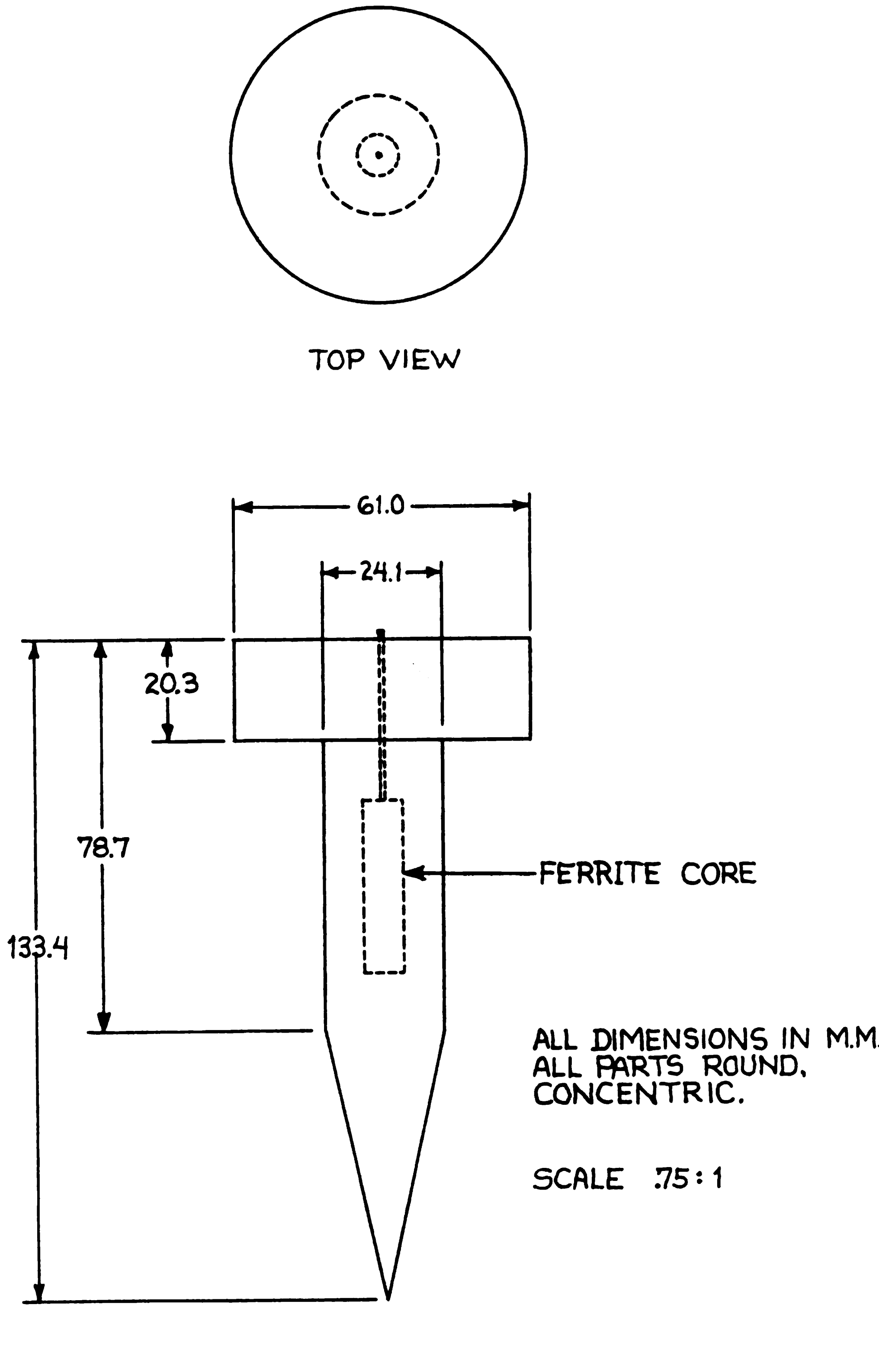


Figure 2.--Float Detail.

upper section. The tapered section of the float measures 51 mm by 24 mm, giving a taper of 14.5 degrees. The float contains a slug of powdered iron which functions to vary the inductive coupling between the three transducer coils. This slug is attached axially to a small threaded rod, which extends through the top of the float. The rod permits vertical adjustment of the position of the slug in relationship to the float and the transducer coils.

In action, the float and all of its supporting structures work in a very straightforward manner. Milk enters the receiver compartment through the tangential inlet. It accumulates in the float cup and the receiver compartment. As the level of milk rises, the float also rises, retracting the tapered portion of the float and opening the orifice. The level of milk will continue to rise until the orifice is large enough to handle the entire flow through the unit at that time. The vertical displacement of the float therefore is proportional to the flow rate of milk through the meter. This displacement is sensed by the transducer coils and the attendant electronic circuitry, which produces a DC output signal proportional to the flow rate through the meter.

A block diagram of the electronic circuitry in the milk-measuring meter is shown in Figure 3. The LVDT circuit as used in this meter is an unusual adaptation

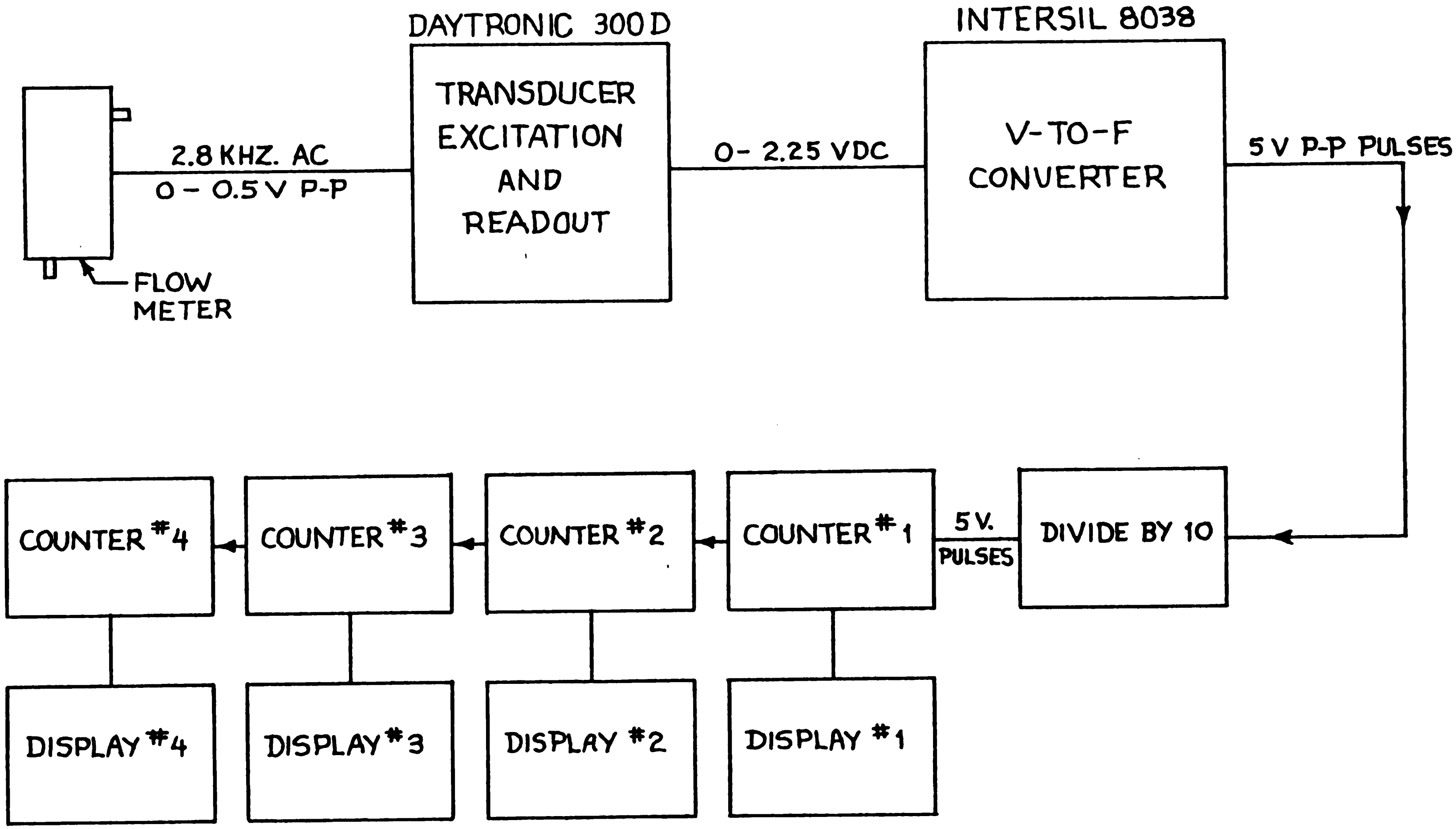


Figure 3.--Block Diagram of Electronics.

of a common concept. The LVDT is a widely used device in industry, being an excellent means of measuring straight-line mechanical displacements with a high degree of accuracy. It is unusual, however, for an LVDT to have both as large an inside diameter and as long a stroke as this unit has. The expanded dimensions of the coils in the meter were chosen to allow sufficient room around the float for milk flow. A Daytronic 300D Measurement Amplifier was used as both an excitation and readout unit for the milk meter. It drives the center coil at 2.8 kHz and also functions as a phase-sensitive AC voltmeter to tell the distance and direction the core is from the null (center) position. This information is available both from a front panel meter and as a 0 - ±10 VDC output signal, with 0.0 VDC corresponding to null position. An important note, however, is that the milk meter as constructed will use only one-half of the available displacement range, specifically only one direction from the null point. This will avoid any possible crossover distortion and slope change of the output curve due to non-symmetry of the coils themselves.

Once the DC signal corresponding to flow rate is obtained, the next step is to convert the signal into a form that can be easily preserved. Since the goal of the improved milk flow meter is to provide a readout of the amount of milk produced, it was decided to integrate the signal over time and convert it to digital form for counting. To accomplish this, an Intersil 8038 voltage-to-frequency conversion IC is used. This circuit uses a variable current source to linearily charge and discharge a timing capacitor at a rate proportional to the flow rate. A 8038 "squares up" the charge and discharge curve of the capacitor with a comparator circuit, giving an output which consists of a stream of 5V square waves whose frequency is proportional to the flow rate. These pulses, which are at digital logic levels, are then fed to a series of decade counters and light-emiting diode (LED) displays which have a total capacity of 9999 counts. This readout is not necessarily tied to any measurement unit but can be calibrated for any reasonable unit by manipulation of the voltage-to-frequency conversion process.

# CALIBRATION AND TESTING

The task of calibrating the improved milk flow meter was approached with two objectives in mind. The first was to prove that the meter operated in a linear fashion, giving a constant change in output level for a unit change in flow rate. The second objective was to determine exactly what the calibration curve was and to adjust the readout circuitry to reflect this curve.

Water was used in this calibration process instead of milk. It had no noticeable effect on the accuracy of the meter as opposed to the use of milk. The specific gravity of milk is 1.030-1.035 and the viscosity of milk is 2.0 centipoise (Jenness, et al., 1965). These figures closely approximate those of water, eliminating the need for any artificial milk formulations, etc., for early development work in this or similar environments. Water also has the advantage that it does not spoil or otherwise make life difficult for those using it.

The calibration of the meter itself and its associated analog readout was accomplished by use of a constant-head water-flow apparatus to smooth out fluctuations in water line pressure, and a stainless steel milk line valve (plug type) to control the flow into the meter. This apparatus was capable of flow rates in excess of 15 kilograms/minute, and as low as 5 grams/minute. The flow rate was adjusted until the readout was at an 0.25 V interval over a 0.0-2.25 V range. A stopwatch was used at each of these settings to measure the time required to fill a test container. This container was weighed before testing to determine the net mass of water it would hold. Dividing this known mass by the filling time in seconds, and then multiplying it by 60, gave the mass flow rate in kilograms/minute. The data obtained in this manner are shown in Appendix B. Simple regression analysis was applied to four replications of this test to produce the calibration curve shown in Figure 4. The coefficient of correlation of this curve gives an indication of the good linearity of the analog portion of the sensor under steady-state calibration conditions.

The calibration of the voltage-frequency conversion section and the counting section was less difficult than the calibration of the analog section. The flow rates developed during the analog calibration were used to compute a corresponding frequency for each flow rate. The voltage-frequency converter was fed voltages at 0.25 V increments and adjusted for the corresponding frequencies. The linearity of the voltage-frequency

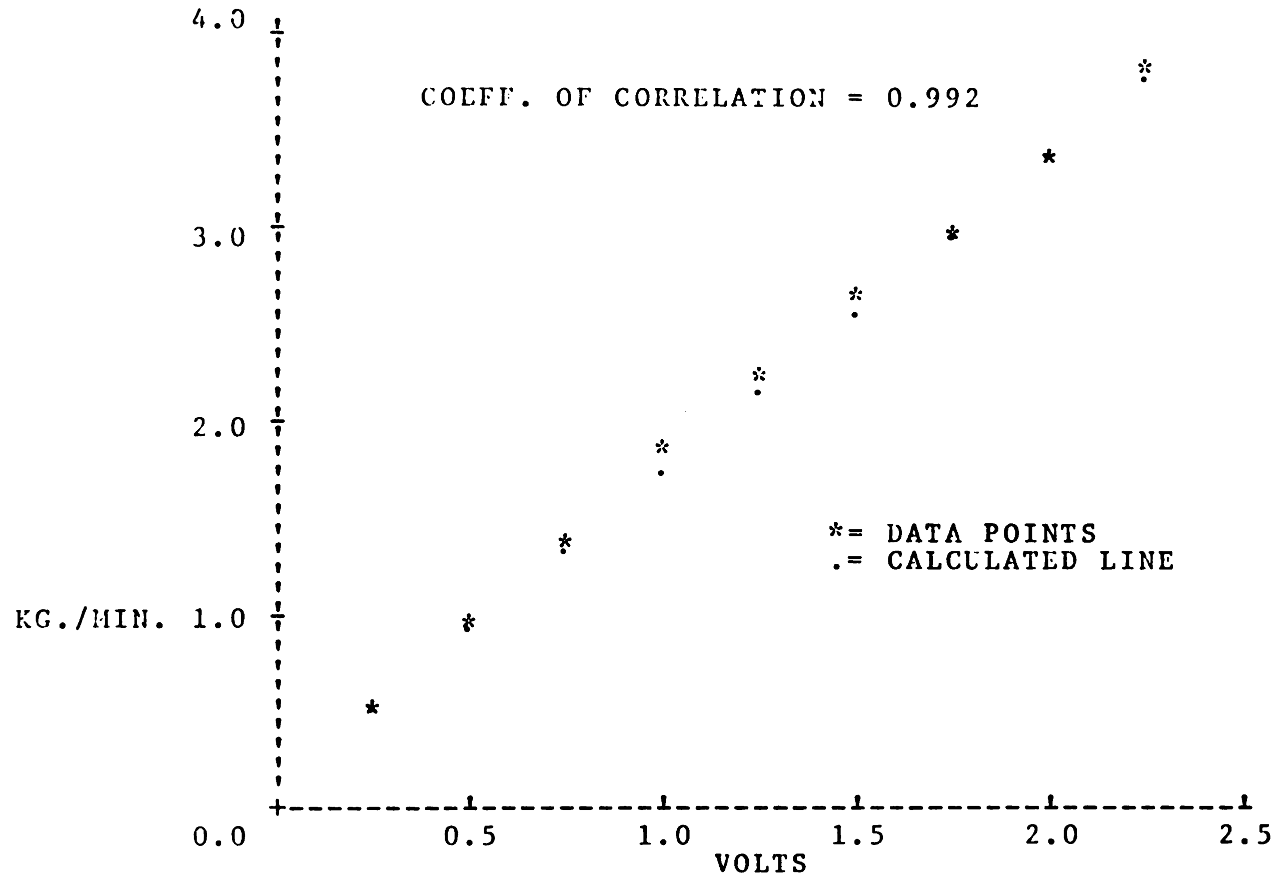


Figure 4.--Calibration Curve.

converter was accepted at the worst-case factory specifications of 2.0%. The counter section was checked for accuracy by feeding it a known number of pulses and verifying the count.

The first testing of the milk meter was done in the laboratory. A total of 0.64 kg. of water was poured through the meter at both slow (1.0 kg./min.) and fast (2.5-3.0 kg./min.) rates. The data from this test are shown in Appendix C.

The true test of the milk meter, however, came in the milking parlor. The pulsating, two-phase flow described earlier is very difficult to produce in the laboratory, thus making parlor testing a necessity. Parlor testing is usually not a desirable situation for a prototype instrument, however, as the parlor is a hostile physical and electronic environment. The large amounts of water, the electrical noise from vacuum pumps and other devices powered by electric motors, and other related problems can induce errors in any circuits that are not thoroughly shielded. Extensive efforts were made to establish solid ground paths and as much shielding as possible.

The parlor tests were conducted using a DHIA-approved weigh jar as a control. The weight was read from the jar in pounds and converted to kilograms to allow comparison to the meter reading. These data can be found in Appendix C.

## ANALYSIS AND DISCUSSION OF RESULTS

The data collected from the laboratory testing consisted of ten repetitions from each of two tests. Each of these repetitions was compared to the expected value for the test and to the other nine replications in the test. To perform this comparison, the sample mean and the standard deviation of the sample for both of the tests were computed.

The results of these computations showed that the slow rate test had a mean of 0.58 kg. and a std. deviation of 0.04 kg. The fast rate test showed a mean of 0.66 kg. and a std. deviation of 0.03 kg. These results, when compared to the expected value of 0.64 kg., show that under laboratory conditions the flow meter has reasonable repeatability, but with some degree of non-linearity. The data collected from the parlor testing, however, were not as positive as that collected in the laboratory. These data consisted of 39 samples of paired data, with each pair consisting of a weigh jar reading expressed in kilograms and a flow meter reading in kilograms. Each of the flow meter readings was compared to its related weigh jar reading, and then all of the pairs of readings were related to each other. The statistical measure chosen as most appropriate for this test was the coefficient of correlation. It was chosen because of its ability to handle two random variables at once, in this case the flow meter readings and the weigh jar readings. The ideal results of this test would have shown that these two random variables had a position correlation coefficient of 1.00. If these results were plotted, they would lie in a straight line running at 45° to the axes. The results that were obtained, however, are shown in Figure 5. Obviously, they do not lie in a straight line. When the correlation coefficient of these data points was computed, it was found to be 0.128. It is very plain after examination of these results that the flow rate readings have very little relationship to the actual weigh jar readings.

A search for reasons which explained why the flow meter does not work satisfactorily was only partially successful. The fact that the flow meter performs reasonably well in the laboratory under both steady-state and intermittent flow conditions leads one to consider problems found only in the milking system as possible reasons for the malfunctioning of the flow meter. One phenomena which was observed during parlor testing was that foam sometimes collected

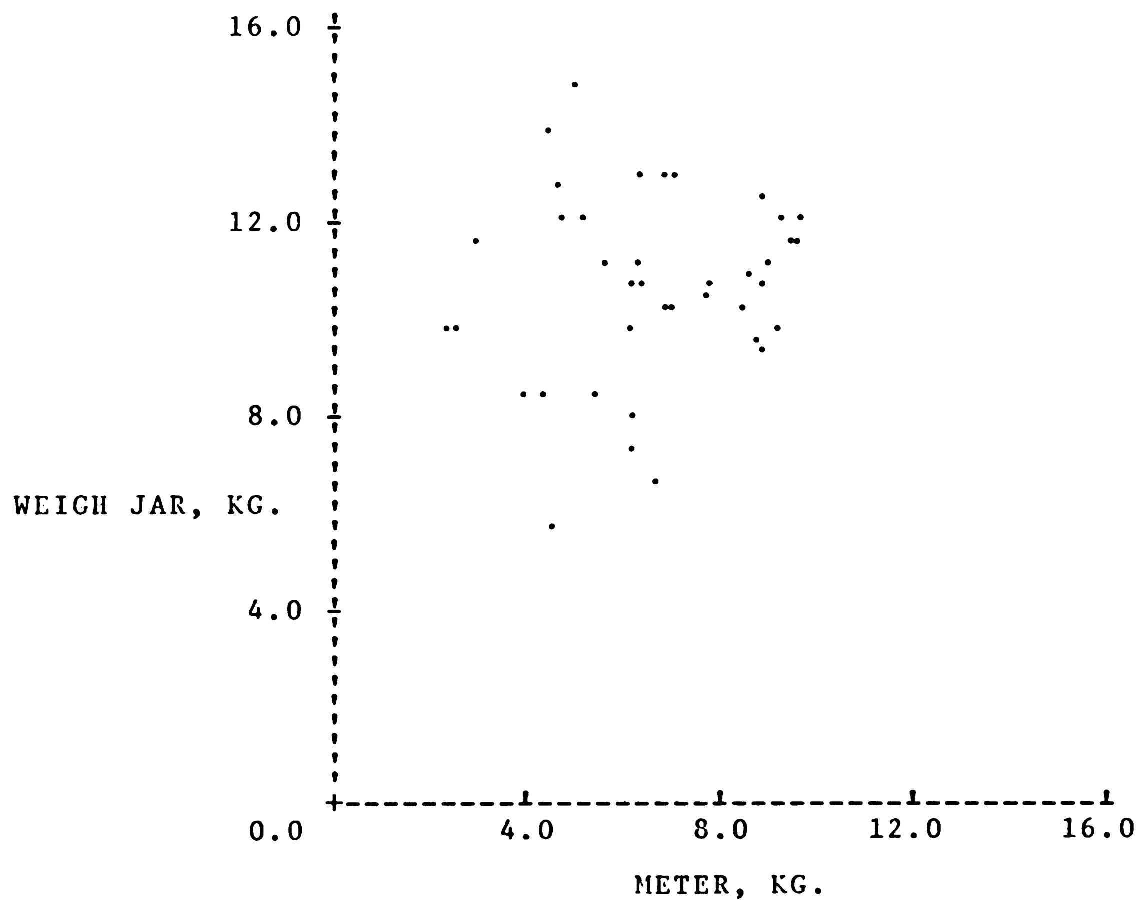


Figure 5.--Flow Meter Testing Data.

under the "mushroom" top of the float. This lowered the bouyancy of the float and allowed it to "hang up" in the float cup. The flow meter would then cease to record flow until after the cow being milked was finished, when the float cup would slowly drain out and free the float.

Other possible reasons for malfunction of the flow meter could include vacuum fluctuations both in the milking system and in the flow meter itself, air entrained in the fluid milk, or impaired frequency response of the float to milk flow transients.

## CONCLUSIONS

1. The flow meter does not meet DHIA standards for total milk weight. The correlation coefficient between the actual milk weight and the weight recorded by the flow meter does not fall within the range established in the DHIA specifications.

2. The flow meter is compatible with the operation of all currently-manufactured pipeline milking systems. It does not introduce vacuum fluctuations or disruptions into the milking system. Also, the flow meter is designed to handle the pulsating flow caused by loops and sags in the milk hose.

3. The flow meter is adaptable to clean-in-place operations. Some method will have to be found to spray both the walls of the vacuum vessel and the inside of the receiver compartment, but this is within the scope of present day clean-in-place systems.

4. The flow meter is compatible with electronic data recording systems. The data stored in the counter units can be latched out to external circuits which will interface it to the data recording circuits.

## RECOMMENDATIONS FOR FUTURE RESEARCH

Work remains to be done on the configuration of the receiver compartment-float cup assembly. It will probably be necessary to increase the volume of the receiver compartment by a factor of 3 or 4. It appears to be important to allow sufficient room for the milk stream to dissipate its kinetic energy after entering the compartment.

Accuracy of the electronics could be improved by the addition of an 8-bit microprocessor and an 8-bit A-D converter to replace the "charge-pump" integrated circuit with its capacitor leakage, and the discrete-chip counter section. The addition of the microprocessor would also greatly expand the potential usefulness of this meter in the parlor for controlling a cow's detacher, feed bowl cover, washer spray, recording her ID, etc. This will truly make it part of a system, rather than just an instrument.

APPENDICES

# APPENDIX A

# SCHEMATIC DIAGRAM OF ELECTRONICS

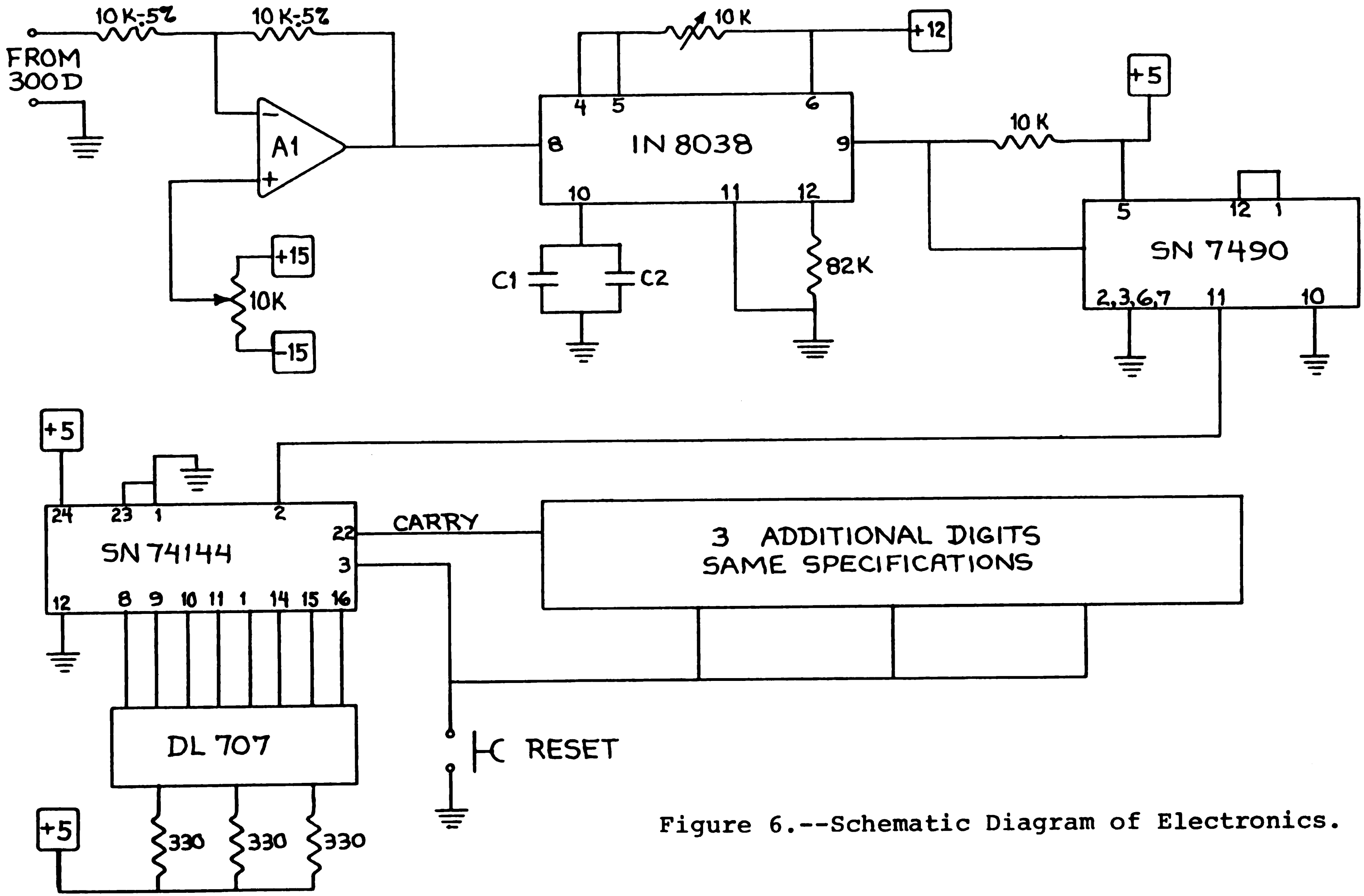


Figure 6.--Schematic Diagram of Electronics.

# APPENDIX B

# CALIBRATION DATA

TABLE 1.--Calibration Data.

| Output Volts | | Seconds | | | |
|---|---|---|---|---|---|
| Run # | 1 | 2 | 3 | 4 | 5 |
| 0.25 | 72.0 | 72.0 | 84.5 | 73.5 | 75.5 |
| 0.50 | 39.0 | 41.0 | 42.0 | 40.0 | 40.5 |
| 0.75 | 27.0 | 29.0 | 29.0 | 27.5 | 28.2 |
| 1.00 | 20.0 | 21.0 | 21.5 | 20.5 | 20.8 |
| 1.25 | 17.0 | 17.5 | 17.5 | 17.0 | 17.3 |
| 1.50 | 14.5 | 15.0 | 15.0 | 14.0 | 14.6 |
| 1.75 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| 2.00 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 |
| 2.25 | 10.0 | 10.0 | 10.5 | 10.0 | 10.1 |

Net calibration mass: 638 gm.

APPENDIX C

TESTING DATA

TABLE 2.--Laboratory Testing Data.

| Test No. | Slow Rate (1 kg./min.) | Fast Rate (2.5-3.0 kg./min.) |
|---|---|---|
| 1 | 0.63 | 0.70 |
| 2 | 0.64 | 0.70 |
| 3 | 0.56 | 0.65 |
| 4 | 0.58 | 0.68 |
| 5 | 0.59 | 0.65 |
| 6 | 0.59 | 0.61 |
| 7 | 0.59 | 0.69 |
| 8 | 0.59 | 0.63 |
| 9 | 0.53 | 0.68 |
| 10 | 0.54 | 0.64 |

Net mass: 0.64 kg.

TABLE 3.--Parlor Testing Data.

| Weigh Jar, Kg. | Flow Meter, Kg. |
|---|---|
| 13.15 | 6.37 |
| 14.06 | 4.50 |
| 9.98 | 2.38 |
| 10.43 | 8.48 |
| 11.34 | 5.66 |
| 11.79 | 2.98 |
| 12.70 | 8.91 |
| 10.43 | 7.01 |
| 11.79 | 9.60 |
| 10.78 | 8.88 |
| 9.75 | 8.78 |
| 8.16 | 6.22 |
| 12.25 | 9.29 |
| 12.93 | 4.69 |
| 5.90 | 4.58 |
| 6.80 | 6.71 |
| 8.62 | 4.36 |
| 11.11 | 8.63 |
| 9.98 | 2.57 |
| 13.15 | 7.09 |
| 11.79 | 9.50 |
| 10.43 | 6.89 |
| 11.34 | 6.32 |
| 11.34 | 9.02 |
| 8.62 | 5.46 |
| 9.98 | 6.18 |
| 9.53 | 8.91 |
| 10.66 | 7.75 |
| 10.89 | 6.42 |
| 8.62 | 3.98 |
| 9.98 | 9.23 |
| 13.15 | 6.91 |
| 10.89 | 7.83 |
| 12.25 | 9.71 |
| 14.97 | 5.07 |
| 12.25 | 4.79 |
| 10.78 | 6.20 |
| 12.25 | 5.20 |
| 7.48 | 6.21 |

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