

VOLUMETRIC GAS METER DESIGN

by

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TABLE OF CONTENTS

INTRODUCTION	3
GENERAL DISCUSSION	5
EFFECT OF LENGTH OF TANGENT ON DISPLACEMENT	16
DERIVATION OF FORMULA FOR CALCULATING LINKAGES	20
APPLICATION OF THE FORMULA	25
CALCULATIONS	31
CONCLUSIONS	37

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INTRODUCTION:

In the early days of the Gas Industry there were no meters with which to measure the commodity sold. Gas was furnished to customers through pipes and burners of a given size. The consumption through burners was estimated and charged for at a rate for use from sunset to a specified time, up to midnight. The rate was for a stipulated number of burners. An inspector made the rounds, at certain hours of the night, to see that the lights were put out according to contract. When lights were found burning beyond the hour set, the inspector notified the household. If the notice was disregarded, he closed a tap attached to the service pipe in the street.

In 1815, Samuel Clegg invented a gas meter, but its adoption was strenuously opposed for a long time, even by the gas companies.

The actual selling of gas by volumetric measurement originated with the Chartered Gas Light Company of London. In 1840, the directors ordered metering of the gas to the exclusion of the contract system.

As the use of the meter became general, the practice of charging for the gas in direct proportion to the volume used, as shown by the meter, became universal.

The customers of the pioneering lighting companies in America were at first charged for the amount of gas used by the hour. With the introduction of the gas meter the necessity for the hourly method of charging went out of vogue.

At first the meters were rated for capacity according to the number of lights they would supply; for example, there were meters for as low as 3 lights, and up to 100 lights. It was early agreed that one light would be equal to six cubic feet per hour. This was done to simplify the capacity ratings of meters of various sizes. This method of rating is still being used to a certain extent but the capacities of the meters have been materially increased for a given number of lights due to the new designs. At the present time a definite relationship does not exist between the number of lights and the capacity of the meters.

Gas meters have been manufactured for about a century. The original patents on the dry meter were obtained by Richards, who was in the services of the Chartered Company, in 1844. A little later the meter was made a commercial

success by Thomas Glover, who introduced tanned leather diaphragms and a square case instead of the cylindrical one used by Richards.

GENERAL DISCUSSION:

This thesis deals only with the dry volumetric gas meters. There has been no radical change in the design of dry gas meters since their invention.

A gas meter is an engine which automatically measures the volume of gas which passes through it. It is therefore essential that the mechanical efficiency of this engine remain constant throughout its entire range of load.

The main working parts of a meter consist of; (1) valves, (2) diaphragms, and (3) connecting mechanisms. It is desired to show in this thesis; with the valves, valve links, and diaphragms coordinated as perfectly as possible that there are definite mathematical relationships existing between the connecting links.

Plate I shows a skeleton frame and working parts of a four-chamber gas meter. It also shows how the mechanisms are coordinated and fastened together to make a complete unit. The long perpendicular shafts at the back of the meter are the flag staffs. A bracket is rigidly mounted on

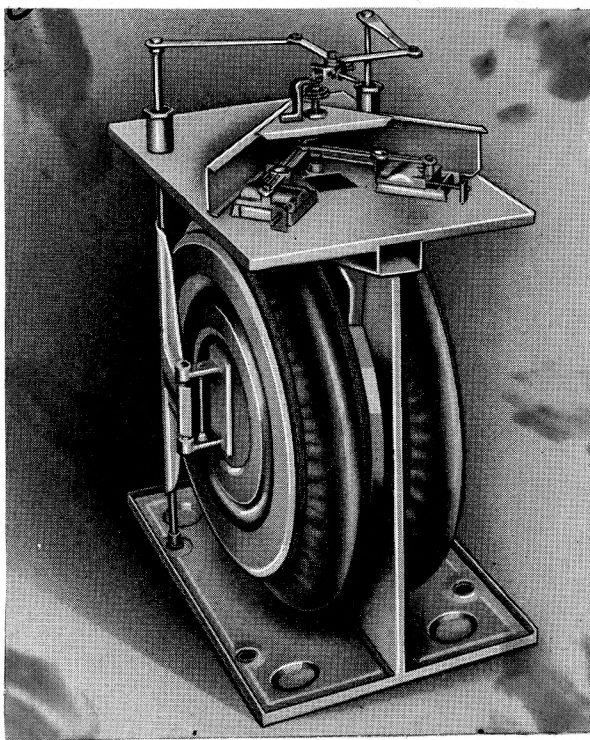
each flag staff, which in turn carries the diaphragm bracket, and this diaphragm bracket in turn carries the diaphragm in its forward and backward motion in its respective compartment. Each compartment below the table, above which are located the linkages and valve mechanisms, is composed of two chambers. The flag staff runs through a stuffing box in the table to the upper compartment called a gallery. The long flag arm connects the top of the flag staff to the short arm. The short flag arm connects the long flag arm to the tangent. There are two short flag arms and two long flag arms but there is only one tangent. The flag arms are sometimes called links or linkages. The tangent is the short adjustable link mounted on top of the crank shaft, rotating about it, which is threaded on the rotating end and carries the adjustment button. The adjustment button is fixed on the tangent by means of two lock nuts. The adjustment button location determines the displacement of the diaphragms, and by moving this button in or out on the tangent, by means of the lock nuts, the meter is brought into proof, which means that the meter then records the correct number of cubic feet on its index for the volume which has passed through the meter. There

is only one crank and crank shaft. Two valve links are connected to the one crank and they drive the valves by means of valve guides, in a reciprocating motion across the valve seats, which are set at 90 degrees from each other so that the valves will function each 90-degree turn of the crank shaft.

If each chamber admits and exhausts the same amount of gas every time the respective valves open and close, the volume of gas passing through the meter in one revolution is easily calculated by multiplying the cubic feet displaced in one chamber by the number of chambers. Then it may be determined how many revolutions are required for one cubic foot, therefore, a train of gears may be designed so that the revolutions of the meter are recorded on an index calibrated in cubic feet.

The diaphragms have a double duty; (1) that of propelling the meter, and (2) the displacement of the correct amount of gas. The valves also have two duties to perform; (1) they must control the time at which gas is admitted and exhausted to keep the meter in operation, and in doing this, (2) they must control the amount of gas passed. The valves and diaphragms must be properly coordinated in order to obtain a perfect meter.

PLATE I



SKELETON FRAME AND WORKING PARTS
OF A FOUR CHAMBER GAS METER

Plate II shows the relative positions of the linkages when the diaphragms are in their extreme travel positions. They connect the diaphragms to one common crank. The legend of Plate II explains the drawing by naming the linkages with the exception of a few details. Points A and B are the locations where the flag staffs go through the table. The long flag arms AF and BF', are nearly perpendicular to each other. The outlines of the valves were omitted for simplicity as they are the ordinary D-slide type and have a small lap of a few thousandths of an inch on each edge. The design and timing of the valves is a separate problem in itself in the design of a gas meter. The crank is approximately 135 degrees ahead of the tangent when they are rotating in a clockwise direction. That is, OC_1 is the crank position when the tangent is at OT_1 , the diaphragm is at D_1 , and the long flag arm is at AF_1 when the back diaphragm is at the extreme back stroke. The back valve would be just ready to admit gas into the back chamber at V_1 . AD_1 would be the position of the back diaphragm bracket. All the functions of the valves and the relative positions of the linkages and flags on the flag staffs, with respect to the diaphragm movements, can

RELATIVE POSITIONS OF LINKAGE MECHANISM OF FOUR CHAMBER METER

LEGEND

- D.— BACK DIAPHRAGM
- D'— FRONT DIAPHRAGM
- F— BACK FLAG ARM
- F'— FRONT FLAG ARM
- T— TANGENT
- C— CRANK
- V— BACK VALVE EDGE
- V'— FRONT VALVE EDGE
- A— BACK FLAG STAFF
- B— FRONT FLAG STAFF

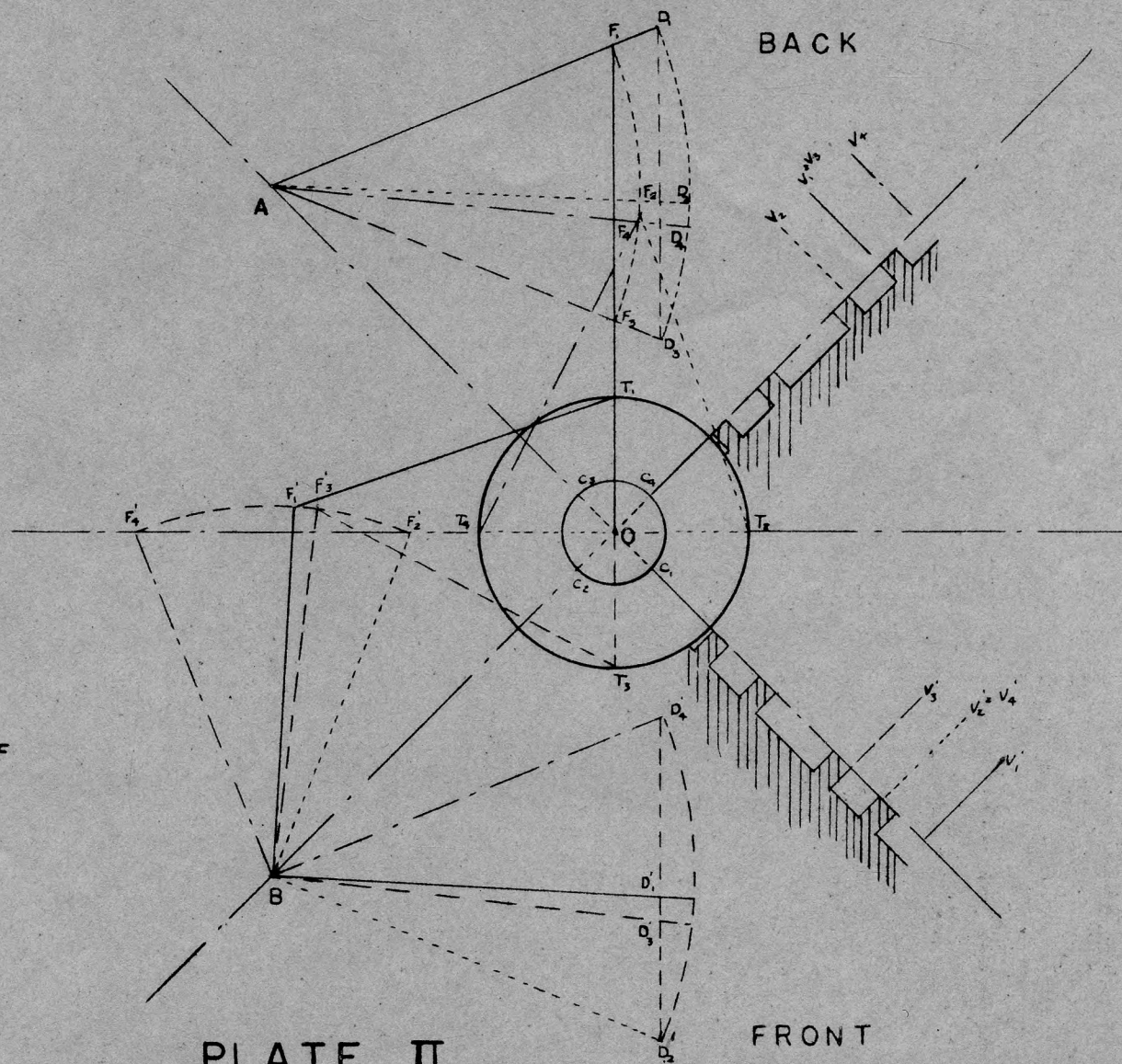


PLATE II

FRONT

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be followed on the plate just as when the meter is in operation. For most meter designs the tangent and crank rotate in a clockwise direction about the point, O. The locations of the linkages are shown only when the front and back diaphragms are in their extreme positions. Also the positions of the linkages are shown for each 90-degree turn of the tangent, for that is when the respective valves function. From Plate II it can be seen that for each 90-degree turn of the tangent and crank, the diaphragms travel through different distances, therefore, displacing various volumes for each 90-degree increment of each revolution of the meter crank and tangent.

To follow through the location of all linkages in one complete cycle of the linkages, refer to the sub-numerals.

The approximate straight line motion of the diaphragms is transmitted through a series of arcs to the adjustment button, from the diaphragm flags to the final circular motion on the crank shaft, by means of the tangent. This circular motion is then changed back to a straight line motion by means of the crank, valve links, and valves, which control the intake and exhaust of each chamber.

When the tangent moves from T_1 to T_2 :-

1. The crank completes a quarter turn of the tangent rotation which is one-fourth of the time necessary to complete one revolution.

2. The back long flag arm has moved from F_1 to F_2 causing the back diaphragm to move from D_1 to D_2 which is more than half way in to the inside extreme position.

3. The back outside chamber has taken in more than half the gas required for a full stroke, yet it has been in motion just one-half the time required to complete a full stroke.

4. The back inside chamber has exhausted more than one-half a chamber but the crank shaft has rotated only through 90 degrees.

5. The front long flag arm, oscillating about point, B, has moved from F'_1 to F'_2 causing the front diaphragm to move from D'_1 to D'_2 which is less than one-half of the entire stroke.

6. The front inside chamber has filled the remaining small part of its chamber.

7. The front outside chamber has exhausted the

last small portion of its chamber.

When the tangent moves from T_2 to T_3 :-

1. Another 90-degree interval of one complete cycle has taken place by the crank or, in other words, one-half of a revolution has been completed.

2. The back long flag arm has moved from F_2 to F_3 or the remaining small half of its instroke causing the diaphragm to move from D_2 to D_3 which is less than one-half of its stroke. However, the entire stroke from D_1 to D_3 has been completed in 180 degrees turn of the tangent.

3. The back outside chamber is completely filled, though its last small portion did so while the crank and tangent were turning 90 degrees. This was less than one-half of the total volume displaced during the entire stroke of the diaphragm.

4. The back inside chamber exhausted less than one-half of its chamber.

5. The front long flag arm moved from F'_2 to F'_3 , causing the front diaphragm to move from D'_2 to D'_3 , its very shortest movement for any of the 90-degree movements of the crank and tangent.

6. The inside front chamber, therefore, exhausted a very small amount of gas compared with the other quarterly displacements of one 360-degree cycle of the meter crank shaft. The displacements of the diaphragm for each 90-degree turn of the crank and tangent are nearly proportional to the arcs D_1D_2 , D_2D_3 , D_3D_4 and D_4D_1 .

7. The outside front chamber took in a very small amount of gas proportional to the arc $D'2D'3$.

To find the comparative diaphragm displacements for the remaining one-half turn of the tangent, follow through with the same procedure.

It will be seen that the diaphragm displacement varies for each 90-degree turn of the tangent. With this type of design there is no way to overcome entirely these differences in displacement for each 90-degree turn of the tangent and valve crank due to the type of mechanism that is used. This variation may be overcome to a certain extent by making the linkages as long as possible, but the dimensions of the meter casing limits the lengths of the linkages.

It has been shown there is not much which can be done thus far in the design of the linkages to make a more

smoothly running meter. But further study was made to determine, if possible, what may be done to minimize these erratic conditions in the design of the linkages of this type of four-chamber meters. It was found that this condition of variation in displacements of the diaphragms for each 90-degree turn of the tangent would be made much worse if the locations of the crank, and flag staffs, also the lengths of the long flag arm, short flag arm and tangent did not have certain mathematical relationships. Up until this study was started no attempt, at least of importance and none to my knowledge was made to design these linkages by using a mathematical formula of any kind.

As the meters are now made, the change in displacement is taken care of by moving the adjustment button in or out on the tangent which connects the common crank to both short flag arms. As the adjustment button is moved out on the tangent the displacement of the meter as a whole, also the displacement of each chamber is increased. If the adjustment button is moved in on the tangent, the displacement is decreased in a like manner. In this way the meter is made to displace the required amount of gas so that the index and the bell prover, by which the

volumetric meters are tested or proven, are in agreement on the volume of air or gas that passes through the meter and bell prover.

A question naturally arises - How does this really affect the displacement and the linkage mechanism if the linkages are in balance? There is only one tangent, and its length controls the stroke of both diaphragms. Therefore when the length of the tangent is changed, both diaphragm strokes are changed on equal amount. As each diaphragm controls two chambers, this one change of the tangent affects the displacements in all four chambers.

EFFECT OF LENGTH OF TANGENT ON DISPLACEMENT:

Before proceeding further, the adjustment for both diaphragms will be analyzed. Assume one diaphragm, due to construction, material used, or flexibility of leather is not the same as the other. A change in the tangent length, provided the valves are properly set, will affect the strokes the same amount on both diaphragms. The change in each section may be the same, but this is really not what is desired. Suppose the meter is running ten per cent fast due to the inaccuracy of one diaphragm and the other is delivering the proper amount of gas. The change

in the tangent affects both diaphragms.

Thus the one diaphragm is adjusted to carry part of the load that the other should be carrying, and although the meter proves accurate there is still an unbalanced condition existing within the meter. This should prove that adjustment by changing the tangent length is not correct and that an adjustment should be made on each individual diaphragm or the diaphragm strokes themselves. Therefore, there should not be an adjustable tangent on a gas meter of this type.

For every different tangent length, the position of the line from the crank shaft to the movable end of the long flag arm at the diaphragm extreme positions changes a certain amount depending on the amount the tangent was lengthened or shortened. The same thing holds true if either of the flag arm lengths are changed, or if the distance from the flag staffs to the crank shaft is changed.

Referring to Plate III, Figure 1, the angle F_1Cn changes for every different length of tangent, t . The valve crank and tangent are mounted rigidly on the crank shaft. Therefore, any change in the angle F_1Cn , changes the timing of the valves with regard to the diaphragm

movements which produce bad performance in the meter. The valves would either admit or exhaust the gas too late or too early thus causing considerable variation in outlet pressures of the meter. This is very objectionable because appliance burners should receive the gas at as near a predetermined constant pressure as possible for the burners to operate properly.

The tangents in meters have three functions to perform, as follows:

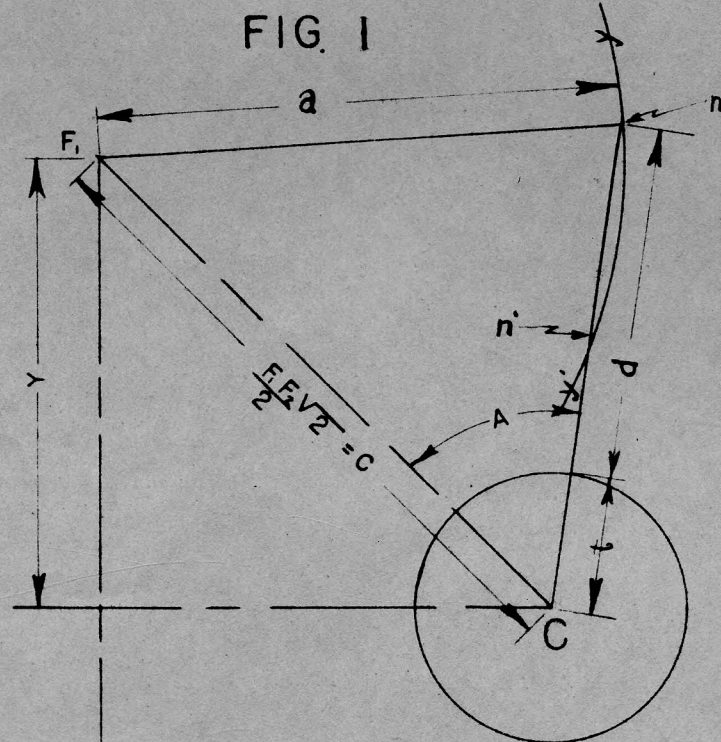
1. Control strokes of diaphragms (displacement).
2. Balance the linkage mechanisms.
3. Timing of valves.

If the tangent of a correct length for the balancing is not correct in length for the displacement, the meter can never be properly adjusted while thus constructed. The tangent once set at the correct length for balancing the linkages should never be changed; which again throws the necessity of a displacement adjustment back onto the diaphragms themselves or diaphragm stroke. Therefore, this is the second good reason for an adjustment on the diaphragms.

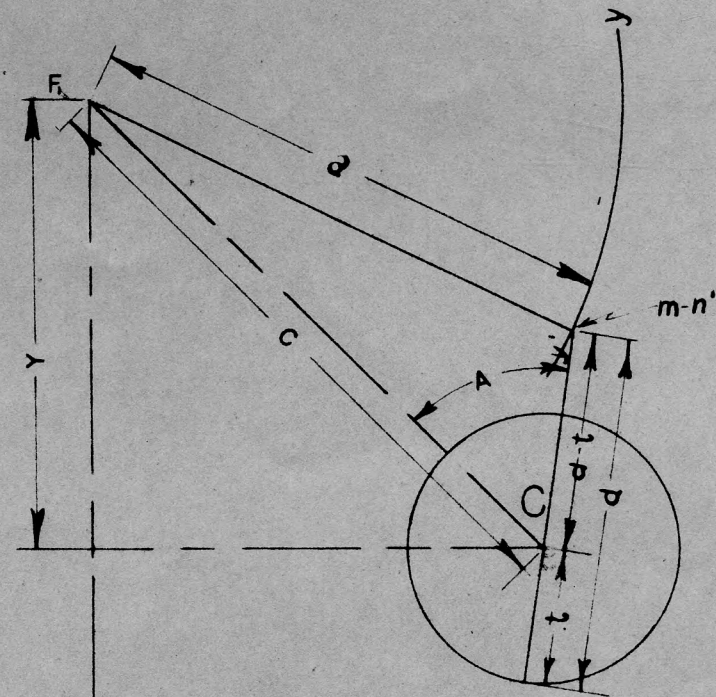
FIG. 1

BACK

FIG. 2

LEGEND

- a - LONG FLAG ARM
 d - SHORT FLAG ARM
 t - TANGENT
 C - FLAG STAFF TO CRANK
 Y - $\frac{1}{2}$ DIST. BETWEEN FLAG STAFFS
 F_1 - BACK FLAG STAFF
 F_2 - FRONT FLAG STAFF



FRONT

EXTREME OUTSIDE DIAPHRAGM POSITION

EXTREME INSIDE DIAPHRAGM POSITION

PLATE III

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DERIVATION OF FORMULA FOR CALCULATING LINKAGES:

Referring again to Plate III, Figures 1 and 2, the linkage positions for the back diaphragm at its extreme strokes, and their relative motions are shown. Figure 1 shows the position of the linkages when the back diaphragm is at its extreme outward stroke. Figure 2 shows the position of the linkages when the back diaphragm is at its extreme inward stroke. The same figures on Plate III apply also to the linkage positions of the front diaphragm when it is in its extreme stroke positions.

The line, F_1F_2 , represents the distance between the two perpendicular flag staffs. Line, c , which equals one-half of F_1F_2 times the square root of two, is an imaginary line from either of the two flag staffs to the crank shaft. Therefore point, C , crank shaft, is equal distance from F_1 and F_2 and is on the perpendicular bisector of the line F_1F_2 . The distance, t , represents the tangent; distance, d , represents the short flag arm; and distance, a , represents the long flag arm. The tangent rotates about the point or crank shaft, C , which causes the long and short flag arms to oscillate. The circle shows the path of rotation of the tangent button which is on the movable end

of the tangent. The arc, yy' , shows the path through which the ends of the two joined flag arms oscillate during one revolution of the tangent.

One end of the short flag arm, d , must follow the arc, yy' , and the other end rotates with the movable end of the tangent, t , in a circle about the crank shaft, C .

When the long flag arm is in its extreme outward position, the tangent and short flag arm will be in a straight line; the length of which, from crank shaft center equals the short flag arm plus the tangent, as is shown in Figure 1, Plate III. This line will cut the arc, yy' , at the points, n and n' .

When the long flag arm is in its extreme inward position, Figure 2, the tangent and short flag arm will also be in a straight line. The length of the short side, Cm , of the triangle then will be equal to the length of the short flag arm minus the length of the tangent. This line will cut the arc, yy' , at some point, m .

These two straight lines should be the same line for proper valve timing and to balance the linkages properly so the point, m , would coincide with the point, n' , if the proper length of tangent is used, provided the long and

short flag arms, a and d , are within reasonable limits. The mathematical relationships of the lengths of these linkages will be shown in a formula later in this thesis.

If these two straight lines are not the same straight line, Figures 1 and 2, Plate III, the meter can never be in balance because the angle between the tangent and crank is always a fixed angle and if the diaphragm is not in the same relative position to the tangent on its extreme strokes, it can never be adjusted so that the diaphragms can be properly timed with the valves.

Referring to Figure 1 again, triangle $F_1 n C$ has two sides of the same length and has the same angle, A , as the triangle $F_1 m C$ in Figure 2. The angles, A , in both triangles are equal because it has been shown that the points, n , n' , m , and C , are in the same straight line.

It is apparent that the third side of the first triangle, Figure 1, is equal to the short flag arm, d , plus the tangent, t ; and the third side of the second triangle, Figure 2, is equal to the short flag arm, d , minus tangent, t .

Then the distances; c , t , d , and a ; may be taken and from them it is possible to obtain their proper lengths to

give a balanced linkage mechanism by the derivation of a mathematical formula so that the angle, A, will be the same in either extreme position of the diaphragm.

The following trigonometric formula may be used to derive the desired formula in order to calculate the proper lengths for the tangent or for either of the flag arms; whichever length may be desired when the other three dimensions are known. But the distance, c, from flag staff to crank shaft, is a function of the distance between the two flag staffs, as has been stated before.

The general trigonometric equation that was used to derive the formula to be used in the design of the linkage mechanism of this type of gas meter is, as follows:

$$\text{Cosine } 1/2A = \sqrt{\frac{s(s-a)}{bc}}$$

Where $s = \frac{a + b + c}{2}$; and a, b, and c, are the sides of the triangles mentioned before in Figures 1 and 2, Plate III, when the diaphragms are at the extreme ends of their strokes. The extreme diaphragm stroke positions of the linkages are used in this derivation because that is the time when the valves must function to insure a smoothly running meter.

This equation is very well adapted to this particular case and it works out excellently in deriving the desired formula by which the desired calculations can be made.

In the first triangle, F_1Cn , Figure 1, Plate III,

$$\text{Cosine } 1/2A = \sqrt{\frac{s(s-a)}{bc}}$$

Where $s = \frac{a + b + c}{2}$, and $b = d + t$.

In the second triangle, F_1Cm , Figure 2, Plate III,

$$\text{Cosine } 1/2A = \sqrt{\frac{s'(s'-a)}{b'c}}$$

Where $s' = \frac{a + b' + c}{2}$, and $b' = d - t$.

Since the angles were proven equal the quantities under the radicals are equal according to trigonometric functions of angles, so the two radical terms can be set equal to each other, as follows:

$$\sqrt{\frac{s(s-a)}{bc}} = \sqrt{\frac{s'(s'-a)}{b'c}}$$

Substituting the values of d and t for the values of b and b' , in the above equation; and solving for the tangent, t , the above formula becomes

$$c^2 + t^2 = a^2 + d^2$$

$$\text{or } t = \sqrt{a^2 + d^2 - c^2}$$

APPLICATION OF THE FORMULA:

As the length of the tangent is determined by other fixed dimensions of the meter linkages, and since there is only one true length for this tangent for these given dimensions, any change from this length throws the linkages out of balance. That is, the valves would not function at the proper time with relationship to the diaphragm movements. If it is desired to change the length of any one of the four linkages that make up the triangle, it is necessary that one of the other three lengths of the linkages be changed by increasing or decreasing the length of that linkage in order to obtain a balanced mechanism. The distance from flag staff to crank shaft, c , cannot be changed unless the distance between the flag staffs, F_1F_2 , is changed because the distance from the flag staffs to the crank shaft is a definite function of the distance between the flag staffs, as has been shown.

Therefore, when it is desired to change the length of the tangent, t , it is necessary to change either the length of the long flag arm or the length of the short flag arm to obtain a balanced linkage mechanism. So the designer must first determine the distance between the

flag staffs so that the distance from flag staffs to crank shaft, c , can be obtained. The larger the meter capacity the greater the distance must be between the flag staffs.

The long flag arm, a , could be made adjustable but that would change the displacement of the diaphragm. In this design it is not desirable to change the displacement through other means than by the tangent. Also by changing the length of the long flag arm, the valves would be thrown out of time. Therefore the long flag arm must be left as it exists in the meter without an adjustment.

Now it is apparent that neither the distance from flag staffs to crank shaft, c , nor the length of the long flag arm, a , should be changed; therefore, by the derived formula the quantity $c^2 - a^2$ must equal a constant for any given meter, and $d^2 - t^2$ equal $c^2 - a^2$. So $d^2 - t^2$ must equal a constant. Hence if any change should be made in the tangent, t , there must be a change made in the short flag arm length, d , to maintain the balanced linkage mechanisms. It must always be kept in mind that the linkages are the connecting links between the valves and the diaphragms and control the functioning of those two sets

of mechanisms, either the two back chambers or the two front chambers, tied together by means of a common crank.

An adjustable short flag arm may be made which would bring the meter mechanisms in balance when the tangent was adjusted to take care of the proper diaphragm displacement. In other words, the tangent would be relieved of the responsibility of balancing the mechanisms but would act only as a displacement adjustment. But any adjustment which would not keep the combined length of the tangent, t , and short flag arm, d , the same would change the timing of the valves because the angle, A , would be changed. Therefore this is another positive reason why there should not be an adjustable tangent on a meter and that the means of adjusting the displacement should be made on the diaphragms themselves.

When any adjustment is made on the linkages, the lines produced by the tangent and short flag arm at the extreme diaphragm strokes would not be in the same straight line intersecting the crank shaft, C . Therefore the timing of the valves would be changed again. An adjustment of the angle between the tangent and the crank would have to be made which is not practical. In other words, it may be summarized, that as the meters are now manufactured, a

change in the tangent length affects the meter, as follows:

1. Displacement of the diaphragms.
2. Balance of the linkage mechanisms.
3. Timing of the valves.

Therefore, when the tangent button is moved in or out on the tangent, to change the displacement of the meter, it also changes the balance of the linkage mechanisms and the timing of the valves.

Balancing the linkage mechanisms would be accomplished by this method but the tangent adjustment would still affect both diaphragms the same amount. But with the linkages of fixed lengths, the diaphragm displacement change would have to be made on the diaphragms themselves.

The best means of maintaining a balanced linkage mechanism and good timing of the valves after they are correctly timed by means of proper designing is to "have an adjustment on each diaphragm and a fixed tangent." With this means of changing the displacement of a meter there would be only two adjustments and the linkages would be in balance and the valves properly timed.

Calculations are given below to show how the formula, $c^2 + t^2 = d^2 + a^2$, maybe used to obtain the correct length dimensions for the linkages that are used in standard four-chamber gas meters today. This formula was used by myself to check the theoretical dimensions of several different sizes and makes of gas meters of this particular design and has proven satisfactory in all cases. To my knowledge this formula, at the time it was derived by myself, had not been used in the design of the linkage mechanisms which were referred to and discussed in the foregoing pages. It applies equally well to both iron and tin meters of similar design and in fact was used on both iron and tin meters by myself in the design investigations of volumetric displacement gas meters.

On the following page is shown a table which gives the "Actual Dimensions" that were taken from a real meter for this study, and the "Theoretical Dimensions" which were calculated by using the proper actual dimensions. These theoretical dimensions were calculated by using the formula, $c^2 + t^2 = d^2 + a^2$, in one of its forms.

Any three actual dimensions of the proper linkages

TABLE I. SUMMARY OF METER CALCULATIONS
Dimensions of Linkages

SYMBOL	L I N K A G E S	D I M E N S I O N S	
		ACTUAL	THEORETICAL
F_1F_2	Distance between Flag Staffs	7.875"	7.9288"
c	Distance, Flag Staff to Crank	5.562	5.6064
a	Length, Long Flag Arm	5.000	4.9501
d	Length, Short Flag Arm	2.750	2.6582
t	Length, Tangent	1.063	1.2753

were substituted in the formula to obtain the fourth dimension. This fourth dimension which was calculated is the theoretical dimension and permits the linkage mechanism to be in balance. The other theoretical dimensions were obtained in a similar manner by substituting the correct actual dimensions of the linkages in the formula. Therefore if any three of the dimensions are known for any particular design of this kind, the fourth term may be easily found.

This formula can readily be used in correcting the lengths of the linkages of meters now in use. Also, it may be used in the design of new meters of any sizes of this type. This formula will be one of the basic formulae which will be used in the future in meter design. At present one or two meter manufacturing companies are using the formula in the design of their meters. Up until the time of development of this formula the linkage lengths had been obtained experimentally.

CALCULATIONS:

These calculations were made by taking dimensions that were obtained from one of several meters which were

being studied at the time these data were compiled. These calculations were made using tin meter dimensions, but either iron or tin meters of any size may have been used for this study. Only four-chamber meters use this type of linkage mechanism or design.

The "Actual Dimensions", Table I, are the dimensions which were obtained directly from the meter by measurement. Therefore, there will be no calculations shown for these.

The "Theoretical Dimensions", are the dimensions which were obtained by using the formula developed in this thesis. One or two of the calculations for the theoretical dimensions will be shown in the following pages.

The calculations for the "Distance Between Flag Staffs" and the "Distance from Flag Staff to Crank" must be carried out together due to the fact that one is a function of the other because of the manner in which the two flag staffs and crank shaft must be placed in a meter of this type.

The distance from flag staff to crank shaft center and the distance between the flag staffs will now be calculated by using the formula, $c = \sqrt{a^2 + d^2 - t^2}$.

The values to be used, and which are taken from the actual dimension column shown in Table I, are listed, as follows:

$a = 5.000 =$ long flag arm.

$d = 2.750 =$ short flag arm.

$t = 1.063 =$ tangent.

This formula is used when the diaphragm is either at its instroke or at its outstroke, as it is applicable in either case. It is necessary to use this formula when the diaphragms are at the extreme ends of their strokes because it is at this position that the valves should function. Hence in these calculations the formula is used when the diaphragm position is on its extreme back stroke so that the tangent plus the short flag arm make the one side of the triangle.

It should be stated here that the instroke position could be used just as well in calculating the various dimensions but it is not necessary because the dimensions of the linkages would be the same in either case because the Angle A must be the same in both extreme stroke positions.

By substituting the above values in the formula and

solving for, c , the distance from the flag staff to the crank shaft center, is found to be 5.6064.

The distance, therefore, between the flag staffs, F_1F_2 , is equal to 5.6064 divided by square root of 2 times 2 or 7.9288. This is true because the crank shaft center is located on the perpendicular bisector of the line between the flag staffs and a distance from this line equal to one-half the distance between the flag staffs. These are the theoretical dimensions which are shown in the table, Table I.

To follow these calculations, it would be desirable to refer to Figure 1, Plate III and to see how readily the formula applies.

The calculations for the theoretical dimensions of the long flag arm, short flag arm and tangent were made by using the formula. The three dimensions of the known linkages were substituted in the formula to obtain the theoretical dimension for the fourth linkage.

The theoretical dimensions of all the linkages are calculated by using the same formula. Therefore, it will not be necessary to show the calculations for other linkages.

About ten thousandths of an inch difference was found between the actual and theoretical dimensions for the lengths of the long flag arm. But it will be shown later that this small discrepancy does make considerable difference in the correct lengths of the short flag arm and the tangent.

In solving for the short flag arm there was found a difference of one-tenth of an inch between the actual and theoretical dimensions. This difference is ten times as great as it was for the long flag arm, when comparing the actual and theoretical correct lengths.

This shows the absolute necessity of making the linkages exactly the theoretically correct lengths. This also demonstrates that it is most important to make the shorter linkages more exact than the longer linkages because a small difference on the short linkages will upset the balance of the meter a greater extent than the same difference in the longer linkages.

The difference between the actual and the theoretical lengths of the tangent was found to be about 0.21 inch. This shows a very great discrepancy between the tangent that was used and the tangent that should have been used to give the meter a balanced linkage mechanism. In fact,

the original tangent should be nearly 25 per cent longer to give the tangent the proper length so that the linkages would be in balance. This unbalanced condition also will not permit the extreme strokes of the diaphragms to occur at each 180 degrees turn of the crank shaft. At one time the crank shaft may turn only about 170 degrees from the extreme outside stroke position to the extreme inside stroke position of the diaphragm, while during the travel of the diaphragm from the extreme inside to the extreme outside position the crank must turn through about 190 degrees to reach its original starting point. When this is true the valves, which are connected to the crank by means of the valve links, will be out of time with the diaphragm movements.

Also since the length of the tangent governs the displacement of the diaphragms and the total displacement of the meter, it will not be possible for the designer to change the length of the tangent without changing the proof of the meter. It would be more practical to change either the length of the short flag arm or the length of the long flag arm to obtain the correctly balanced linkage mechanism, as this change in either of the flag arms would not cause a change in the displacement of the meter. If a

change in the displacement of the meter is made, a new index would have to be designed to give the proper registration.

CONCLUSIONS:

On meters as now constructed, when the tangent button position is either moved in or out on the tangent, the length of the tangent is changed. This is done to change the displacement of the meter to calibrate it. When the length of the tangent is changed, and when the diaphragms are in their extreme stroke positions, a different angle will be produced at C, angle F_1Cn , figures 1 and 2, Plate III. Owing to the angle between the tangent and the crank being a fixed angle and the angular position of the crank shaft being changed when a different length of tangent is used, the valve timing will be altered.

Any change in the angle, F_1Cn , Plate III, Figure 1, will change the timing of the valves with regard to the diaphragm movements which is commonly known to produce undesirable performance in a meter. At the present time when the tangent length is changed the valves must be re-timed due to the linkages being thrown out of balance. A little change in this valve timing will cause considerable fluctuations in pressures in all of the meter chambers

and will change the calibrations of the meter to a great extent.

It is impossible to have an adjustable tangent and maintain a balanced linkage mechanism at all times, and take care of changes in diaphragm displacements that may be required. Whenever the meter is out of proof due to a change in the leather or wear, the strokes of the diaphragms should not be changed by means of the tangent, but by an adjustment on each diaphragm.

The linkages must have a definite mathematical relationship to each other for the linkages to be in balance and for the valves to be properly timed. Therefore this shows conclusively there should not be an adjustable tangent on a meter where linkages are used to connect the valves and crankshaft to flag staffs and diaphragms.

It is a commonly known fact that some leather varies to a great extent in diaphragms; sometimes shrinking and other times stretching. This causes some diaphragms to displace more or less than they should, which is one of the most important reasons why the change in the displacement should not be controlled by adjusting the tangent button.

Instruments have been made to obtain indicator cards from the various chambers of meters, thus showing excellently the pressure conditions in each individual chamber. They demonstrate that there are considerable variations in pressures in each of the chambers and that these erratic conditions could best be eliminated by changing the displacement of each diaphragm independently. Also a device can be made for checking the volume displaced in each chamber. From this information the proper adjustment for displacement may be made on the diaphragms which are displacing more or less than they should.

No adjustments for displacement should be made by changing the lengths of the linkages, but the proper adjustments can be and should be made on each diaphragm separately. This new design will insure proper balance of the linkage mechanisms and the proper timing of the valves at all times. There is at least one meter now being manufactured which has a displacement adjustment on each diaphragm, and the valves are timed independently of the linkages.

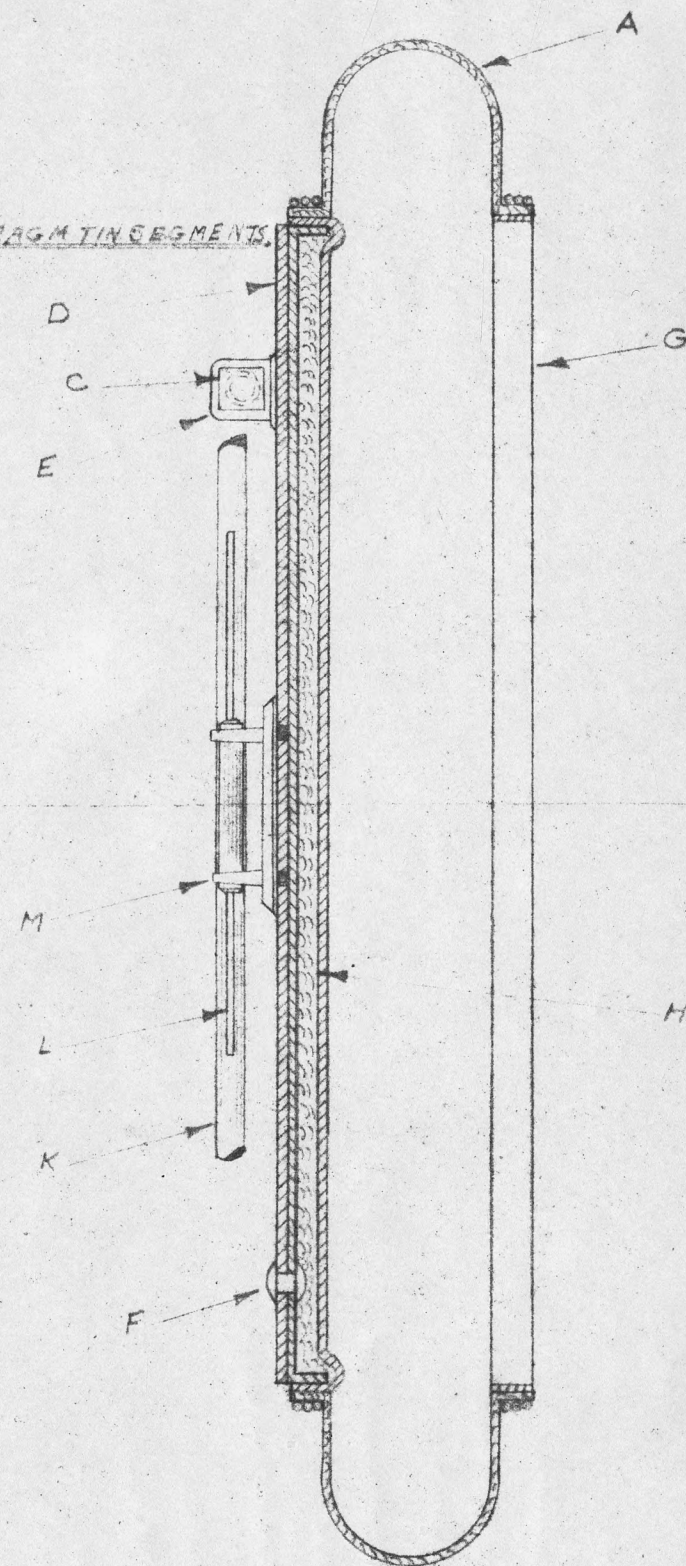
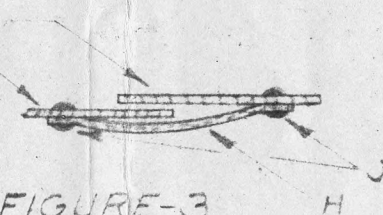
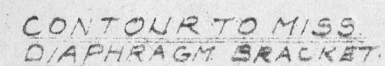
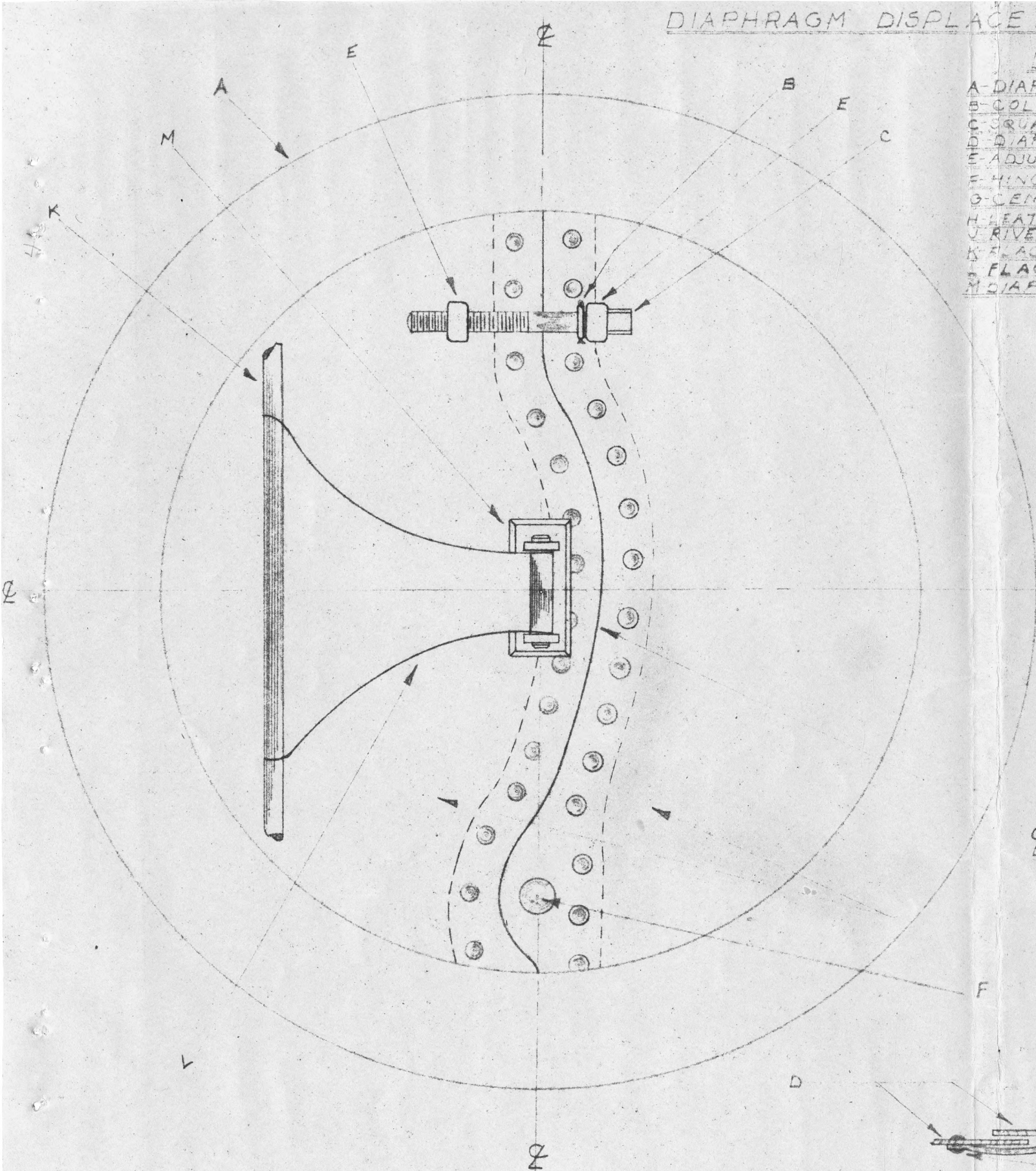
The reciprocating portion of the diaphragm, which is analogous to a piston in an engine, can be so constructed

that by means of a screw and two lugs on the two segments of the tin portion of the diaphragm the diaphragm area can be enlarged or decreased. The strokes of the diaphragms would always be the same and the displacement would be changed by increasing or decreasing the diameter of the effective portion of the diaphragms.

Plate IV shows a diaphragm so designed that the displacement of same can be changed by increasing or decreasing the effective area of the tin portion. There would be very little or no change in the present design of the diaphragm leather. The diaphragm leather, A, would be attached in the same manner as it is at the present time. The diaphragm tin, D, would be made up of two segments and hinged together by means of a rivet or small bolt at F. Each diaphragm segment would have a lug soldered to the tin near the top and held together by means of an adjusting screw C. By means of the adjusting screw and the lugs, the effective area of the diaphragm itself would be increased as desired to bring the meter into proof. One turn of the adjusting screw will change the displacement between one and two per cent. So this design allows all the adjustment that would be necessary. A strip of leather, H, would be riveted and cemented to the two segments, and

LEGEND.

- A. DIAPHRAGM LEATHER.
B. COLLAR (PINNED).
C. SQUARE HEAD ADJUSTING SCREW.
D. DIAPHRAGM TIN SEGMENTS.
E. ADJUSTING SCREW BRACKETS.
F. HINGE (RIVET OR BOLT).
G. CENTER PARTITION (TIN).
H. LEATHER FLAP ATTACHED TO DIAPHRAGM TIN SEGMENTS.
I. RIVETS OR BOLTS.
K. FLAG STAFF.
L. FLAG.
M. DIAPHRAGM BRACKET.



the leather would be loosely attached so as to permit the maximum amount of diaphragm segment adjustment necessary for proper calibration of the meter. This piece of leather would be placed on the opposite side of the diaphragm tin segments from the diaphragm bracket, M. The right hand segment would be cut in such a shape so that it would not strike the diaphragm bracket when adjustments were made. The flag staff, K; flag, L; and diaphragm bracket, M; design would be the same as those used now. The small drawing at the bottom of Plate IV shows how the strip of leather is attached to the tin segments so that the joint must be gas tight. Therefore this readily shows how a simple means can be provided for the proper adjustment on the diaphragms themselves and then the valves always would be in time. Also the adjustments would be just as simple to make as they are at the present time. Also with the adjustment on the diaphragms the linkages would always be in balance and valves would always be in time which would make a much more smoothly operating meter. Also when these requirements are obtained they would insure a much more accurately measuring instrument over a much longer period of service.

To have the meters of the type discussed in this thesis operate most efficiently, adjustments to the displacement should be made on each diaphragm independently and not by means of an adjustable tangent.

