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Testing Large-Capacity Rotary Gas Meters

By Howard S. Bean, Matthew E. Benesh,[1] and Frank C. Witting[2]

The paper describes two methods of testing rotary gas meters of large capacity. In one method, known as the field test method, the necessary equipment is taken to the meter location. In the other method, termed the "transfer method," the test is made in a shop where conditions can be controlled more closely. Results obtained by the two methods are compared.

Tests made to study the instantaneous pressures within the closed measuring pockets of rotary meters and the effect of pulsations at the meter inlet are described, and the results discussed.

Contents

[1] Chief Research Engineer, The Peoples Gas Light & Coke Co. [2] Research Engineer, The Peoples Gas Light & Coke Co.

I. Introduction

During the last 20 years the use of gas as an industrial fuel has increased many fold. As examples, many bakeries (from the small neighborhood shop to the large wholesale bakery), enamel and paint drying ovens, and heat-treating ovens for tools and machinery parts use gas as their source of heat. To measure the gas supplied to these users, a number of different types and sizes of meters have been developed. It is fortunate that this has occurred, as no one type or size possesses the necessary characteristics to fulfill satisfactorily all the conditions encountered.

The development of these meters and the increase in their unit capacity (particularly in the rotary type) introduces the problem of testing such meters. Some of the meter manufacturers have gasometer-type provers of as much as 3,000-ft.^{3} capacity. The chief disadvantage of using these provers for testing some of the largest meters is that the high inertia of the moving parts of both meters and provers makes it difficult to perform tests at uniform rates of flow anywhere near the rated capacities of the meters or even their normal rates of operation. Moreover, moving some of the largest meters to a prover is so expensive as to practically prohibit routine testing of them by that method. Hence, the development of equipment and methods for testing these meters to their full capacity and for checking their condition while in service is of importance to meter manufacturers, users, and public utility commissioners.

Technical and commercial associations through appropriate committees, as well as individual companies, have given considerable attention to the metering of gas and testing of gas meters. The Bureau has cooperated in several of these efforts, as one of its functions is to assist in the development of methods of testing. The work here described was done in cooperation with the Peoples Gas Light & Coke Co., Chicago, Ill., under arrangements similar to those that applied in connection with the Joliet reference meter investigation described elsewhere.[3]

[3] H. S. Bean, M. E. Benesh, and F. C. Witting, Joliet reference gas meter, J. Research NBS **17**, 207 (1936) RP908.

II. General Outline of Methods and Conclusions

1. Rotary Meters

The rotary meters referred to in this paper are the two-lobed impeller type. A cross-sectional elevation of such a meter is shown in figure 1. Air or gas flowing through the meter in the direction indicated by the broken arrows causes the impellers to rotate in the direction shown by the solid arrows. The volume of air or gas trapped within a pocket such as that formed between impeller *A* and the semicircular portion of the case *C* is discharged into the meter outlet. Four such pockets are filled and discharged during the course of each revolution. Theoretically, the two impellers, *A* and *B*, should be in continuous rolling contact with each other and continuous sliding contact with the two semicircular parts of the meter case, *C* and *D*. Under these ideal conditions, which no actual meter fulfills exactly, the volume of each pocket may be computed from the dimensions of the case and impellers, as the cross-sectional outline of each impeller is developed by geometric curves and the inside of the case is a semicircle. Therefore, the area of one meter pocket is equal to one-half the impeller sectional area subtracted from the area of the semicircular portion of the meter case, *C*. Multiplying this area by four and then by the impeller length gives what may be called the "dimensional" displacement per revolution.[4]

In an actual meter, the true displacement differs from the dimensional displacement defined above because it is necessary to avoid impeller wear and excessive differential pressures across the meter. To do this, there are small but significant clearances provided between the impellers and the case. Also the surfaces of the impellers are not in actual rolling contact, and the proper phase relationship between the impellers is maintained by spur gears on the impeller shafts outside the impeller chamber.

These small but necessary clearances introduce two modifications to the simple relationship

[4] In the past, one manufacturer has used this mathematical derivation of meter displacement in computing the listed displacements for his meters.

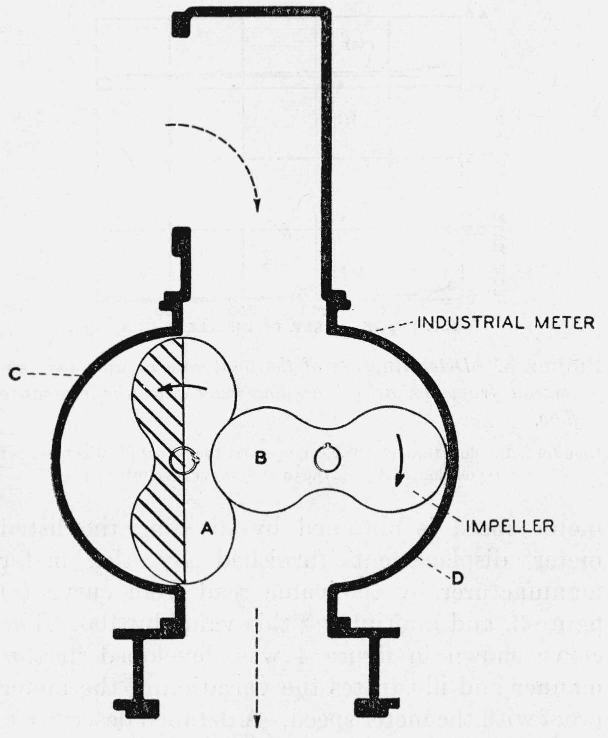

FIGURE 1.—*Cross-sectional elevation of a rotary gas meter.*
The broken arrows indicate the direction of gas flow, the solid arrows the direction of rotation of the impellers

between meter dimensions and displacement. The first is that the actual displacement per revolution differs from that computed from the actual dimensions. The second is that a small quantity of gas will pass through the clearances without affecting the meter indications. The magnitude of the first modification is a function of the meter clearances only, whereas the second, in addition to being a function of the meter clearances and the density and viscosity of the gas, is also a function of the pressure drop across the meter, which is a variable.

In order to evaluate the magnitudes of these modifications, two methods of testing rotary meters have been developed and are here described. One of these is called the "field method" because by it an industrial meter may be tested in either the meter shop or its actual service location. The other, referred to as the "transfer method", is a laboratory method and is applicable to the testing of any type of meter that operates close to atmospheric pressure and has a capacity range within that of the available testing equipment (96 to 1,000,000 ft^3/hr in the present case).

The transfer method and the equipment used with it were developed first and used to test a large number of rotary meters. An analysis of the results of these tests led to the development of the field method. Representative meters, previously tested by the transfer method, were tested again by the field method to establish its reliability. The remarkable agreement between the results obtained with the two methods is illustrated by a detailed example in Section II and by other examples summarized in Section III.

2. Field method of meter calibration

The field method of meter calibration consists of three individual determinations (1) the true meter displacement, (2) the quantity of air or gas that passes through the clearances of the meter, and (3) the pressure drop across the meter at several rates of operation.

The meter displacement is determined by driving it mechanically at a very slow rate of speed (equivalent to 1 percent or less of its rated capacity), and maintaining a zero pressure difference across the impellers. The discharged air or gas is measured by a small, accurate reference meter, which in turn is calibrated by comparison with a primary standard. (In this instance the primary standard is a piston meter).[5] The result is reported in terms of cubic feet per revolution.

The measurement of the quantity of air or gas passing through the meter clearances consists of accurately determining the flow through the impeller clearances under static conditions and subsequently converting this information by means of an empirical relationship to the dynamic conditions occurring during the actual performance of a meter. Original data for this procedure are obtained from two simple tests. The first of these tests, referred to as the "clearance test," consists in accurately measuring the rate at which gas flows through the meter clearances at various specified differential pressures when the meter impellers are externally driven at a very slow and uniform rate of speed. The second is the "rate test," and consists in measuring the differential pressures across the meter while it is operating normally at various speeds throughout its operating range.

The results of the two tests are then combined to correlate the flow of gas or air through the impeller clearances with the meter speed. The method of

[5] See Sec. III, 2, (a), (2).

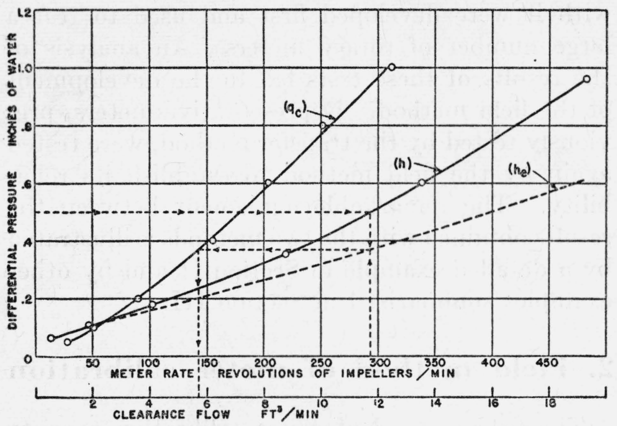

FIGURE 2.—*Curves for the relationship between meter speed· clearance flow, actual pressure drop, and effective pressure drop of a rotary gas meter.*

q_e (ft³/min) = rate of flow through the clearances.
h (in. H_2O) = actual pressure drop through the meter.
h_e (in. H_2O) = the pressure drop which is effective in producing the flow through the clearances.

doing this is illustrated in figure 2. Curve (h) is taken directly from the rate test and shows the variation of the observed differential pressure with the meter speed. Curve (h_e) is derived from (h) by an empirical relation [6] and shows the variation of the effective differential pressure with the meter speed. Curve (q_c) is taken directly from the clearance test and shows the variation of the clearance flow with the differential pressure. From these curves the clearance flow corresponding to any observed differential pressure or meter speed is obtained.

Dividing any value of the clearance flow, in cubic feet per minute by the corresponding meter speed in revolutions per minute gives the rate of flow through the clearances in cubic feet per revolution. Adding this quotient to the measured displacement per revolution gives the total rate of flow through the meter at the particular speed. The result of this operation for several different meter rates is illustrated in figure 3, in which curve (e), representing the total flow, is obtained by adding to the ordinates of curve (c), for the clearance flow, the amount of the actual displacement value (s).

The results of gas meter tests are most commonly reported by the gas industry in terms of the meter proof. It is the factor, expressed as a percentage by which the indications of a meter must be divided to obtain the true volume of gas metered. The meter proof for any particular

[6] See sec. III, 1, (c).

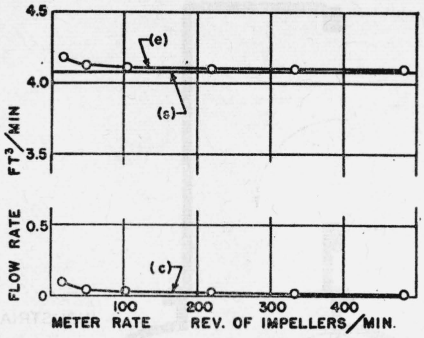

FIGURE 3.—*Determination of the total rate of flow per revolution from the actual displacement and the clearance flow.*

Line (c) is the flow through the clearances, (s) the actual displacement per revolution, and (e) is the total flow per revolution

meter speed is obtained by dividing the listed meter displacement furnished by the meter manufacturer by the value read from curve (e) figure 3, and multiplying this value by 100. The curve shown in figure 4 was developed in this manner and illustrates the variation of the meter proof with the meter speed. A detailed description of the equipment, procedure, and necessary computations are given in section III,1.

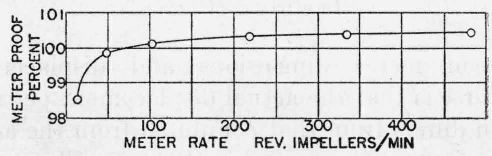

FIGURE 4.—*Proof curve of a rotary gas meter.*

This curve was developed with data from figures 2 and 3.

3. Transfer method of meter calibration

In this method, which could also be designated as one of substitution, air or gas is circulated at a desired rate of flow through the meter under test until conditions (i. e., rate, pressure, and temperature) are constant. Then, without altering any of these conditions, the entire flow is diverted into a large storage container whose static pressure is not only very close to atmospheric pressure but also completely independent of volume or rate of change of volume. The flow into the storage container is continued until the container is nearly full and then diverted back to the original circulation. The time during which the flow is thus diverted or the difference in meter readings between the start and finish of the diversion are recorded as precisely as necessary. The air or

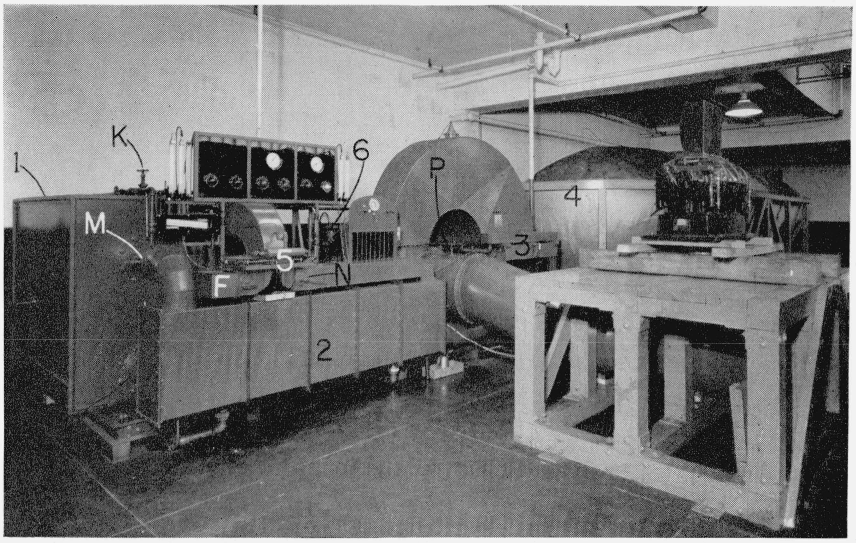

FIGURE 5.—*Transfer testing method equipment with a small rotary meter in place for testing.*

1, Housing of large secondary reference meter; 2, the heat exchanger; 3, large slide valve; 4, transfer receiver; 5, small slide valve; 6, engine. The lettered valves correspond to those of figure 17.

gas in the storage container is then measured out through a reference meter at whatever rate is most suited to the operation of the reference meter. The pressures and temperatures of the air as it passes through the meter under test and the reference meter are measured and recorded, and these data are used to reduce the indications of the two meters to a common basis for comparison.

The reference meter may be any meter of suitable capacity that has been carefully calibrated or is of sufficient accuracy because of its design and mode of operation (e. g., the piston meter).[7] The proof of the meter under test is obtained by dividing the volume indicated by it by the volume indicated by the reference meter and multiplying by 100.

Figure 5 shows the transfer equipment being used in testing a small rotary meter. The detailed description of the equipment, procedure and necessary computations are given in section III, 2.

4. Comparison of the two test methods

The results obtained from testing a 10-in. by 30-in. rotary meter by both methods are shown in figure 6, and attention is called to the close agreement between the two results. The curve is the same as shown in figure 4, and was derived from the results of the field test, while the individual points are the values obtained by the transfer method. Incidentally, the two sets of tests, although made on the same meter, were carried out under very different conditions; that by the transfer method being made in a special testing room under controlled conditions, whereas that by the field method was carried out in the field with part of the equipment exposed to a light snow, and with air temperatures much below the ground (and incoming gas) temperature.

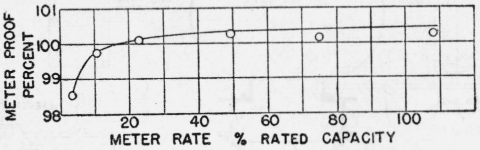

FIGURE 6.—*Results of testing a meter by field method and transfer method.*

The curve was derived from the field test method and the individual points are from the transfer method.

[7] See RP908, p. 218.

5. Summary of results and conclusions

The following is a summary of the results of tests of more than 17 rotary gas meters, ranging in capacities from 12,000 to 800,000 ft^3/hr.

1. The average proof of the meters, in good mechanical condition, over the range of 5 to 150 percent of rated capacity, is between 98 and 101 percent.

2. The proof curve of any individual meter is within ± 0.25 of the group average over the range of 20 to 150 percent of rated capacity, and is within ± 0.5 percent of the group average over the range of 10 to 20 percent of rated capacity.

3. The size of a meter has very little influence on its proof curve when the meter speed is expressed as a percentage of the meter speed at the manufacturer's rated capacity or speed for the meter.

4. The static displacement of a rotary gas meter appears to be almost unaffected by corrosion or deposits, even those resulting from unpurified gas. Hence, having been once determined, it will seldom be necessary to be redetermined.

5. After a rotary meter has been tested once by the field method, including a hand-operated clearance test for reference, its condition at any subsequent time may be ascertained by making a simple hand-operated clearance test. If the result of this test does not differ by more than 50 percent from the original, the percentage change can be applied directly to the clearance curve and a new calibration curve developed.

6. The internal surfaces of a rotary meter can be cleaned satisfactorily, with a minimum interruption to the customer's service by several flushings of the meter with a noncorrosive solvent.

7. Pulsations, or pressure, waves created by the action of the impellers may be reflected from some part of the inlet piping so as to cause a slight irregularity in the meter proof curve. Theoretically, the maximum effect of such pulsations will occur when a single positive or negative pulse of the fundamental wave produced by a rotary meter is completely reflected and returns to the meter inlet at the exact instant to produce a maximum effect on the density of the gas about to be trapped in an impeller pocket. In these tests, the maximum reflection of pulsations was obtained with open-ended inlet pipes, and the magnitude of their effect upon the density of the

gas in the meter and the proof of the meter was about 0.6 percent.

8. The maximum effect that pulsations reflected into the meter inlet could produce upon its indication was determined by measuring the instantaneous static pressures at the meter inlet over normal operating range of meter speeds and various phase angles of the impellers. The maximum effect upon the meter proof, indicated by these measurements, amounted to about 0.8 percent, and occurred within a very narrow range of meter rates.

From the experience gained in developing these methods of testing large-capacity gas meters, and from the results of using these methods in testing rotary gas meters, as summarized above, the following conclusions have been drawn:

1. The capacity range of gas meters which may be tested by the transfer method, using the equipment herein described, is from about 95 to about 1,000,000 ft^3/hr.

2. It is believed that the results obtained by the transfer method, as used in the testing of rotary gas meters, are correct to within about ± 0.1 percent.

3. The field method equipment here described can be set up and disconnected by two men. A third man is needed only while the test is in progress.

4. The results obtained from tests of rotary gas meters by the field method are of nearly the same degree of accuracy as those obtained by the transfer method.

5. In general, the mechanical condition of a rotary meter can be estimated while in operation by comparing the pressure drop across it with that observed in the original test for the same meter speed. So long as there is no radical change in the speed–pressure-drop relation, its condition may be assumed to be satisfactory.

6. The effect of pulsations can be eliminated completely by the recording of the instantaneous pressure within each meter pocket at the exact time the pocket is sealed off and this value used as the static pressure in the meter.

III. Detailed Description of Methods and Equipment

1. Field method of meter calibration

(a) Description of equipment

As stated in section II, the field method of testing rotary gas meters is made up of three separate tests, namely: determination of the displacement of the meter, usually referred to as the displacement test; determination of the rate of flow through the meter clearances corresponding to different pressure drops across the meter, referred to as the clearance test; and the observation of the pressure drop across the meter when it is operating at different rates is referred to as the rate test. When the second, or clearance, test is made with air an additional test is needed by which the clearance flow with gas can be calculated from the rate obtained with air, and this test is referred to as the auxiliary clearance test.

The principal items of equipment used to make these several tests, shown diagrammatically in figures 7, 8, and 9, include a small reference meter with a driving motor and gearing, a second motor and gear system for driving the industrial meter, mechanically operated breather, rubber bag differential pressure indicator, small suction-type air blower, diaphragm-type gas meter, brake, and such additional items as thermometers, manometers, and stop watch. A better understanding of the testing procedure will be gained if some of these items are described in detail.

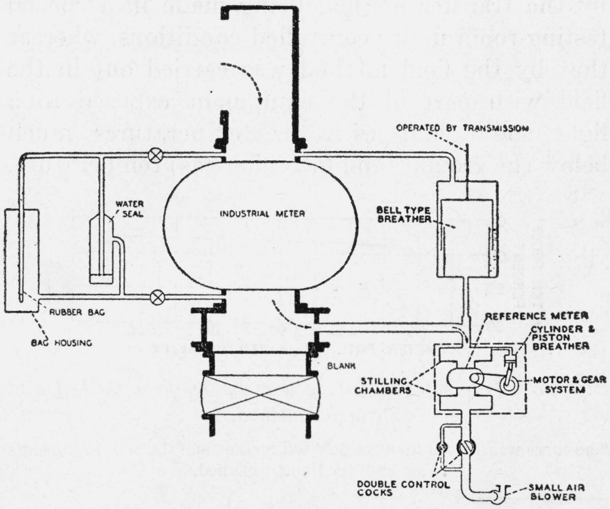

FIGURE 7.—*Diagram of the equipment and connections for the displacement test of a rotary gas meter.*

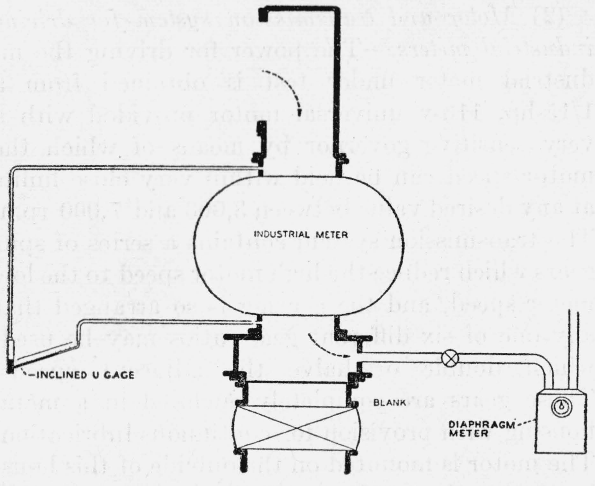

FIGURE 8.—*Diagram of the equipment and connections for the clearance of a rotary gas meter.*

(1) *Reference meter.*—The reference meter forming a part of the equipment for the field method tests described in this paper was obtained by the addition of various special parts to a standard 2½- by 3-in. rotary blower provided with special inlet and outlet flanges.[8] The conversion of a small rotary blower into a very accurate displacement meter is accomplished by providing the exact amount of external power necessary at all times to permit the blower to operate without any flow through its impeller clearances. The external power is supplied by a 1/20-hp induction motor through a six-step variable-speed reducer and chain-drive system. These six speeds permit the meter speed to be varied from 96 to 1,475 rpm in steps of equal geometric progression. As the operation of this type of meter tends to produce pulsations, particularly in the inlet chamber, which may affect the accuracy of the meter indications,[9] large chambers are attached to the inlet and outlet openings of this meter to suppress these pulsations, and as a further aid the inlet chamber, which is the larger, is filled with wire cloth.

These chambers are suitable for the suppression of high-frequency pulsations, but their capacity is insufficient for the low-frequency pulsations occurring during the operation of the meter at the lowest meter speeds. As the suppression of low-frequency pulsations is difficult unless chambers of very large size are used, these low-frequency pulsations are eliminated at their source by the use of a compensating piston and cylinder breather. The cylinder of this breather is connected to the reference meter inlet while the piston is operated by the driving system of this meter at such a rate that it travels through four complete cycles for each revolution of the meter. A steady rate of flow of air into the meter is obtained by synchronizing the motion of this piston with the positions of the meter impellers.

Regulation of the rate of flow of air or gas through the reference meter, and therefore through the service meter under test also, is by means of the parallel connection of a 2- and a ⅜-in. plug cock attached to the reference meter outlet. The condition of zero pressure drop through the reference meter is indicated by a gage consisting of an oil bead about 1½ in. long in a slightly bowed glass tube with self-draining enlargements at each end. The number of revolutions made by the reference meter during the interval of a test is obtained from a revolution counter driven from one impeller shaft through a clutch that can be engaged or disengaged without lost motion, slippage, or overrun.

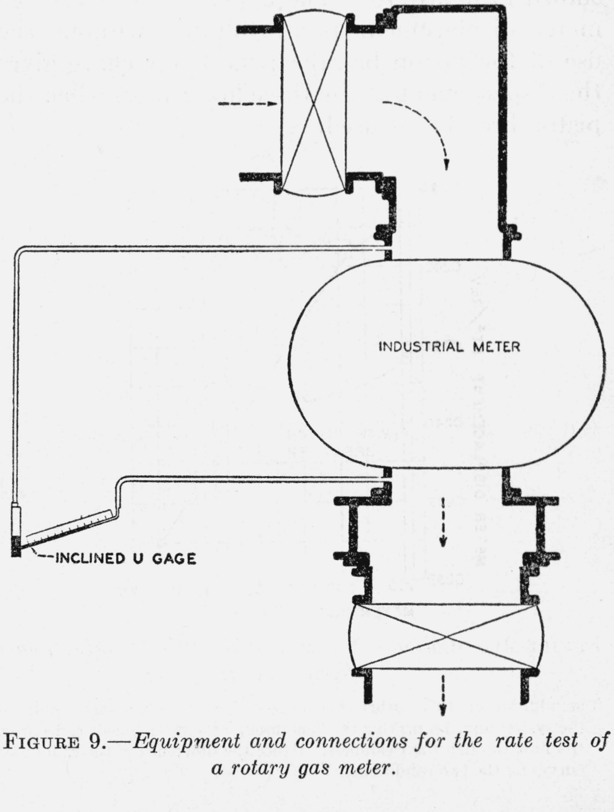

FIGURE 9.—*Equipment and connections for the rate test of a rotary gas meter.*

[8] It is not essential that this meter be of the rotary type. Flow meters could be used, but the calculation of the results with them would be much more tedious. Other types of displacement meters could be used if they are sufficiently accurate and retain their calibration within less than 0.1 percent for a reasonable period of time.

[9] See sec. IV, 2.

The reference meter, its stilling chambers, breather, gear box, and revolution counter are assembled in a common wooden case, as this not only aids in temperature control but also provides protection and greater convenience in moving. The control cocks and differential-pressure indicator are, of course, on the outside of the case. The driving motor is mounted on the top of the case so that heat from it will not affect the meter.

This assembled meter unit was calibrated by operating it in series with the piston meter, which is taken as our primary standard. The influence of pressure pulsations on the accuracy of the reference meter was checked by interposing various size cavities between the two meters. These cavities were connected to assimilate the outlet connection volumes of various sizes of industrial meters, and it was found that the calibration of the reference meter was unaffected by the size of these cavities when the meter was operated at the four highest of the six meter speeds or when the piston breather was used with the lower speed operations. In the subsequent use of the assembled reference meter unit the piston breather was used whenever the meter was operated at the three lower meter speeds.

The results of calibrating the reference meter are shown in figure 10. The upper curve gives the meter displacement per revolution without the use of the piston breather; the lower curve gives the displacement at the three lower rates when the piston breather is used.

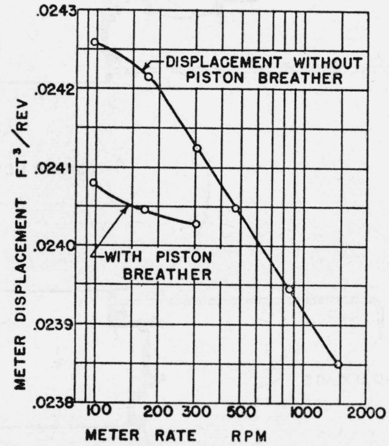

FIGURE 10.—*Calibration curves of the 2½- by 3-in. rotary reference meter.*

The addition of the breather changes the capacity or clearance volume of the system and, by making the flow through the meter steadier, decreases the flow through the clearances. Hence the difference in the calibration curves for the two conditions.

(2) *Motor and transmission system for driving industrial meters.*—The power for driving the industrial meter under test is obtained from a 1/15-hp, 110-v universal motor provided with a very sensitive governor by means of which the motor speed can be held within very close limits at any desired value between 3,000 and 7,000 rpm. The transmission system contains a series of spur gears which reduce the high motor speed to the low meter speed, and the gearing is so arranged that any one of six different gear ratios may be used, which double or halve the adjacent speeds. These gears are completely enclosed in a metal housing with provision for continuous lubrication. The motor is mounted on the outside of this housing so that the two form a single piece of apparatus.

The output from this unit is suitable for driving all sizes of meters up to and including the 12- by by 36-in. size. For driving the larger sizes of meters both lower speeds and greater torque are required, and these are obtained by the addition of a second gear box. The combinations of gear ratios that can be obtained in conjunction with the variations in motor speed make it possible to drive meters at speeds of less than 1/15 to over 15 rpm. When in use, the output shaft is alined with and coupled to the meter handwheel. The weight of the unit and its reaction due to driving the meter are carried by an adjustable support bolted to the transmission housing.

(3) *Mechanical breather.*—The displacement test of the industrial meter is based on the requirement that there be no appreciable pressure difference between its inlet and outlet. Also, the use of another rotary meter operated at constant speed as the reference meter for this test imposes the additional requirement that the flow reaching the reference meter shall be steady and nonpulsating. As the discharge from a rotary meter pulsates with a frequency four times the meter speed it is necessary to apply some means of neutralizing the pulsations, and this is accomplished by the combined actions of a properly synchronized mechanical breather for neutralizing the larger flow irregularities and a very lightweight breathing diaphragm (the differential pressure indicator), for removing the small remaining irregularities.

Two sizes of mechanical breathers are used in this work to cover the full range of sizes of rotary displacement meter. The smaller of these breathers, used in the testing of all meters up to and including the 12- by 36-in. size, is an accordion-type bellows mounted within a pressure vessel. One face of the bellows is fastened to the inside face of the pressure vessel. The other face is movable, with its actuating rod passing through a packing gland. The bellows are operated from a cam that is a part of the mechanical drive and transmission system, and the amplitude of the bellows movement is regulated by an adjustable linkage system between the cam and bellows. The cam rotates at four times the speed of the industrial meter and is synchronized with the meter impellers at the time of attaching the driving unit to the meter. The space within the bellows is connected to the meter inlet, and that between the bellows and pressure vessel is connected to the meter outlet.

A simple prover bell suspended by a wire and enclosed within a pressure vessel serves as the large breather. A larger size cam and linkage system is used with this breather, but otherwise the method of its connection and operation is the same as with the smaller. This breather is illustrated diagrammatically in figure 7.

(4) *Differential pressure Indicator.*—This piece of apparatus is formed by a long, wide and narrow bag of very thin rubber, suspended within a pressure chamber. The narrower sides of this chamber contain glass windows, and the bag is suspended so that when hanging freely, the narrow edges of the bag are visible through the windows. The inside of the bag is connected to the inlet side of the meter under test, and the space between the bag and the pressure chamber is connected to the meter outlet. Thus any difference between the inlet and outlet pressures will cause the bag to swell or flatten. As the force opposing any such pressure difference is due to the small horizontal component of the weight of the bag, it follows that extremely small differences of pressure will distort the bag. A continuous distortion of the bag in one direction does not mean that the pressure difference is increasing so much as it means that the direction of the difference remains unchanged. As will be mentioned later, the method of keeping the bag in its neutral, or zero, position is by regulation of the speed of the motor used to drive the industrial meter. The relatively large capacity of the chambers of this differential pressure indicator make it possible to reduce the number of speed adjustments necessary to maintain zero pressure difference. Furthermore, this large capacity assists in smoothing out any small fluctuations in the rates of flow through the industrial meter and small reference meter.

The extended range in size of the rotary meters makes it necessary to provide two sizes of differential pressure indicators, one having 10 times the volume of the other. To protect these indicators against injury from excessive pressure differences, they are provided with shallow water seals, which are part of their cases.

(5) *Small air blower, diaphragm meter, and brake.*—The small air blower is a direct-connected electrically driven blower capable of withdrawing 2,000 ft^3 of air per hour at a negative pressure of about 2 in. of water and discharging it into the atmosphere. This blower is used to draw air (or gas) through the industrial and reference meters during the displacement test.

As explained later in the description of the clearance test, a diaphragm meter is used to measure a small flow of air or gas vented from the outlet side of the industrial meter. Two sizes of ordinary diaphragm meters, of commercial design and accuracy, are required to cover the large range in sizes of rotary meters. The smaller of these two meters has a capacity of 150 ft^3/hr and is used in the testing of 10 by 30-in. and smaller rotary meters. The larger diaphragm meter has a capacity of 1,000 ft^3/hr and is used in the testing of the larger rotary meters. It is desirable that these meters be equipped with observation indexes.

The brake is a simple wooden clamp that fits over an enlargement of the extension of the impeller shaft, which is not directly driven by the motor and transmission system. The purpose of this brake is to supply sufficient braking force to take up all the backlash in both the meter gears and the gears in the driving system.

The remaining equipment required for the field method includes a stop watch, four thermometers, one vertical water manometer, one inclined water manometer, a revolution counter, and all necessary tools, pipe fittings, and rubber hose required to connect the various units to the industrial meter.

(b) Methods of conducting tests

(1) *Displacement test.*—As the displacement test is usually made with air[10] the first step is to close the inlet and outlet valves of the industrial meter,

[10] This test is not influenced by the gas composition. The line gas can be used where there is no difficulty in its disposal; however, the number of installations of this type are few.

to seal the outlet line with a blank plate,[11] and to remove a short section of the inlet piping, or to otherwise open the meter inlet to the air. The testing equipment is then connected as shown in figure 7, with the small air blower connected to the outlet to draw air through the system. The meter is then purged of the gas first by manual rotation of the impellers and then by operating the small air blower to remove any gas remaining in the system. The location of the meter handwheel is checked to see that it engages the proper impeller shaft so the driving system will rotate the meter in its normal operating direction. The driving system is coupled to and aligned with the handwheel. The cam for operating the breather is loosened and rotated until its position bears the correct phase relationship to the meter impellers and then locked in position.

The reference meter is set in a level position, its zero differential pressure indicator is adjusted so that the oil bead is centered in the bowed tube, and a water manometer is connected to measure the static pressure in the meter. The gears of the driving system for the meter are set to operate the meter at a displacement rate equal to 1 percent or less of the rated capacity of the industrial meter to be tested. To bring the system into final adjustment for a test, the cocks in the lines to the zero differential indicators of both the industrial and reference meters are closed, and the motors driving the industrial meter, the reference meter, and the blower are started simultaneously. The flow of air through the reference meter is adjusted by placing the ⅜-in. cock in about midopen position and adjusting the 2-in. cock until, upon cracking the zero differential indicator cocks, the oil bead remains near the midposition. The indicator cocks are then fully opened and the zero differential pressure is maintained by constant manual adjustment of the ⅜-in. valve.

Next, the rate of rotation of the industrial meter is adjusted to correspond with the rate of flow through the reference meter. To do this, the cocks to the differential indicator of the meter are cracked, and by regulation of the speed of the driving motor the meter speed is adjusted until the rubber bag remains in a neutral position. The indicator cocks are then opened wide, and the meter speed is further adjusted until the bag shows no definite tendency to swell or flatten. However, the bag will usually show a hunting, or oscillating motion, and this is reduced to a minimum by adjusting the amplitude of the mechanically operated breather.

While these adjustments are being made, as well as throughout the test, the brake installed on the industrial meter is set to maintain just enough braking force to eliminate all backlash between the meter gears and to maintain a slight load on the driving motor.

Thermometers are placed in the inlet and outlet connections of the two meters, and the equipment is ready for test as soon as the inlet and outlet temperatures of each meter agree within ±1.5 deg F. The rest positions of the two zero differential pressure indicators are checked, and a record of the reading of the reference meter counter is made just before a test is started. The start of a test occurs as a mark on the industrial meter handwheel passes some reference point, and the reference meter counter is started at the same instant by the engagement of its clutch. While the test is in progress one operator regulates the speed of the industrial meter and another regulates the ⅜-in. cock so that zero differential pressure is maintained across each meter. A third observer reads the meter thermometers and inlet pressures every 2 min throughout a test, and keeps a record of the number of revolutions made by the industrial meter, either by direct count or by observation of the meter counter readings at the start and finish of a test. He also measures the duration of a test with a stop watch.

The usual duration of a displacement test is from 15 to 20 min. It is concluded by disengaging the reference meter index as the mark on the industrial meter handwheel again passes the reference point. The reference meter index reading is recorded, each observer is shifted to perform different duties, and a second test is made as soon as all conditions have been verified.

Upon completion of the second test the rest positions of the two zero differential gages are checked to be sure there has been no shift, and the results from the two tests are computed. These results by different observers should agree within 0.15 percent, and are computed by the equation

$$d_i = \frac{d_r N_r}{N_i} \times \frac{p_r T_i}{p_i T_r},$$

[11] If a blank plate cannot be installed in the outlet line, the line between the meter and outlet valve should be sealed with water.

in which

d (ft^3) = displacement per revolution

N = number of revolutions

p (in. Hg) = absolute pressure at meter inlet

T (° F) = mean of the average inlet and outlet absolute temperatures, i. e., observed temperatures +458 deg.

Subscripts i = industrial meter under test

r = reference meter.

Table 1 shows the observed data and computed result from the displacement test of the 10- by 30-in. meter already mentioned.

TABLE 1.—*Meter displacement test*

Meter No.: 11246 Meter size: 10 by 30 in.
Location: Southport and Courtland. Date: November 20, 1940.

Time intervals		Industrial meter				Reference meter			
		Index reading	Static pressure	Temperatures		Index reading	Static pressure	Temperatures	
				Inlet	Outlet			Inlet	Outlet
1		2	3	4	5	6	7	8	9
min	*sec*	*rev×4*	*in.* H_2O	° *F*	° *F*	*rev×1*	*in.* H_2O	° *F*	° *F*
0	0	28, 265	0.0			53226. 45	0.0		
1	0			51. 9	50. 7			53. 7	54. 5
3	0			51. 9	50. 8			53. 5	54. 5
5	0			52. 0	50. 8			53. 3	54. 5
7	0			52. 0	50. 8			53. 1	54. 3
9	0			51. 9	50. 8			53. 0	54. 2
11	0			51. 9	50. 9			52. 9	54. 1
13	0	28, 387		51. 9	50. 9			52. 7	54. 0
15	28		0.0			58412. 81	0.0		
Revolutions		30. 5				5186. 36			
Averages			0. 0	51. 97	50. 81		0. 0	53. 17	54. 30
				51. 39				53. 74	
Absolute			29. 59	509. 39			29. 59	511. 74	

Reference meter displacement, from figure 10 for 335 rpm, $d_r = 0.024108$ ft^3.

Industrial meter displacement,

$$d_i = \frac{0.024108 \times 5186.36}{30.5} \times \frac{29.59}{29.59} \times \frac{509.39}{511.74} = 4.0806$$

(2) *Clearance test.*—The purpose of this test is to determine the relation between the pressure drop across a meter and the rate of flow through the clearance spaces of the meter. The procedure employed consists in developing a pressure difference across the impellers by mechanically driving the meter with the outlet closed. The gas that is thereby pumped into the closed outlet chamber by the rotation of the impellers returns to the inlet chamber through the clearance spaces.

As the inner surface of a meter case is slightly uneven, the width of the clearances between the impellers and case will vary for different angular positions of the impellers. Hence in trying to maintain a constant pressure difference across the impellers, it would be necessary to vary the rate of rotation throughout each revolution, going faster as the impellers pass a wide clearance space and slower as they pass the narrower spaces. This, however, would not give a true leakage-time relation because the time interval taken to pass a given arc of narrow clearance will be longer than that taken to pass an equal arc of wide clearance. To overcome this disadvantage the meter is driven at a constant rate of rotation by the driving system used with the displacement test, and the pressure difference is maintained constant by venting a small variable flow of air or gas from the discharge chamber of the meter. This vented gas or air is metered with the diaphragm meter, and its volume reduced to the conditions (i. e., temperature and pressure) that exist within the rotary meter. The simple subtraction of this metered volume from that calculated by multiplying the meter displacement by the number of revolutions gives the clearance flow during the test period.

As the rate of flow through the clearance spaces will vary with the specific gravity (i. e., density) and viscosity of the gas, it is desirable from this standpoint to make this test with the same kind of gas that the meter is to measure. To do this, the removed section of inlet pipe is replaced, the inlet valve opened, the meter completely purged of air, and the testing equipment used with the displacement test replaced with that shown schematically in figure 8. It is noted that both breathers are removed and replaced by the inclined draft gage and the small rotary reference meter is replaced by the diaphragm meter. During a test the observed quantities are draft-gage reading, number of meter revolutions, time interval, and volume of gas vented through the diaphragm meter. Determinations of the volume of clearance flow are made at a number of different pressures covering the operating range of the meter, and the result from each is expressed in terms of cubic feet per minute by using the equation

$$q_c = \frac{(Nd - V_i)60}{t},$$

in which

q_c (ft^3) = clearance flow per minute
N = number of revolutions
d (ft^3) = displacement per revolution
V_i (ft^3) = volume of vented gas (difference of diaphragm meter readings)
t (sec) = test period.

Table 2 shows the observed data and computed results from the clearance pressure drop test of the 10- by 30-in. meter. It should be noted that these tests were made with air to facilitate the comparison of this method with the transfer method made previously with air.

TABLE 2.—*Clearance test*

Meter: 11246.
Meter size: 10 by 30 in.
Rated hourly capacity: 110,000 ft^3/hr.
Meter displacement listed by manufacturer: 4.115 ft^3.
Date: November 22, 1940.
Location: Southport & Courtland.

Differential pressure	Time interval	Volume displaced by rotation of meter	Volume through diaphragm meter	Volume through clearances, col. 3—col. 4	Rate of flow through clearances, 60×col. 5 ÷ col. 2
1	2	3	4	5	6
in. H_2O	*sec.*	*ft*^{3}	*ft*^{3}	*ft*^{3}	*ft*^{3}*/min*
0.05	92.2	4.115	2.35	1.765	1.15
.10	63.4	4.115	2.14	1.975	1.87
.10	64.0	4.116	1.93	2.185	2.05
.10	64.0	4.115	1.95	2.165	2.03
.20	54.1	4.115	0.87	3.245	3.60
.40	55.2	8.230	2.73	5.48	5.96
.40	54.9	8.230	2.57	5.66	6.19
.40	54.9	8.230	2.54	5.69	6.22
.60	53.4	12.345	5.07	7.28	8.18
.60	53.4	12.345	5.05	7.30	8.20
.80	53.4	12.345	3.44	8.90	10.00
.80	53.2	12.345	3.39	8.96	10.11
1.00	61.4	16.46	3.73	12.73	12.44
1.00	61.1	16.46	3.73	12.73	12.50

(3) *Auxiliary clearance test.*—In most installations the industrial meter is in a location where small amounts of gas discharged through the diaphragm meter cannot be vented conveniently, so the clearance test is made with air. In this case the test is performed in the manner just described, the only difference is that in setting up the equipment the inlet section of pipe is not replaced and the small blower is connected to draw air through the diaphragm meter. Afterward an auxiliary test is made to obtain the factors for computing the rates at which gas would flow through the clearances. To do this all flow through the diaphragm meter is stopped, and the differential pressure across the impellers is held constant by varying the speed of the industrial meter. This speed variation, as well as the driving force necessary to operate the meter, is obtained by the manual operation of the handwheel, and the only test equipment required is a draft gage and a stop watch. One series of tests is made with air in the meter and another series of tests is made after the meter has been reconnected and purged with gas just previous to the removal of the blank in the meter outlet for its return to service. The tests in this series are made at the same differential pressures as were recorded during the regular clearance test with air; individual conversion factors are thus obtained for each originally recorded differential pressure.

Although this procedure may not be quite as accurate as that of making the clearance test with gas, no significant differences have been noticed. On the other hand, it has the advantage that it furnishes clearance data on meters independent of the gas being metered at the time and thus facilitates the comparison of meter tests, and also provides a basis for a simple method of checking the condition of the meter in the future.

(4) *Rate test.*—This test consists of observing the differential pressure across the meter impellers corresponding to various operating rates of the meter. The differential pressure is read from the draft gage, and the rate of operation of the meter is determined with a stop watch and the direct observation of a revolution counter or tachometer.

As this test is affected by the gas composition it is always performed in the field under normal operating conditions. To place the meter under these conditions, the handwheel is disengaged, the inlet section of pipe replaced (if it was not replaced earlier), the blank or water seal in the meter outlet is removed, and all the special test equipment except the draft gage is removed. Figure 9 shows the meter connections for this operation, and columns 1 and 2 of table 3 show the observed data taken during the test on the 10- by 30-meter.

It should be noted from figure 10 that the industrial meter is now connected in the line so all the gas passed through the meter goes to the user whose consumption the meter has been installed to measure. As it is desirable to vary the meter speed to cover an extended operating range, it will be necessary either to have a bypass around

TABLE 3.—*Speed test and meter proof*

Meter: No. 11246
Meter size: 10 by 30 in.
Meter speed at rating: 445.5 rpm.

Date: March 24,1939.
Location: 3921 Wabash Avenue.

Meter speed	Observed differential pressure, h	Adjustment for tip velocity $(4/3)h_c$	Effective differential pressure, h_e	Gas flow through clearance channels, q_c		Meter displacement at—			Meter proof	Meter speed, % rated capacity
						Zero pressure difference	Observed pressure difference	Listed by manufacturer		
1	2	3	4	5	6	7	8	9	10	11
rpm	*in.* H_2O	*in.* H_2O	*in.* H_2O	*ft³/min*	*ft³/rev*	*ft³/rev*	*ft³/rev*	*ft³/rev*	%	%
14.41	0.061	0.000	0.061	1.4	0.0972	4.0806	4.1778	4.1150	98.50	3.23
48.16	.102	.003	.099	2.0	.0415	4.0806	4.1221	4.1150	99.83	10.81
102.31	.177	.016	.161	3.1	.0300	4.0806	4.1106	4.1150	100.11	22.96
219.11	.356	.072	.284	4.7	.0214	4.0806	4.1020	4.1150	100.32	49.18
333.94	.603	.168	.435	6.6	.0197	4.0806	4.1003	4.1150	100.36	74.95
481.87	.963	.349	.614	8.3	.0172	4.0806	4.0978	4.1150	100.43	108.16

the meter or to arrange with the user to vary the rate of consumption to suit the various rates desired in the test. In some cases the total consumption of the user may be considerably below the rated capacity of the meter, but this is not objectionable as long as the actual operating range is covered during the test.

(c) Computation of the meter proof

The proof curve of a rotary industrial meter is obtained from the results of the tests described above by a combination of graphical and mathematical steps. The first step is to plot the results of the clearance test and the rate test on a common mat, as illustrated by lines (h) and (q_c) of figure 2. The next step is to compute and plot the values of the effective pressure drop, (h_e), across the clearance channels for the determination of the net clearance flow. The reason for this step, and a fuller explanation of it, are briefly as follows.

When the impellers of a rotary meter are in motion, a velocity pressure is produced just ahead of each impeller tip where it is closest to the meter case. Also, a negative velocity pressure is produced immediately behind each tip. Each of these pressures is equivalent to the velocity pressure corresponding to the tip speed of the impellers. The combined effect of these two velocity pressures tends to produce a flow of gas or air through the clearance space in a direction counter to the flow produced by the normal differential pressure across the meter. Similar velocity pressures, acting to produce more flow in the same direction as the main gas flow through the meter, are produced at the so-called contact line between the two impellers. However, the differences between the velocities of the impeller surfaces at this line are lower than those between the impeller tips and case. Similar velocity pressures are produced between the ends of the impellers and meter case, but again the average velocity difference between the two surfaces is less, and in addition the length of these clearance channels is much greater.

An analysis of the probable effects of these velocity pressures together with studies of the results of numerous meter tests indicated that their combined effects are very nearly equal to the pressure required to produce a gas velocity equal to 4/3 the velocity of the impeller tips. The effective pressure drop (h_e) is evaluated by the empirical equation.

$$h_e(\text{in. } H_2O) = h - (4/3)h_c, \tag{1}$$

in which

$h(\text{in. } H_2O)$ = total observed pressure drop across the meter corresponding to a particular meter speed

$h_c(\text{in. } H_2O)$ = velocity pressure corresponding to the tangential velocity of the impeller tips.

The value of h_c is computed as follows: Let

D (in.) = maximum diameter of the meter impellers

N (rpm) = meter speed

G (ratio) = specific gravity of the gas, air = 1

v (ft/sec) = velocity, and using

0.075 (lb/ft³) = average density of air at meter

62.34 (lb/ft³) = average density of water in manometer

32.17 (ft/sec²) = acceleration of gravity.

Then

$$h_c=\frac{v^2}{2g}=\left[\frac{ND\pi}{(12)(60)}\right]^2\left[\frac{(0.075)(12)(G)}{(2)(32.17)(62.34)}\right] \quad (2)$$
$$=4.27G(ND)^2\times10^{-9}.$$

Columns 3 and 4 of table 3 show values of $(4/3)h_c$ and (h_e) computed for the 10- by 30-in. meter, and the values of (h_e) plotted against revolutions per minute are shown by the dotted line in figure 2.

The third step in the computations is to obtain values of the net clearance flow by means of the three curves of figure 2, corresponding to each observed value of the pressure drop (h), column 2, table 3. This is done by starting on line (h) with one of the values from column 2, moving vertically down to the line (h_e), then horizontally to the left to the intersection with the line (q_c), and vertically down to the clearance flow scale to read the net value of (q_c). This is recorded in column 5 of table 3.

The fourth step is to divide the values of (q_c) in column 5 by the corresponding values of N, column 1, thus giving values of the clearance flow per revolution. These values are then added to the static meter displacement obtained from the displacement test, thus giving the dynamic displacement per revolution, column 8.

The results of gas-meter tests are commonly reported by what is known as the proof of the meter. It is the factor, expressed as a percentage, by which the indications of a meter must be divided in order to obtain the true volume of gas metered. Hence, the fifth step is to compute the values of the meter proof by dividing 100 times the listed meter displacement, as given by the manufacturer, by the several values in column 8 and listing the results in column 10.

These computations are all that are needed as far as any individual meter is concerned. However, in order to be able to compare the proof curves of meters of different design and size, it is desirable to refer them to a common basis. Such a basis is obtained by expressing the meter speed as a percentage of the meter speed at rated capacity. The speed at rated capacity is obtained by dividing the rated capacity of the meter, as given by the manufacturer (usually in ft^3/hr), by 60 times the listed displacement. Hence, the sixth and last step in the computation is to divide 100 times the meter speeds of column 1 by the rated capacity speed and listing the results in column 11. The result of plotting the values in column 10 against those of column 11 is shown by the curve of figure 6.

2. Transfer method of meter calibration

(a) Description of equipment

In this method the flow of air through the meter under test is discharged into a suitable container. The time interval of filling the container or the meter readings at the start and end are recorded. The air in the container is then measured out through calibrated meters. The indications of the meters are then referred to a common density basis for use in the computation of the proof of the first meter. The principal items of equipment for this method are the transfer container, the reference meters for measuring the air out of the container, and the blowers for circulating the air. Other items of equipment, which contribute to the smoothness of operation and accuracy of results, are the slide valves and heat exchanger in the air ducts and the electric-spark revolution recorders on the meters. A description of the equipment, the method of conducting a test, and making the necessary computations follows.

(1) *Transfer container.*—The transfer container used in this method is a collapsible rubberized fabric bag with a maximum capacity of about 2,500 ft^3. When this bag is inflated it takes the shape of a cylinder with hemispherical ends. It is mounted with the axis of the cylinder horizontal and supported at the maximum horizontal cross section by a wooden frame. To aid in the maintenance of a uniform pressure within the bag during inflation and exhaustion, especially at the start of the inflation period and end of the exhaustion period, small counterweights are attached by strings leading over pulleys to tabs along the top of the bag. By this means the pressure in the bag is maintained at all times, at about 0.05 in. of water above the atmospheric pressure, which facilitates the final evacuation of the bag.

(2) *Primary reference meter.*—The primary reference meter is the same piston meter used as a part of the Joliet reference gas meter described in Bureau Research Paper 908. This meter, on removal from Joliet to its present location, was opened and carefully inspected, and, upon being reassembled, a few minor changes were made to improve its operation at or close to atmospheric pressure. The oil sump was enlarged and a

vacuum system added to assist in the removal of air pockets from the hydraulic system and to aid in the drainage of oil from the chambers for the collection of internal oil leakage. Electric solenoids were provided for operating the fourway oil cock and an electric recording unit was added to count and record piston strokes. The heat exchanger on the inlet line was enlarged, a new water-spray system was installed, and the entire meter was enclosed in a galvanized sheet-iron housing.

(3) *Secondary reference meters.*—The larger secondary reference meter is a 6- by 18-in. rotary meter particularly machined to permit it to operate at speeds up to 2,000 rpm, which is about three times the rated speed of a commercial meter of this size. The meter is fitted with special inlet and outlet connections to improve its calibration characteristics and to minimize the pressure drop when the meter is operated at high speeds. To aid in regulating its temperature, the meter and inlet and outlet connections are enclosed in a sheet-metal housing and sprayed with water drawn from a storage basin forming its base. This storage basin is supplied with both hot and cold water so that the temperature of the circulating water, which determines the temperature of the meter, can be adjusted to any desired value. The housing of this meter is shown at the extreme left in figure 5.

The smaller secondary reference meter is a 6–C tin-case diaphragm meter, and it is used to withdraw the final volume of air from the bag, because a rotary displacement meter is not suited for such low and nonuniform rates of flow. This meter is also used to introduce an initial volume of air into the transfer container to lift the top of the bag away from the duct opening. Therefore, it is so arranged that air can be metered through it in either direction.

(4) *Heat exchanger.*—The heat exchanger shown in the foreground of figure 5 forms a part of the inlet duct to the large secondary reference meter. The purpose of it is to bring the temperature of the air entering the secondary reference meter to that of the meter. This heat exchanger, through which is circulated the same water that is used to spray the meter, was designed to reduce the temperature difference between the outlet air and inlet water to 0.1 deg F when the initial difference between the inlet air and outlet water is 30 deg F.

(5) *Air blowers.*—Two blowers of a type commonly used in ventilating work are used to circulate the air through the ducts connecting the meter under test, the storage bag and the reference meters. Their cases were made tight by welding, and leakage around the shafts is prevented by special packing glands into which oil is fed under a pressure greater than that of the air on either side. The large blower, when operated at 1,740 rpm, is rated to deliver 16,000 ft^3/min against a back pressure of 9 in. of water. The small blower is rated to deliver 1,600 ft^3/min against the same back pressure when operated at a speed of 1,800 rpm.

(6) *Prime mover.*—The prime mover furnishing all the power required to operate the blowers and auxiliary equipment is a stock automobile engine equipped with a governor for automatic maintenance of constant speed. Although an electric motor would doubtless serve the purpose as well or better, the engine was selected because originally it was planned to have the equipment portable and independent of the availability of electric power.

(7) *Shutter valves.*—The shutter valves for diverting the air flow in and out of the transfer bag were designed to operate without displacing any air from one passage into another. As the further operating requirements to be fulfilled by the larger valve are more exacting, the construction and operation of this valve will be described in greater detail. The major operating requirements are a large port area, no leakage, no air displacement during motion, and a very short time of travel—a small fraction of a second. Studies of the possible valve designs to meet these conditions led to the development of a shutter or slide valve constructed entirely of standard cold-rolled steel members.

The seat and valve cover are made from milled sections of cold-rolled steel fastened together to form a grilled framework supporting the valve slide. When assembled the seat is mounted on a 2- by 3-ft rectangular frame with a central partition bisecting the two shorter sides to form the beginning of the dividing wall between the two outlet ducts. Oil grooves in both seat and cover completely encircle the openings, and oil under a slightly higher pressure than the air on either side of the valve is fed into these grooves to seal the valve. These grooves are covered at all times by the valve slide or by narrow spring-operated bars that slide over and cover the grooves whenever they are uncovered by the movement of the main slide plate. Figure 11 shows a vertical section

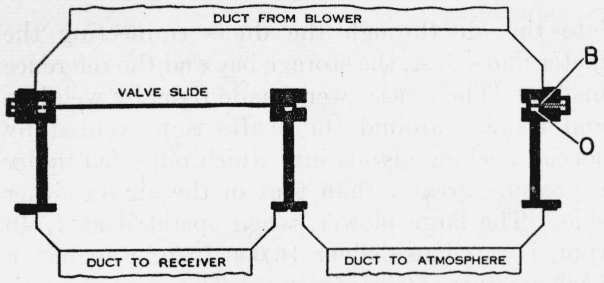

FIGURE 11.—*Longitudinal section through large shutter valve, showing relation of valve slide, oil grooves, and oil groove covering bars.*

through the valve and illustrates the location of the oil grooves and sliding bars when the valve slide is in one of its two rest positions.

The valve slide, or plate, is a single piece of ⅛-in. flat, cold-rolled steel plate, about 15 by 38 in. It moves in a direction parallel to the short dimension, and the relation of its width to that of the valve seat is such that, as it starts to close one port, it simultaneously starts to open the other. Thus the total area of open passage through the valve remains constant. Motion of the valve is obtained from three oil cylinders and pistons connected to the center and ends of the slide.

The oil cylinders, connections, and supports are designed for an operating oil pressure of 500 lb/in^2. With this pressure, the force transmitted by each piston rod is 750 lb. and the mounting for the cylinders and valve frame is such that the application of the total combined force of 2,250 lb. on the valve slide does not cause any deflection in the valve slide, seat, or cover, in excess of 0.002 in.

A cross section of one of the oil cylinders is illustrated in figure 12. The cylinders are double-acting, with the piston rods extending through bearings in both ends to insure that the actuating forces in the two directions are equal. The piston rods are square, to facilitate adjusting for clearance changes and heavy enough to withstand the full operating force in both tension and compression.

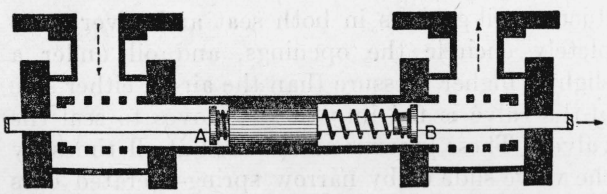

FIGURE 12.—*Longitudinal section of a cylinder, showing the outlet ports which are closed by the piston, thereby decelerating it.*

The main purpose of this particular oil cylinder design is to assure a very short time of valve travel by providing for maximum acceleration at the start of the valve movement and a controlled deceleration at the end. The two plungers, *A* and *B*, on opposite sides of the piston are free to slide on the piston rod, and when unrestrained the springs cause them to assume a position about 3 in. from the ends of the piston. The illustration shows plunger *B* in about this position, with the piston moving from left to right. As the piston nears the end of its stroke, plunger *B* closes the exit oil port at the end of the cylinder and causes all the remaining oil to be discharged through ports in the side of the cylinder. These side discharge ports are closed by the piston during the final 2 in. of valve travel, and are shaped to give a uniform deceleration to the valve. At the end of the valve movement the end of the piston is flush with the inside face of the plunger *B*, and plunger *A* is being separated from the piston by its spring. This separation is completed before the valve moves in the opposite direction, as it takes but a few seconds, a time interval which is always less than that between successive movements of the valve. To start motion in the opposite direction, oil is introduced through the large port at the end of the cylinder, and as the piston moves through the first 2 in. of its stroke, additional oil ports are opened. Figure 13 shows the valve in course of construction.

The oil for operating the pistons is circulated by a high-pressure gear pump, and its flow to and from the cylinders is controlled by a four-way plug cock. Particular attention was given to the design of this cock to assure a very smooth action. The core of the cock is suspended in the body by two double-row precision-ground ball bearings. When fully open in either direction the area of the oil passage through the cock is equal to the combined area of the three oil pistons. Rotating the core of the cock through 90° diverts the high-pressure oil from one end of the cylinders to the other, and at the same time permits oil from the discharging ends of the cylinders to flow back to the oil sump.

Two steel bottles, each of about 100-in.^{3} capacity, are mounted in parallel above the four-way cock and serve as accumulators or reservoirs for high-pressure oil. When the shutter valve is ready for operation about 40 percent of the volume of these accumulators is filled with carbon

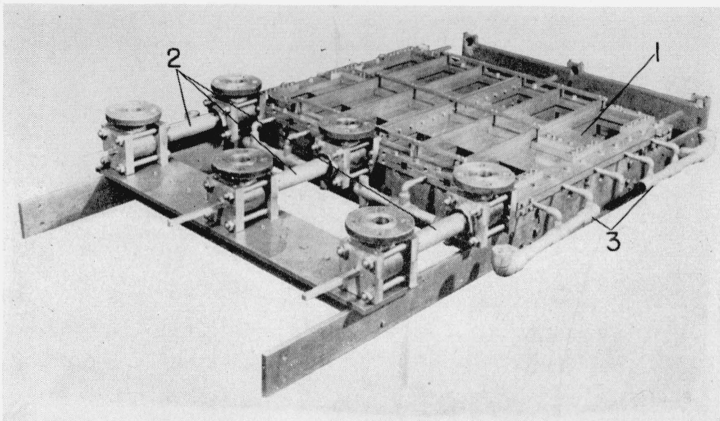

FIGURE 13.—*Large slide valve nearly ready for installation, viewed from the top or inlet side.*

Valve slide, 1, is in midposition; the operating cylinders, 2, with their pistons have been mounted; and one oil distribution header, 3, supplying the sealing oil grooves is nearly completed.

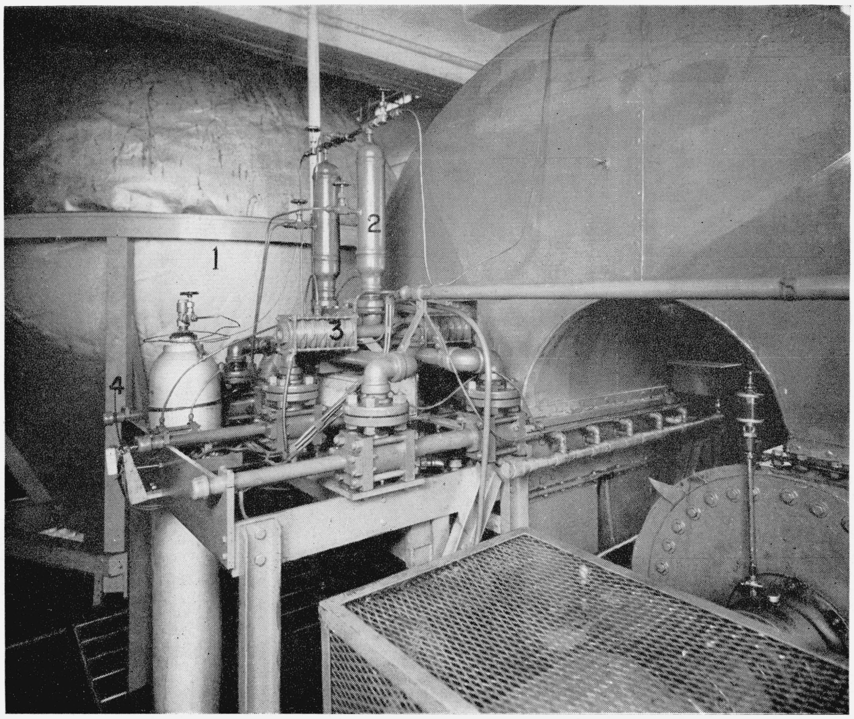

FIGURE 15.—*Completed assembly of large slide valve.*

1, Transfer receiver; 2, accumulators; 3, solonoid for the large four-way oil valve; 4, microswitch in series with industrial meter recorder.

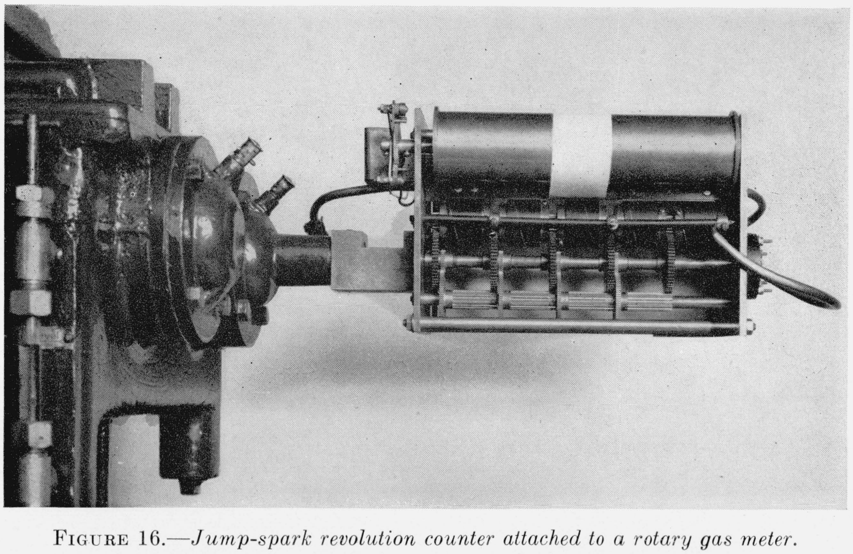

FIGURE 16.—*Jump-spark revolution counter attached to a rotary gas meter.*

In an actual test, the width of the paper used is equal to the full length of the roll.

dioxide from high-pressure storage. When the four-way cock is rotated the carbon dioxide, by expanding, causes the rate of oil flow into the cylinders to be greatly in excess of the pump output, thus effecting very rapid operation of the valve slide. By this expansion and ejection of oil the pressure in the accumulators drops about 40 percent, and it requires about 8 seconds for the pump to refill the accumulators and restore the original pressure. This pressure may be maintained at any desired value up to 500 lb/in.^{2} by the adjustment of a relief valve on the pump discharge. This method of supplying power for the slide movement, together with the shape of the cylinder ports, provides a very rapid acceleration and controlled deceleration.

Two large electric solenoids, each capable of exerting a pull of about 40 lb through a distance of 4 in. are used to rotate the core of the four-way cock. The current for these solenoids is obtained from two 6-volt storage batteries connected in series and controlled by two switches that are interlocked by a system of relays. The first of these is a double-throw toggle switch, and the side to which it is thrown determines which solenoid is to be energized and thus the direction in which the shutter valve will move. The second is a rotating switch driven by the meter being tested, which insures that the meter impellers are always in the same position when the valve slide starts to move in either direction. The electric circuit used to accomplish this result is shown in figure 14.

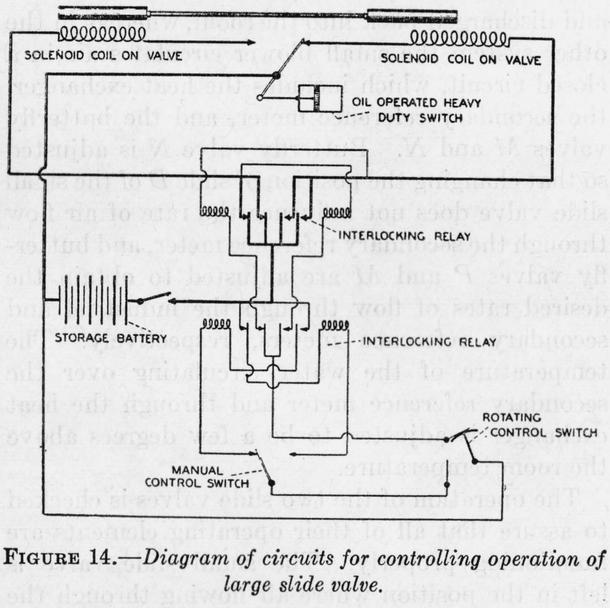

FIGURE 14.—*Diagram of circuits for controlling operation of large slide valve.*

The solenoid circuits are automatically opened by an oil-operated, heavy-duty snap-acting knife switch a fifth of a second after the movement of the four-way cock so as to avoid having the relay contacts open under the heavy current (100 amperes or more). Also all other electric circuits controlling the energizing of the solenoid circuits are automatically opened immediately after their respective relays have completed their individual movements and are not energized again until the start of the next movement. The short time the various electric circuits are energized permits the use of very heavy currents in order to obtain maximum speed of action without danger of overheating the relays or solenoids. Figure 15 shows the valve in its actual service location, the entrance and exit ducts, the oil headers for sealing the valve, the hydraulic cylinders, the accumulating bottles, the four-way cock, and the two electric solenoids.

The small shutter valve is similar to the large one, but it is much simpler because of its smaller size and the fact that the time interval between successive valve movements can be measured in minutes rather than seconds. The valve seat and cover are each made from a single piece of flat cold-rolled steel 3/4 in. thick with ports and oil grooves milled out. The valve slide is a single piece of 1/8-in. cold-rolled steel plate with the piston rods attached to extensions at the four corners and operated by two double-acting cylinders. These two oil cylinders with their pistons are designed to control the acceleration and deceleration like those for the large valve, but the design is not as elaborate because the mass and required speed of the valve slide are much less than those of the larger valve. A simple 1/4-in. four-way cock operated by a pair of solenoids is used to control the operation of this small shutter valve. The same type of relay control system is used, with the rotary switch being operated by the secondary reference meter. The high-pressure oil line to the four-way valve is taken directly from the oil-pump discharge that connects it indirectly to the two high-pressure accumulators of the large shutter valve. The total port area of this small valve is about 20 in.^{2}, and the stroke of the valve slide is about 3¼ in. This small shutter valve with its inlet, its two outlet ducts, and its oil reservoir are visible just above the heat exchanger in the foreground of figure 5.

(8) *Revolution recorders.*—It has been mentioned previously that it is necessary to start and finish

the test of a rotary meter without any change in the meter speed, so it is necessary that the meter reading at the start and finish be taken while the meter is in operation. As it is impossible to read by eye the index of any operating meter at the exact instant of the beginning or ending of a test, a form of electric recording index was developed that is attached to both the reference meter and the meter under test. Figure 16 shows one of these recorders, which has a series of five rotating helices geared together so a 10-to-1 relation exists between revolutions of successive helices. Each helix is formed by winding Nichrome wire in a helical groove cut in a Bakelite spool with a uniform advance of 1 in./revolution. In attaching the recorder to the meter, the first helix is connected directly to the regular meter index shaft; in the case of a rotary meter this is an extension of one of the impeller shafts.

The record is obtained by causing an electric spark to pass from each helix wire through a sheet of paper to the sharpened edges of stationary stainless-steel strips mounted parallel to the axes of the helices. The gap between the metal strips and the helical wires is just enough to pass a sheet of writing paper freely. The electric sparks burn small holes in the paper, thus locating and recording the exact positions of each helix at the instant of current flow. The paper is advanced automatically after each record, and at the end of a test it is removed and placed on a transparency frame, where the spark record is read with the aid of a suitable scale.

Two ordinary automobile engine ignition coils are used with each recorder to supply the high-voltage current. The secondary, or high-tension, winding of one coil is connected to the first two helices, which are series connected, while the secondary of the other coil is connected to the remaining three helices, which are also series connected. Each of the primary windings of the two coils are connected in series to make and break switches and a source of current—dry cells in this case. Two such switches are used with each of the recorders for the meter under test and the secondary reference meter; those of the former are mounted on the large shutter valve and those of the latter on the small shutter valve. These switches are three-way microswitches, with condensers connected across the switch points, and mounted so one is operated as the shutter starts moving and the other is operated as the shutter completes its movement. In this manner the time of motion of the large shutter valve is recorded in terms of the movement of the meter under test, and the time of motion of the small shutter valve is recorded in terms of the movement of the secondary reference meter.

Similar jump-spark recorders are used with the piston meter and the small secondary reference meter, but these meters are stationary when the recordings are made, so the operation of the primary circuit make-and-break switches and the advancement of the paper are done by hand. A smaller operating range is required with these two meters, so four instead of five helices are used. Also, as the function of the piston meter recorder is to count the number of piston strokes and not revolutions, a solenoid operated ratchet is used to advance the first helix one-tenth turn for each stroke.

(b) Method of Conducting Tests

(1) *Testing of industrial meters.*—To test an industrial meter, such as a rotary meter, the outlet of the meter is connected to the suction side of the large blower, as shown in figure 17. The revolution recorder is connected to the meter index shaft or an end of one impeller shaft, and other test equipment such as thermometers and pressure gages are installed. With the shutter valves in the positions shown in figure 17, the engine and blowers are started and brought up to the desired speed. In one system this causes air from the room to be drawn through the industrial meter and discharged back into the room, whereas in the other system the small blower circulates air in a closed circuit, which includes the heat exchanger, the secondary reference meter, and the butterfly valves M and N. Butterfly valve N is adjusted so that changing the position of slide D of the small slide valve does not influence the rate of air flow through the secondary reference meter, and butterfly valves P and M are adjusted to obtain the desired rates of flow through the industrial and secondary reference meters, respectively. The temperature of the water circulating over the secondary reference meter and through the heat exchanger is adjusted to be a few degrees above the room temperature.

The operation of the two slide valves is checked to assure that all of their operating elements are functioning properly. The small slide valve is left in the position where air flowing through the

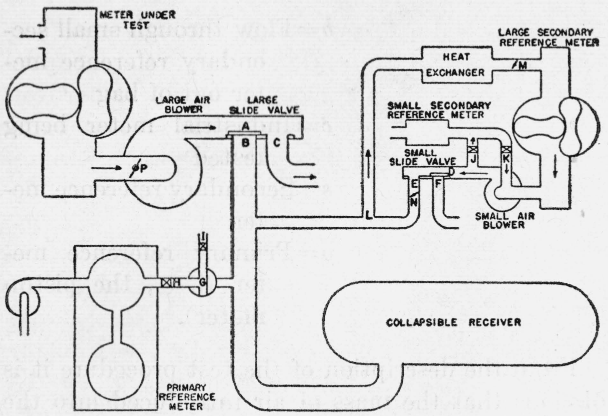

FIGURE 17.—*Diagram of the arrangement of equipment used in the transfer method of testing large-capacity gas meters.*

secondary reference meter is discharged into outside air until practically all the air in the bag has been withdrawn and is then returned to the position shown in figure 17.

Before starting a test all remaining air must be removed from the bag. This is done by adjusting valve *N* to produce a back pressure on the blower discharge of about 2.5 in. of water above atmospheric pressure, and then valve *J* is opened, which permits air from the bag to be discharged through the small secondary reference meter to the outside. As the last of the air is withdrawn from the bag the pressure at the blower outlet drops to atmospheric pressure, while at the blower inlet the pressure drops to 2.5 in. of water below atmospheric pressure. Operation of the equipment under these conditions is continued until successive spark records spaced 5 min. apart show a change of meter reading of less than 0.2 ft^3, as it has been found that this provides a reproducible criterion of complete evacuation of the air from the bag. Also, it provides a very good check against leakage, because if there is any leakage sufficient to affect the results adversely, it will not be possible to reduce the rate of outflow to as low a value as this. The last spark record made while evacuating the bag also becomes the first record for the test, which can be started as soon as valve *J* has been closed.

The first step in the test procedure is to measure a small amount of air into the bag to separate the top and bottom surfaces. This is done in order that the bag can receive a large and suddenly diverted flow of air into it without injury and without causing any appreciable resistance to this air flow. To accomplish this, valve *K* is opened a predetermined amount and butterfly valve *N* is changed back to its original setting. This draws air from the room through the small secondary reference meter and discharges it into the bag at a rate of about 10 ft^3/min. At the end of 5 min valve *K* is closed and a record of the index of the meter is made with the jump-spark recorder. The temperature of the air flowing through the meter is recorded every minute during this introduction period, and the average of these temperatures is taken as the meter temperature and used as such in the computations.

The second step in the test procedure comprises the main portion of the test, wherein air measured by the industrial meter being tested is discharged into the transfer bag. As this meter has been operating at the desired rate during all the preparation period so that it should have reached a condition of temperature equilibrium with the air of the room, we proceed by closing the switch, which will shift slide *A* of the large shutter valve. This closes duct *C* and opens duct *B*, causing the air flowing through the meter to be discharged into the transfer bag. When the bag is nearly full, the slide *A* is returned to its starting position. During each movement of the valve slide two records are made on the jump-spark recorder. The difference between the means of each pair of records [12] represents the number of revolutions the industrial meter has made while it was discharging air into the bag, and the difference between the two records of a single pair represents the number of revolutions the meter has made while the valve slide was shifting positions. Other data that are recorded at frequent intervals during this portion of the test procedure include the air temperature at both inlet and outlet of the meter, pressure drop through the meter, gage pressure at the meter inlet, and various operating readings that show the functioning of the meter-testing equipment but are not needed in the computations.

The next step is to measure the air out of the bag through the secondary reference meters. As the larger reference meter has been in operation for considerable time and has reached equilibrium condition, this step is started by the movement of

[12] The mean value was used to reduce the effects of any variations in rate of valve travel. However, as the rate of valve travel proved to be very uniform, the use of either set of extremes would not change the test results appreciably.

slide D of the small shutter valve to close port E and open port F. With this change, air is drawn from the bag, through the heat exchanger, through the secondary reference meter, and discharged into the room. It normally requires 6 to 7 min for this operation, and during this time the static pressure, pressure drop through meter, and both inlet and outlet meter temperatures are recorded every minute. Just before the bag is completely deflated the small shutter valve slide D is moved back to its starting position. The same type and number of jump-spark records are made with each movement of this small shutter valve as were made with the large shutter valve; thus a record of the speed of the valve action and number of revolutions made by the secondary reference meter is obtained.

The final step is to complete the evacuation of the bag, metering it out through the small secondary reference meter in the manner already described, with the exception that in this case the temperature of the air entering the meter is read every minute.

(2) *Computations of test results.*—To illustrate the computations involved in these tests, the following symbols will be used:

C (ratio) = Coefficient or correction factor of the meter under test

d (ft³) = Displacement per cycle or per revolution

M (lb) = Total mass of air passed through the meter

n = Number of cycles or revolutions made by the meter

P (percent) = "Proof" of meter under test

p (in. Hg. at 32° F) = Average absolute static pressure of air at meter inlet

T' (°F) = Average temperature of air flowing through meter

ρ (lb/ft³) = Density of the air

Subscripts a = Flow through small secondary reference meter (i. e., the diaphragm meter) into bag

b = Flow through small secondary reference meter out of bag

c = Industrial meter being tested

s = Secondary reference meter

p = Primary reference meter (i. e., the piston meter).

From the description of the test procedure it is obvious that the mass of air introduced into the bag is equal to the mass of air withdrawn from the bag, providing there has been no leakage or condensation of any moisture in the introduced air. It should be noted that the test procedure includes a test for leakage and also that the temperatures of the secondary reference meters are maintained slightly higher than that of the room. Care is also exercised to prevent any condensation of moisture within the bag. Under these conditions the following equations apply:

$$M_a+M_c=M_s+M_b \tag{5}$$

or

$$M_c=M_s+M_b-M_a \tag{6}$$

also

$$\left.\begin{aligned} M_a&=\rho_a\times d_a\times n_a\\ M_c&=\rho_c\times d_c\times n_c\times C_c\\ M_s&=\rho_s\times d_s\times n_s\\ M_b&=\rho_b\times d_b\times n_b \end{aligned}\right\} \tag{7}$$

The density ρ may be computed by [13]

$$\rho=\frac{(1.3225)\,(p-0.378e)}{458+T'}, \tag{8}$$

in which e (in. Hg at 32° F) is the partial pressure of water vapor in air. This equation can be rearranged to the following:

$$\rho=\frac{(1.3225)\left(1-\dfrac{0.378e}{p}\right)p}{458+T'}. \tag{9}$$

As the equipment is operated to assure the absence of water-vapor condensation in any of the metering systems, the percentage of water vapor in the air flowing through each of the four meters remains constant. The factor $0.378e/p$ is directly proportional to the water-vapor percentage, so it becomes a constant and may be combined with

[13] See equation 7, BS J. Research 7, 118 (1931) RP335.

other constants in equation 9, into a single constant

$$K=1.3225\left(1-\frac{0.378e}{p}\right) \qquad (10)$$

and thus

$$\rho=K\left(\frac{p}{458+T'}\right). \qquad (11)$$

Applying equations 7 and 11 to equation 6 gives

$$\frac{Kp_cd_cn_cC_c}{458+T'_c}=\frac{Kp_sd_sn_s}{458+T'_s}+\frac{Kp_bd_bn_b}{458+T'_b}-\frac{Kp_ad_an_a}{458+T'_a}, \qquad (12)$$

which may be reduced to the following:

$$\frac{p_cd_cn_cC_c}{458+T'_c}=\frac{p_sd_sn_s}{458+T'_s}+\frac{p_bd_bn_b}{458+T'_b}-\frac{p_ad_an_a}{458+T'_a}. \qquad (13)$$

The correction factor for the industrial meter is

$$C_c=\frac{\frac{p_sd_sn_s}{458+T'_s}+\frac{p_bd_bn_b}{458+T'_b}-\frac{p_ad_an_a}{458+T''_a}}{\frac{p_cd_cn_c}{458+T'_c}}. \qquad (14)$$

To conform with the general practice in the gas industry, the results of meter tests are presented in "percent meter proof." The relation between the meter proof and the correction factor is

$$P_c=\frac{100}{C_c}, \qquad (15)$$

and by applying this to equation 14, we have

$$P_c=\frac{\frac{p_cd_cn_c}{458+T'_c}\times 100}{\frac{p_sd_sn_s}{458+T'_s}+\frac{p_bd_bn_b}{458+T'_b}-\frac{p_ad_an_a}{458+T'_a}}. \qquad (16)$$

Equation 16 is the formula which could be used to calculate the "percent meter proof" of the industrial meter if neither of the reference meters required calibration. Actually these reference meters require periodic calibration to determine their correction factors. By the use of these correction factors, equation 16 becomes

$$P_c=\frac{\frac{p_cd_cn_c}{458+T'_c}\times 100}{\frac{p_sd_sn_sC_s}{458+T'_s}+\frac{p_bd_bn_bC_b}{458+T'_b}-\frac{p_ad_an_aC_a}{458+T'_a}}, \qquad (17)$$

which is the equation used to compute the proof of a meter tested by this method. It should be noted that the formula not only includes a correction factor for the larger reference meter but also includes two separate correction factors for the diaphragm reference meter, one factor for the meter operating in one direction, the other factor for the meter operating in the reverse direction. The results of some of the many tests on industrial meters are shown in section III, 3.

(3) *Calibration of secondary reference meters.*—The two reference meters are calibrated against the piston meter without removing either from their operating locations. This is done by measuring air into the bag through the piston meter and withdrawing it through one or both of the reference meters. As the final evacuation of the bag is always made through the diaphragm meter, the correction factor for this meter when measuring air out of the bag must be used with all calibrations. The correction factor for this diaphragm meter measuring air into the bag is obtained by comparing its indication after a volume of air has been measured into the bag with its corrected indication on measuring the same air out of the bag.

In the process of determining the correction factor of the larger reference meter it is not necessary to start the inflation of the bag through the diaphragm meter because the operating rate of the piston meter is low enough that the discharge from it can be diverted into the completely collapsed bag without affecting the pressure equilibrium conditions of the meter. As in the testing of an industrial meter, most of the air is withdrawn through the larger reference meter, and the final evacuation is completed through the diaphragm meter. Thus the determination of the correction factor for the larger reference meter involves the use of that for the diaphragm meter. This, however, is not objectionable, because even a rather large uncertainty in the latter would have no significant effect on the former, since the volume metered by the diaphragm meter is only 2 to 4 percent of the total volume of over 2,000 ft^3 in the bag.

(c) Discussion of some of the special features of the equipment and operating procedures

One of the most important features of this equipment is the use of the jump-spark recorders. These recorders eliminate personal errors in the reading of the meters and provide permanent records of the meter readings. Also, as mentioned previously, they furnish information on the operating speed of the shutter valves.

As previously described, both the piston meter and the larger secondary reference meter are enclosed so that their temperatures can be regulated by water sprays. When preparing to use the piston meter a sufficient length of time is allowed for the meter temperature to reach that of the spray water before a test is started. As the spray-water temperature is never more than 2 or 3 deg F from the room temperature, it seems reasonable to take the water temperature as the temperature of the meter and the air therein. While no direct comparisons have been made, indirect checks obtained from several calibrations of the secondary reference meter and calculations of the heat-exchanger capacity indicate that the probable uncertainty this may introduce is well under 0.5 deg F.

In the case of the secondary reference meter, the air temperature is measured as it enters and leaves the meter housing, and the mean of these is taken to represent the temperature of the air in the meter. The thermometers used to indicate these two temperatures were interchanged from time to time, which accounts for most of the 0.2 to 0.4 deg differences of temperature observed between these two points. No corrections for calibration or emergent stem were applied to any of the thermometer readings, as such corrections would not modify the final results enough to justify their use.

It is not practical to control the temperatures of the meter under test with a spray system and heat exchanger because of the enormous differences in the sizes of meters involved. This is compensated for as much as possible by operating the industrial meter under steady conditions for a sufficient length of time before the test is started to obtain a practical degree of temperature equilibrium with the air in the room. Also frequent readings of both inlet and outlet temperatures are taken, and the average of the two sets of readings is used as the temperature of the air passing through this meter.

An estimate of the degree to which the deflation of the bag is reproduced may be made from a comparison of the tests of the small secondary reference meter. In three tests of this meter with the piston meter the maximum departure from the average was 0.4 ft ^{3}, while in two comparisons of the meter, operating first in one direction and then the other, the departure from the mean was 0.2 ft ^{3}. As the degree of bag deflation is not the only possible source of variation, it seems probable that the maximum difference in the volumes of air remaining in the bag on successive deflations will not exceed 0.4 ft ^{3}. Since the total volume of air transferred to or from the bag in any test usually exceeds 2,000 ft ^{3}, the 0.4 ft ^{3} difference in residual volumes represents an uncertainty of only ± 0.02 percent.

(d) Discussion of the sizes and types of meters that can be calibrated

Although this equipment has been used almost exclusively in testing rotary-displacement meters, its usefulness is not limited to such meters. It can be used for testing almost any type of gas meter, such as rotary, bellows, and rate of flow, or head, meters, provided the meter can be operated at approximately atmospheric pressure and the pressure drop across the meter will not exceed 9 in. of water. For example, a low differential-pressure orifice meter can be calibrated very readily. In a test of this kind the orifice meter would be connected to the large blower inlet, and the operation of the large shutter valve would be linked to a suitable timing mechanism so that an accurate record would be obtained of the interval of time during which air is discharged into the bag. The total volume of air discharged into the bag would be measured out of the bag by the secondary reference meter, and from these data the actual rate of flow through the orifice meter would be calculated.

The range of gas-meter capacities that can be tested is very wide. The upper limit is governed by the capacity of the large blower and the resistance of the ducts to the movement of air through them. The maximum rate obtained thus far was about 700,000 ft^3 of air per hour and at this rate the operating data, which are not reported, indicated a relatively high pressure drop between the industrial meter and the suction of the large blower. If this flow resistance were reduced by replacing the 23-in. duct with a 30-in. duct, which was the size of the industrial meter connection, a rate approaching 1,000,000 ft ^{3}/hr would be obtained. The lower limit of capacity is not as well defined as the upper one because generally it is not necessary to test meters at rates below 2,000 ft^3/hr, although some tests were made below this figure. If very many tests of a meter are necessary below this figure, it is better to connect the meter in series with the piston meter and make a direct calibration. The low-rate tests of the 4- by 12-in. meters reported in section 3 were made in this way. Also, the small rotary meter, used in the displacement tests of the field method, was calibrated in this manner, at rates as low as 100 ft ^{3}/hr.

3. Comparison of results of testing meters by the two methods

Figures 18, 19, and 20 illustrate the results of tests made by the two test methods on rotary meters ranging in size from a listed displacement capacity of 12,500 to 800,000 ft ^{3}/hr. The service-meter groups represented by these figures are new meters, meters from service of 5 to 15 years on both purified and unpurified gas, and a single meter that had been injured by improper cleaning. The conditions under which the two test methods were used and the dates differed considerably. The tests by the transfer method

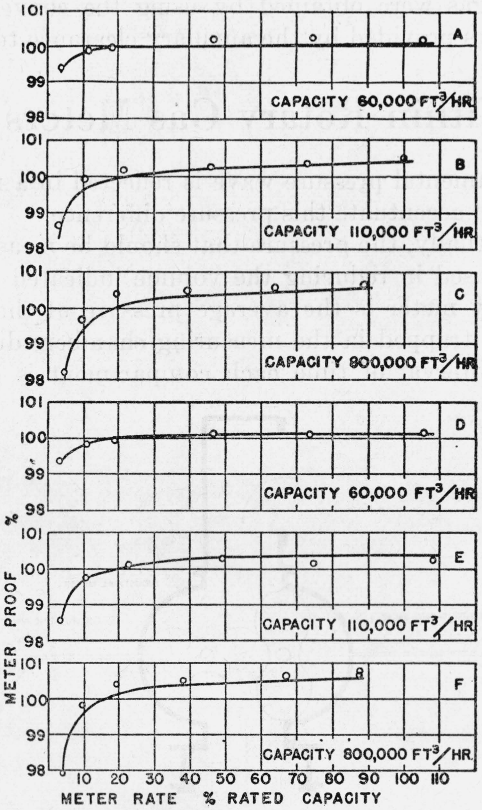

FIGURE 18.—*Results of testing service meters by the two methods, both as received and after cleaning and oiling.*

The solid lines were developed from the results by the field test method while the points are the results by the transfer method.

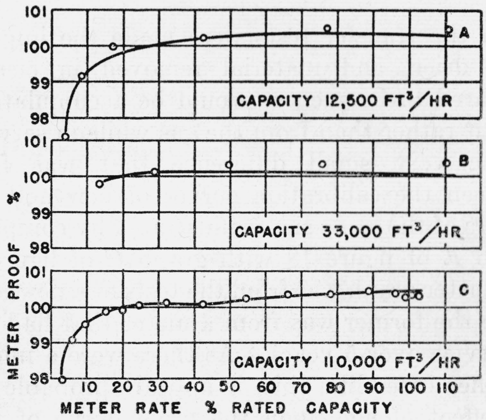

FIGURE 19.—*Results from tests of new meters by the transfer method (points) and the field test method (lines).*

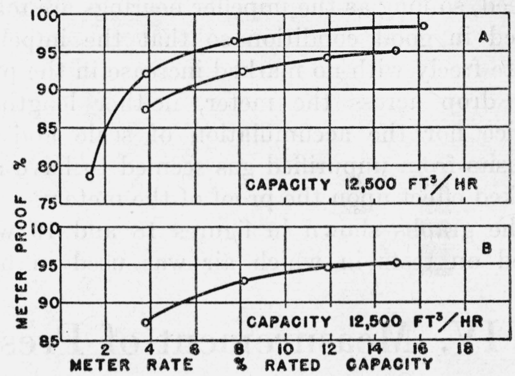

FIGURE 20.—*Results of tests by the two methods of a rotary meter having excessive clearances.*

were made in the shop under closely controlled conditions, whereas the tests by the field method were made under whatever conditions of temperature and weather existed at the time. The time interval between the test by one method and the other was from 1 to 2 years for most of the meters.

In figure 18, the top three graphs show the results of testing the meters as taken from service; the bottom three graphs are the results after the impellers had been cleaned and oiled. By comparing the first with the fourth, and so on, it appears that the cleaning and oiling of the impellers had almost no effect on the value of the meter proofs. However, the spread between the results by the two methods, as represented by the lines and points, is slightly less in the second group than in the first. An explanation for this may be that when making the field tests on meters at their point of service, it was observed that the impellers were covered with a film of oil, whereas when the transfer tests were made the impellers were drier, and material removed in cleaning appeared to be such as would be accumulated in transit rather than from the gas while in service.

The very small difference that was found between the calibration curves of new and used meters of the same size is illustrated by comparing graph *E* of figure 18 with graph *C* of figure 19. The latter graph was from the tests of a new meter while the former was from a meter that had been in service over 5 years. As there were a number of other cases like this, it appears probable that the effect of age upon the proof curve of these meters is almost negligible, at least within the age limit of meters tested (about 20 years). Indeed, so long as the impeller bearings are maintained in good condition so that the impellers rotate freely with no marked increase in the pressure drop across the meter, neither length of service nor the accumulation of scale and tar deposits from unpurified gas seemed to have any marked effect upon the proof of the meters.

The graphs shown in figures 18 and 19 were based on tests in which air was used in both methods of calibration. In order to illustrate in an exaggerated manner the differences between meter-proof curves for air and fuel gas, as mentioned in connection with the field method clearance tests, tests were made upon a meter in which the clearances had been increased far beyond those which could be accepted in an industrial meter. The results of these tests are shown in figure 20. In both graphs the lines represent the results obtained by the field method, and the circles are the individual tests by the transfer method. The upper curve and test points in *A* illustrates the direct comparison of the two test methods when the meter was calibrated with air. The lower curve and test points in *A* illustrate the direct comparison of the two test methods when the meter was calibrated with fuel gas. In *B* the circles are the results by the transfer method when using fuel gas. The curve was derived from the field method when the clearance test was made with air, and the values of both clearance flow and meter proof to be expected when metering fuel gas were obtained by using the conversion factors provided by the auxiliary clearance test.

IV. Measurement of Pressures Within Rotary Gas Meters

1. Instantaneous pressures within the closed measuring pockets of a rotary meter

The rate of discharge from a rotary gas meter, operating at a constant pressure and speed, fluctuates slightly. These fluctuations have a highly distorted sine wave shape with maximum and minimum rates, respectively, about 1.75 percent above and below the average rate. Four complete wave cycles occur with each revolution of the meter. The momentum of the rotating impellers opposes any shift in their rotating speed, while the momentum of the gas flowing through the meter and adjacent piping opposes any shift in the flow rate through the meter. The result of these two opposing forces causes pressure waves, or surges, to be set up in the inlet and outlet connections of the meter. This condition may cause slight irregularities in the proof of a rotary meter by imposing on the gas, as the metering chambers close, momentary pressures that are higher or lower than the average inlet static pressure. Also, the arrangement of the inlet piping and the meter speed may be such that a portion of the fundamental pressure wave is reflected in a manner to accentuate this pressure difference.

Actually, the pressure that should be measured and used in reducing the volume indicated by a rotary meter is the average pressure of the gas while trapped in the measuring chambers during the interval of time each compartment is com-

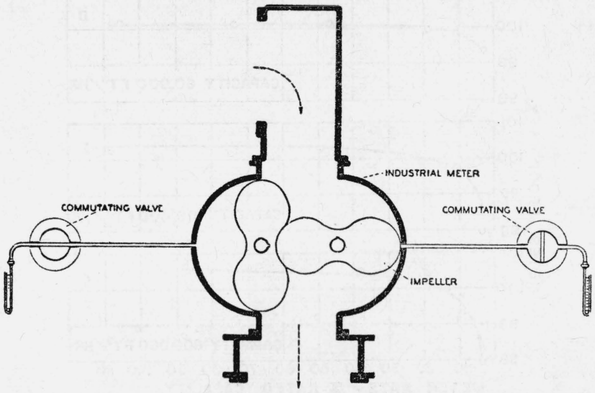

FIGURE 21.—*Diagrammatic representation of method of measuring the instantaneous pressure within a closed metering chamber.*

The cores of the commutating valves were gear driven from the impeller shafts at twice the impeller speed.

pletely closed. In order to measure this pressure, two special commutating valves were built. These valves were driven by the meter through a gear train at twice the meter speed, and were so synchronized with the impellers as to be open only during the interval each respective chamber was completely closed. Inclined water manometers were used to measure the pressures, and connections from the meter chambers through the valves to the gages were made as short as possible. These connections are shown diagramatically in figure 21, and figure 22 shows two sectional views of the valves.

Using these commutating valves, a meter was tested by the transfer method with various inlet piping arrangements. These piping arrangements were chosen to create exaggerated pulsating conditions at the inlet of the meter by the reflection of pressure waves from the open end of various lengths of pipe attached to the meter inlet. The rates of meter operation were selected to include those at which maximum differences were observed between the average static pressure at the meter inlet and the instantaneous pressures within the metering chambers.

The conclusions drawn from this series of tests, which are summarized in table 4, are: First, with no pipe connected to the meter inlet (i. e., the normal test arrangement), the average static pressure, as measured at the regular inlet pressure tap, is a satisfactory pressure value for use in computing the meter proof and introduces no appreciable error. Second, regardless of the inlet piping arrangement and its resonant characteristics, the use of the instantaneous static pressure within the meter chambers while closed will practically eliminate the effects of pulsation. Third, the magnitude of the effects of reflected pulsations obtained with two different lengths of inlet pipe were practically the same and were relatively small, the maximum being about 0.6 percent.

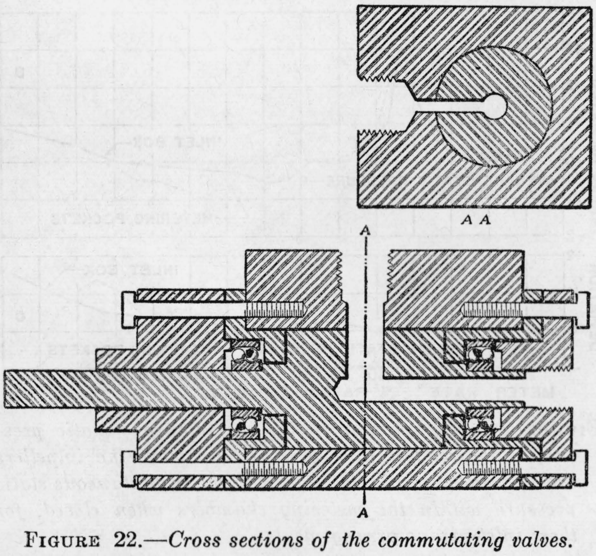

FIGURE 22.—*Cross sections of the commutating valves.*

TABLE 4.—*Effects of pulsations in the meter inlet upon the proof of a 6- by 18-in. rotary meter*

Test number	Date	Pressures			Meter proof		Meter speed, percentage of rated capacity
		Differential across meter	Average inlet	Closed measuring pockets	Average inlet pressure	Closed measuring pockets	
1	2	3	4	5	6	7	8
A—ONE 8-IN. ELBOW AND 16 FT. OF 8-IN. PIPE CONNECTED TO METER INLET							
		in. H_2O	*in.* H_2O	*in.* H_2O	%	%	%
612	6-4-40	0.408	−0.04	+0.213	99.67	99.74	25.49
611	6-3-40	.542	−.11	+.456	99.91	100.06	40.81
610	6-3-40	.774	−.25	−.204	100.21	100.19	60.81
609	6-3-40	1.37	−.69	+1.61	99.92	100.49	99.92
608	6-3-40	1.55	−.75	+.150	100.22	100.44	103.57
607	5-29-40	1.52	−1.19	−2.20	100.65	100.42	131.28
606	5-29-40	1.86	−1.48	−1.77	100.45	100.41	144.17
B—ONE 8-IN. ELBOW AND 8 FT. OF 8-IN. PIPE CONNECTED TO METER INLET							
605	5-29-40	0.429	−0.09	+0.163	99.70	99.76	26.75
604	5-29-40	.618	−.11	+.340	99.85	99.96	40.02
603	5-28-40	.830	−.20	+2.21	99.60	100.20	54.67
602	5-28-40	.891	−.27	+.276	100.08	100.21	63.63
600	5-28-40	1.38	−.77	−1.70	100.52	100.29	106.70
626	6-7-40	1.37	−.74	−1.63	100.60	100.38	107.03
601	5-28-40	1.74	−1.37	−1.26	100.35	100.37	141.77
C—NORMAL INLET ARRANGEMENT—NO PIPE ON METER INLET							
620	6-6-40	0.390	−0.02	−0.071	99.90	99.90	26.32
621	6-6-40	.518	−.06	−.144	100.13	100.10	40.03
622	6-6-40	.725	−.15	−.226	100.27	100.25	59.90
623	6-6-40	1.21	−.45	−.734	100.49	100.42	99.97
624	6-6-40	1.49	−.77	+.32	100.30	100.57	132.33
625	6-6-40	1.69	−.94	−1.23	100.49	100.40	149.49

It should be kept in mind that the pulsations discussed here are those which originate from the action of the meter itself, and not from an outside source. Also, the open-end pipes produce the maximum reflection that is to be obtained.

2. Instantaneous pressure at the inlet pressure tap of a rotary meter

The tests described above gave rise to the suggestion that at some angle of the impellers the instantaneous pressure, measured at the regular inlet pressure tap of the meter, would agree very closely with the instantaneous pressures within the closed metering chambers, regardless of the meter rate or the resonant characteristic of the inlet piping. To test this, the inlet pressure tap of the meter was connected to an inclined manometer through another commutating valve. The commutating element of this valve was a disk having four holes near the periphery and 90° apart. This disk rotated over the inlet port of the valve and was coupled directly to one of the meter impeller shafts. The azimuth of the disk on its shaft could be changed rapidly and easily, without interrupting the operation of the meter, so that the open position of the valve could be made to occur at different phase angles of the impellers.

In this group of tests the meter was run at different speeds throughout its operating range. At each speed measurements of the instantaneous static pressure at the regular inlet pressure tap were made for nine angular positions of the impellers. In the first of these the valve was fully open when one impeller was vertical. The setting of the disk was changed between each group of readings by steps of 3.75° so that on the ninth setting when the valve was fully open the impeller had dropped back to 30° from vertical. At the same time, readings were made of the average static pressure at the inlet tap, and of the instantaneous static pressure in the closed metering chamber. In this manner three sets of pressure surveys were made using the inlet piping arrangement listed in table 4.

Plots of the instantaneous inlet pressures for three of the nine angular positions of the impellers are shown in figure 23. The graphs *A*, *B*, and *C* refer respectively to the three inlet piping arrangements. The zero line in each graph represents the average inlet pressure as measured by the regular pressure tap and gage.

A comparison of these pressure lines, for all nine positions of the impellers, with the line of the closed chamber pressure showed that when an impeller is 7.5° in advance of the vertical the instantaneous inlet pressure corresponds very closely with the closed chamber pressures. Figure 24 shows plots of these two pressures for the three inlet arrangements. In considering the results of these instantaneous pressure measurements, as illustrated by figures 23 and 24, it should be noted

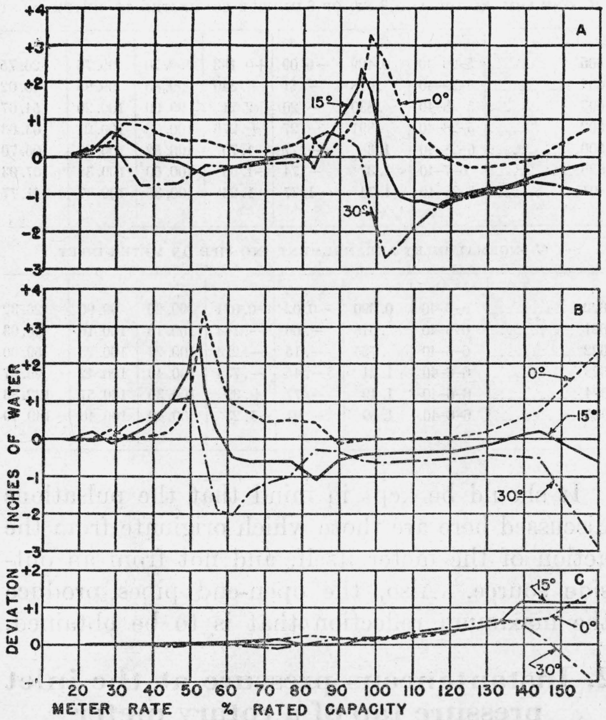

FIGURE 23.—*Variations of the instantaneous static pressure at the regular inlet-pressure tap for three phase angles of the impellers and three inlet-piping arrangements.*

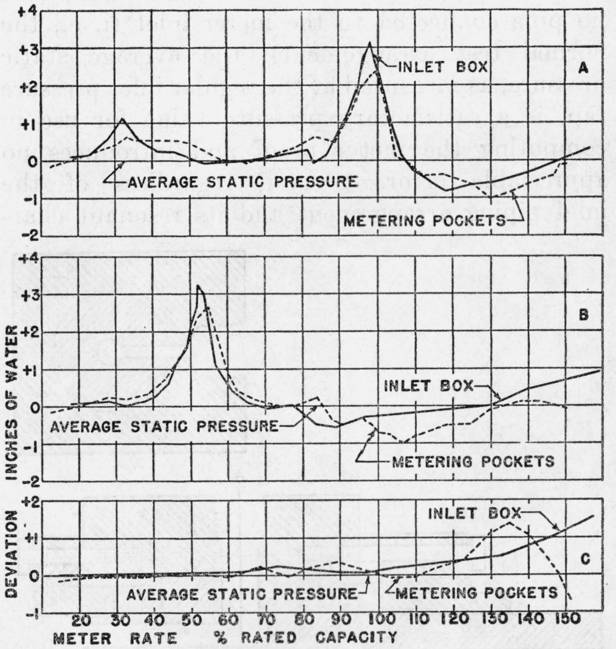

FIGURE 24.—*Comparison of the instantaneous static pressure at the regular inlet pressure tap when the impellers are 7½° ahead of the close-off, with the instantaneous static pressure within the metering chambers when closed, for three inlet-piping arrangements.*

that a variation in the static pressure of 2 in. of water will affect the meter proof by 0.5 percent. Hence, the maximum effect from pulsations, which could be produced in these tests, would amount to about 0.8 percent in the proof of the meter. Moreover, these maximum effects occurred over a very narrow range of meter rates. Over the major portion of the operating range of the meter the difference between the average inlet pressure and either the instantaneous inlet pressure, or the pressure in the closed metering chamber is too small to have any significant effect on the meter proof. This is especially so for the open-inlet condition, graph *C*, as normally used in testing these meters.

Although pressure waves are generated by the action of these meters, the very small spread of the lines in graphs *C* indicate that these pressure waves do not directly affect the closed metering chamber pressure, or, therefore, the proof of the meter. The only effect from these pressure waves occurred when they were reflected by the inlet pipe at such a frequency as to enter the metering chamber when the impeller was 7.5° from the close-off position. This is a function of the meter speed and the resonance of the inlet piping, not of the meter.

As the open-end pipes used in these tests reflected pressure waves move effectively than will the usual closed piping system on the inlet of an installed meter, it is probable that the effects of reflected pulsations in any actual meter installation will be very much less than shown by these tests. Also, for pulsations from any outside source to have any effect upon the meter, it will be necessary for their frequency and phase to be such that they reach the metering chambers as the impellers are 7.5° from the close-off position. Such a condition seems remote indeed. However, if the question arises in connection with an actual meter as to whether pulsations from any source are affecting the inlet pressure measurement or the measuring chamber pressure, a survey can be made of the instantaneous pressures at the inlet pressure tap by the use of a commutating valve. From the results thus obtained the magnitude of any pulsation effects may be determined and a method of taking account of them agreed upon.

WASHINGTON, August 8, 1945.