AD 673447

TURBINE TYPE FLOWMETERS
"STATE OF THE ART" LITERATURE SURVEY

A Research and Development Report
NAVSECPHILADIV Project A-771
SF013-06-02, Task 3950
30 June 1968

by

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31

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

ABSTRACT

A survey of the literature was conducted in order to evaluate the ability of the turbine meter to meet the flow measurement needs of the Fleet. Parameters effecting meter performance were investigated as well as pertinent related topics. The turbine meter is burdened with the inherent weaknesses peculiar to most velocity sensing meters. It was found suitable for future use in shipboard automation and fueling-at-sea applications under the following provisos: a turbine meter satisfying current shipbuilding specification access flange requirements should be developed, or the specifications making this demand revised. If one of these cannot be accomplished, investigate other pulse output meter types which will meet the access flange requirement and may also drive direct totalising devises. Application guidelines and standard practices should be prepared for the meter type(s) ultimately selected for control-input and fueling-at-sea use.

SUMMARY PAGE

THE PROBLEM

To study the state-of-the-art of the turbine flowmeter in order to assess its suitability for use in the naval environment. Acquire information of the type needed to prepare specifications, application guidelines and standard practices for the turbine meter.

FINDINGS

The turbine meter is judged to be suitable for use, with limitations, in shipboard automation (control input) and fueling-at-sea applications provided that manufacturers develop a meter meeting the access flange requirement of existing shipbuilding specifications or that these requirements be revised. Failure to accomplish at least one of these measures virtually disqualifies the turbine meter from future consideration.

RECOMMENDATIONS

Actively solicit development by the industry of a turbine meter meeting the access flange requirements in effect today. Simultaneously re-evaluate this requirement with revision in mind. In the event that both of these efforts fail, investigate other meter types with a pulse output which can satisfy the access flange requirement and may also be capable of driving direct totalizing devices. Prepare standard practices and application guidelines for the turbine meter or any meter type deemed appropriate for similar applications. Encourage development of a flow condition standardizing mechanism which might circumvent approach effects on most velocity sensing meters.

ADMINISTRATIVE INFORMATION

This project was authorized by reference (a). Costs of the project were charged to SF013-06-20, Task 3950. This is a final report.

References:

(a) NBTL Semi-Annual Program Summary of 1 May 1966 (NOTAL)

NOMENCLATURE

d_n = various internal diameters, ft

D = meter bore diameter, ft

e = base of natural logarithms

E = fluid modulus of elasticity, lb/ft^2

F = force, lb

K = calibration factor, cycles/gallon

n = rotor angular velocity, RPM

Q = flow rate, ft^3/min

API = American Petroleum Institute

ASME = American Society of Mechanical Engineers

ASTM = American Society for Testing and Materials

Greek Symbols

ρ = fluid mass density, $lb\ sec^2/ft^4$

μ = fluid absolute viscosity, lb sec/ft

ν = fluid kinematic viscosity, ft^2/sec

REPORT OF INVESTIGATION

INTRODUCTION

Beginning in World War II, new flow metering requirements in many industries caused instrument engineers to look beyond the traditionally used variable area, variable head, and positive displacement type flowmeters. There was a new need for instruments of higher accuracy, faster response, and greater versatility under extreme operating conditions. This search began in the aircraft engine industry where powerplants for larger airframes and supersonic speeds were being developed. Later, the missile, chemical, and petroleum industries required similar meter characteristics although in widely-differing applications. Instrument manufacturers responded to these needs with the turbine type flowmeter or transducer. These meters have been developed to the point where they are widely used industrially on many types of flow measurement and control applications - custody transfer, process controls, production testing, batching, and blending to name a few. Their use on shipboard, however, has been infrequent for a variety of reasons. Notable among these are existing safety regulations and the expense of necessary associated electronic equipment as well as its maintenance. Despite these present day factors minimizing their use, it is felt that the turbine flowmeter can make a future contribution as shipboard automation becomes more prevalent and fueling-at-sea techniques more sophisticated.

FLUID DYNAMIC CHARACTER OF TURBINE FLOWMETERS

A generally accepted statement concerning operation of the turbine flowmeter is that the fluid flowing through the meter causes the rotor to turn at a speed directly proportional to the average velocity of the fluid. This is not entirely true. The effective angle of the rotor blades determines the actual speed at which the rotor turns for a given fluid volume flow (1)[1]. It is the "imperfect" characteristics of fluids which cause a large part of the deviation from ideal meter performance, as well as confusing the understanding of turbine meter operation. The flow of any real fluid produces tangential frictional forces which are called viscous forces. The action of such internal shearing forces results in a degradation of mechanical energy into heat or unavailable thermal energy (2). In hydraulic terminology, these shearing forces are referred to as "absolute viscosity" or the ratio of shearing stress to the rate of shearing strain. Absolute viscosity is referred to widely as "dynamic viscosity". The English units of absolute viscosity are pound-second per square foot. Also used widely is the term "kinematic viscosity" which is the ratio of dynamic viscosity to fluid mass density. The English units of kinematic viscosity are feet squared per second.

In the operation of a turbine meter, it is not possible to have the relative velocities of the various portions of the turbine rotor perfectly matching those of the passing fluid. This is true because the rotor must

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1 Numbers in parentheses designate references listed in the bibliography.

move in a circular path, which is at right angles to the general direction of the fluid flow and secondly, the distorted velocity profile (due to the annular shape of the passage) makes it impossible for bladed rotors to present a constant effective angle to the flowing fluid. This shearing action coupled with the dynamic viscosity of the fluid causes a motion opposing torque or force to be exerted upon the rotor. This viscosity-created torque will always tend to cause the rotor to move more slowly than ideal. The rotation-restraining-torque resulting from the effects of viscosity is directly proportional to the fluid velocity. This means that if the fluid velocity is doubled, the viscous drag force would double.

In order for the passing fluid to turn a turbine rotor, it must be able to exert a force that creates a turning torque upon the rotor. This turning torque is needed to overcome the rotor's own inertia and the viscous drag upon the rotor. For a fluid to exert such a force, it must possess both an appreciable mass and velocity. With a given density fluid, the force that can be exerted is a function of the square of velocity. Thus, if the fluid velocity were doubled, the turning torque available for the rotor would be four times greater. At a fixed fluid velocity, the torque available would be directly proportional to the density of the fluid. Therefore, the fluid density and velocity level both determine the energy available for turning the rotor. The greater the available energy, the closer a rotor's speed approaches the ideal speed. The "ideal speed" is the speed which is directly proportional to fluid velocity.

Restating the key facts brought out above, it can be said that the effects of viscous drag tend to reduce the rotor speed by a factor directly proportional to the fluid velocity. Also, the turning torque capability of the fluid is directly proportional to its density and to the square of its velocity.

FACTORS AFFECTING PERFORMANCE

The turbine type flowmeter is categorized broadly as a velocity type meter (3). The metered fluid may be either a liquid or a gas with the entire pipe flow passing through the meter.

Figure 1 shows a typical turbine type flowmeter. This type meter transmits information concerning rotor rotation by generating electromagnetic pulses in a pickup coil outside the meter casing. Pulses in the pickup may be generated by magnetized blades (one pulse per blade), or by passage of a steel blade past the magnetized core of the pickup coil (one pulse per pole). The pulses are transmitted through the unbroken non-magnetic wall of the meter casing. A slight magnetic attraction between rotor and pickup coil provides an additional resisting torque that affects the useable limit of the meter's range. The pulses in the pickup coil must be amplified and then either counted by an electronic totalizer, electronically counted for a predetermined gated time interval for rate indication, or delivered to a frequency meter for rate indication.

The turbine meter is affected in varying degrees by many factors. These include flow rate, viscosity, density, temperature, pressure and upstream piping configuration to name a few.

These effects, as nearly as is possible, will be isolated and discussed separately.

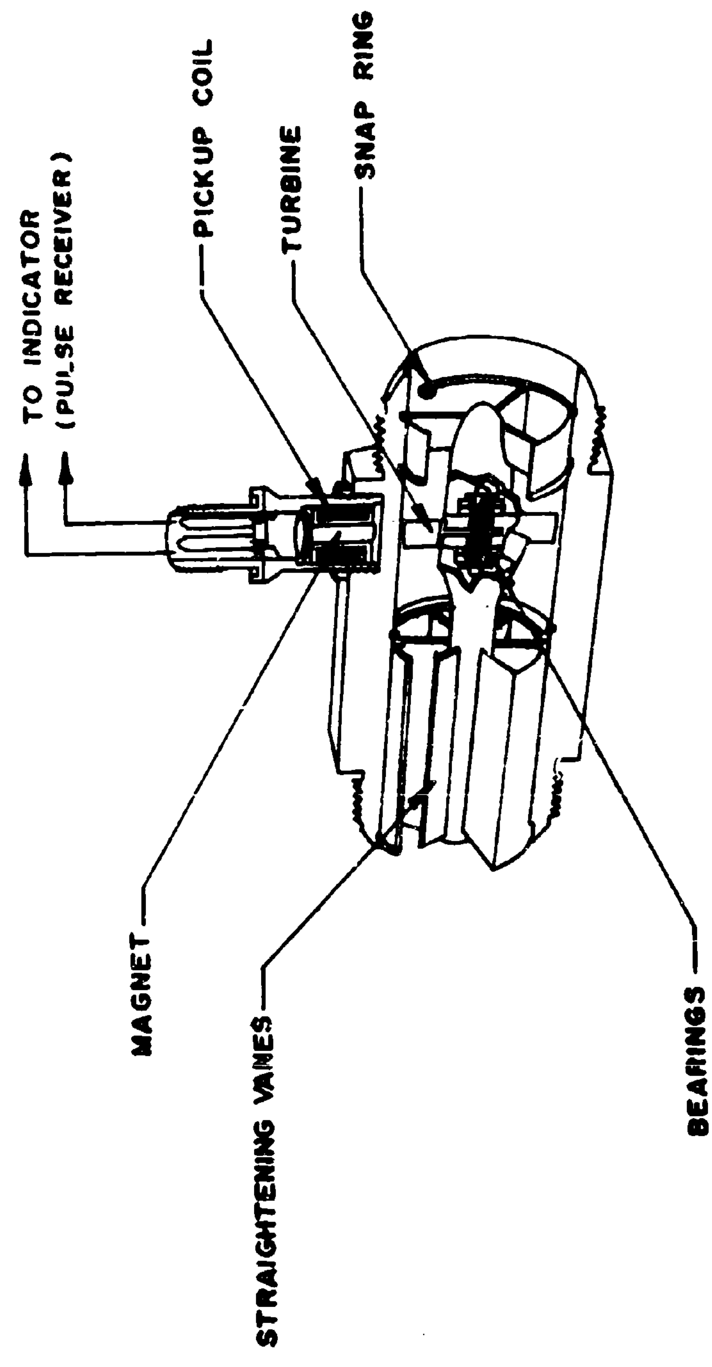

FIGURE 1 - TYPICAL TURBINE FLOWMETER

Flow Rate

When considering application of the turbine flowmeter, the instrumentation engineer is interested in pressure loss, voltage magnitude, frequency of electrical signal, and the calibration factor expressed in electrical pulses generated per unit volume of flow. These values are all functions of flow rate. Figure 2 shows typical performance characteristics for a turbine meter operating on a low viscosity fluid.

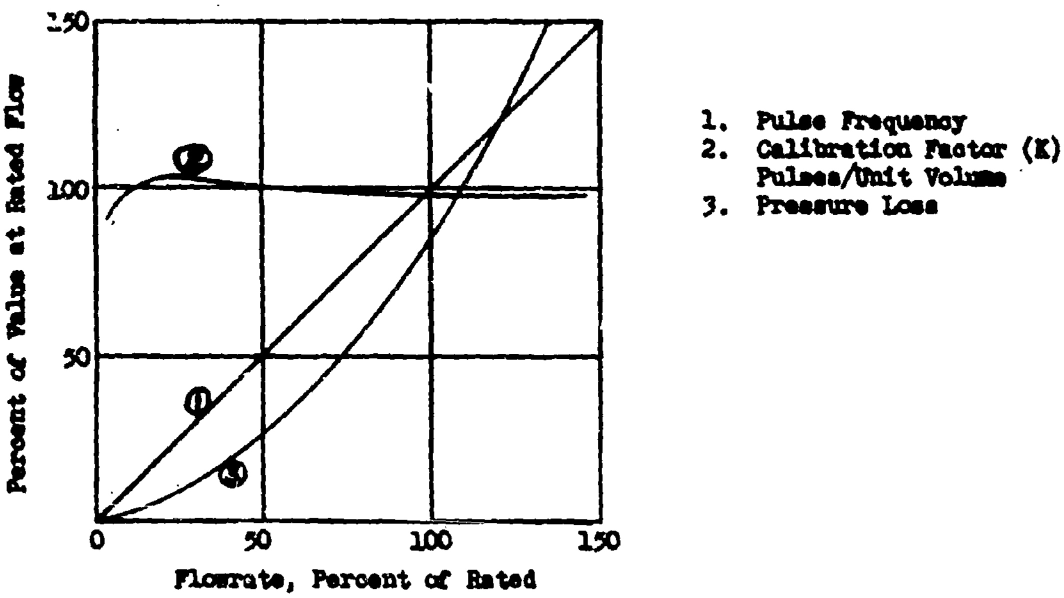

FIG. 2 TYPICAL TURBINE METER PERFORMANCE

Turbine meters are designed to have a pressure loss of five to ten psi at the rated maximum flow rate. The pressure loss is approximately proportional to the square of flow rate. Care must be exercised when applying the turbine meter to maintain a sufficient minimum pressure level in order to eliminate the hazards of cavitation. This minimum pressure level varies with the particular meter and fluid in use. Thus, satisfactory meter performance requires a higher supply pressure than might be indicated by pressure loss alone.

The AC voltage generated in the pickup coil has a magnitude approximately proportional to turbine velocity or rate of flow. It is generally in the range of 100 to 1000 millivolts RMS depending on the make and type of meter. The frequency of the generated AC voltage is proportional to flow rate or turbine velocity and ranges from 200 to 4000 Hertz at a maximum rated flow depending on meter design. There are both high and low frequency meters on the market today with the high frequency meters possessing the advantage of greater readout resolution and the disadvantage of reduced range of linear operation.

As shown in Figure 2, the calibration factor (K) is a function of flow rate. The K factor is usually linear within ± 0.5 percent for flows within the range 15 to 100% of rated flow. This statement is true for operation with low viscosity fluids. The range of linear operation is, however, affected by the design and size of the meter, and fluid viscosity. The nonlinear portion of the K factor curve is caused by the retarding forces produced by electromagnetic and mechanical loading on the turbine as well as changes in flow pattern within the meter. The value of the K factor varies with meter design and can range from less than 100 cycles per gallon to several hundred thousand cycles per gallon.

Viscosity

The importance of viscosity effects on turbine meter performance cannot be overestimated. In addition to being a function of flow rate, K factor is also a function of viscosity. Hochreiter (4) performed a dimensional analysis of turbine type flowmeters in terms of flow rate Q, rotor angular velocity n, meter bore diameter D, fluid density ρ, and fluid absolute viscosity μ. He develope the following dimensionless relationships:

$$\frac{Q}{nD^3} = f\left[\frac{nD^2\rho}{\mu}\right] \tag{1}$$

Substituting kinematic viscosity ν, for absolute viscosity, the following was obtained:

$$\frac{Q}{nD^3} = f\left[\frac{nD^2}{\nu}\right] \tag{2}$$

These quantities can be correlated against one another in the same way that conventional orifice coefficients may be correlated against Reynolds number.

Previous to Hochreiter's work, an analysis of the kinematic flowmeter was performed by Head (5) to include some external force F, fluid compressibility E and additional geometric variables such as internal or rotor diameters, d_1 and d_2 to produce the following relationships:

$$\frac{Q}{nD^3} = f\left[\frac{nD^2}{\nu}, \frac{F}{\rho n^2 D^4}, \frac{E}{\rho n^2 D^2}, \frac{d_1}{D}, \frac{d_2}{D}\right] \tag{3}$$

These dimensional relationships are applicable to any type of continuous motion device such as the various designs of positive displacement, turbine and propellor type meters currently available. The flow coefficient $\frac{Q}{nD^3}$ and the viscosity parameter $\frac{nD^2}{\nu}$ can be used to describe the performance of turbine meters if the retarding forces acting on the turbine are insignificant and an incompressible fluid is being metered. Experimental work by Schafer (6) shows that significant deviations from a smooth plot of these two quantities are caused by retarding forces whose effect depends upon meter design and varies considerably between different sizes and makes. Therefore, the parameters developed by Hochreiter cannot be used for turbine meters with the same precision as, for example, the Coefficient of Discharge versus Reynolds number relationship for orifices.

The effect of viscosity on turbine meter linearity is explained by one manufacturer (7) in terms of boundary layer. The skin friction (viscous effect of the boundary layer) is a function of Reynolds number. Flow in the boundary layer is laminar at low Reynolds numbers and turbulent at high Reynolds numbers while in the transition region there is a gradual change from laminar to turbulent flow. Let us consider the application of a given size meter to a low viscosity fluid, where flow is turbulent at the meter's minimum operating frequency. An increase in fluid viscosity at this minimum frequency produces a decrease in Reynolds number which, if large enough, will produce flow in the transition region. In this region, viscous drag actually decreases with a corresponding increase in K factor at this frequency. A further increase in viscosity and decrease in Reynolds number causes laminar flow with an attendant decrease in K factor due to increasing viscous drag.

This short discourse explains the characteristic "hump" and rapid "drop off" in the K factor curve in Figure 2. The exact shape of this curve depends on meter geometry, manufacturer and flow range. In low capacity meters, the viscous drag may be of such magnitude as to eliminate linearity entirely, i.e. the entire curve will have a significant positive slope. It can be said that low flow rates, small meter sizes and high viscosities all tend to decrease the linear range of a meter.

In summary, the exact influence of viscosity on a particular turbine meter cannot be accurately estimated. To obtain precise meter calibration information, a meter should be calibrated under viscosity conditions as near as possible to those to be encountered in use. Viscosity corrections obtained for a particular meter should be used carefully since they are not always applicable to other meters of the same make and size.

Temperature

The temperature effects on turbine meter performance are manifested in several ways. Most obvious is the thermal expansion of the meter bore with an increase in temperature. Its exact value depends on the materials of construction. Thermal expansion will cause a lower fluid velocity and in turn, K factor, for a given rate of flow. This effect can be significant but in manufacturing circles is felt to be predictable. According to a leading manufacturer (8), the correction for thermal expansion of 1000 degrees Fahrenheit is about minus two percent and is linear.

Other temperature related phenomena are the effects of fluid viscosity and lubricity. The interaction of thermal expansion and viscosity influences caused by an increase in temperature can conceivably have opposite and at times cancelling effects.

The temperature induced viscous effect with oils can be sizeable as discussed earlier. For water service, this is generally negligible since turbine meters operate most effectively in the region of the viscosity of water (about one centistoke).

Large increases in the temperature of water cause the more difficult to analyse problem of diminishing fluid lubricity. The effects of decreasing fluid lubricity can be significant with water, particularly at the low end of the flow range. Its magnitude depends largely on the bearing materials and design which are used.

High pressure, high temperature turbine meter calibrations performed at NAVSECPHILADIV (9) showed a marked difference in the performance of meters submitted by two major manufacturers. In the unsatisfactory meter, it was found that at high temperatures, large deviations in K factor occurred due to increased bearing friction caused by greatly decreased fluid lubricity.

Pressure

The fundamental design of the typical turbine type meter permits its use in high pressure applications without fear of catastrophic failures. The manufacturer merely selects the appropriate weight pipe and end connections (usually flanges for high pressure work) to accomodate a given pressure level.

The two main areas of interest when considering pressure effects on turbine meters are; minimum pressure necessary to prevent cavitation and pressure pulsations.

Cavitation will affect not only the calibration factor, but may also produce mechanical affects on such internal meter parts as the rotor and bearings. For the purposes of this report only the former will be discussed. The occurrence of cavitation in a meter automatically indicates the presence of gases in the liquid flow stream. These gases are present when the static pressure level is below some minimum which is a function of fluid vapor pressure, maximum flow rate and meter design. These errors are generally small but may be a problem in applications requiring extreme accuracy. To avoid this difficulty, it is recommended that the meter outlet pressure be at least 10 psi higher than the minimum required to prevent vapor formation (6). An operating pressure of 50 psia will avoid most cavitation problems. This value is for liquids of approximately zero vapor pressure and should be adjusted upwards for fluids of higher vapor pressure. Limiting the maximum flow may also avoid cavitation difficulties.

Of greater importance than cavitation in most cases is the influence of pulsations in the flow line. This phenomena is present in most systems which include rotating machinery such as pumps. The influence of pulsations is felt to be more important than the relatively insignificant effects of pressure on viscosity and density of the liquid.

The amplitude and frequency of the pulsations is dependent upon pressure level, configuration of the high pressure flow circuit and pump speed. "Fluid Meters" (10) states: "The effects of pulsations on a flowmeter, with the possible exception of shunt arrangements in branching circuits, is to make the meter read an indicated flow whose average is greater than the true average". The text also states that it is the pulsations in flow, not pressure level, which influences the performance of fluid meters. The direct measurement of flow pulsations is very difficult as compared to the measurement of pressure pulsations. Since flow pulsations are directly related to pressure pulsations, this problem is usually considered in terms of the latter.

In tests conducted by Shafer, et al, (11) it was found that calibration factor increases significantly at low flow rates when using high pressure levels and high pump speeds. These increases were as large as 1.36% for a given meter at a pump speed of 3000 rpm. The authors found that pulse attenuation with a simple accumulator in line did not greatly minimize the pulsation effects. The accumulator in conjunction with special fittings was more successful.

In summary, it is important to emphasize that a precise high pressure calibration is not feasible unless provisions are made for adequate control of pulsations in the flow line.

Density

Density, in itself, is not considered to be a major influence on turbine meter performance in liquid flow measurement applications. It is of somewhat greater importance in gas flow measurement.

The main difference between gas and liquid measurement with a turbine meter is the effect of a much lower gas density. The turbine rotor slip resulting from nonfluid retarding torques (mainly bearing load and magnetic pickup load) is inversely proportional to the density of the fluid being measured. The densities of most liquids are relatively high and their variations with pressure and temperature are small. Therefore, it is not difficult to design a liquid turbine flowmeter (except one of very small size) to have sufficiently low nonfluid retarding torques so that within a reasonable operating flow range the resulting rotor slip is small. This is true even though the retarding torque attributable to bearing load may vary considerably depending upon the lubricity of the fluid being measured.

The effects of density changes are manifested at the two extremes of the flow range. For example, consider a turbine meter designed to operate over a given frequency range with liquids of 1.0 specific gravity. If a liquid of 1.5 specific gravity is used, there will be a 50% increase in driving force available at the maximum rated frequency. The differential pressure across the meter is increased a similar amount. This increased pressure drop can reduce the life of the bearings. Conversely, a decreased fluid density will reduce the linear range of a meter since at the low end of the range, the nonfluid retarding forces tend to become large as compared to the driving fluid forces.

Fluid density while not a major factor in liquid flow measurement applications should be considered by the engineer. Its influence is predictable and can be a factor at the high and low ends of the meter flow range.

Condition of Flow

The turbine flowmeter, fundamentally a velocity sensing mechanism, is sensitive to nonstandard approach conditions. This sensitivity to abnormal velocity profiles is one of the problems confronted in applying these meters to shipboard use.

The flow characteristics of a fluid stream entering a meter are established by the piping upstream of the meter. When this piping is of standard straight length, normal roughness, and devoid of disturbance inducing valves, etc., the flow into the meter is "normal". A flow disturbance is defined as any factor which modifies this flow. These modifications can take the form of changes in the normal velocity profile or in the creation of a significant vortex or swirl flow. Velocity profile changes can be either a skewing of the normal profile or development of a nonstandard profile shape.

Skewed profiles are caused by nonsymmetrical disturbances such as valves, regulators, and single or multiple bends. Abrupt changes in upstream pipe diameter also cause nonstandard symmetrical velocity profiles.

The most serious of the aforementioned upstream flow abnormalities is rotational flow or swirl. It has the effect of changing the angle of attack between the liquid and the turbine blades with a corresponding change in rotor speed for a constant flow rate. Swirl, present in most piping systems, is caused by some pumps and sharp bends and will not be eliminated by using straight lengths of pipe upstream of the meter. To avoid this problem, straightening vanes or sections of the form recommended by ASME (12) should be used upstream of the meter. Two types are shown; the tube bundle type, and the perforated plate type. The former is quite adequate for removing swirl but is of minimal value in correcting unusual velocity profiles. The perforated plate type is excellent for both profile and swirl corrections but is more costly to manufacture and causes a larger permanent pressure loss in the line.

In an effort to minimize swirl influences on their meters, most manufacturers include simple straightening vanes in their design. These vanes are only a partial solution at best. Therefore, to obtain high accuracy, the internal straighteners must be supplemented by flow straighteners designed primarily to eliminate swirl so that the flow pattern may be normalized. Where possible, the flow straightener should be physically attached to the meter with both transferred from system to system as a unit. Precautions to eliminate swirl and maintain turbulent flow should be taken if accuracies of one percent or better are desired.

Manufacturers customarily recommend straight pipe requirements of 10 pipe diameters upstream and 5 pipe diameters downstream. This is a bare minimum. A good general rule is to provide as much profile settling upstream piping before the meter as system design will permit. The manufacturers downstream recommendation of 5 diameters is adequate unless some severe obstruction is placed at this point in the system.

Meter Orientation

In most cases, a turbine meter will operate satisfactorily in all positions. Sleeve bearing meters are more vulnerable to orientation effects than ball bearing type meters. Such effects are non-uniform and are generally confined to the lower one third of the meter range.

Orientation can be a factor in two ways; where the meter itself is in a vertical line with upward flow as opposed to a horizontal position, and where the pickup coil is in an angular position during horizontal operation.

Tests run by Shafer (6) show the effect of vertical versus horizontal operation to be small (0.2%) at maximum flow and increasing gradually to 3% at one tenth of rated flow. These tests were run with a 100 gpm capacity meter with a fluid whose viscosity was 1.2 centistokes.

Similar tests show that for a 180 degree rotation of the pickup coil from its normal position during horizontal operation, the difference between an up or down position of the pickup coil can affect the K factor by one percent or more in the lower one third of the meter range. Deviations of this size are rare but differences in K factor of 0.2 percent are not.

Accurate prediction of the magnitudes of these effects is difficult due to the physical differences between meters of varying manufacture, size and design. A good general rule is to calibrate the particular meter in the same position or orientation in which it is to be used.

DYNAMIC RESPONSE

For many years, the turbine type flowmeter was used almost entirely for steady state flow measurement in rocket and jet engine applications. Recently, there has been a growing interest in the measurement of instantaneous values of oscillating flow rates. This new interest causes the transient response of the turbine type flowmeter to be considered significant.

The transient response of this type of instrument is best described by the time constant of the rotor when subjected to a step change in fluid velocity. In other words, if an instantaneous increase in flow rate occurs, the rotor will accelerate from a speed corresponding to the original flow rate to a speed corresponding to the new flow rate. The time required to accelerate the rotor to its new speed (or some percentage of its new speed) is a measure of the time constant. It is customary to compute the time required to reach a fraction (1-1/e) of the imposed velocity increment, where e is the base of natural logarithms. This required time is called the time constant.

Grey (13) performed a theoretical analysis on the transient response of turbine flowmeters in which he predicts time constants of one to ten milliseconds in response to a step function. The variation in response was found to be a function of blade angle, meter size and flow rate. It was also determined that the size of the assumed step increment of velocity had no effect on the time constant (i.e. on the time required to reach a fixed percentage of the corresponding rotor speed increment). This is in accord with expectations for a meter with linear response to flow rate. Similar experiments conducted at the National Bureau of Standards corroborate Grey's predicted response times but found pressure wave travel time and liquid inertia to be an important part of the overall system response phenomenon. In manufacturer's literature, response times of 2-5 milliseconds to as high as 20-50 milliseconds are given. This wide variation makes it imperative that, in areas where quick response is significant, this value be investigated and evaluated for adequacy prior to purchase of a given meter.

In many transient applications, pressure wave travel time and liquid inertia may be more significant influences than the response of the turbine meter.

ASSOCIATED INSTRUMENTATION

The turbine flowmeter, with an electrical pulse output which is roughly a linear function of flow rate, lends itself to many and varied applications. Several of these applications in the area of shipboard systems automation include: automatic data logging, automatic development of tank contents information, automatic control of fuel-tank selection and automatic deballasting control (14). The effective use of the turbine meter in these areas required sophisticated and often expensive associated instrumentation. This equipment generally falls into two categories, digital and analog readouts. These readout systems sense and convert the frequency, rather than voltage magnitude, of the signal produced, to units of flow.

The digital system, using a conventional electronic counter to indicate either pulses per unit time or total pulses received from the meter, provides the highest readout precision. These instruments will totalize the pulses generated by a flowmeter over a preselected time interval to an accuracy of plus or minus one pulse. Direct digital readout of flow rate or total flow can be obtained with electronic counters having selectable time bases. Where indication in gravimetric units is desired, instruments containing provisions for manual adjustment of fluid density must be used. In a typical industrial application, the flowmeter can be used in series with a densitometer with both signals fed into a computer whose output drives a mass flow rate indicator or recorder.

In the analog system, the meter output is fed into a converter which generates a DC voltage directly proportional to meter frequency. A null-balance type instrument, such as a potentiometric indicator, would typically be used to indicate or record the magnitude of the generated voltage in terms of flow rate units of pounds per hour or gallons per minute. The overall accuracy of a good quality converter-indicator combination is usually in the area of 1/4 to 1/2 percent of full scale. Because of the slow response and internal damping of null-balance indicators they are not appropriate for use in fast transient applications. The frequency converter alone should be designed to have a time constant equivalent to that of the flowmeter. This will provide satisfactory flowmeter-frequency converter transient performance for many computer and recording applications.

In designing a system using either digital or analog electronic equipment, care should be taken to select a readout sensitive enough to sense each and every pulse generated by the flowmeter in its operating range. Also, spurious electrical pulses must not be permitted to bias the readout indication. The choice of readout instrumentation depends upon the particular application and readout accuracy required. The readout instrumentation selected should be compatible with the frequency and voltage ranges of the turbine flowmeters to be used. These values vary widely among the manufacturers and models available.

CALIBRATION

Calibration of any flow measurement device requires adherence to the accepted general principles of flowmeter calibration practice recommended by such authorities as ASME (10) and API (15). Precise calibration of turbine flowmeters requires a knowledge and control of the previously discussed factors which may influence meter performance.

The basic problem in any calibration system is to insure accurate, precise and repeatable calibrations while keeping cost within externally imposed limits. In a given calibration system, the most accurate calibration is obtained by testing the meter at conditions as near as possible to those encountered in use.

Calibration systems can take many forms. The most frequently used methods are static weighing systems, dynamic weigh systems and the comparison method utilizing a transfer reference meter. The static-weigh method of flowmeter calibration is considered to be capable of greater accuracy than dynamic methods because the latter introduces additional dynamic errors (16). Both of these methods are superior to the comparison metho.. It must be said, however, that dynamic calibration methods are advantageous to use since the time required to perform a calibration is usually only a fraction of that required using the static method.

It is the experience of NAVSECPHILADIV, which uses the static weight method of calibration shown in Figure 3, that the largest sources of calibration error are the result of temperature, weight and specific gravity determination. These factors are discussed separately.

Temperature

Such influences as density, viscosity, and to a lesser extent, flow condition are some function of temperature. This relationship makes it imperative that temperature be measured with calibrated instruments to an accuracy of 1 F or better. A one degree error in temperature measurement corresponds to an uncertainty of about 0.08% in the volume-weight ratio of a hydrocarbon fuel. Probable fluid temperature variations within a system make it important to locate the sensor as close to the test meter as possible. To avoid the effects of temperature stratification in a pipeline, the sensor should also sample a large percentage of the flow stream.

Weight

The least count of the weigh scale used determines the quantity which must be weighed to acquire acceptable weight resolution. For scales with a 1/4 pound least count, a normal calibration run of 100 gallons, weighing

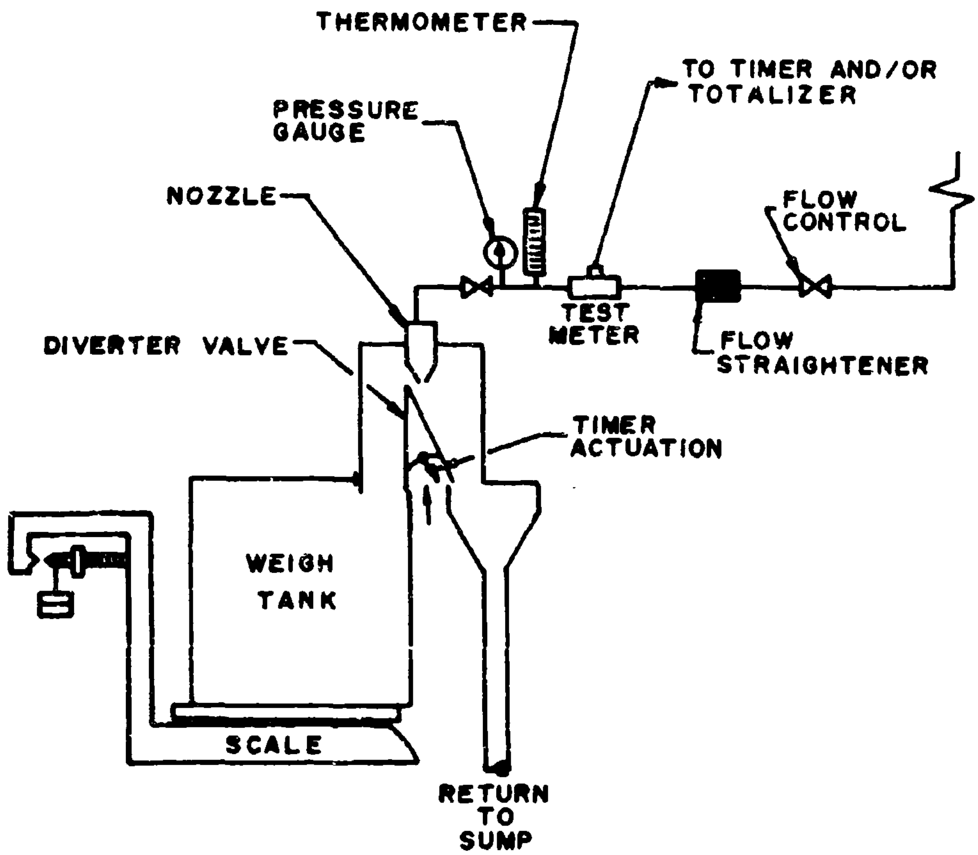

FIGURE 3-STATIC GRAVIMETRIC CALIBRATOR

a nominal 800 pounds, would produce a weight uncertainty of about 0.03%. Scales should be calibrated periodically in order to maintain the desired level of calibration accuracy. Records of these calibrations should be kept to permit detection of deleterious trends in scale calibration.

Fluid Specific Gravity

It is our experience that the largest single source of error in oil calibrations is the specific gravity determination, usually expressed in degrees API. Inaccurate gravity determination will affect all subsequent calculations which make use of this value, e.g., gallons per pound or its reciprocal. ASTM D287-55, GRAVITY OF PETROLEUM PRODUCTS, notes that the degree of repeatability of the API measurement by hydrometer (which is the method most often used) is about ±0.2 API. An error of 0.2 will produce an error of approximately 0.14% in the conversion from weight to volume.

These factors are the most significant in a static gravimetric calibration. Such effects as air buoyancy and fluid pressure are present but are relatively insignificant.

There are a number of costly dynamic weighing calibrators available commercially today. These systems are used where the time consuming aspect of static systems is undesirable. Usually dynamic calibrators determine the time interval required to collect a preselected weight of liquid, the weighing being performed while the liquid is entering the scale, tank or other weight-determining collector. From the typical dynamic weighing calibrator shown in Figure 4, it can be seen that three important dynamic phenomena take place during the weigh cycle. They are: the change

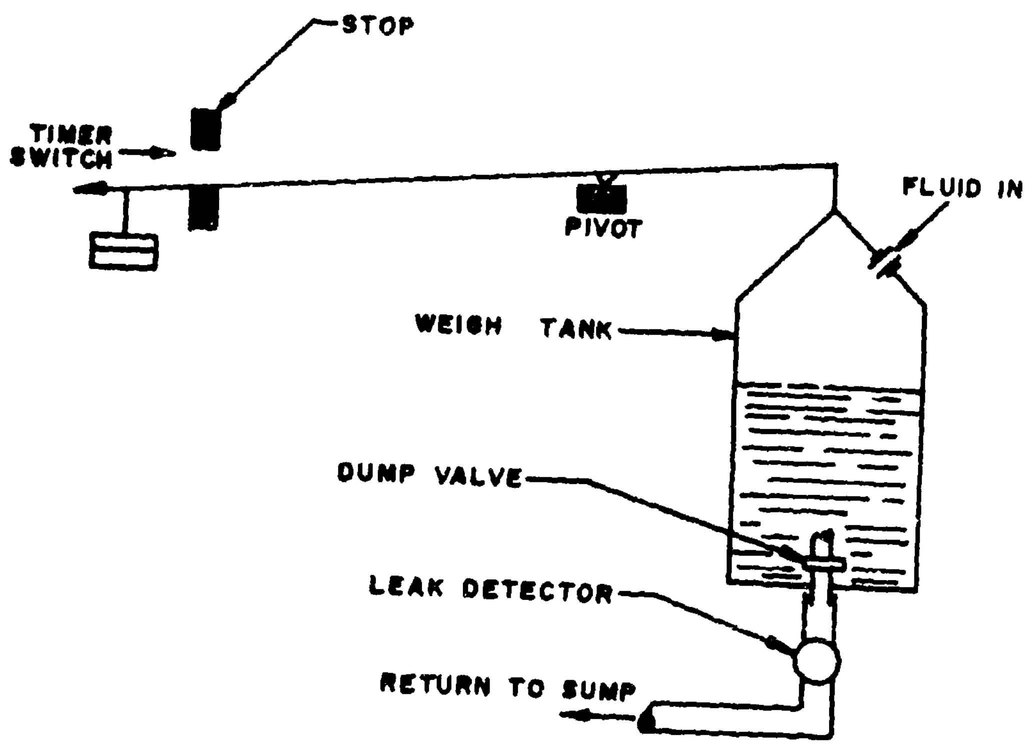

FIGURE 4 - DYNAMIC GRAVIMETRIC CALIBRATOR

in impact force between initial and final weigh points; the collection of an extra amount of fluid from the falling column by the rising level in the tank; and the change in inertia of the scale and weigh tank with a resultant change in time required to accelerate the weigh beam past the timer trip point (17). The effect of these factors though not discussed here in quantitative terms, is to make the dynamic calibrator a sophisticated and costly device which can only be used economically where a large volume of calibrations are performed.

In using either calibration system, care must be taken to provide adequate control of the flow pattern. While each meter contains integral straightening vanes, the calibration system should include flow normalizers from the types discussed earlier. The system should also refrain from using such disturbance producers as valves or elbows near the test meter. A useful guide to distances to be used under various conditions is provided by ASME (12).

A turbine meter calibration system, whether static or dynamic in principle, must use certified standards of mass, time, temperature and density to produce precise calibrations. Piping should be designed so that disturbances peculiar only to the calibrator are not induced.

CONCLUSIONS

Performance characteristics of the turbine flowmeter were found to be very well documented. The qualitative effects of various combinations of environmental conditions are well known. Precise quantitative determination of these effects on meter performance is difficult since they are a function of meter design, size, manufacturer, age, upstream piping configuration and many other factors.

Future improvements in the turbine meter field seem most promising in the areas of materials technology, bearing design and in the reduction in cost of compact and durable peripheral electronic equipment. Improved materials and bearings would expand the already wide range of commercial applications but would not be of immediate value to the Fleet. It is felt that a less costly meter-readout package, without compromising performance, could make the turbine meter a desirable alternative in meeting the future needs of the Fleet. This is particularly true in the area of semi or fully automated ships of the future where meter outputs would be used as control inputs.

Heretofore, the turbine meter has not been used widely on shipboard for reasons including its inherent weaknesses and the requirements of existing shipbuilding specifications. The principal factor prohibiting their use is the access flange requirement which says that the meter interior parts must be capable of removal without removing the meter from the pipeline. Development of a turbine meter with this capability would permit its widespread use in such areas as fueling-at-sea and condensate flow measurement.

Development by the industry of devices which would serve to standardize if not normalize the condition of the flow stream would be desirable. An example in this area is a turbulence producing device, highly repeatable in effect, which in performing its function would not introduce greater problems than it would solve. This device could be either an integral part of the meter or a separate unit to be installed at some point upstream of the meter.

The information obtained in this survey provided the inputs necessary for preparation of a proposed detail military specification on the turbine meter and could, if called upon, be the base for preparation of application guidelines and standard practices for their use.

For the aforementioned reasons, the originally planned broad based test program is considered unnecessary and will not be conducted. However, future advances in the field will be closely monitored and test programs initiated as deemed necessary.

RECOMMENDATIONS

So that Fleet flow measurement practices may keep pace with future needs and developments in such areas as shipboard automation and fueling-at-sea, actively encourage application of the turbine meter where it is compatible with existing requirements.

Toward this end, solicit the cooperation of turbine meter manufacturers in developing and subsequently producing a turbine meter which can satisfy the access flange requirement of shipbuilding specifications. At the same time, re-evaluate existing shipbuilding specifications for possible areas of revision. If development of the redesigned turbine meter is not accomplished or specification revisions are found to be impossible, investigate other meter types with a pulse output which can meet the access flange requirement and may also be capable of driving direct totalizing devices.

Prepare standard practices and application guidelines for the turbine meter and any other meter type deemed appropriate for similar uses.

Encourage development of a flow condition standardizing mechanism which might circumvent approach effects on most velocity sensing meters.

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NAVSECPHILADIV 6711F(2), 6711D02, 6760, 6761(7)

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Naval Ship Engineering Center Philadelphia Division Philadelphia, Pa. 19112	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP	
3. REPORT TITLE Turbine Type Flowmeters "State of the Art" Literature Survey		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) A Research and Development Final Report		
5. AUTHOR(S) (First name, middle initial, last name) Joseph S. Castorina		
6. REPORT DATE 30 June 1968	7a. TOTAL NO. OF PAGES 30	7b. NO. OF REFS 1
8a. CONTRACT OR GRANT NO. b. PROJECT NO. NAVSECPHILADIV Project A-771 SF013-06-20, Task 3950 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NAVSECPHILADIV Project A-771 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ship Engineering Center	

13. ABSTRACT

A survey of the literature was conducted in order to evaluate the ability of the turbine meter to meet the flow measurement needs of the Fleet. Parameters effecting meter performance were investigated as well as pertinent related topics. The turbine meter is burdened with the inherent weaknesses peculiar to most velocity sensing meters. It was found suitable for future use in shipboard automation and fueling-at-sea applications under the following provisos: a turbine meter satisfying current shipbuilding specification access flange requirements should be developed, or the specifications making this demand revised. If one of these cannot be accomplished, investigate other pulse output meter types which will meet the access flange requirement and may also drive direct totalizing devises. Application guidelines and standard practices should be prepared for the meter type(s) ultimately selected for control-input and fueling-at-sea use.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Flowmeters						
Turbine Meters						
Flow Measurement						
Transducers						