Turbine Meters for Liquid Measurement

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Introduction

Although the liquid turbine meter principle dates back many decades, the axial flow turbine meters presently employed for liquid measurement are quite new. The axial flow turbine meter was first used where accuracy of measurement was not the prime factor, reliability was of greater importance, so parts were made rugged and the rotor was designed to be more non-clogging than accurate. Thru time, the turbine meter has maintained its reliability and ruggedness while attaining a high degree of accuracy.

The aerospace industry has found the turbine meter to be an excellent answer to many of their measurement problems. They were mainly interested in a high degree of reliability, providing an accurate result, and having an output signal that was suitable for telemetering. The one moving part meant simplicity, ease of maintenance, and a high degree of reliability. The improved designs produced accurate results. The electrical frequency outputs were suitable for telemetering.

The official recognition of the turbine meter by the petroleum industries took place in March 1970 with the publication of API Standard 2534. The publication of this standard has opened the door to use turbine meters for custody transfer of refined products and pipeline systems, tanker, barge, and truck loading or unloading. This has brought the turbine meter to worldwide recognition as a primary register for the exchange of energy.

Principle of Operation

Liquid turbine meter measurement combines the turbine and electronics to measure total flow and/or flow rate within a piping system. The turbine meter is a volumetric measurement device. It functions by sensing the linear velocity of the fluid passing through the known cross sectional area of the meter housing to determine the volumetric flow rate.

The fluid, as it passes through the meter, imparts an angular velocity (RPM) to the rotor, which is proportional to the linear velocity of the flowing fluid. Since the linear velocity of the flowing fluid though a given area is directly proportional to the volumetric flow rate, it follows that the speed of rotation of the rotor is directly proportional to the volumetric rate.

The development of turbine meters giving accurate measurement over a wide range of flow rates for a large number of fluids, coupled with the advances made in the electronics industry in utilizing the turbine output for flow control and integration, are the reasons for universal acceptance of the turbine principle.

Construction

The construction of the liquid turbine meter is relatively simple, as shown below. It consists of a cylindrical housing similar to a flanged pipeline spool piece, containing a precisely balanced free-running rotor, mounted co-axially on the pipe centerline. A pick-up assembly positioned as close to the rotor as practical without penetrating the housing wall. The fluid passes through the meter causing the rotor to rotate which generates pulses in the pick-up coil. Each pulse represents a distinct unit of volume. The total number of pulses integrated for a period of time represents the total volume metered. The exact design of the essential components differs with the size and make of the meter, but general features of these components can be discussed.

The turbine rotor is mounted on a shaft within the meter housing and supported by one or two hanger assemblies. The hanger assemblies are utilized to support and position the rotor and bearing co-axially on the centerline of the meter housing. They are not intended to act as flow straighteners. The rotor contains a number of blades, set at a predetermined angle. The angle of the blades governs the angular velocity and therefore the output frequency.

Measurement of the rotor speed is accomplished by interaction between the rotor and pick-up coil.

The rotor is supported on a journal bearing set, which is lubricated by the metered fluid. Most turbine meter manufacturers use the floating rotor principle to reduce wear on the thrust faces when using journal bearings. This is not required when ball bearings are utilized.

Performance Characteristics

Characteristics that may be of interest in the application of turbine meters include the accuracy, which is subdivided into linearity and repeatability, pressure loss, voltage output, resolution, frequency output and rangeability. Each of these is a function of flow rate and fluid properties.

Accuracy is a measure of how close to a true flow the turbine meter is indicating. Accuracy is a composite statement of repeatability and linearity over a stated range of flow rates.

The linearity of a turbine meter is a percentage of true reading over a stated flow range. The repeatability is the ability of the turbine meter to indicate the same reading each time the same flow condition exists.

Turbine meters exhibit excellent repeatability and for many control applications, this parameter is of more importance than linearity. This is particularly true in a batch operation.

The resolution of the turbine meter is a measure of the smallest increment of total flow that can be individually recognized. Turbine meters have an inherently high resolution, which may be increased by extra pick-up coils or by extra buttons or slots on a rimmed rotor.

Rangeability is the ratio of maximum flow to minimum flow over which the specified accuracy will be maintained.

The pressure loss of the liquid meter is a function of the flow rate squared. This is the permanent pressure loss and does not include the pressure required to accelerate the liquid to meter entrance velocity. Further, there is a minimum operating backpressure level that will prevent cavitation, depending on the characteristic of the specific fluid. A conservative statement of sufficient back pressure necessary when utilizing a turbine meter is given in API Publication 2534.

The pulsed signal generated in a stationary pickup coil by the rotation of the rotor is the parameter, which the readout system senses as an indication of flow.

Piping Installation

The turbine meter, as a velocity dependent device, is influenced to varying extents by disturbances in the upstream velocity profile (flow pattern). The most common types of disturbances encountered are in the form of fluid pulsation, swirl, and non-uniform velocity profile introduced by upstream piping configuration, valves, pumps, flange misalignment, or other obstructions.

Pulsating flow is defined as cyclic variations in which the flow is never steady for any length of time. Pulsating flows are an ever-present problem and what is required is that a meter gives an accurate mean flow no matter how violent the pulsations. The turbine meter has a rapid response rate and depending on the mass of the rotor and the size of the meter, response times as low as 3 milliseconds are obtainable. The rapid response of the turbine is explained by the fact that it is a momentum device which impacts the force produced by a rapid change in flow is directly applied to a free-running rotor. The turbine meter, as expected, demonstrates significant advantages over conventional meters under pulsating conditions; however, the choice of readout equipment is important.

The particular upstream disturbance, which has the greatest influence on metering accuracy, is rotational flow or swirl. Swirl will change the angle of attack between the liquid and the turbine blades with a resultant effect dependent on the direction of the swirl in relation to the rotor to increase or decrease the turbine speed at a constant flow rate. The available data on effects on a turbine meter in rotational flow seem to indicate that there is no broad range of operating conditions in which a meter is not affected by swirl.

The remaining disturbance to be discussed is that of non-uniform velocity profiles. This non-uniform profile is usually in the form of a slanted profile whether the fluid is moving faster along one side of the pipe than the other side. Such a slanted profile results as fluid exits bends and elbows in the piping system. Many tests have been made on the effects of upstream bends and elbows. The results, although not part of a systematic investigation into installation effects, indicate a magnitude of from a 1% decrease to a 10% increase in meter factor, depending upon the specific upstream element.

For these reasons, a properly designed meter run, incorporating a flow-straightening device, is an important aspect of the turbine meter installation. It is recommended that the upstream run be approximately ten pipe diameters long and have a straightening vane assembly two to three diameters long utilizing multiple small diameter, thin wall tubing. It is also recommended that a downstream portion of the meter tube be utilized that is a least five pipe diameters long. These installation recommendations are in accordance with the API Manual of Petroleum Measurement Standards.

Fluid Properties and Conditions

The variation of fluid properties and conditions can have significant impact upon the performance of the turbine meter. Those fluid properties and conditions most affecting the turbine's performance are temperature, pressure, viscosity, and specific gravity.

If the conditions of temperature and pressure are individually considered, excluding their effect on flow rate, viscosity, or specific gravity, then the change in temperature and pressure affects the physical dimensions of the liquid and the materials of the meter. Changing the temperature and/or pressure of the flowing liquid within the meter from that which existed during calibration results in:

1. Changes in the relative volume of the liquid
2. Changes in the physical dimensions of the meter

These effects, attributable to variations in pressure and temperature, can be expressed mathematically in terms sufficient enough to obtain reasonable measurement accuracy.' However, the reliability of these mathematical expressions decreases as the magnitude of temperature and pressure variations increase.

The effects that variations in the liquid viscosity and specific gravity have on the turbine meter are related to the linear rangeability, calibration coefficient, and pressure differential performance.

Changes of the liquid viscosity alone tends to vary the rangeability of the meter thru loss of low flow linearity, to cause shifts in calibration coefficient (pulse per unit volume) at a given flow rate, and to vary the pressure differential across the meter. The exact extent to which increases in viscosity will decrease the rangeability and shift the calibration coefficient of the meter is dependent upon:

1. The specific type of meter bladed or rimmed)
2. The specific operating conditions. (temperature, pressure, specific gravity)
3. The particular tolerances within a given meter.

An approximation of the effect of viscosity variations can be obtained for a special size and type of meter, based on empirical data, from a generalized viscosity curve. This plot shows that as viscosity increases, the low flow linearity begins to vary, resulting in a shift in the calibration coefficient. The exceptional repeatability of the turbine meter remains unaffected. This plot also shows that the larger the meter the less the variation. This difference could obviously result in a metering error. It is, therefore, essential that the meter be proved on the flowing fluid at operating conditions to obtain the maximum accuracy.

The remaining property to be considered is that of liquid specific gravity. Variations in the specific gravity of the flowing fluid result in changes in the pressure loss across the meter and shift in the meter's capacity.

The shift in meter capacity resulting from a change in specific gravity is due to the resultant driving torque of the fluid. For a given flow rate, the total driving torque diminishes as the specific gravity decreases, resulting in a reduction of low volume rangeability. Therefore, in order to maintain a minimum driving torque for a decrease in specific gravity, the minimum flow rate must be increased. The required shift in the meter capacity can be estimated from the following expression:

$$Q \min (x) = Q \min (w) \times \left[\frac{1}{32}\right]^{3/4}$$

Q min (x) = Minimum Flow at Operating Conditions
Q min (w) = Minimum Flow on Water

SG = Specific Gravity

This expression is particularly important when measuring light fluid such as butane, propane, ethane, etc... using this expression insures that the meter is maintaining maximum accuracy.

Comparative Application

Probably the two main advantages of the turbine meter over conventional differential head devices are:

1. The extended and more accurate registration of flow in the low flow range of operation, which results from the registration being proportional to the velocity rather than the velocity squared.
2. The comparatively low head loss across the meter.

The turbine meter has several advantages over the conventional positive displacement (P.D.) meters. The turbine can handle two to three times the flow of its equivalent size P.D. meter, resulting in a cost savings. Second, the turbine, because of its inherent design, can withstand severe service such as sand, over-ranging, and salt water, with less maintenance and better life.

In general, other advantages include a wide range of fluid applications, fast response and convenient read-out for control purposes. Each application must be considered on its own merit, and economic consideration between the turbine and other metering is a necessity. Depending on the type of read-out and the control required, the turbine meter system compares favorably with other metering systems. However, where maximum accuracy, wide operating range, repeatability, and convenient control is needed, the turbine meter must receive the primary consideration.