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FUNDAMENTALS OF LIQUID TURBINE METERS

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Dave Seiler
Director of Marketing
Daniel Measurement and Control, Inc.
11100 Brittmoore Park Drive
Houston, Texas USA

Introduction

Liquid turbine meter design has changed little from the original Potter design developed in the 1960's. Although originally designed for low – accuracy water flow measurement, its application into the aerospace industry called for higher accuracy and reliability as well as simplicity in design.

At the same time petroleum and petrochemical industries adopted the meter. With the publication of API 2534 in March 1970, the liquid turbine meter became a recognized meter for use in custody transfer of refined products and pipeline systems as well as tanker and barge loading or unloading of crude oil.

Principle of Operation

The liquid Turbine Meter is an axial flow rate measuring device, which has a rotor driven by the velocity of the flowing liquid in a closed conduit. The fluid, as it passes through the meter housing, imparts an angular velocity on the turbine meter rotor, which is directly proportional to the linear velocity of the flowing fluid and consequently the volume flow rate. In doing so, the rotor accelerated until the driving torque on the rotor blades balances the sum of the resisting torque's, consisting of hydraulic and bearing drag.

The angular velocity of the turbine rotor is taken through the turbine meter wall by means of a magnetic pickup. Rotor blades or buttons, made of ferro-magnetic material, rotate past the pickup coil generating irregular shaped voltage pulses.

The frequency of these pulses is linearly proportional to the angular velocity of the rotor and thus the flow rate. Additionally, each pulse is incrementally proportional to a small unit of volume.

The turbine rotor blade causes the magnetic field produced by the coil to deflect as it passes the coil tip causing a voltage to be generated in the coil.

As each blade passes the coil tip, a distinct voltage pulse is produced. The turbine meter output is rated in pulses per actual cubic volume.

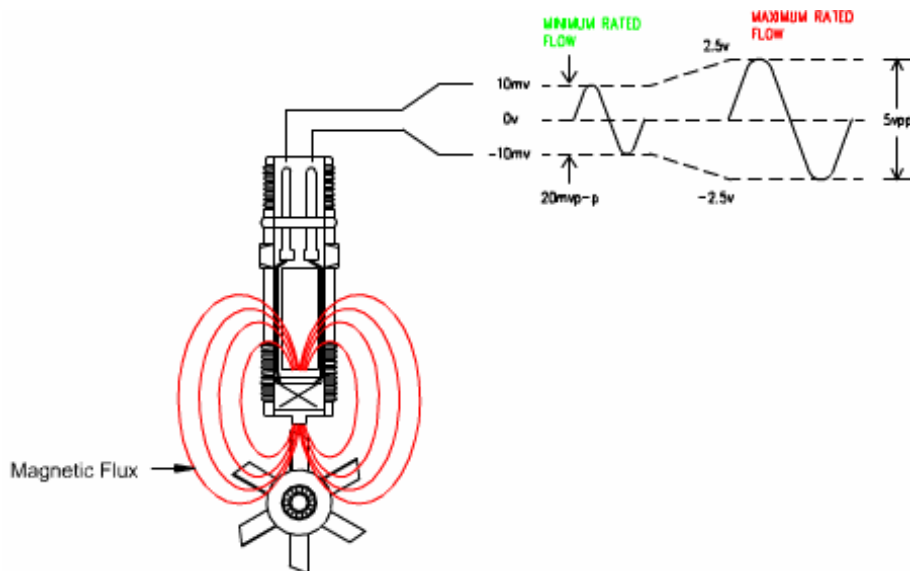


Figure 1. Output from Pickup Coil

The output signal from the pickup coil is proportional in both frequency and amplitude to the velocity of the rotor which in turn is directly proportional to the velocity of flow passing through the meter.

Because the signal from the pickup coil is relatively low amplitude and sinusoidal in nature, in most cases this signal is used as an input to a preamplifier which is normally mounted directly on the meter.

The purpose of the preamplifier is to amplify the signal and convert the sinusoidal signal into an industry standard square wave signal that can be read by most read out instrumentation.

Construction

A typical turbine meter consists of meter housing – a cylindrical body with specified end connections that are capable of being installed in a pipeline – for example flanges or NPT threads.

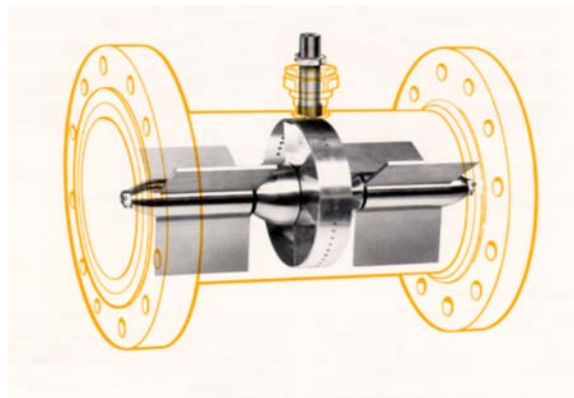


Figure 2. Rim Type Turbine Meter

The meter housing contains a precisely balanced free running rotor, mounted co-axially on the meter centerline. The magnetic pickup assembly, while positioned as close to the rotor as possible, typically does not penetrate the meter body.

The turbine rotor is mounted on a shaft and supported by up and downstream hanger assemblies. These hangers serve to position the rotor exactly on line with the meter housing and pipeline flow.

There are several rotor designs available. Straight and helical bladed rotors and also rim or shrouded designs. Each offers positive advantages for specific applications.

The rotors ride on a variety of bearing types. Sleeve bearings are the most common followed by ball bearings for light hydrocarbon clean services.

The flowing fluid is directed through the rotor by an upstream cone. The downstream cone allows for fluid departure from the rotor without a dramatic drop in pressure across the rotor.

The up and downstream cone design also prevents the rotor riding on the up or down stream thrust washer and was developed as the “floating rotor” principle.

The principle designates that as the flowing fluid enters the turbine meter, through the upstream hanger; it encounters the sharp angle of the upstream cone and is deflected outward increasing its velocity and causing a slight static pressure drop. As the fluid leaves the blade area, flow is redistributed, velocity is reduced slightly and the static pressure has increased proportionally. The difference between the two velocity pressures causes the rotor to move upstream into the fluid flow. The cross sectional area of the upstream cone is designed to be smaller than the rotor hub so that some of the flow impinges onto the rotor hub generating a downstream thrust. As a result, the rotor floats in balance. This ensures improved rangeability for the meter and reduced wear.

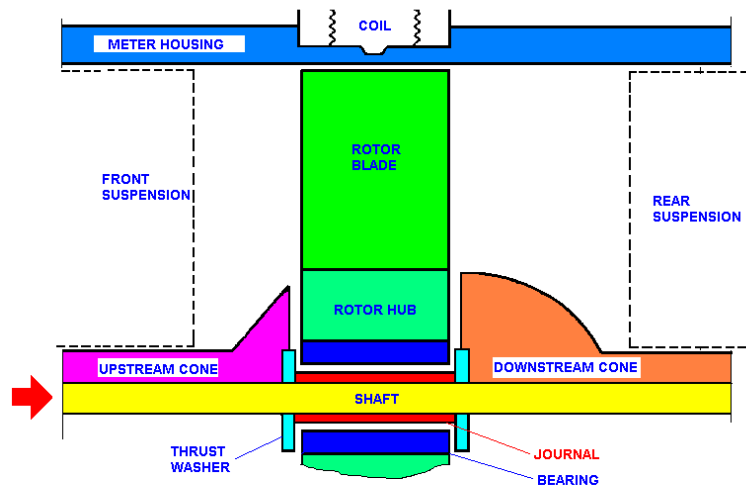


Figure 2. Floating Rotor Principle

Performance Characteristics

The characteristics that pertain to the application of the turbine meter are:

1. Linearity, which is subdivided into;
 - a) Accuracy
 - b) Repeatability
2. Resolution
3. Rangeability
4. Pressure Loss
 - a) Back pressure
5. Voltage Output
6. Frequency Output

- 1) Accuracy can be defined as how close to the true or actual flow the instrument is indicating. When this is applied over a flow range, it can then be described as linearity. Typical linearity's are $\pm 0.15\%$ over a 10:1 turndown.

The repeatability of the turbine meter is the ability of the meter to indicate the same reading each time the same flow conditions exist. Typical repeatability's are $\pm 0.02\%$ over the full range of the meter.

Turbine Meters exhibit excellent repeatability and for many control applications, this parameter is of more importance than linearity.

- 2) The resolution of the turbine meter is a measure of the smallest increment of total flow that can be individually recognized. This is determined on a turbine meter by the number of rotor blades or buttons and the rpm of the rotor. Additional pickups can also increase the number of pulse outputs for the meter.

- 3) Rangeability is the ratio of the maximum flow to the minimum flow over which the specified accuracy will be maintained. This is sometimes also referred to as the meter turndown. Typical turbine meter ranges are 10:1 or greater at +/- 0.15% linearity or greater. Most manufacturers offer a normal flow range with specified linearity and extended minimum and maximum ranges.
- 4) The pressure loss of the liquid turbine meter is a function of the flow rate squared. This pressure loss is usually within the range of 4 psi for the normal flow and 6 psi for the extended flow. This is a permanent pressure loss through the meter.
 - a) Further to this there is a minimum operating pressure level, which will prevent cavitation. API chapter 5 section 3 states that "Flow separation and vaporization in the turbine meter, are best controlled by operating the meter within the manufacturers stated range and at a minimum back pressure immediately downstream, of twice the pressure drop across the meter plus 1.25 times the absolute vapor pressure at maximum temperature of the flowing fluid."

Minimum Back Pressure =

$$2 \times AP + 1.25 \times VP$$

5) Voltage Output

In the turbine meter, an AC voltage is generated in the stationary pickup coil through varying reluctance of the magnetic field, as influenced by the blades or buttons of the turbine rotor. The magnitude of this voltage is proportional to the rotor velocity and can range from a minimum of 30mV to a maximum of about 5 volts peak to peak, depending on the size and type of rotor.

- 6) The frequency of the AC voltage is the parameter which the readout system senses as an indication of flow. This is always linearly proportional to the rotor velocity and can range from 10 Hz minimum to 2,000 Hz at the maximum flowrate.

Application

When considering using a turbine meter for liquid measurement, it is important to consider the following:

- a) The type of liquid the meter will measure, i.e. viscosity, specific gravity, vapor pressure and corrosivity.
- b) The range of operating flow rates and whether the flow will be continuous or intermittent.
- c) Performance Characteristics; Linearity, Repeatability, etc.
- d) Range of operating pressures and maximum allowable pressure loss through the meter.
- e) Temperature range the meter will operate.
- f) Space available for meter installation.

Turbine meters are suitable for a variety of flowing conditions including light hydrocarbons and crude oils. They typically require some form of electronics for readouts and corrections.

They are susceptible to swirl, pressure pulsations, excessive surges and typically require some form of flow conditioning. They also require sufficient back pressure to avoid cavitation. They routinely require a strainer upstream to prevent particulate damage to meter internals.

Turbine Meters are sensitive to large changes in viscosity although are capable of measuring accurately, fluids which have non-fluctuating high viscosities at high flow rates.

Installation

As previously stated, the turbine meter as a velocity device is influenced by disturbances in the upstream velocity profile. The most common disturbances being fluid pulsation, swirl and non-uniform velocity profile induced by upstream piping configurations, valves and pumps.

Pulsating flow is defined as cyclic variations in which flow is never steady for any length of time. As a turbine meter has a rapid response rate the effect of pulsation on the meter is immediately felt as the rotor reacts to keep

pace with the pulsations. If the pulsations are of a particularly violent nature, bearing wear can be excessive leading to a breakdown in performance.

The particular upstream disturbance, which has the greatest influence on metering accuracy, is rotational flow or swirl. The change of angle of attack between the liquid and the rotor blades results in an increase or decrease of turbine speed dependent on the direction of rotation. API recommends straightening vanes and increased pipe lengths in the upstream piping, prior to the meter, to eliminate the effects of swirl.

More recently conditioning plates and tube bundles are being combined in an attempt to reduce the effects of interference from swirl as well as conditioning the profile of the flow.

API Chapter 5 section 3 recommends 20 pipe diameter of straight pipe or 10 pipe diameter of straight pipe with straightening vanes upstream of the turbine meter as well as 5-pipe diameters of straight pipe downstream of the meter.

Pipe diameter of 2" and less are typically recommended with 20 diameters of straight pipe upstream.

Meter Proving

The proving operation re-verifies the meter factor and assures proper and accurate meter operation.

When the turbine meter is installed in service its K-factor, or calibrated pulses per unit volume, is programmed into the accompanying instrumentation. Although K-factors rarely change appreciably with time, the turbine meter should be periodically proved at regular intervals to assure accuracy and repeatability.

Several methods are available offering in – situ proving as well as returning complete meters or meter internals back to the factory.

The most popular methods are:

Bi-directional Prover

When a proving run is to be made, the flow is diverted through a 4-way valve and through a large calibrated volume. The valve switching operation does not disturb the main flow.

The size of the meter prover is a function of the desired velocity of the piston or ball displacer. Velocity should be high enough to ensure good flow-rate through the meter and to prevent surges or other disturbances of flow. API manual of Petroleum, Chapter 4, Proving systems, suggests 5 feet per second (fps) as a design optimum for a bi-directional system and up to 10 fps for uni-directional. The prover volume typically allows for a minimum of 10,000 pulses generated by the meter between detector switches for any one-way run.

Small Volume Prover

The use of small – volume provers have been made possible by using highly repeatable displacer-position detectors used in conjunction with pulse interpolation methods.

Small Volume Provers (SMV'S) require meter pulse discrimination using a pulse interpolation technique since the SMV does not have the capacity to total 10,000 pulse counts in one passage of flow.

When one meter is reserved for proving purposes it is normally known as the master meter. A comparison of the two-meter outputs is the basis of the master meter proving method.

Conclusion

Turbine meters are generally small in weight and size. They offer the benefits of long bearing life as well as a history of performing with excellent repeatability and accuracy over a wide range of flow rates and fluid applications.