APPLICATION OF TURBINE METERS IN LIQUID MEASUREMENT
Class # 2020.1

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Introduction

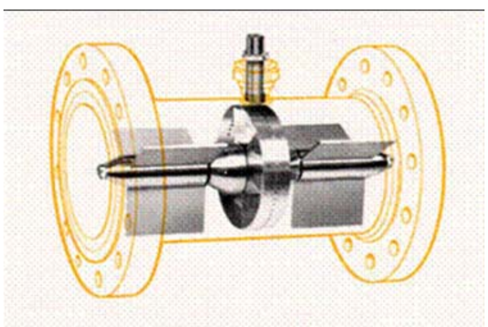
The purpose of this paper is to provide both novice and experienced measurement personnel with a better understanding of the operating principles and requirements of turbine meters used in liquid measurement applications. Most if not all material herein pertains to the custody transfer measurement of refined products, natural gas liquids (NGL), anhydrous ammonia (NH3), and crude oils.

Liquid turbine meters range in size from 1” to 24” in most cases, with some smaller and larger exceptions. Newer turbine meter technologies include the helical rotor design which can be very accurate and less susceptible to the effects of higher viscosity fluids such as crude oils. Newer design electronics offer multiple outputs and can be more immune to electromagnetic interference (EMI) and radio frequency interference (RFI) when properly installed. Turbine meters are available with ANSI pressure ratings from 150# to 2500# making them a practical measurement solution for a variety of applications in the petroleum industry.

Design Characteristics

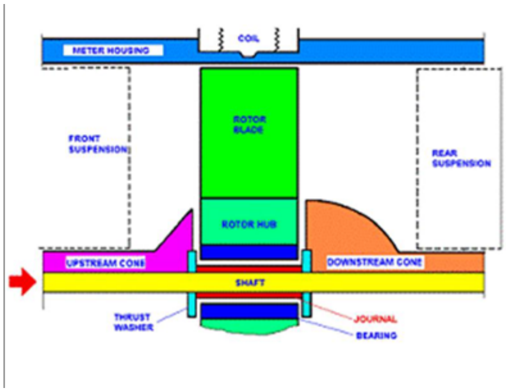
Typical turbine meter construction consists of the meter housing or body fabricated from meter tube quality pipe with flange connections welded on to the ends. The internal assembly is made up of the rotor, end hangers or stators to support and secure the internals in the body, rotor shaft and tungsten carbide bearings on which the rotor turns. The dual stator or hanger design supports the internals at both upstream and downstream ends while the cantilever design supports the internal assembly at the upstream end only.

The rotor design can be either blade type or rim type depending on application requirements and meter size. The rotor blades are typically made of magnetic material while the rim type rotor may have either magnetic buttons or slots machined in the rim. The slotted rim is magnetic material and the mass between the slots rather than buttons or blade tips excites the pickup coil generating a pulse output. The rim or shroud provides additional rigidity for the rotor blades especially in 8” and larger meters. The magnetic buttons or slots number more than the blades thereby providing more pulses per rotor revolution and a higher pulse resolution. The rim or shroud can also help with viscosity compensation in certain applications.



A reluctance type pickup coil installed in a pickup boss or pad produces a magnetic field that when the rotor blade or rim passes through the magnetic field a sinusoidal wave or pulse is generated. These pulses are proportional to the flow rate or product velocity turning the rotor. These low voltage pulses or sine waves are then transmitted to a preamplifier also mounted on or in close proximity to the turbine meter. The preamplifier is typically powered by 12-24 VDC and produces a square wave output of signal amplitude sufficient to be transmitted up to several thousand feet.

All turbine meters of this type incorporate the floating or balanced rotor design. Without this design the natural tendency would be for the flowing stream to force the rotor downstream causing the downstream bearing or thrust washer to wear out prematurely. The upstream cone design directs the flow through the rotor while the downstream cone allows fluid to pass from the rotor with a minimal drop in pressure across the rotor.



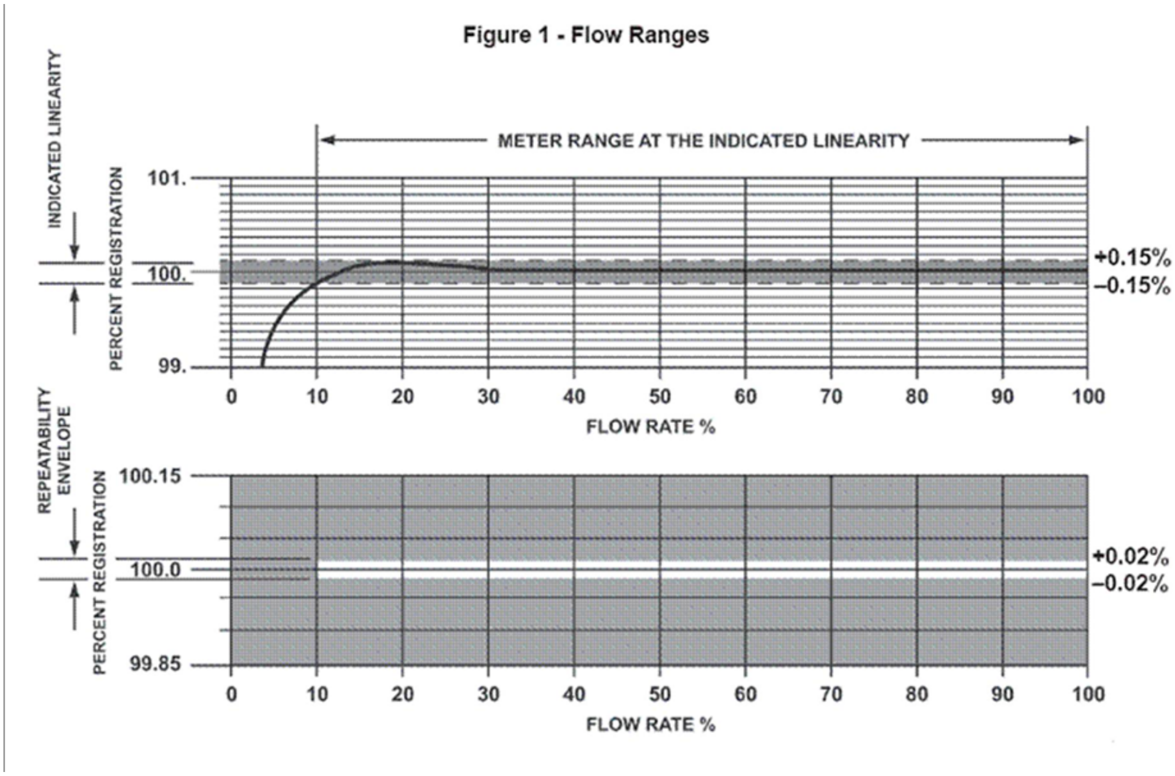
Measurement Characteristics

For years prior to turbine meters acceptance positive displacement or PD meters were an industry standard. The measurement principles are different between a turbine meter and PD meter in that a PD meter divides the flowing stream into segments, counts the segments, returns the segments to the flowing stream and transmits this action to mechanical counters/totalizers and other accessories by means of a gear train. The turbine meter is an inference type meter in that it infers flow rate from the measurement of the movement of the rotor in the flowing stream. As the fluid flow impinges on the turbine blades causing the rotor to spin the angular or rotational velocity of the turbine rotor is directly proportional to the fluid velocity passing through the meter.

Performance Characteristics

Accuracy can be defined as how close to the actual flow or known standard the meter is indicating. When this is applied over a flow range, it is then described as linearity such as +/-0.15% over a 10:1 turndown.

Repeatability is the ability of the meter to indicate the same reading each time the same flow conditions exist. Turbine meters, by virtue of only one moving part, the rotor, have a very repeatable flywheel action that provides a typical +/-0.02% repeatability specification over the same 10:1 turndown provided operating conditions remain stable. See Figure 1



Application Considerations

Turbine meter performance is affected by several things that must be carefully considered when engineering a turbine meter system.

Viscosity

The reaction type turbine meter as discussed in this paper is viscosity sensitive. As product viscosity increases the turbine meters linearity begins to suffer. Viscosities at or above 4 centipoise require all specifications to be considered especially the minimum flow rate requirement. By calculating the systems Reynolds number meter performance can be predicted. A Reynolds number is a dimensionless number used to calculate turbulence in the flowing stream. Using the formula, Re = Vd/v will provide the system Reynolds number.

V = fluid velocity
d = pipe diameter
v = kinematic viscosity

The turbine meter performs best in turbulent flow conditions as opposed to laminar flow. A high Reynolds number indicates turbulent conditions. When Reynolds number is low the velocity profile of the stream becomes parabolic shaped (bullet nosed) with the velocity disproportionately higher in the center of the pipe than the pipe walls. The turbine rotor cannot accurately measure the average stream velocity when these conditions occur. By increasing the meter size (d in the formula) will increase the Reynolds number and provide better performance. Flow rangeability will still be adversely affected at the lower rates and the traditional 10:1 turndown could be decreased by as much as 50% in some cases.

Specific Gravity or Density

The turbine meter like the PD meter is affected by specific gravity (SG). With the reaction type turbine meter this effect starts when specific gravity drops below .7. As the specific gravity or product density decreases the lift forces on the rotor blades decrease requiring higher velocity flow to provide necessary energy to maintain the rotor turning at optimum speed. The reduced energy is overtaken by bearing friction at lower flow rates thereby requiring the flow range to be shifted upward at both low and high ends. Example: A 3” turbine meter with standard turndown of 100 to 1000 BPH with a .7 > SG would have its flow range shifted up to 183 to 1260 BPH when used in an application with a SG of .55 to .65.

Flow Conditioning
Turbine meters unlike PD meters do require flow conditioning in order to achieve best performance. The incoming fluid at the turbine meter should be devoid of swirls and excessive turbulence. In order to avoid these conditions piping immediately upstream of the turbine meter should be free of obstructions, elbows, reducers, reduced port valves, and strainers. API Manual of Petroleum Measurement Standards, Chapter 5.3 provides recommendations on straight piping requirements to accomplish desired flow conditioning.

In order to achieve proper conditioning flow straighteners are incorporated in almost all system designs. A flow straightening section is typically fabricated from a straight pipe section 10 pipe diameters in length and contains a tube bundle or straightening vanes positioned parallel to the flowing stream. The downstream section is usually another straight pipe of 5 pipe diameters in length. Technology has produced a variety of flow conditioners other than the traditional 10D upstream section with tube bundle. The writer suggests all interested parties avail themselves of these newer flow conditioning technologies by reviewing other ISHM papers describing in detail how these devices work.

Back Pressure
All meter systems should have a control valve located downstream of the measurement equipment. The control valve's function is to limit flow rate and maintain system pressure in order to ensure adequate back pressure of the system in order to prevent cavitation. Cavitation will occur when the meter/piping is not liquid full due to a two phase (part vapor, part liquid) condition due to lack of back pressure. If cavitation occurs the meter will over register and at very least cause measurement errors. If severe cavitation occurs bearing failure will follow very soon thereafter. In extreme cases rotor blades can be damaged to the point of deformity or even sheared off of the rotor hub.

Minimum back pressure requirements can be calculated using the following formula:

$$BP = 2P + 1.25VP$$

BP = back pressure
P = pressure drop in psig across the meter at max flow rate
VP = vapor pressure of the product measured in psig and at operating temperature

Troubleshooting Tips
Start at the beginning and assume nothing. Many hours have been lost by taking it for granted that some normal condition exists when in fact it does not. Verify that isolation valves are fully open and strainers/filters are free of foreign material and free flowing. If flow rates are lower than they should be or the meter factor has shifted significantly or repeatability is out of spec it may be necessary to remove the upstream section to ensure there are no blockages at the straightening vanes or flow conditioner.

The next steps require a quality digital multi meter (DMM) to measure resistance (Ohms), both AC and DC voltage, and frequency in Hertz (Hz). Some newer DMM also have an oscilloscope function that can be valuable in troubleshooting. First disconnect power to the preamp to avoid stray counts/pulses or shorting out the preamp. Start with the pickup coil by disconnecting the leads from the preamp and measure the coil resistance. Verify the proper resistance values with the manufacturer. If the coil resistance is in tolerance re-connect the pickup coil leads to the preamp and restore electrical power. Check the supply voltage to the preamp; most preamps require 12-24 VDC again verify this with the manufacturer. With flow established once again, check the pickoff sinusoidal (sine) wave signal amplitude of the pickoff coil and preamp square wave signal amplitude output (VDC) to ensure it is in tolerance. This is where an oscilloscope could be used to look at both the sinusoidal wave output of the pickoff and the square wave pulse output from the preamp to ensure the signals are free of interference, frequency modulation, ground loop noise, and have a steady pulse output signal amplitude.

If an oscilloscope is not available a frequency (Hz) reading can be taken to verify the preamp output to the flow rate. To calculate the approximate meter frequency output use the following formula if measuring units per minute (GPM, LPM, etc)

$$\frac{\text{Meter K factor x Flow Rate}}{60} = \text{Frequency} \qquad \text{Example: } \frac{\text{K factor of 25 x 500 GPM}}{60} = 208.33 \text{ Hz}$$

If measuring units per hour (BPH, M3hr) use 3600 for the denominator in the formula.

The next step requires checking the wiring between the meter preamp and its termination point at a junction box, flow computer, preset, or totalizer/rate indicator. Wiring should be quality multi conductor cable of sufficient wire gauge so as to not cause signal loss due to line resistance. The multi conductor cable should be shielded with a drain wire terminated on one end, preferably at the case ground point of the flow computer, preset, etc.

If all of these steps check out within specifications, the next step will be to block in and drain the line and remove the turbine meter to visually inspect the upstream piping and flow conditioner, the meter internals and body, and the downstream piping for any foreign material, blockages, or deformities. Disassemble the meter and internals as per the manufacturers' recommendations, clean, inspect, and replace worn or damaged parts as required.

If all these steps have been completed and you are sure of your test equipment, procedures and results and the problem still exists, then the problem does not lie with the meter but with other components within the measurement system.

Conclusion

Proper application of any flow meter is critical to successful performance. Turbine meters have been used in flow measurement for approximately 40 years and have proven to be reliable, accurate, and low maintenance instruments. Some turbine meter designs are suitable for vertical as well as horizontal installation.
This can be especially valuable for truck/rail car loading applications where space is at a premium.

Although technologies in manufacturing and electronics have changed considerably over the years, the basic design of the turbine meter has not. Since its development in the 1960s and recognition by American Petroleum Institute with the publication of API 2534 in the early 1970s, the turbine meter continues to be a widely accepted custody transfer measurement device for pipelines, truck, rail car, and barge/tanker loading and off loading applications.

While newer technologies such as Coriolis and Ultrasonic are becoming more prominent in the flow measurement industry every year, all appearances indicate the turbine meter will continue to be a flow measurement standard for some time to come.

References

-API Manual of Petroleum Measurement Standards Chapter 5.3
-Brooks Instrument Technical Bulletin T-082 Turbine Meter Area of Operation
-Daniel Measurement & Control Liquid Turbine Meter Technical Guide TG-0807
-Smith Meter Bulletin TP02001 Fundamentals of Liquid Turbine Meters Technical Paper 103B