Smith Meter™ PD Meter

Displacement Meters for Liquid Measurement

Technical Paper

Issue/Rev. 0.2 (10/98)

Bulletin TP01007

Introduction

The purpose of this paper is to examine the positive displacement (PD) meter. The emphasis will be on the factors influencing the design and performance of the meter for liquid petroleum measurement. However, these factors can be applied to other liquids as well.

History

PD meters have existed for over a century. Many of the designs were developed from either pumps or compressors. By the late 1930's, PD meters were being used extensively for custody transfer measurement of petroleum liquids on tank trucks, loading terminals, and pipelines. By the 1960's, PD meters had been developed that could handle flow rates in excess of 12,000 barrels per hour for large pipeline and ship-loading facilities. Most will agree that even today there is not a more accurate means of petroleum measurement available than the PD meter.

Design and Construction

PD meters can be broken into three basic groups of components: the housing, the measuring element, and the flow information output (mechanical or electronic).

Housing

The housing consists of inlet and outlet connections and serves as the pressure vessel containing the measuring element. The connections can range in size from 3/4 inch up to 16 inch and can be ANSI or DIN flange, NPT, RTJ, or Victaulic. The working pressure, depending upon the construction, can be up to 1,480 psi (ANSI Class 600). Higher pressures are also available. The maximum flow rate varies with the connection size up to 12,500 BPH.

PD meters can be either of single- or double-case construction. In the single-case construction, the external housing serves both as a pressure vessel and as the measuring element housing; whereas, with double-case construction, the measuring element is surrounded by the separate external housing. This offers the advantage of eliminating the pressure differential across the measuring element. In some cases, pressure variations as small as 20 psi can significantly affect the accuracy of a single-case meter.

Another advantage of the double-case meter is that the measuring element can be easily removed for hydrotest and line flush on start-up or for service.

Sometimes, line connections can impart significant stress into the meter. The measuring element is less likely to be affected by these stresses in the double-case meter.

Measuring Element

PD meters measure flow directly by separating the flow stream into discrete volumetric segments (measuring chambers). By totalizing these segments, it is possible to determine the quantity passed through the meter.

The measuring element also serves as a hydraulic motor, absorbing energy from the flow stream to produce torque to overcome internal friction and to drive accessories in the mechanical flow information output.

Figure 1 illustrates some of the most common PD meter measuring elements.

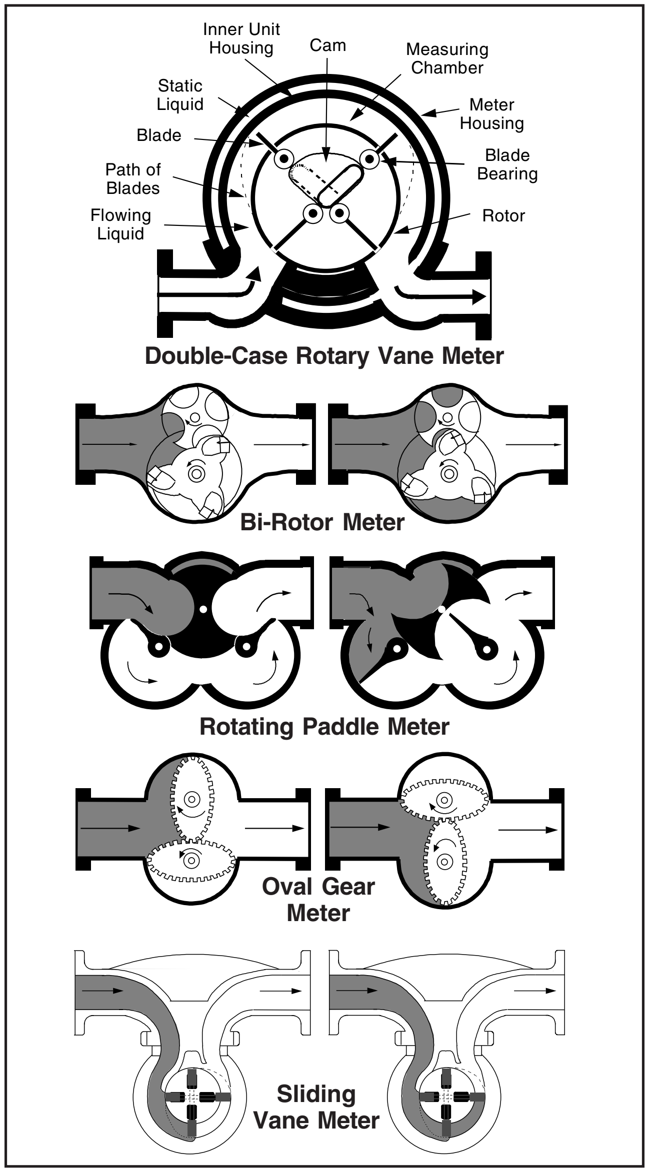


Figure 1 — PD Meter Measuring Elements

In addition to being able to accurately measure liquid throughput, a high performance measuring element will have the following design features:

a. **Low Pressure Drop** - minimizes pump size and operating costs and also helps to produce accurate measurement.
b. **Low Mechanical Friction** - improves the service life and helps to produce accurate measurement.
c. **High Driving Torque** - especially important when the meters mechanical flow information output is fitted with a "stack" of accessories.
d. **Non-Jamming Rotation** - allows handling of large foreign particles in large pipeline applications where sudden stops can cause damaging pressure surges.

Flow Information Output

PD meters normally have a mechanical flow information output that is fitted with either mechanical counters or pulse transmitters. Mechanical counters directly register the volume while pulse transmitters must be connected to electronic volume registration instrumentation. In either case, a gear train is used to convert the somewhat arbitrary displacement volume of the measuring element into a convenient volume-per-revolution of the accessory drive. For example, a two-inch Smith Meter™ Rotary Vane PD Meter has a nominal displacement of 0.364 gallons for every revolution of the rotor. The gear train will convert this into a more convenient nominal one revolution of the accessory drive for every five gallons passing through the meter.

Since the gear train begins with the rotation of the measuring element (inside the meter) and ends with the accessory drive (outside the meter), a packing gland is required on the shaft which penetrates the housing (see Figure 2). The gear train normally reduces the speed of the shaft at this point which reduces the torque generated by the measuring element to overcome this high friction point. The packing gland is subject to wear and, therefore, requires periodic service.

Some meters use a magnetic coupling instead of a packing gland to transfer the drive through the housing, thereby eliminating the friction and solving the wear problem.

a. Mechanical Counters

When mechanical counters are used to indicate the true volume throughput, the meter is generally fitted with an adjuster or calibrator. This device is used to make fine adjustments compensating for manufacturing variations and liquid properties. The Smith Meter™ PD Meter uses a double overriding, clutch-type calibrator. This device is variably adjustable to increase the revolutions coming into it by up to 10%. Therefore, the gear train must under-register the throughput so the calibrator can add the correct (adjustable) amount to provide true volume indication. Ninety-six percent gearing is common in a Smith Meter™ PD Meter. In other words, the input to the calibrator in the 2-inch meter mentioned above would be a nominal 0.96 revolutions for every five gallons passing through (96%, 5:1 gallon gearing). The calibrator is then adjusted under operating conditions to produce exactly one revolution for every five gallons passing through the meter. Other gearings, such as 1:1 gallon, 1:1 dekalitre, 1:1 barrel, are available as the application requires.

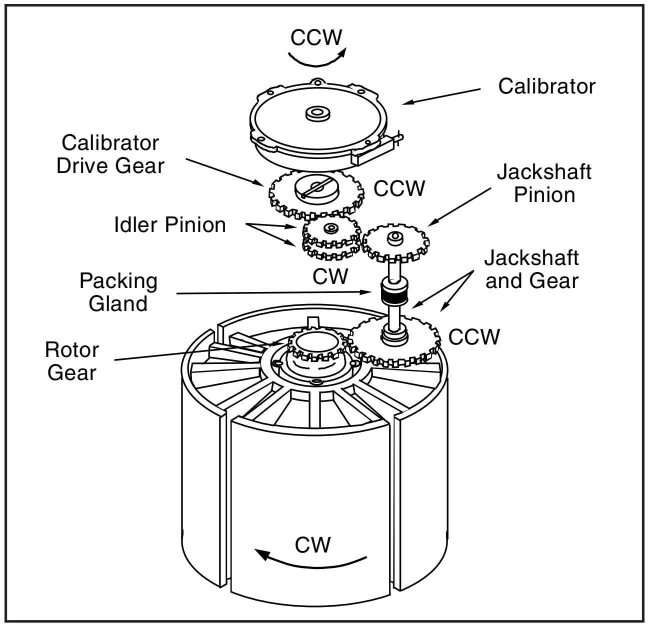


Figure 2 — Accessory Drive

Sometimes nominal 100% gearing is used and the "live" calibrator is replaced with a "dummy" calibrator. The dummy has a spacer shaft that drives the accessories and is not adjustable. When it is used, it is necessary to multiply the registration by a meter factor in order to obtain true volume throughput.

b. Electrical Pulsers

It is very common for PD meters to be fitted with pulse transmitters. In this case, the throughput information coming from the measuring element is converted into a precise ratio of pulses per volume. Normally, in this case, there is no adjustor or calibrator used since the electronic instrument is programmed to make the adjustment to true volume.

There are PD meters available now that have no mechanical output. They produce pulses directly from the rotation of their rotor. The Smith Meter™ PRIME Meter and the Brooks P Style meters are example of this technology. The advantage is no packing gland and non-cyclic pulse rhythms that allows for repeatable consecutive proving runs when proved with a small volume prover. (See figure 3)

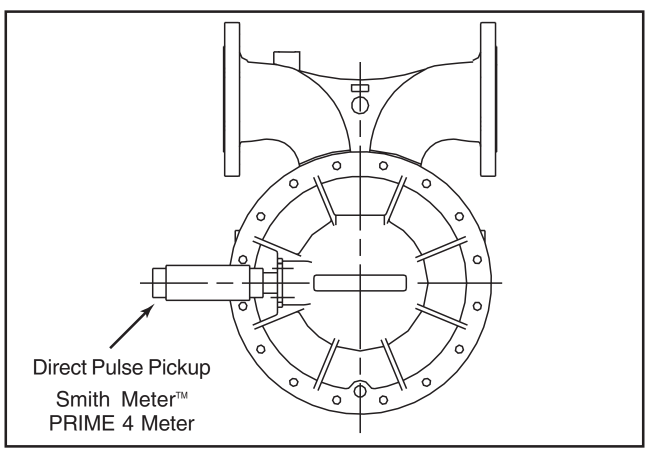


Figure 3 — PRIME Meter Section

Accuracy Theory

The factors affecting the accuracy of the PD meter can be divided into two groups; those that affect the displacement of the measuring element and those that affect the amount of slippage bypassing the measuring element.

1. *Displacement*

The displacement of a PD meter is determined by the size of the volumetric segments formed in the measuring element. Factors influencing the physical and apparent size of these segments will affect the accuracy of the meter:

a. ***Temperature***
Increasing the temperature increases the displacement of the meter because of thermal growth. This can be related to the cubical expansion coefficient of the material forming the segments. In the standard Smith Meter™ Rotary Vane PD Meter, the aluminum blades grow faster than the other cast iron parts. This causes the effective displacement to increase because the blades "sweep" a greater volume. The combined effect is typically about 0.02% for a 10°F change in fluid temperature.

b. ***Wear***
Wear has the effect of increasing the displacement. In the Smith Meter™ Rotary Vane Meter, as the cam or blade bearings wear, the blade is allowed to move outward, sweeping a greater volume. Wear is normally slow and predictable.

c. ***Viscosity***
The viscosity of liquids causes a film to cling to the surfaces of the measuring element. As the film thickness increases, the displacement is reduced to the point where the film can be no thicker because of the wiping action of the parts. Further increases in viscosity have no effect on the displacement.

d. ***Coatings***
Like the film created by the viscosity of the liquid, coatings or deposits can build up and reduce the displacement of the measuring element. If the coating thickness remains constant, there is normally no problem. However, the thickness of the coating can vary dramatically in some crude oils containing paraffin which has a melting point near the operating temperature. Formation or melting can occur with slight changes in temperature and can significantly change the displacement.

2. *Slippage*

PD meters have clearances between moving and stationary parts in the measuring element. These are sometimes referred to as capillary seals. Differential pressure across these parts will cause a flow that is not accounted for in the displacement. This flow is commonly referred to as "slippage." Figure 4 shows slippage as a percentage of flow through the meter.

There are two causes of differential pressure across a meter: hydraulically-induced because of flow and mechanically-induced because of internal friction and external accessory driving torque. The net result of these differential pressures and the corresponding slippage explain the reason for the accuracy of a PD meter varying with the flow rate.

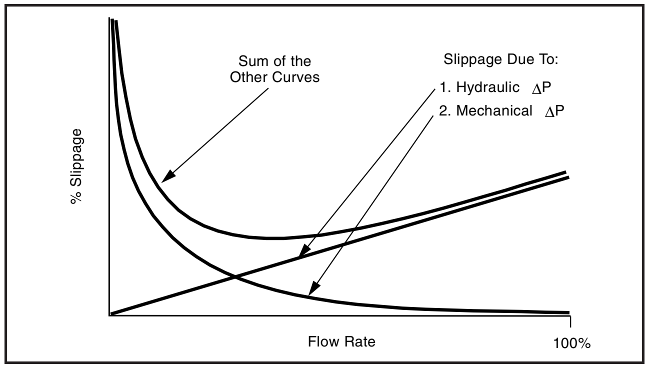
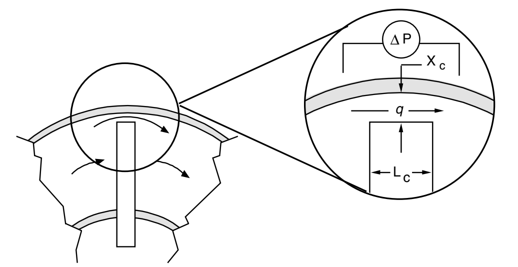


Figure 4 — Accuracy Curve



$$\text{Slippage } (q) = K \frac{X_c^3 \, \Delta P}{L_c \, \mu}$$

Where:
K = Units Constant
X_c = Clearance Width
L_c = Clearance Length
ΔP = Pressure Drop Across the Clearance
μ = Absolute Viscosity of the Liquid

Figure 5 — Slippage Through PD Meter Clearances

Slippage through the clearances is characterized by the equation shown in Figure 5 and is affected by the following factors:

a. ***Flow Rate***
As shown in Figure 4, the percentage of slippage changes with flow rate due to the varying differential pressure produced by hydraulic and mechanical friction.

b. ***Viscosity***
As the viscosity of a liquid increases, it is more difficult for it to pass through the clearances of the measuring element.

Figure 6 shows how the accuracy curve of a PD meter is affected by the viscosity of the liquid being metered. Note that doubling the viscosity results in halving the percentage of slippage. At viscosities greater than about 16 cP, the amount of slippage

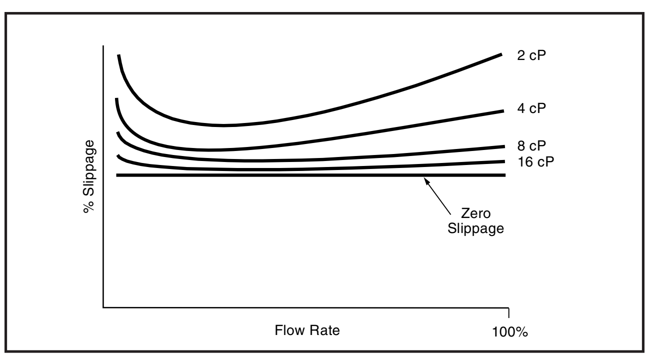


Figure 6 — Effect of Viscosity on the Accuracy Curve

nears zero and the percentage change in slippage at various flow rates is negligible.

c. ***Friction***

When mechanical friction increases, more pressure differential is required across the measuring element. Figure 7 shows how the accuracy curve is affected by high friction. If the percentage of slippage is not lower at 50% of flow rate than at 100%, there is probably abnormally high mechanical friction. It could be because internal parts have worn and are dragging or it could be due to excessive accessory loads.

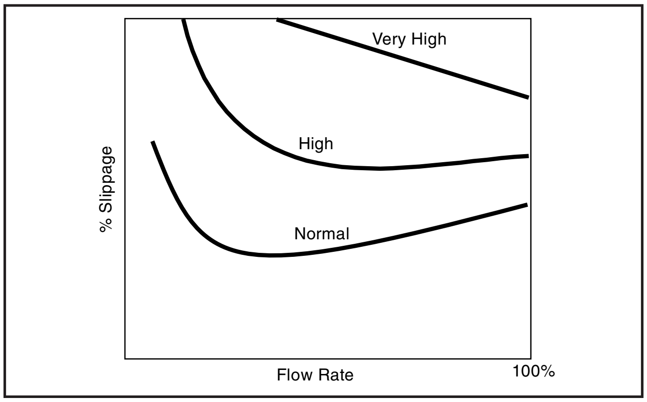


Figure 7 — Effects of Mechanical Friction on the Accuracy Curve

d. ***Wear***

As parts wear, the clearances in the measuring element will change. Small variation in the clearances can cause significant changes in the amount of slippage (see Figure 8). This is due to the cubical relation of the clearance to the slippage (Slippage Equation).

Loss of rotor end clearance in the horizontal Smith Meter™ Rotary Vane Meter will cause the compounding effect of increasing the slippage through the upper rotor end clearances and increasing the slippage through all clearances due to the high friction load.

A good measuring element must have very small clearances between the moving parts in order to maintain low slippage. However, with small clearance there is little room for wear before contact will cause high friction.

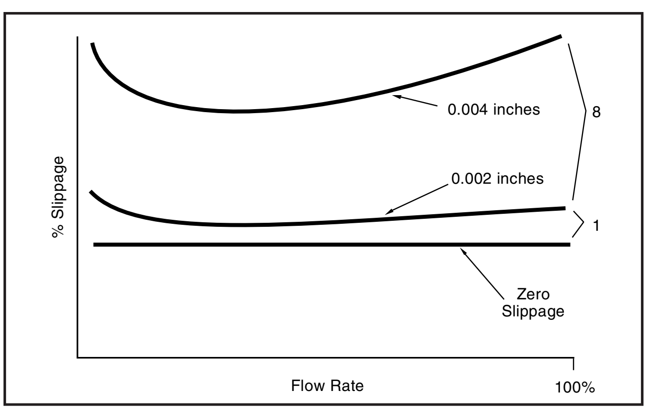


Figure 8 — Effects of Clearances on Accuracy Curve

Application Considerations

When measuring a flow stream with a PD meter is desired, there are several factors which must be considered:

1. ***Flow Rate***

Line size is an important factor in sizing a meter; however, flow rate and flow range are usually the deciding criteria. In high flow rate situations, multiple parallel meter runs are normally more economical since the prover (normally a permanent part of the system) can be much smaller. Another advantage of multiple meter runs is the ability to isolate one meter for servicing while diverting the flow stream to the other meters.

Generally, it is advisable to operate the meter at reduced flow rates. This will have the effect of extending the life of the meter. The life of a PD meter is considered to be inversely proportional to the square of the flow rate. Therefore, operating a meter at 80% of maximum will extend its life by about 50%.

2. ***Pressure***

The maximum working pressure rating of the meter should always be higher than the maximum pressure of the application. Thermal relief must be considered if the meter can be isolated between valves.

3. ***Temperature***

It may be necessary to alter the construction of the meter to suit the operating temperature. If the temperature is very low (less the -20°F), it may be necessary to consider low temperature steel for the housing. As the operating temperature increases, it may be necessary to apply special clearances that anticipate thermal growth of parts in the measuring element.

4. ***Viscosity***

When the viscosity of the liquid being metered is very low, the lubricity is also very low. Special construction utilizing low friction bearings is recommended on LPG and lighter liquids.

Most PD meters can handle viscosities up to 400 cP. Higher viscosities may require increased clearances in the measuring element or derating the maximum flow rate of the meter.

5. ***Strainers***

It is normally advisable to protect the meter with a strainer. The Smith Meter™ Rotary Vane PD Meter can pass fairly large particles without damage. A four-mesh strainer will normally provide adequate protection for the meter. In large pipeline applications, this is important since it helps keep the pressure drop low.

6. ***Material Compatibility***

Care must be taken with the compatibility of the meter's material of construction and the liquid to be metered. Different seals and metals are usually available to handle most petroleum applications.

Conclusion

The petroleum industry demands precise measurement for custody transfer. While there are other metering technologies available, the PD Meter continues to be the meter by which all other meters are compared. Figure 9, from the API Manual of Measurement Standards shows that PD meters excel when the application is on higher viscosity oils. While many are using turbine meters to replaced PD meters, the PD meter continues to be the preferred meter when accurate and dependable measurement is imperative.

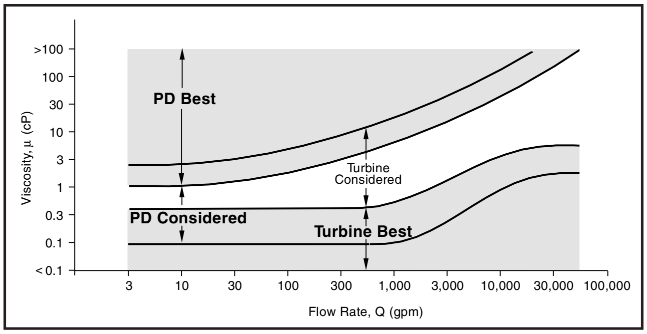


Figure 9 — PD and Turbine Meter Selection Guide

Acknowledgment

This paper was originally presented at the International School of Hydrocarbon Measurement (ISHM), University of Oklahoma, May 1997.

The specifications contained herein are subject to change without notice and any user of said specifications should verify from the manufacturer that the specifications are currently in effect. Otherwise, the manufacturer assumes no responsibility for the use of specifications which may have been changed and are no longer in effect.

Headquarters:
1803 Gears Road, Houston, TX 77067 USA, Phone: 281/260-2190, Fax: 281/260-2191

Gas Measurement Products:
Houston, TX USA Phone 281/260-2190
Thetford, England Phone (44) 1842-82-2900
Kongsberg, Norway Phone (47) 32/286-700
Buenos Aires, Argentina Phone 54 (11) 4312-4736

Integrated Measurement Systems:
Corpus Christi, TX USA Phone 361/289-3400
Kongsberg, Norway Phone (47) 32/286-700
San Juan, Puerto Rico Phone 787/274-3760
United Arab Emirates, Dubai Phone 971 +4/331-3646

Liquid Measurement Products:
Erie, PA USA Phone 814/898-5000
Los Angeles, CA USA Phone 661/702-8660
Slough, England Phone (44) 1753-57-1515
Ellerbek, Germany Phone (49) 4101-3040
Barcelona, Spain Phone (34) 93/201-0989
Moscow, Russia Phone (7) 495/564-8705
Melbourne, Australia Phone (61) 3/9807-2818

Beijing, China Phone (86) 10/6500-2251
Singapore Phone (65) 6861-3011
Chennai, India Phone (91) 44/450-4400

Visit our website at www.fmcmeasurementsolutions.com