PROVING LIQUID ULTRASONIC METERS

Class No. 4180

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Introduction

Proving is the process that determines the accuracy of a meter. A prover is a device with detector switches that define a precise, known volume. The prover is connected in series with the meter being proved so that as flow passes through the meter, the same flow, and only that flow must pass through the prover. The flow moves the displacer in the prover until it touches the first detector switch, the pulses coming from the meter start being counted by a prover counter. When the displacer touches the second detector switch, the pulses from the meter stop being counted. In this way, the exact number of pulses generated by the meter for an exact amount of flow is determined and the actual volume registration of the meter can be compared to the known volume of the prover. The ratio of the volume of the prover to the volume registered by the meter is called the Meter Factor. The proving process involves taking the average of several tests (comparisons) of the above mentioned ratio and checking the consistency of the tests. For example, if 5 tests or proving runs are made, the ratios must agree within 0.05%. If they do, then statistically, the uncertainty of the average Meter Factor will be within 0.027% and will meet industry requirements.

Ultrasonic Flowmeters

Liquid ultrasonic meters have been used for the measurement of liquid petroleum since the 1970s; however, it wasn't until the mid 1990s that they could be considered for application requiring precise measurement. It was the implementation of multiple chordal paths that provided the evolution in accuracy needed to be considered for custody transfer applications. By measuring the flowrate along multiple chordal paths, the meter could react to changes in the flow profile caused by rate and/or viscosity changes and therefore accurately measure the flowstream. Their advantages over conventional meters have been instrumental in securing their place in the industry. Some of these advantages include their ability to be made in large sizes to measure high volume flowstreams. Because ultrasonic flowmeters are all electronic, they have no moving parts to wear out. The meter has no intrusions into the flowstream to catch debris and therefore, ultrasonic flowmeters have a very low pressure drop. Some ultrasonic flowmeters can be characterized over a range of Reynolds numbers allowing them to provide accurate measurements regardless of flowrate or liquid viscosities that fall within the characterized range. However, one of the shortcomings of the ultrasonic flowmeter has been a relatively poor repeatability when being proved. Ultrasonic flowmeters measure flow by sending pulses of ultra-high frequency sound back and forth across the flowstream at an angle so that in one direction the pulses must travel upstream, while in the other direction they must travel downstream. The difference in the transit times allows a measure of the average flowstream velocity along the path. Figure 1 is a "clear view" of an ultrasonic flowmeter showing an array of acoustic transducers forming four paths across the flowstream.

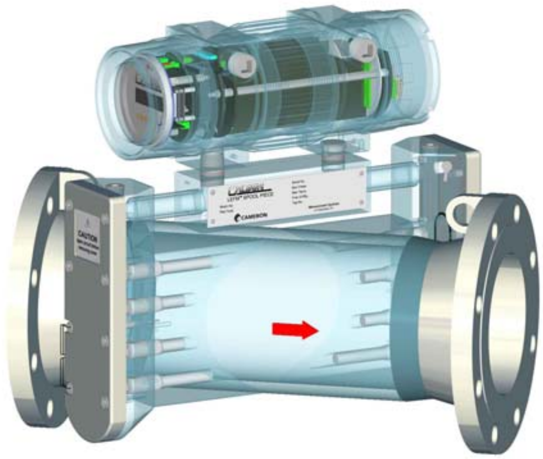

Figure 1 - Four-path Ultrasonic Flowmeter

The spacing of the paths and their predetermined weighting factor are in accordance with the statistical technique known as Gaussian Quadrature integration which allows a determination of the average flow through the meter.

Unless the liquid has a very high viscosity and/or a very low velocity where the flowstream can be in the laminar region (Reynolds number under around 10,000), there will be turbulence. This turbulence is made up of eddy currents with a wide spectrum of frequencies and amplitudes. The highest intensity and lowest amplitude eddies are near the inside surface of the pipe wall while the lowest intensity and highest amplitude eddies are in the central portion of the flowstream - See Figure 2

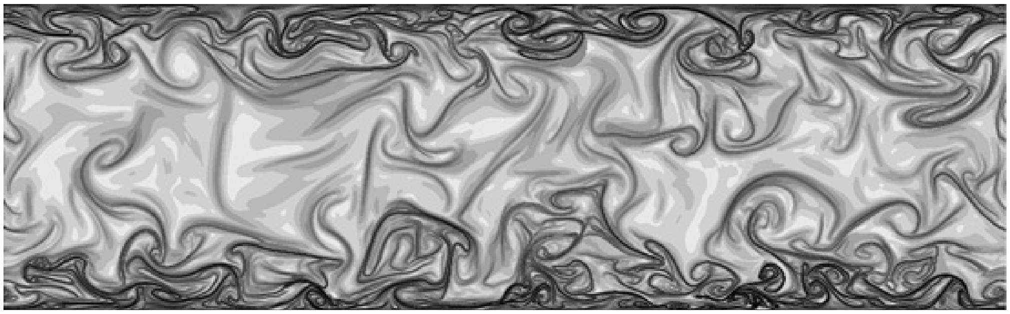

Figure 2 - Turbulence within the Flowstream for Reynolds Number Greater than 10-12,000

The transit times of acoustic pulses passing through this turbulence, especially the eddies that are larger than the diameter of the acoustic beam, are caused to vary, depending upon the particular alignment of the eddy. This transit time variation is the root cause of poor proving repeatability.   Figure 3 shows the performance of a 6 inch four-path ultrasonic flowmeter as tested on 2.0 cSt oil at the Caldon Ultrasonic Technology Center in Coraopolis, Pennsylvania. The prover was a Brooks 18” compact prover with a base volume of 0.72 BBL.

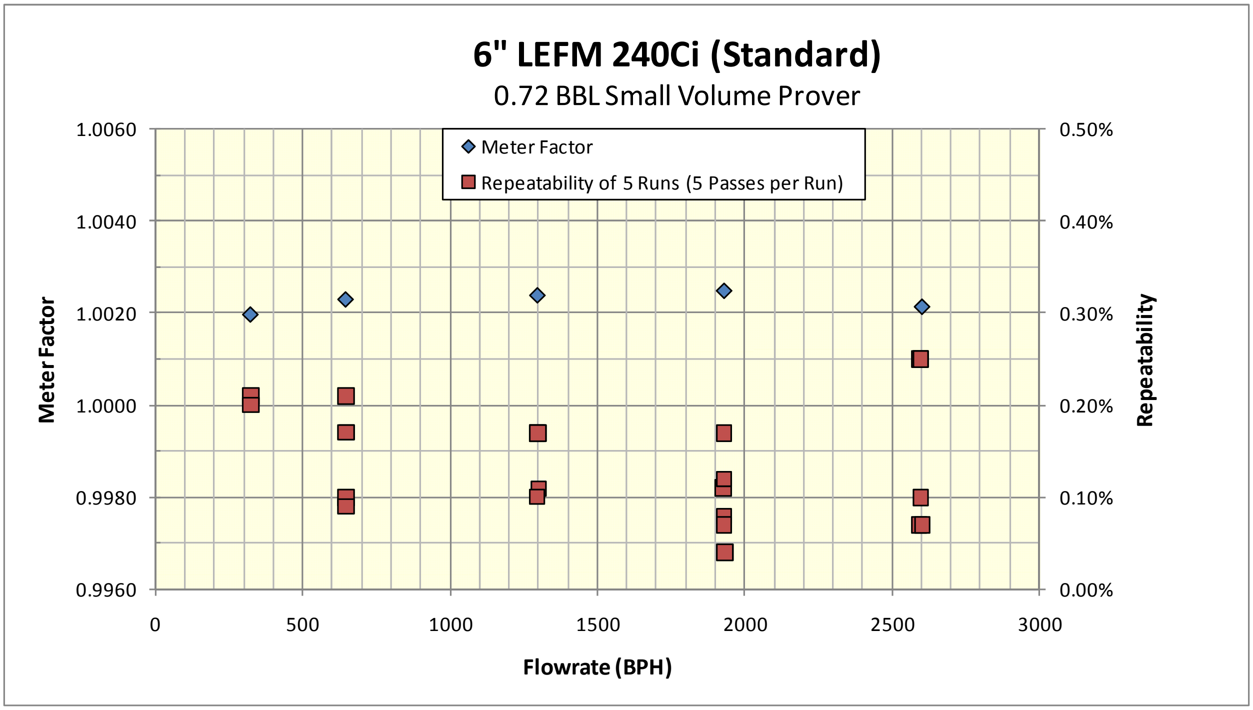

Figure 3 – Linearity and Repeatability Test of 6" Four-path Ultrasonic Flowmeter (Caldon LEFM 240Ci)

The proving was conducted with 5 passes per run and 5 runs per proving. Consider the prover volume in this case to be 3.6 BBL (5 x 0.72 BBL). During the linearity testing there were 29 provings at 5 different flowrates of which only 1 met the repeatability criteria of 0.05%. The average repeatability of the 29 provings was 0.149%. 31% of the provings (9 of 29) had repeatabilities of 0.10% or under.

It has been established that proving repeatability is a function of the reciprocal of the square root of prover volume[1], i.e.:

$$Repeatability \cong 1/\sqrt{V}$$

Where: $V = Prover\ Volume$

Using this relationship to estimate the prover volume required to meet the criteria of 5 runs agreeing within 0.05% repeatability, the repeatability will need to improve by a factor of 4 (from 0.20% to 0.05%), the prover volume would need to increase by a factor of $4^2 = 16$. In order to increase the apparent prover volume by 16 times, it will be necessary to have about 70 passes per run ((16 x 3.2)/0.72).

Figure 4 shows a diagram of an 8-path ultrasonic flowmeter where the meter bore is somewhat located downstream of a compound reducing nozzle. After the acoustic transit times are measured, the bore is gradually increased back to the original size in a way the recovers most of the pressure drop caused by the restriction. Figure 5 shows a 6" LEFM 280CiRN ultrasonic flowmeter that employs the features described above. This meter differs from the one shown in Figure 1 in two fundamental ways; it has 8 acoustic paths (Figure 1 shows a 4-path meter) and within the throat of the meter there is a reducing nozzle that constricts the flowstream (Figure 1 shows a full diameter meter).

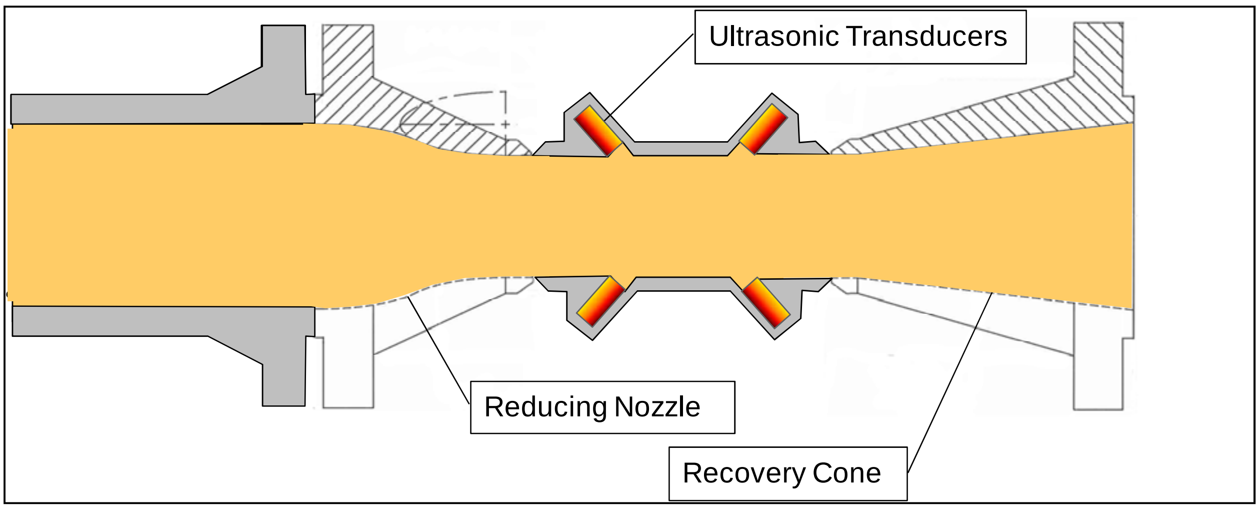

Figure 4 - Reducing Nozzle 8-path Meter

The 8-path meter is like there are two 4-path meters measuring the same flowstream so it is reasonable to take the root-mean-square of the two readings. This improves the repeatability by the factor of the square root of 2 (1.414). It is also believed that the reducing nozzle tends to stretch the turbulent features in the axial direction which reduces their amplitude. This reduction tends to reduce the variations in the transit times and results in an improvement in the repeatability.

The test results (Figure 6) show this meter has better repeatability than the 4-path meter. The average repeatability improved from 0.149% to 0.092% and test with repeatabilities of 0.10% or under went from 31% to 70%. The explanation for this improvement is because the 8-path meter is making more measurements of the flowstream and the reducing nozzle has reduced the magnitude of the turbulent features within the flowstream.

[1] Don Augenstein, Class 2430 "Proving Liquid Ultrasonic Flow Meters", 2007 ISHM, Oklahoma City, OK

Figure 5 - Reducing Nozzle Meter (Caldon LEFM 280CiRN)

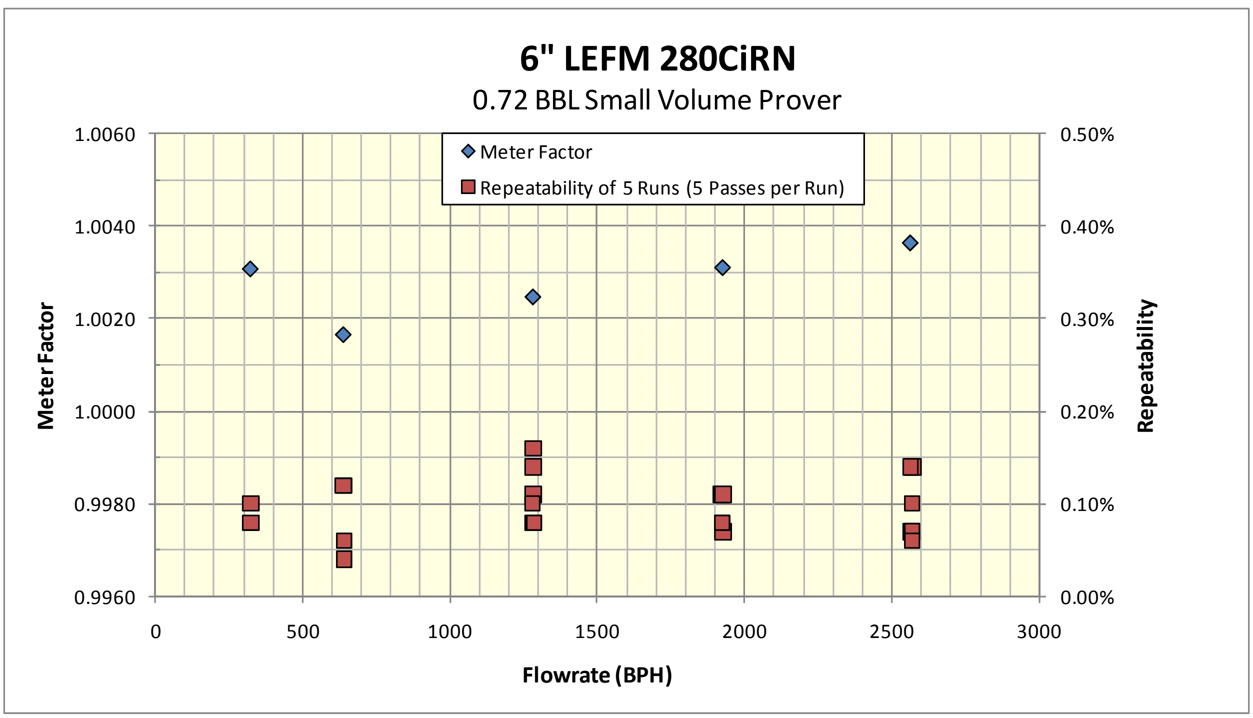

Figure 6 - Linearity and Repeatability Results of 6" Reducing Nozzle Meter (LEFM 280CiRN)

In order to further reduce the variation in transit times due to turbulent features within the flowstream, research has led to the development of a turbulence conditioner called an REI (Repeatability Improving Element). The RIE consists of a matrix of small apertures, like a honey comb, that breaks up the turbulent features, see Figure 7. It is placed immediately upstream of the meter with the idea that turbulent eddies will be reduced in size momentarily and if they are smaller in size than the acoustic beam they will be dissolved and cease to cause or certainly reduce the variations in the transit times, thereby improving the repeatability of proving runs.[2]

Figure 7 - Repeatability Improving Element (RIE)

Figure 8 shows the test result for the 6" LEFM 280CiRN with the RIE installed immediately upstream of the meter. As can be seen, the repeatability has substantially improved with the average being 0.058% with 61% of the provings having repeatability under 0.05%. 86% of the provings had repeatabilities of 0.10% or under. These proving results demonstrated that the Caldon LEFM 280CiRN fitted with the RIE can be proved with an ordinary sized small volume prover with only 25 strokes of the displacer, i.e., 5 runs with 5 passes per run. When compared to the "Standard" meter that was calculated to require 350 strokes of the displacer (5 runs with 70 passes per run) in order to meet the 0.05% repeatability requirement, this is a truly significant improvement. Many in the industry would agree that test results show that this meter is nearly as easy to prove as a turbine meter.

In order to establish that the linearity results were not being biased because of the Small Volume Prover (SVP), the ultrasonic meter was master meter proved using a turbine meter that had been proved with the same SVP. Figure 8 shows that the meter factors at three rates fall in line with the meter factors taken directly using the SVP. It has been established within the industry that flowrate changes during a proving run can result in bias errors in meter factor, particularly when using a SVP since the prove times are often quite small[3]. This error can be summarized as follows:

$$Error = \frac{Meter's\ Time\ Constant\ (Q2 - Q1)}{Time\ of\ the\ Prove}$$

Where: *Q2* = Flowrate as measured by the meter at the end of the proving pass
Q1 = Flowrate as measured by the meter at the beginning of the proving pass

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[2] Donald R. Augenstein, et al, "Method, Apparatus and Computer Medium for Correcting Transient Flow Errors in Flowmeter Proving Data", U.S. Patent 7,366,625, issued Apr. 29, 2008

[3] Don Augenstein, Class 2430 "Proving Liquid Ultrasonic Flow Meters", 2007 ISHM, Oklahoma City, OK

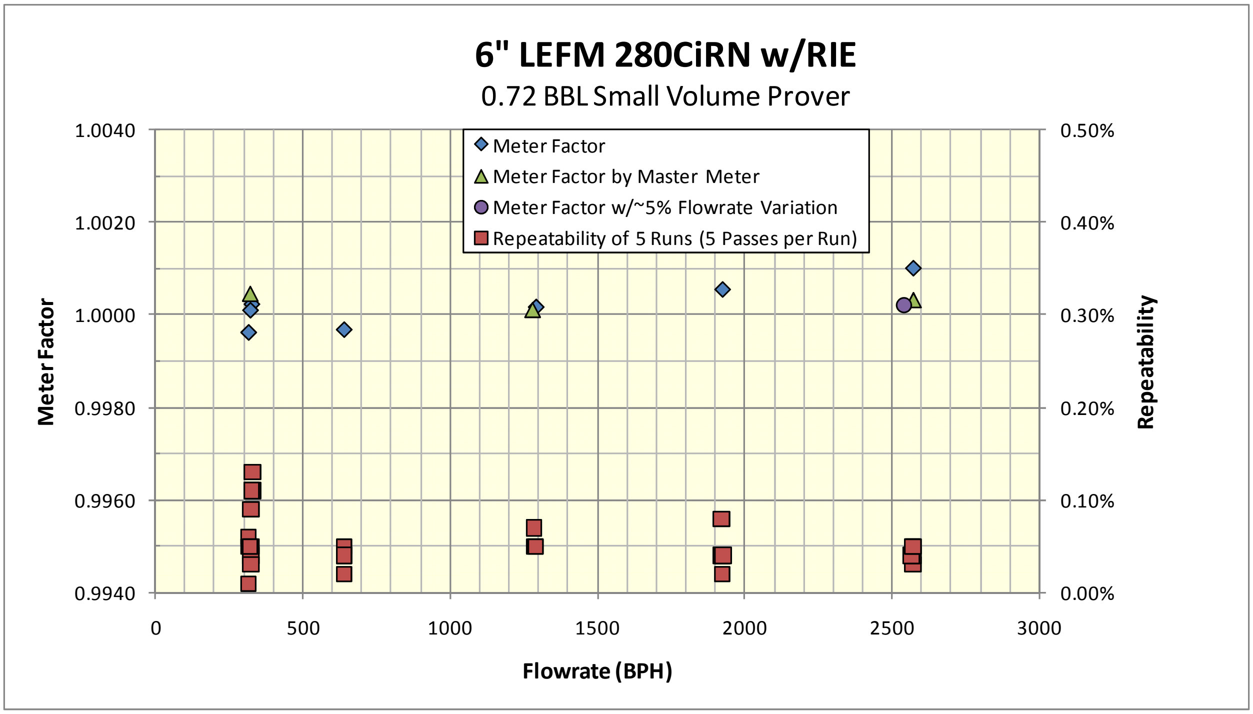

Figure 8 – Linearity and Repeatability Results of 6" Reducing Nozzle Meter with the RIE (Caldon LEFM 280CiRN)

Notice that all of the variables needed to determine the error mentioned above are known by the meter. Therefore, it is possible to correct for this error when proving the meter. Also shown in Figure 8 is a test point at high flow rate where the proving run time is small and the potential for bias error is greatest, the flowrate was deliberately varied rapidly by about 5%. As can be seen, since the bias correction was employed, the meter factor determined was in line with those previously determined.

Figure 9 - 16" Reducing Nozzle Meter (Caldon LEFM 280CiRN)

Figure 9 shows the 16” Caldon LEFM 280CiRN installed in the test loop. The current version of API MPMS Chapter 5.8 shows that in order to prove a 16” ultrasonic meter in 5 proving runs with 0.05% repeatability or better, a 522 BBL prover would be required. Figure 10 shows the test results, again using 2 cSt oil, of a 16” Caldon LEFM 280CiRN meter proved with the 63 BBL uni-directional pipe prover at the Caldon Ultrasonic Technology Center. A linearity curve was generated at five flowrates involving 62 proving runs (5 runs per proving). 81% of the provings meter the repeatability criteria of 0.05%. The average repeatability was 0.040%.

In other words, it is possible to prove the 16” Caldon LEFM 280CiRN using the criteria of 5 proving agreeing within a repeatability of 0.05% over 80% of the time. This is about what would be expected with a 16” turbine meter on this size of prover.

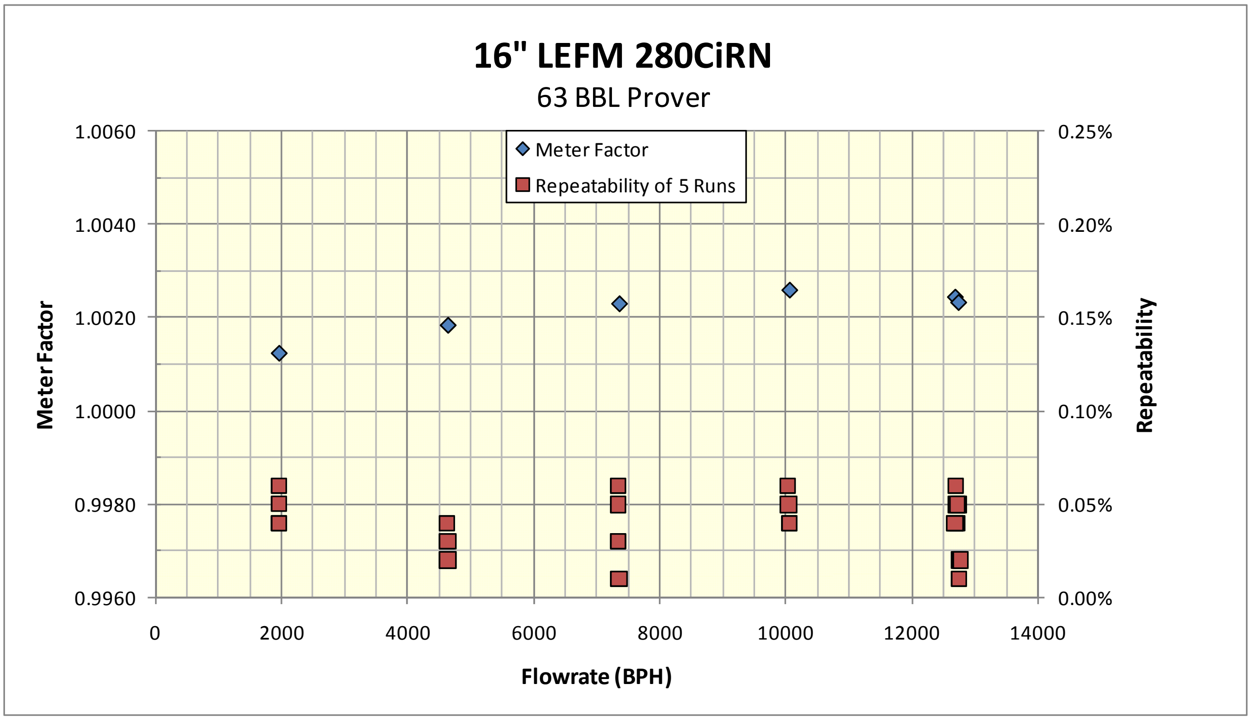

Figure 10 – Linearity and Repeatability Results of 16” Reducing Nozzle Meter (Caldon LEFM 280CiRN)

Conclusion

Many in the industry have expressed reluctance to use ultrasonic flowmeters in critical applications because of the difficulty in proving brought about by poor proving repeatability. The solution to this proving difficulty offered in API MPMS Chapter 4.8 of opening the repeatability tolerance and taking more proving runs has not been satisfactory for many. First of all, it takes more time and causes more wear on the prover. Also, it is well established that there are poor repeatability causes unrelated to the meter, e.g., electronic noise, chipped prover ball, leaking four-way valve, product flashing, etc. These alternate causes of poor repeatability can be masked when the repeatability limit is increase. The reducing nozzle meter and the RIE, if used, provide an ultrasonic flowmeter that can be easily proved using the traditional technique. As can be seen from the data presented above, the results conclusively establish that ultrasonic flow measurement technology available today can provide a meter not only significantly easier to prove than the standard ultrasonic meter, but an ultrasonic meter that can be proved in 5 runs with a prover no larger in volume that that used by the conventional PD meter or turbine meter.