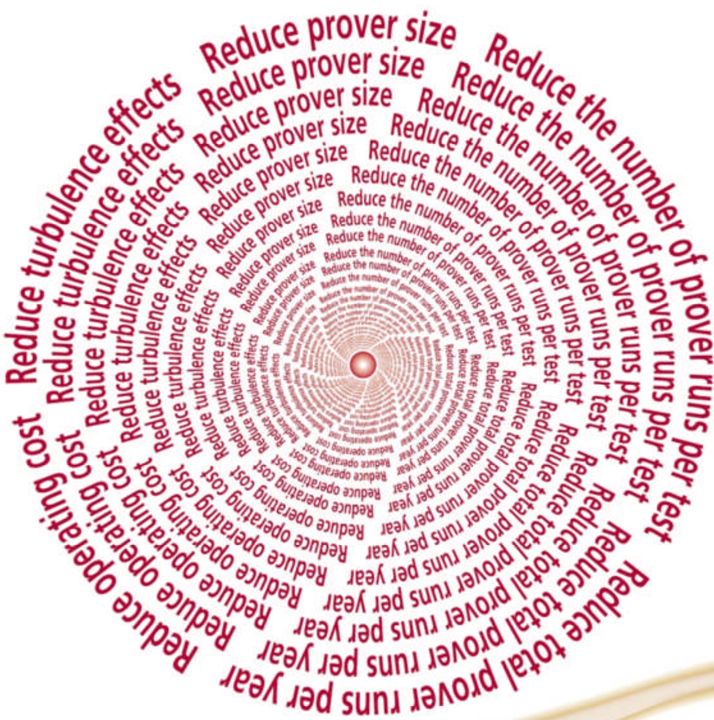
Technical Paper No. 162 Rev. 0

Proving Liquid Ultrasonic Flowmeters

Summary of

Testing
Conducted
January 2011



LEFM 280CiRN

Proving Liquid Ultrasonic Flowmeters
Summary of Testing Conducted January 2011

Introduction

Ultrasonic flowmeters have been used for precise liquid petroleum measurement for nearly two decades. They have several advantages over conventional meters that 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, there are 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 then 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 is these 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.

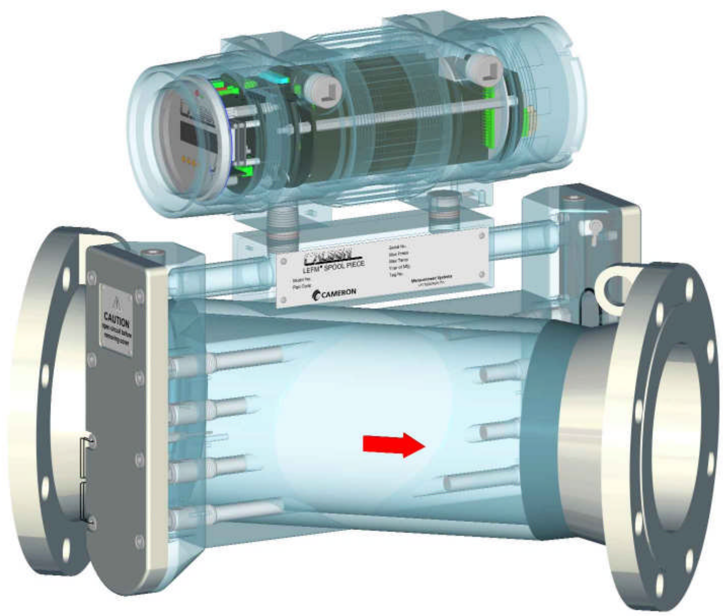


Figure 1 - Caldon LEFM 240Ci Ultrasonic Flowmeter (Standard)

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

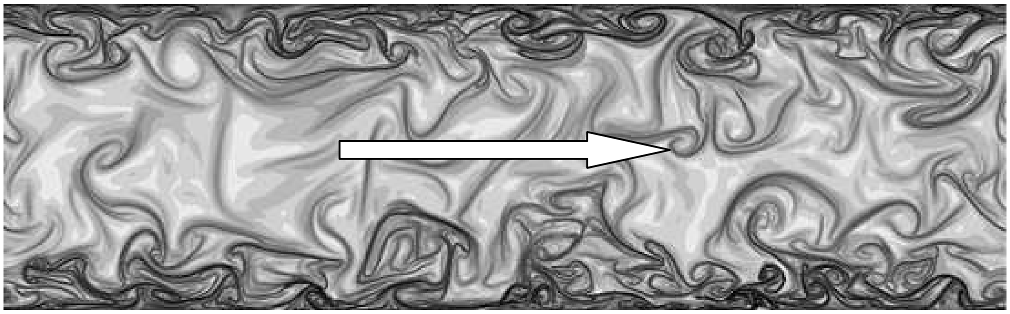


Figure 2 - Turbulence within the Flowstream for Re > 10,000

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.

Testing

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. 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%. Most of the provings (26 of 29) had repeatability under 0.20%. 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 is the 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 located downstream of a compound reducing nozzle. After the acoustic transit times are measured, the bore is gradually increased back to the original size which 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 above in two fundamental ways; it has 8 acoustic paths (the LEFM 240Ci "Standard" meter has 4 acoustic paths) and within the throat of the meter there is a reducing nozzle that constricts the flowstream (the "Standard" meter has a full diameter bore).

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

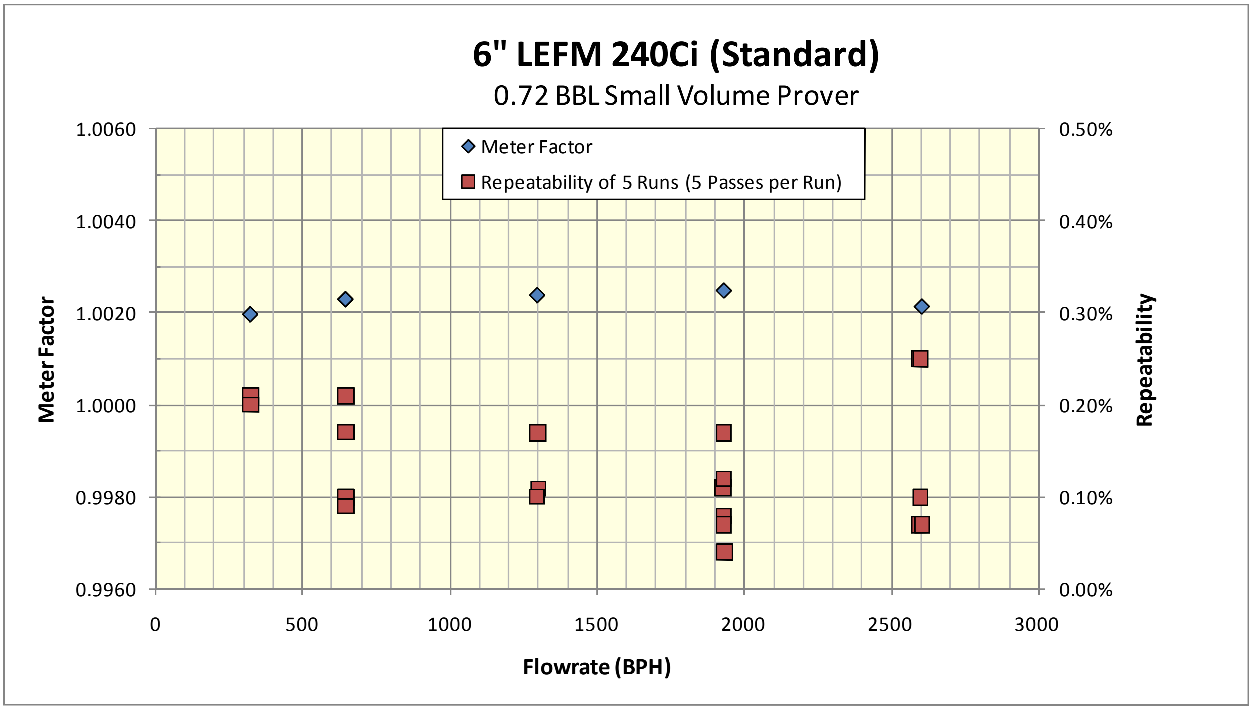


Figure 3 - 6" Caldon LEFM 240Ci Linearity and Repeatability with an 0.72 BBL SVP

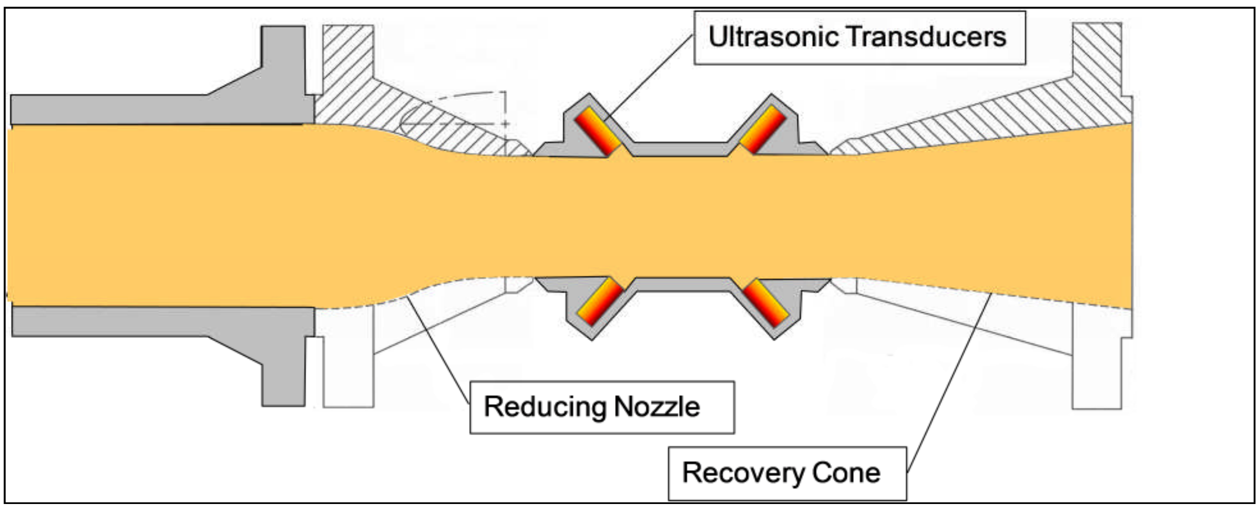


Figure 4 - 8-Path Reducing Nozzle and Recovery Cone

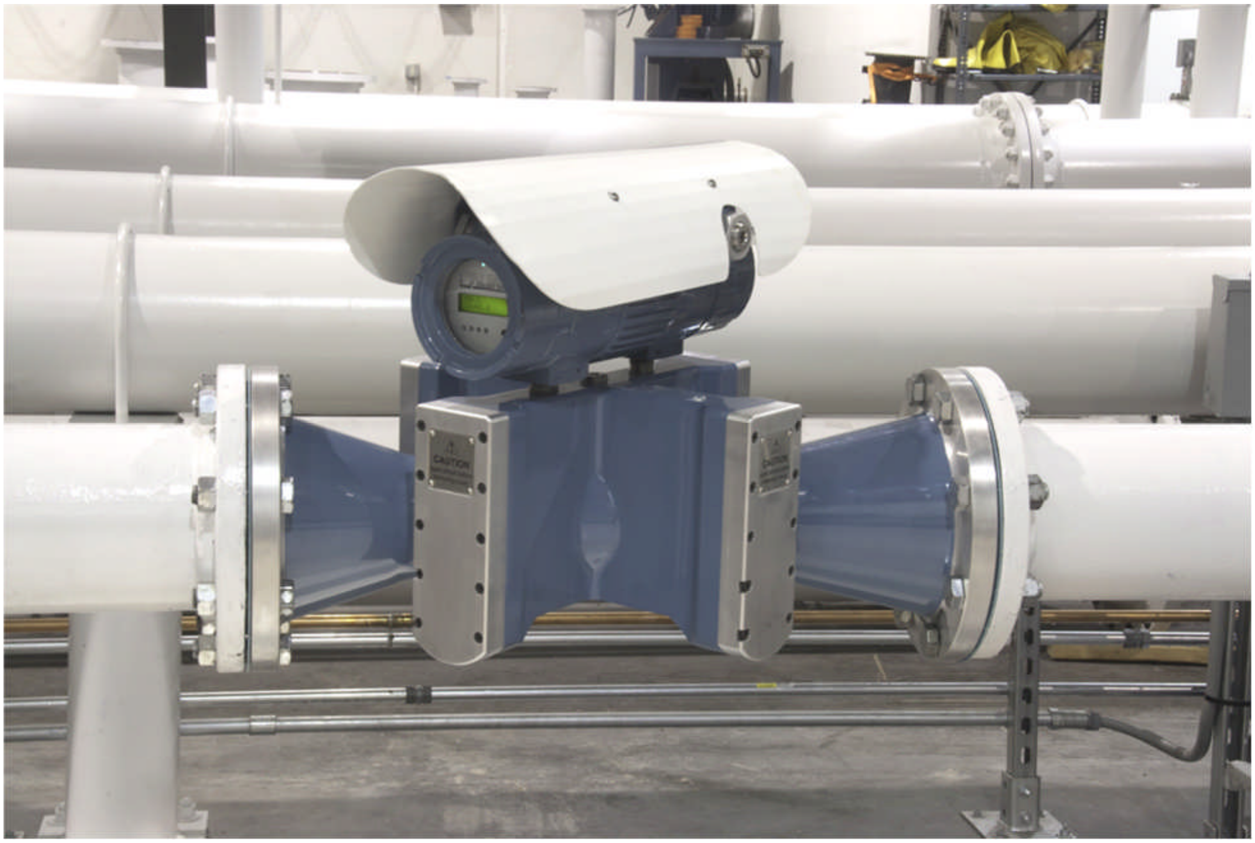


Figure 5 - 6" Caldon LEFM 280CiRN

In essence, it 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 which 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, reducing their amplitude. This reduction tends to reduce the variations in the transit times and results in an improvement in the repeatability as well.

The test results (Figure 6) show this meter has better repeatability than the standard meter. The average repeatability improved to 0.092% and nine (9) of the thirty (30) proving had repeatabilities under 0.10%. Twenty-nine (29) of thirty (30) provings had repeatabilities under 0.15%. The explanation for this improvement is because the 8-path meter is making more measurements of the flowstream.

In order to reduce the variation in transit times due to turbulent features within the flowstream, research led to the development of a turbulence conditioner[2]. This device, also called an RIE (Repeatability Improving Element) consists of a matrix of small apertures, like a honey comb, that break up large turbulent feature, see Figure 7. The RIE 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] Gregor Brown, et al, "Turbulence Conditioner for Ultrasonic Flow Meter and Method" U.S. Patent 7,823,462, issued Nov. 2, 2010

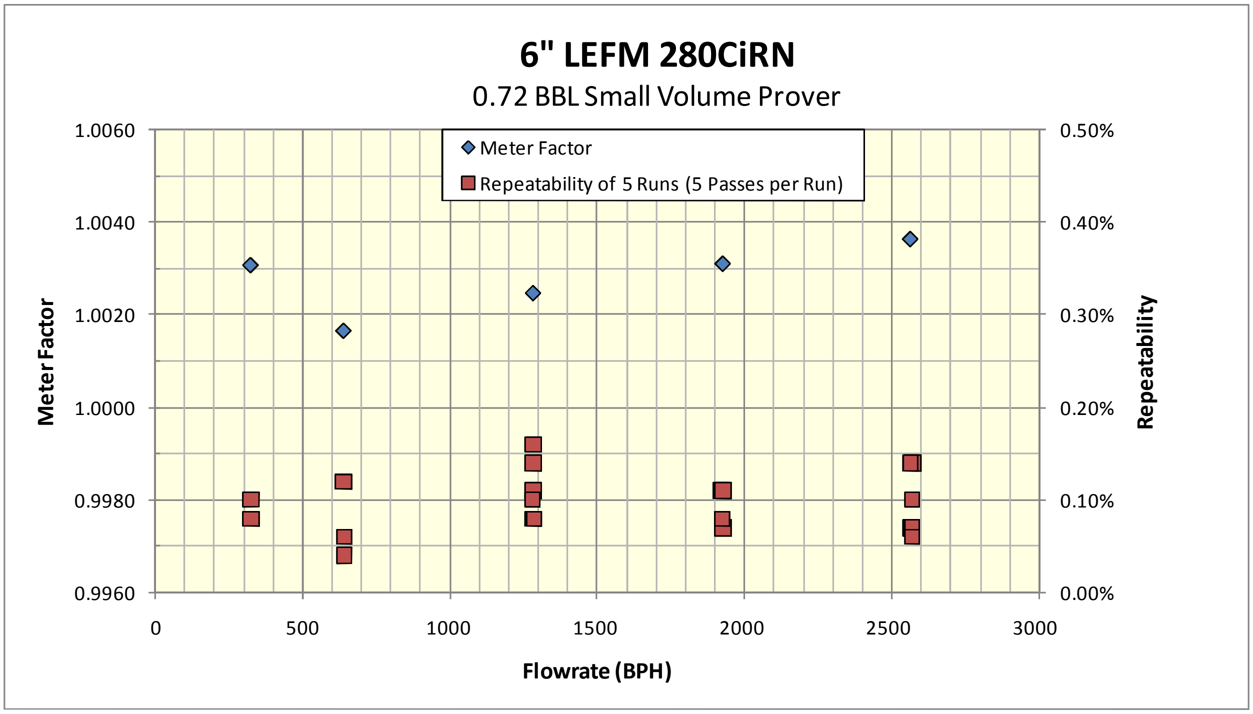


Figure 6 - LEFM 280CiRN Test Results Show Improved Repeatability

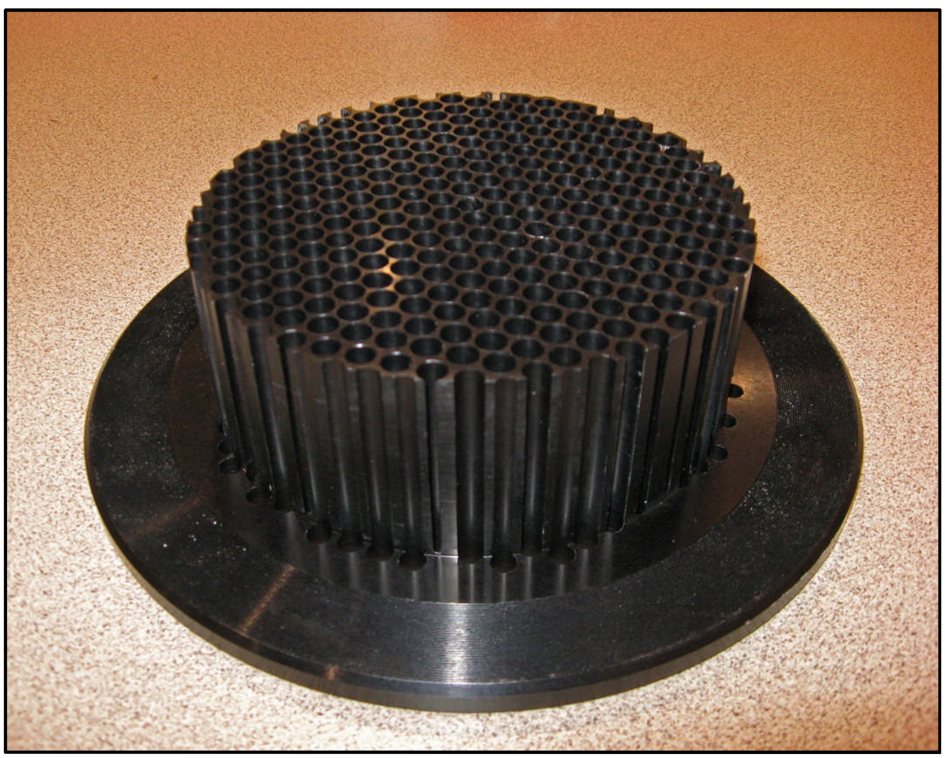


Figure 7 - 6" Repeatability Improving Element (RIE)

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 twenty-six (26) of forty-two (42) proving having repeatability under 0.05%. Thirty-six (36) of forty-two (42) proving had repeatabilities under 0.10%. 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 and a turbine meter.

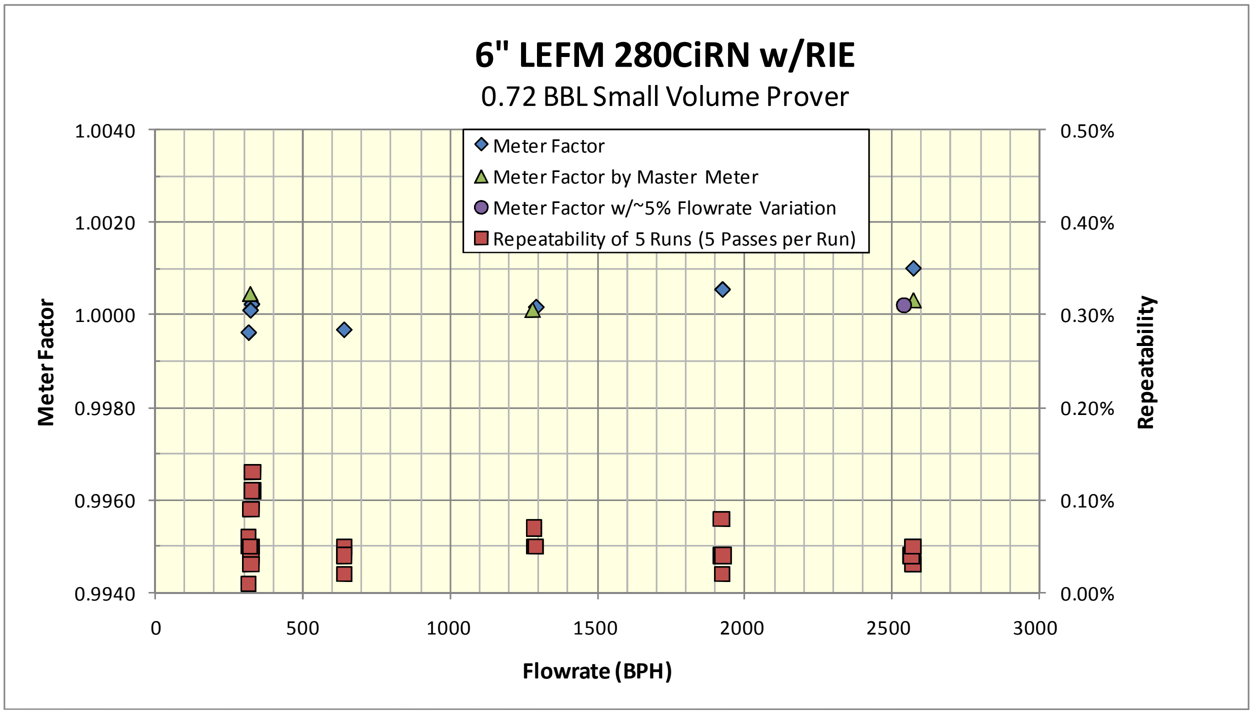


Figure 8 - 6" LEFM 280CiRN with RIE Test Results

In order to establish that the linearity results were not being biased because of the SVP, it was decided to prove the ultrasonic meter 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. This error can be summarized as follows[3].

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

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

What is interesting about the bias error phenomenon is that all of the variables needed to determine the maginitude of the error are known by the meter, i.e., the meter's time constant, the flow rate at the end of the proving pass and the flow rate at the beginning of the proving pass. Therefore, it is possible to correct

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

for this error when proving the meter[4]. Also shown in Figure 8 is a test point at high flow rate where the proving run time is short 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 shows the 16” Caldon LEFM 280CiRN installed in the test loop. Unfortunately, a 16 in. standard meter was not available for this testing; however, the current version of API MPMS Chapter 5.8 shows that in order to prove a 16” ultrasonic meter in 5 proving runs, a 522 BBL prover would be required.

Figure 9 - 16" Caldon LEFM 280CiRN Ultrasonic Flowmeter

Figure 10 shows the test results of a 16” Caldon LEFM 280CiRN meter proved using 2 cSt oil 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 (5 runs per proving). In twenty-nine (29) of thirty-six (36) provings the repeatability criteria of 0.05% was met. 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.

[4] 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

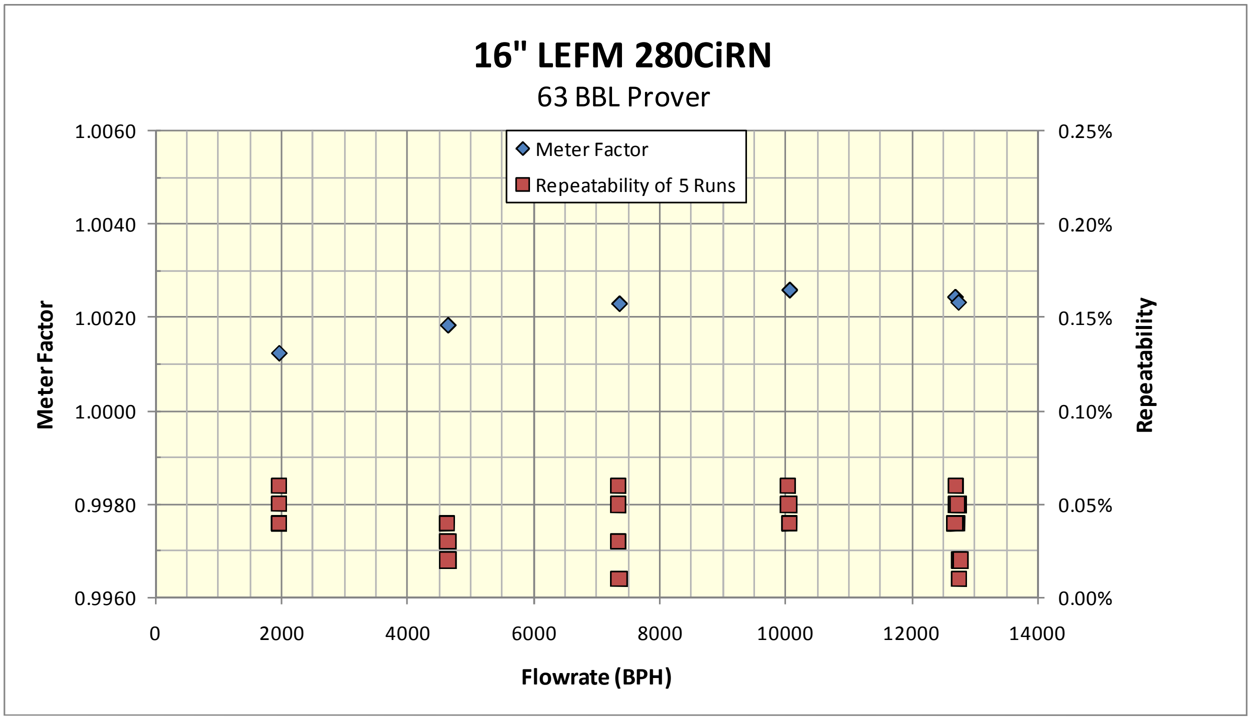


Figure 10 - 16" Caldon LEFM 280CiRN Test Results

Figure 11 shows a 16" RIE. Notice that the aperture size is still about the same size as that used for the 6" RIE. This is because the acoustic transducers used on the 16" meter are the same diameter as those of the 6" meter and therefore, the acoustic beam is the same size. If larger diameter acoustic transducers were installed in the meter, the apertures of the RIE could also be larger.

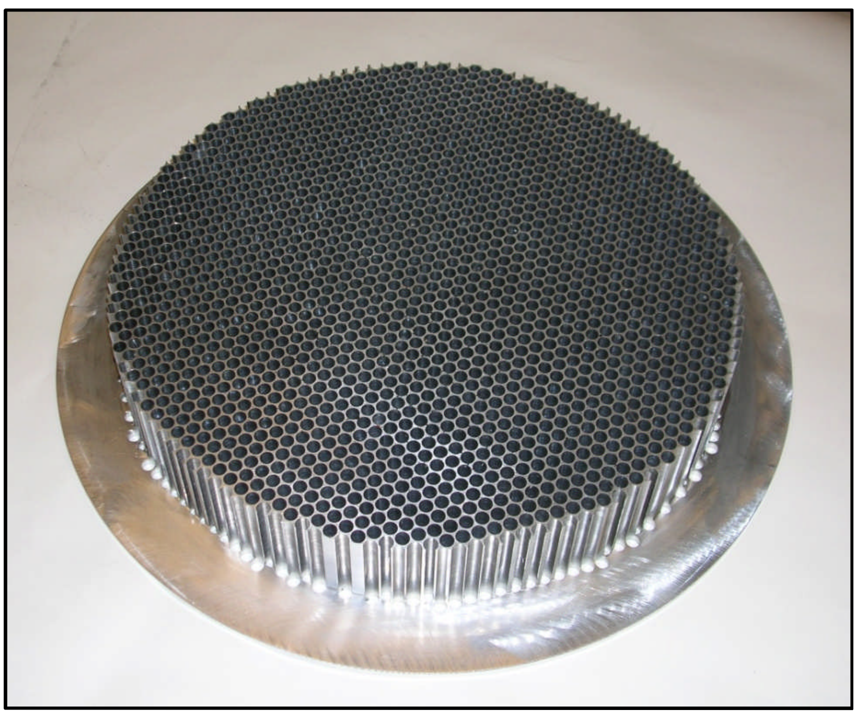


Figure 10 - 16" RIE

Figure 12 shows the test results of the 16" LEFM 280CiRN with the RIE installed immediately upstream. Notice that the prover size is now only 42 BBL. This is because the previous test had already established that this meter could meet the 5 run, 0.05% criteria. Therefore, in this test with the RIE, the prover volume was reduced. The prover volume reduction is possible without actually changing the prover because the 63 BBL uni-directional prover is fitted with intermediate detector switches at 21 BBL and 42 BBL and these volumes each carry their independent calibrations. A linearity curve was determined at 5 flow rates over forty-eight (48) proving. The average repeatability was 0.045% with thirty-four (34) of forty-eight (48) (over 70%) meeting the 0.05% criteria. Most in the industry would consider this success ratio acceptable. The ability of the 16" LEFM 280CiRN fitted with the RIE to be proved meeting the 5 run, 0.05% criteria would certainly match, and possibly exceed that expected from a 16" turbine meter being proved on a 42 BBL prover.

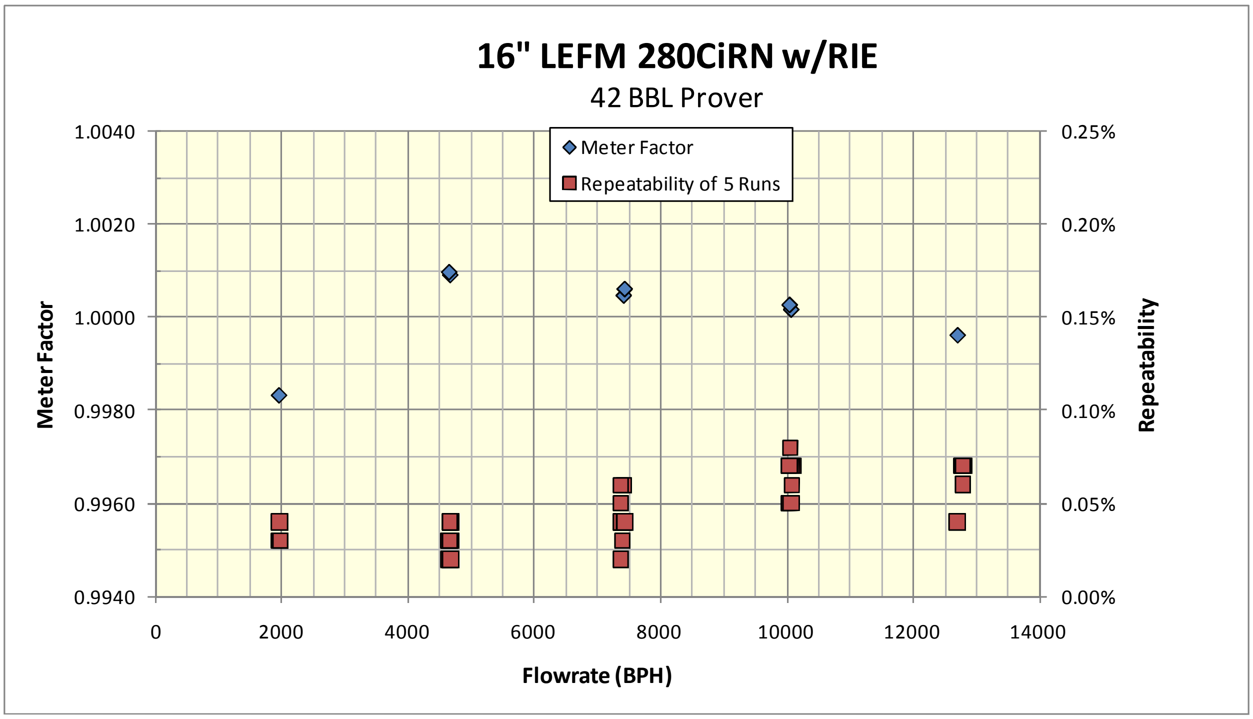


Figure 11 - 16" Caldon LEFM 280CiRN with RIE Test Results

Conclusions

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 be satisfactory. 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. What is really needed is an ultrasonic flowmeter that can be easily proved using the traditional technique of 5 runs with a maximum repeatability of 0.05%.

While the testing described above was conducted by Cameron at the Caldon Ultrasonic Technology Center near Pittsburgh, Pennsylvania, it was planned and witnessed by a joint industry group (JIG) representing four major oil and pipeline companies and one service Company. As can be seen from the data presented above, the results conclusively establish that the Caldon LEFM 280CiRN meter is not only significantly easier to prove that the standard ultrasonic meter but can be proved in 5 runs with a prover no larger in volume that that used by the conventional PD meter or turbine meter.