HIGH PERFORMANCE FLOW CONDITIONERS

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OVERVIEW

Accurate flow measurement is best achieved with an optimized flow profile. All those involved in the design, implementation and operation of a custody transfer station benefit from flow profile standards of accuracy that far exceed those of the past 40 years. By including flow conditioning in their latest metering station design standards, the American Petroleum Institute (API), American gas Association (AGA) and ISO have recognized a technology that insures an unparalleled degree of flow accuracy. This technology is a High Performance Flow Conditioner—placed upstream of a flowmeter—which conditions the flow such that it enters the flowmeter with a uniform, non-swirling, fully developed profile. This happens regardless of the pipe configuration prior to the conditioner.

Recent developments in High Performance High Performance Flow Conditioner technology have created a paradigm shift in the design and application of natural gas custody transfer metering stations. Whether it is Orifice Turbine or Ultrasonic applications, High Performance High Performance Flow Conditioners have brought increased accuracy and simplified installations to the industry at large. This paper discusses the high performance High Performance Flow Conditioner technology; it's application and recent calibration results from a number of calibration facilities in North America. In addition the paper with discuss the integration of a High Performance Flow Conditioner with an Acoustic Filter element.

PERFORMANCE VS. CAPITAL COST

When consideration is given, during the design phase of a fiscal metering facility, to capital cost of equipment one important point that needs to be front and center in the decision making process of equipment selection needs to be the total cost of ownership of the facility. This incorporates not only the capital cost of the equipment purchased but also the full term cost of the performance of the design. The net effect of the cost of performance, *i.e.,* uncertainty, will have a drastic effect on the bottom line of the meter station, the inclusion of High performance High Performance Flow Conditioners in the design fits well into equation of cost vs. benefit in terms of overall performance and equipment justification.

The following are the major economic drivers that effect the selection of High performance High Performance Flow Conditioners:

- Reduced Meter Station size
- Improved meter performance
- Standardized meter station designs
- Reduced LUAF

By deploying a High Performance Flow Conditioner the operator is assured of achieving the best possible flow environment for the flowmeter under most piping configurations.

INSTALLATION EFFECTS AND METER SELECTION

All inferential flowmeters (for example, orifice, ultrasonic, and turbine meters) are subject to the effects of velocity profile, swirl, and turbulence structure. The meter calibration factors or empirical discharge coefficients are valid only if geometric and dynamic similarity exists between the installed and calibration conditions or between the installed and empirical database conditions—in other words, under fully developed flow conditions commonly referred to as the Law of Similarity.

In the industrial environment, multiple piping configurations are assembled in series, generating complex problems for standards-writing organizations and flow metering engineers. The challenge is to minimize the difference between the actual flow conditions and the fully developed flow conditions in a pipe, in order to maintain minimum uncertainty associated with the selected metering device's performance.

Research programs in both Western Europe and North America have confirmed that many piping configurations and fittings generate disturbances with unknown characteristics. Even a single elbow can generate very different flow conditions—from "ideal" to "fully developed" flow—depending on its radius of curvature (that is, mitered or swept). In addition, the disturbance that piping configurations generate is further influenced by the conditions prior to these disturbances.

In general, upstream piping elements may be grouped accordingly:

- Those that distort the mean velocity profile but produce little swirl.
- Those that both distort the mean velocity profile and generate bulk swirl.

As a result, today's measurement industry is increasingly focused on lowering uncertainty levels associated with these distorted flow conditions.

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The problem, then, is to minimize the difference between real and distorted flow conditions on the selected metering device, thus maintaining the low uncertainty required for fiscal applications. For clarity, this will be referred to as "pseudo-fully developed" flow.

A method to circumvent the influence of the fluid dynamics on the meter's performance is to install a High Performance Flow Conditioner in combination with straight lengths of pipe to "isolate" the meter from upstream piping disturbances. This isolation, however, is never perfect.

PSEUDO-FULLY DEVELOPED FLOW

From a practical standpoint, we generally refer to fully developed flow in terms of swirl-free, axisymmetric, time average, velocity profile in accordance with the Power Law or Law of the Wall prediction.

To bridge the gap between research and industrial applications, the term *pseudo-fully developed flow* will be defined as follows:

> "The slope of the orifice meter's discharge coefficient deviation or meter factor deviation that asymptotically approaches zero as the axial distance from the flowmeter to the upstream High Performance Flow Conditioner increases."

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To truly isolate flowmeters, a High Performance Flow Conditioner, placed in series before the flowmeter, should achieve the following design objectives:

- Low permanent pressure loss (low head ratio).
- Low fouling rate.
- Rigorous mechanical design.
- Moderate cost of construction.
- Elimination of swirl [less than 2°—when the swirl angle is less than or equal to two (2) degrees, as conventionally measured using pitot tube devices, swirl is regarded as virtually eliminated].
- Independence of tap sensing location (for orifice meters).
- Pseudo-fully developed flow for both short and long straight lengths of pipe.

For turbine and ultrasonic meters, when the empirical meter factors for both short and long piping lengths are approximately ±0.10% for *liquid* applications, or approximately ±0.25% for *gas* applications, and if it is also shown to be independent of axial position, then it is assumed to be at a minimum and to be pseudo-fully developed.

For orifice meters, the term Cd deviation (%) refers to the percent deviation of the empirical coefficient of discharge or meter calibration factor from fully developed flow to the disturbed test conditions. Desirably, this deviation should be as near to zero as possible. As explained above, a minimal deviation is regarded as ±0.25% for gas applications.

EXPERIMENTAL RESULTS

Several High Performance Flow Conditioners have been evaluated by the Gas Research Institute for comparison purposes as part of their Installation Effects Research Program. For these tests, the same test loop or apparatus was used, to provide consistency between experiments.

For the test loop, gas enters a stagnation bottle and flows to a straight section of pipe. The gas then enters a 90° elbow or tee followed by a meter tube and flowmeter. The High Performance Flow Conditioners tested are positioned at various upstream distances, *X*, from the orifice plate. To obtain dimensionless terms, the distance *X* was divided by the meter tube nominal diameter, *D*.

For the experiments, the selected flowmeter was a concentric, flange-tapped, square-edged orifice meter with Betas of 0.67 and 0.75. The internal diameter of the meter tube, ID_p, was 102.29 mm (4.027 inches) and the length of the meter tube, L_1, was 17 nominal pipe diameters (17*D*). For certain AGA tube bundle measurements, the length of the meter tube, L_1, was increased to 45*D* and 100*D* lengths. The flow disturbance was created by either a 90° elbow or a tee installed at the inlet to the meter tube.

ANALYSIS OF RESULTS

The results obtained for the AGA design, using meter tube lengths of 17D, 45D, and 100D, indicate a minimal deviation when:

- L_1 = 17*D*; and *X/D* = 12 - 15
- L_1 = 45*D*; and *X/D* = 8 - 9
- L_1 = 100*D*; and *X/D* = 8 - 9 or > 45

Tests on four High Performance Flow Conditioners in a 17*D* long test pipe with a tee were funded by GRI. The

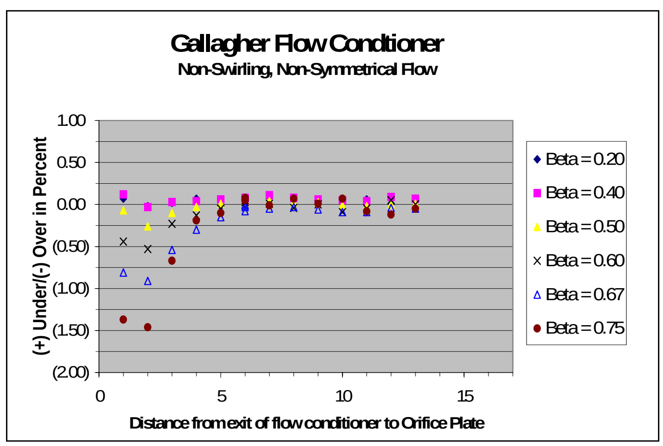


FIGURE 1.

Beta for the orifice meter was 0.67 and the Reynolds number was approximately 900,000.

These results are not surprising in light of current understanding of pipe flows. The tube bundle—long relied upon to condition the disturbances present in gas flow—does an excellent job of eliminating swirl. However, the fixed diameter tubes generate an unstable turbulence structure that begins to redevelop rapidly. Also, the constant and high radial porosity does not offer a method to redistribute any asymmetric flow patterns.

A new breed of High Performance Flow Conditioners produces pseudo-fully developed flow conditions for both short and long piping configurations. This is evidenced by the slope of the orifice meter's discharge coefficient deviation or meter factor deviation asymptotically approaching zero as the axial distance from the flowmeter to the upstream High Performance Flow Conditioner increases. The new breed of High Performance Flow Conditioners has also demonstrated an insensitivity to tap sensing location, confirming the presence of pseudo-fully developed flow.

MEASUREMENT STANDARDS AND RECENT TESTING

Orifice Meters

The latest revision to both AGA3 and IO 5167 standards clearly demonstrate the recognition of the effectiveness of the High performance High Performance Flow Conditioner technology by allowing for it's inclusion as a way to resolve installation effect induced errors.

With respect to installation effects and the near-term flow field, the correlating parameters that impact similarity vary with flowmeter type and design. However, it is generally accepted that the concentric, square-edged, flange-tapped orifice meter exhibits a high sensitivity to time average velocity profile, turbulence structure, and bulk swirl and tap location.

In North America, previous design practices utilized short upstream piping lengths with a specific High Performance Flow Conditioner—AGA tube bundles—to provide pseudo-fully developed flow in accordance with the applicable measurement standard (ANSI 2530/A.G.A. 3/API MPMS 14.3). Most North American installations consist of 90° elbows or complex header configurations upstream of the orifice meter. Tube bundles in combination with piping lengths of 17 diameters (17*D*) have been installed to eliminate swirl and distorted velocity profiles. Ten diameters (10*D*) of straight pipe are required between the upstream piping fitting and the exit of the tube bundle, and 7 diameters (7*D*) of straight pipe are required between the exit of the tube bundle and the orifice meter.

Since the last IFFS, further research data was released relative to the use of High Performance Flow Conditioners in compact orifice meter station design studies, as discussed in previously issued papers, the intent of the research was to discover if it was practical to design a compact meter station using the High performance High Performance Flow Conditioner technology as a core component, it was subsequently found from the test that a two piece High Performance Flow Conditioner deployed with only 10*D* of straight pipe upstream of the Orifice Flow meter could produce the following Cd deviation performance:

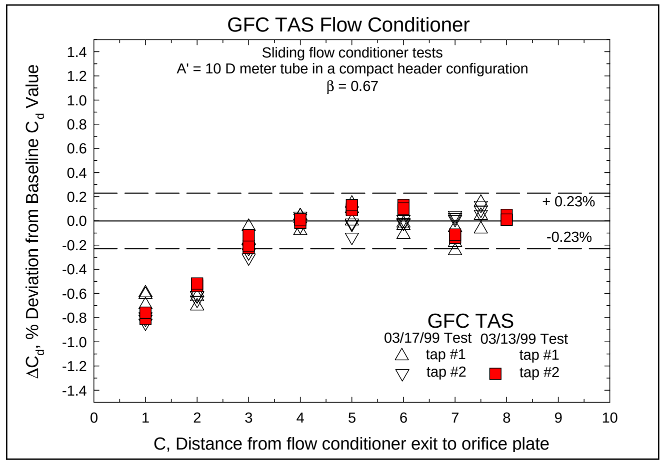


FIGURE 2.

With the deployment of High Performance Flow Conditioners and the inclusion of the technology in the revised AGA and ISO orifice standards the user community now has another tool available to minimize one area of uncertainty, piping induced disturbances, in the use of orifice flow meters.

ULTRASONIC METERS

Ultrasonic meter technology has been adopted extensively for gas fiscal metering applications over the past five years and is becoming increasingly accepted in critical large volume liquid metering applications. From power plant connections to gathering systems this technology has tremendous potential to become the fiscal measurement method of choice and, with correct

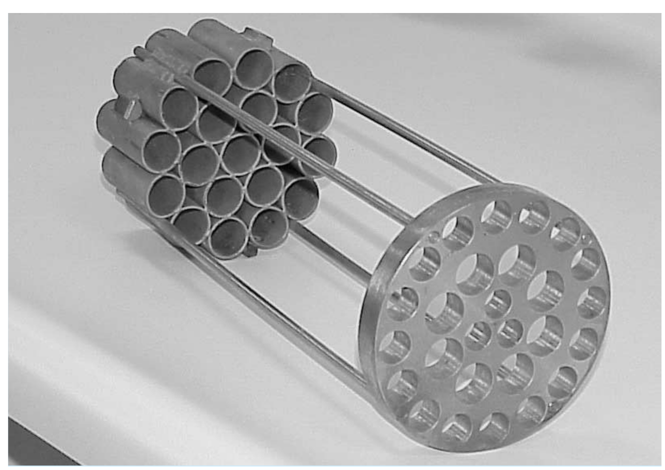


FIGURE 3.

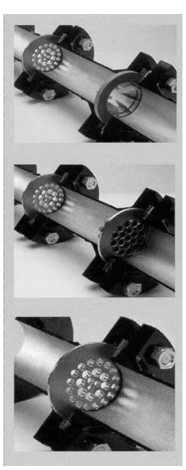
installation and operation has the capability to present performance levels that are equal to or better than most world-class flow calibration laboratories.

The original adoption of AGA Report 9 and the current efforts to revise the report has focused a lot of attention on the use of High Performance Flow Conditioners and the installation thereof. Originally AGA 9 did not specifically recommend or define the use of High Performance Flow Conditioners other than to allude to it as an option available to the user community. Since the original publication of AGA report 9 the user community has elected to use High performance High Performance Flow Conditioners in, conservatively, over 70% of all MUSM installations.

Extensive research has indicated that the use of High Performance High Performance Flow Conditioners with Ultrasonic flowmeters provides the user with the assurance of consistent meter performance over extended flow ranges and with varying piping configurations. It is important to note that the relationship between the USM and the High Performance Flow Conditioner needs to be considered a packaged performance as the two separate elements combine to create a single calibrated artifact. The interaction between the High Performance Flow Conditioner and USM and the interpretation of the flow field by the USM needs to be allowed for during Dynamic Calibration as different pairings of meters and High Performance Flow Conditioners will elicit different results. That being said it should always be remembered that the offset in meter factor created by the MUSM and High Performance Flow Conditioner artifact far outweighs the uncertainty associated with the impact on a meter of a non-flow conditioned flow field in a bare meter installation with multiple piping configurations.

THE STATE OF THE ART

Advances in High Performance Flow Conditioner technology and pragmatic demands of the industry have lead to the development of a matrix of products that satisfy the requirements of the many varied applications of this technology. Solutions are now available with the following mechanical features:



- Two Piece High Performance Flow Conditioners for Orifice meter applications
- Single Plate designs (flange mount) for Orifice meter applications
- Single Plate designs (in-line, pin mount) for Orifice meter applications
- Two Piece High Performance Flow Conditioners for USM applications
- Single Plate designs (flange mount) for USM applications
- Two Piece High Performance Flow Conditioners for Turbine Meter applications
- Single Plate designs (flange mount) for Turbine Meter applications

This added product flexibility allows the user to better select that design that meets the needs of installation complexity, performance requirements and budget constraints.

Different manufacturers recommend different piping configurations for the installation of this technology, the clear reason for this is the varied techniques used to condition the flow, the different deployment of TAB designs, thick plates and other techniques are all offered with different levels of performance in mind. The following (Figures 4 and 5) are some typical examples of installation recommendations.

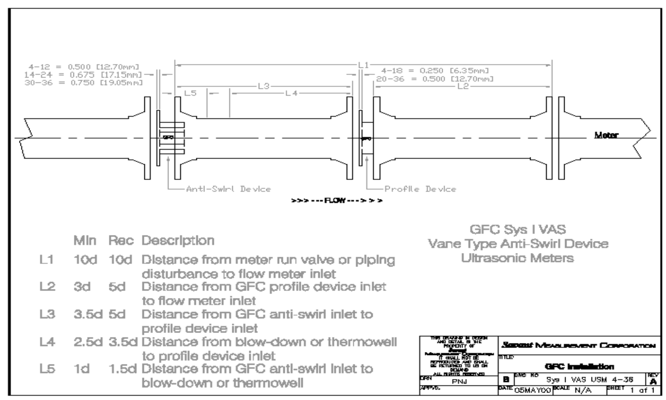


FIGURE 4.
Two Piece High Performance High Performance Flow Conditioner with USM

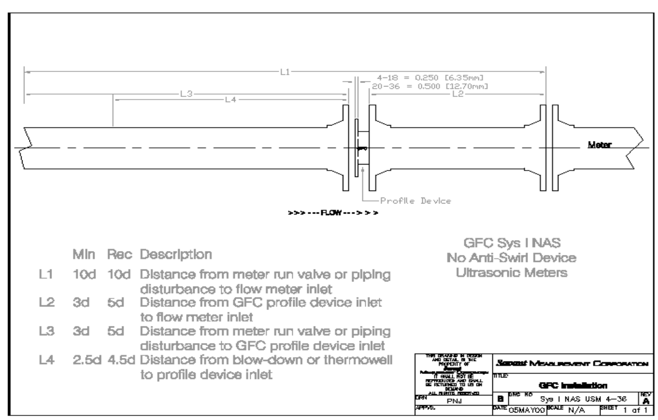


FIGURE 5.
One Piece High Performance High Performance Flow Conditioner with USM

While the various designs of High Performance Flow Conditioners have been optimized for certain defined minimum installation lengths upstream of the meters, from numerous calibrations and tests the extension of those lengths, while having both a negative size and cost impact on the installation, do not negatively impact the performance of the High Performance Flow Conditioner and therefore the overall performance of the USM\High Performance Flow Conditioner artifact. When considering the use of any High Performance Flow Conditioner technology the following factors should be considered:

- Permanent Pressure Drop allowed
- Complexity of installation upstream of the meter
- Allowable space for the total station footprint
- Allowable weight for the meter station design (offshore)
- Whether the meter run may be deployed as an asset into a different installation in the future.

HIGH PERFORMANCE FLOW CONDITIONERS AND PRESSURE DROP IN BOTH LOW PRESSURE PRODUCTION AND LARGE GAS TRANSMISSION

The following (Figures 6, 7, 8, and 9) are some recent calibration curves with MUSM and High Performance Flow Conditioners which demonstrates the high level of performance that can be achieved by these two technologies.

NOISE AND A NEW TECHNOLOGY

Manufacturers of High Performance Flow Conditioners are commonly asked what level of noise can a user expect from the use of the technology, particularly with the high velocity applications associated with USM's. The first question to address is what kind or frequency of noise is of concern? Ambient (Audible) noise or Ultrasonic Noise.

The installation of fiscal metering stations are increasingly encroaching closer and closer to the population of our towns and cities and conversely the population is expanding closer to existing meter stations, consequently audible noise is of increasing concern to gas transmission companies in particular.

Clearly anything that can be done to reduce audible noise levels works to the advantage of all concerned, however the deployment of a typical High Performance High Performance Flow Conditioner, two piece *or* one piece will present a natural restriction to the flow and under high velocities may act as a transmitter of noise either from itself or from piping upstream of the device. Techniques may be used in an attempt to reduce these audible noise levels including extreme chamfering of holes and other techniques, however in the design of these devices the entrance and

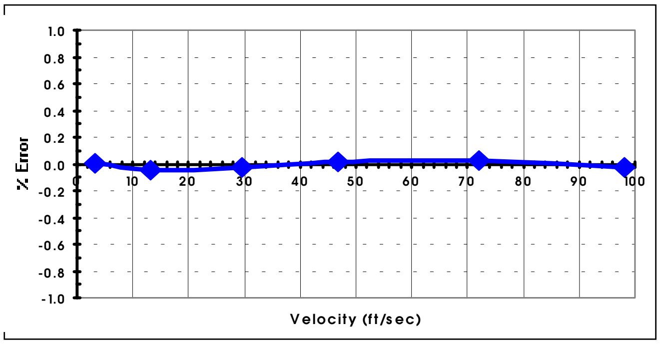


FIGURE 6.
16″ MUSM with Two Piece High Performance High Performance Flow Conditioner

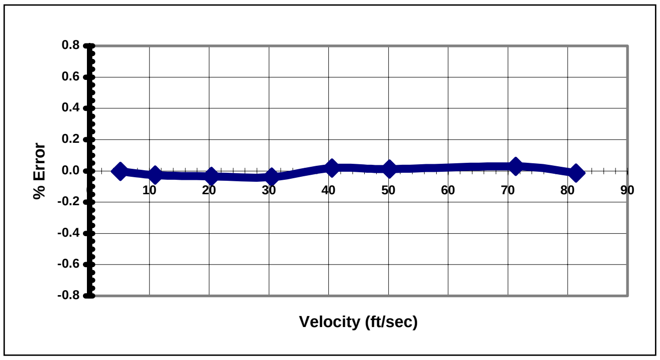


FIGURE 8.
6″ MUSM with Two Piece High Performance High Performance Flow Conditioner

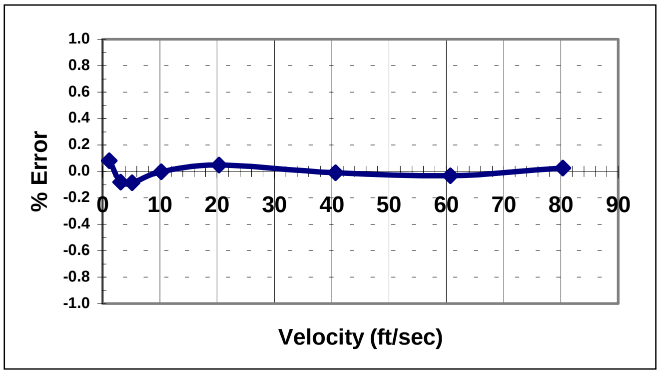


FIGURE 7.
12″ MUSM with Two Piece High Performance High Performance Flow Conditioner

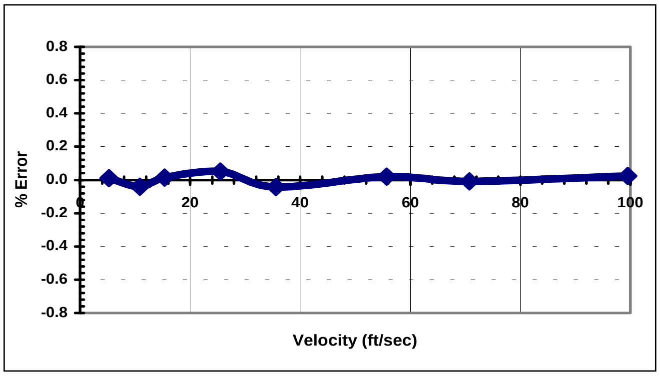


FIGURE 9.
4″ MUSM with two piece High Performance High Performance Flow Conditioner

exit finish of any High Performance Flow Conditioner aperture is critically designed to allow for the rapid construction of a pseudo-fully developed flow profile, therefore in an attempt to fix any noise “problem” the efficacy of the High Performance Flow Conditioner should not be compromised.

This is not to say that audible noise generated by a High Performance Flow Conditioner is accepted as a fact however the level of noise may be minimized by selecting High Performance Flow Conditioners that have lower permanent pressure drop factors and designs that have been optimized for high velocity USM applications.

The intensity of a sound wave is the amount of wave energy transmitted per unit time per unit area normal to the direction of sound propagation; that is, the intensity of sound is the power transmitted per unit area. In the *audible* classification of noise, the significant intensities for the human species are —

	Intensity (W/m^2)	**Intensity Level** (dB)
Hearing threshold	1E-12	0
Whisper	1E-10	20
Conversation	1E-06	65
Street traffic	1E-05	75
Train in tunnel	1E-02	100
Pain threshold	1E+00	120

The USA’s Occupational Safety and Health Administration (OSHA) has mandated federal regulations to protect the human ear from permanent or temporary damage due to audible frequencies with intensity levels above a certain limit. The allowable OSHA intensity levels vary with the time exposed to the source of noise.

24″ MUSM TEST

The following test was conducted on a 24″ USM at varying velocities to determine the audible noise levels being transmitted to the environment. The noise levels were taken using a standard noise meter with the microphone positioned within 2″ of the flanges containing either the conditioning plate or entrance to the USM.

Velocity	FC (dB)	Meter (dB)
100 ft\sec	92	86
87	92	83
70	86	81
60	76	72
50	79	70
40	68	67
30	66	65
20	60	60
10	60	60

Unfortunately no data was available for a comparative test without the High Performance Flow Conditioner in place; however, it is considered highly probable that the noise levels would have been comparable without the High Performance Flow Conditioner. Further research is planned on this important subject.

Noise can also be a significant installation challenge when the frequency of the sound is in the Ultrasonic Frequency range at which the USM’s typically operate 100khz to 200khz. To pursue this technical challenge a new technology is proposed that combines the strengths of a commercially available Ultrasonic Noise Acoustic Filter, the S.A.F.E.® and a commonly used High Performance Flow Conditioner the GFC® both manufactured by Savant Measurement Corporation.

The Acoustic Filter is designed to significantly reduce the level of ultrasonic noise created by commonly used control valves and as previously discussed, the High Performance Flow Conditioner in question utilizes both a separate anti-swirl element in addition to a conditioning plate. The proposal for the new design of hybrid conditioner and acoustic filter would use the acoustic filter **as the anti-swirl element** in the flow conditioning system thus eliminating uncertainty associated with both flow field variations and ultrasonic noise from valves, fittings etc.

The installation for the new hybrid technology would typically be:

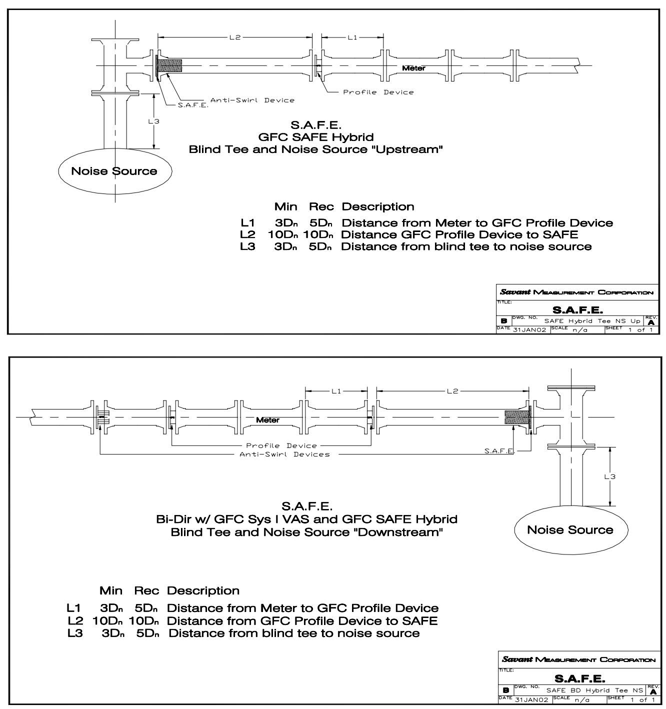


FIGURE 10.

The S.A.F.E.® Acoustic Filter has been tested and proven to reduce ultrasonic noise by as much as 45-50 dB with indirect noise and 25-30dB with direct noise, *i.e.,* noise emanating from a source directly in-line with the S.A.F.E.

OUTLOOK

Designing and operating an accurate flowmeter application requires understanding of the fluid's physical properties. An envelope must be drawn around the process (or operating) conditions, and the identification of any special conditions. Understanding the physical principles upon which the selected flowmeter is based and comprehending its sensitivities to physical and process conditions is critical. Most important, designing and operating an accurate measurement facility requires compliance with the Law of Similarity, which is what the High Performance Flow Conditioner insures. Placing a High Performance Flow Conditioner prior to the flowmeter will condition the disturbed fluid entering the conditioner so that it proceeds to the flowmeter with a virtually ideal bullet-shaped profile for extremely accurate measurement.

Manufacturers of High Performance Flow Conditioners must continue to innovate to be able to provide the measurement industry and the user community specifically with revolutionary and more cost effective products to satisfy the continuing drive towards more effective solutions and practical solutions.

FIGURE 11.
S.A.F.E.® Acoustic Filter

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