New Ideas in Differential Pressure Flow Measurement
Using Cone Meter Technology

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Abstract

Flow Measurement Technology is advancing at an ever increasing rate, new engineering methodology in the art of flow measurement are forcing a change for the better.

Newer technologies often bring advances to the operational processes within many industries. which can improve management and production.

This paper details the design and operation of a new genre of differential pressure cone meter

A technical explanation and overview of the technology will be discussed in the paper together with application ideas.

Generic Cone Meter Overview (original invention)

The meter consists of a differential producer fixed concentrically in the center of the pressure retaining pipe by which a differential pressure can be obtained across the interface of two cone frustums via an internal port-way system.

This allows the downstream pressure *P2* to be measured in the center of the closed conduit.

The upstream pressure *P1*, being measured at the pipe wall. (see figure 1.0)

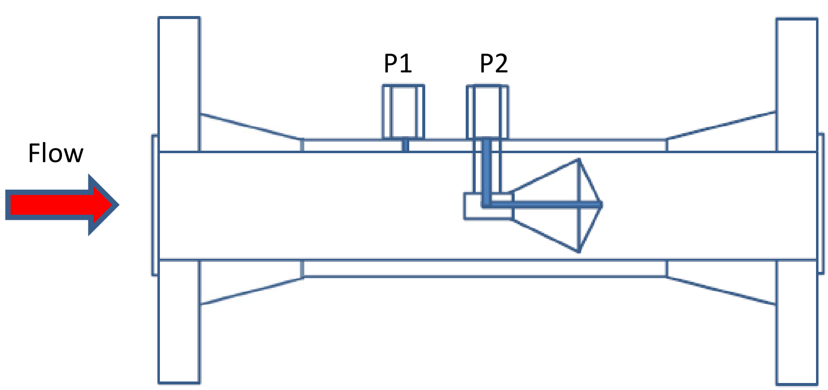

Fig 1.0 Generic Cone Meter

Welded Fabrication (Generic Cone Meter)

The afore mentioned generic design (fig1.0) is either fabricated from steel pipe and flanges with a cone sat on a cantilever support, this method of construction whilst can be robust may can have some issues regarding cone concentricity due to heat from welding and requires calibration for each meter manufactured, the cone element diameter on this type of device are fixed and cannot be changed after manufacture.

The concept of using the center of the cone above to collect the downstream pressure has certain advantages over conventional differential pressure devices such as the following:

a) Flow Conditioning.
b) Large Turndown
c) Static Mixing
d) Wet Gas usage with Lockhart & Martinelli values up to 0.3.

Cone Meter Calibration

The common mode of checking that cone meters are working correctly is to calibrate each device over the Reynolds number that it will operate at. This is great if the in Field ***ReD*** numbers can be reached by the laboratory used to calibrate the device however this calibration is usually managed in a water flow laboratory which may not achieve the desired flow range.

This means that to calibrate a welded type cone meter properly it needs to be calibrated on an equivalent in field Reynolds number range. This may be costly to provide per meter usually tested on air, the advantage is that the meter will have the correct C.d. with this methodology over the range tested provided the laboratory is approved to ISO 17025 or other national standard.

Similitude

This is a concept used in the testing of engineering models and can be applied to all kinds of applications, and is heavily used in aeronautical and aircraft design.

A model is said to have similitude with the real application if the two share geometric similarity, kinematic similarity and dynamic similarity.

1. **Geometric similarity** - The engineered model is the same shape as the application, but usually scaled.
2. **Kinematic similarity** - Fluid flow of both the model and real application must undergo similar time rates of change motions. (fluid streamlines are similar)
3. **Dynamic similarity** - Ratios of all forces acting on corresponding fluid particles and boundary surfaces in the two systems are constant

A recent API standard has concluded the acceptability of the geometric similitude method for acceptance in the scaling up of meter geometries, et al MPMS API chapter 22.2.Differential Pressure Test Protocol.

This is based on the testing of various diameters with the same geometric shape to type test a meter this does not relinquish the need to properly calibrate metering devices that are dependent on external C.d determination by laboratory calibration (due to manufacturing differences between devices caused by the welding process) but is intended to give confidence to a manufacturers claim of fidelity over conditions of operation expected in the field condition.

Some cone meter manufacturers have commenced having their devices verified according to this API 22.2 standard and have independent data to confirm claims about the performance of their devices.

The previous comment on similitude is valid only if the models have identical manufacturing parameters and scaled geometries with tolerances that are realistic in nature.

A New Idea (next generation)

One cone meter manufacturer has taken the concept of geometric similitude very seriously by using CNC machined castings or forgings to develop a range of devices that have inherent mechanical repeatability in the meter tube, housings and primary elements.

Some of the major issues in the manufacture of identical cone type meters had been the concentricity of the cone element, the repeatability of the attachment method, and the definition of surface roughness in the throat of the meter.

The use of a casting or forging and a final machine tolerance applied over the meter internal will satisfy the geometric similitude and if performed correctly should enable congruent results between throat internal diameter's primary cone element, roundness, and surface tolerance.

This particular manufacturer has also developed a unique way to enable beta ratio changing by using a CNC machined removable area ratio changer (ARC) or separate cone section to effectively enhance the range- ability available by allowing the differential producer element to be varied according to the flow rate range needed.(See figure 2 below)

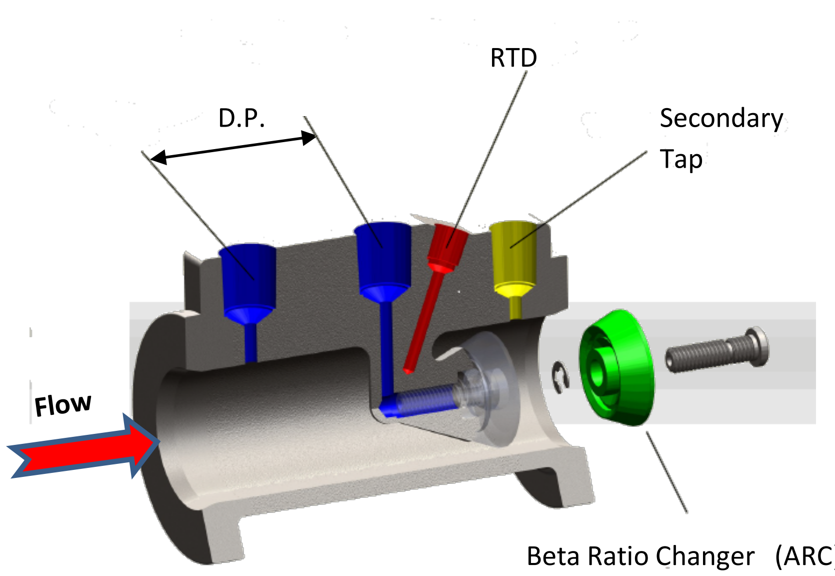

Figure 2 – Artifact Calibrated Cone Meter Design

Artifact Calibrated Meters

The standardized orifice plate flow meter is an artifact calibrated metering system using a proven pre-determined geometry per pipe diameter and similitude for the location of the plate, and orifice size , the surface roughness, the tap position and tap geometry, also its position in the pipe and location in the meter tube with its concentricity taken into account .

If any of these parameters are skewed the orifice calculation (which is based on the original artifacts (test meters) used to determine the national and international standards) will be wrong.

The idea regarding the cone meter (fig 2) is to also intended develop an artifact calibrated system methodology that also uses geometry, manufacturing stability and repeatability to obtain similitude between devices of the same meter diameter !

This concept had tremendous advantages over previous executions of the cone meter device these can be listed as follows -

1) Calibration traits of the artifacts (original prototypes) transferred to the meter (provided that the CNC machining tolerances are valid between devices)minimum calibration.
2) Meter turndown can be determined after manufacture to suit the application and controlled – this will be discussed later on in the paper.
3) Concentricity of the meter and subsequent area ratio (beta) changers can be controlled at a high level.
4) Tap design, Position and repeatability of design
5) Surface roughness control by CNC machine – very important for dynamic similarity.

All the above items are major parameters needed in the fight to achieve a mechanically repeatable manufactured cone meter that has a good consistent performance between units.

Calibration and Range-ability (D.P meters)

After manufacturing a meter that has the traits mentioned above the operation can be defined to obtain the optimum range-ability versus uncertainty over that range.

In the past generic cone meter designs have been operated at a 10-1 turndown encompassing a Coefficient of Discharge (C.d) linearity shift that changes in certain regions of the Reynolds number / flow rate range, this effect of change has been seen in D.P and orifice plate meters.

The use of an interchangeable cone (ARC) can really help a meter application when the flow rate of a well has declined and the meter needs to be re-ranged whilst providing the optimum DP across the differential producer. Changing out the differential producer can adjust the range and bring it back to a useable number, whilst also re affirming the performance /uncertainty by operating in the linear part of the calibration curve.

Whilst the orifice plate has a good performance if installed correctly the upstream condition flow condition and flatness profile is important for the meter uncertainty to be acceptable.

A big advantage that an artifact calibrated cone meter brings to the table is the improved immunity to disturbed flow profile effects, as it is known and has been physically demonstrated that the generic cone meter centrally mounted element re distributes the velocity profile to the meter internal wall or throat region when you add this fact to a device that has a CNC machined construction the performance and closeness of discharge coefficients between subsequent production run meters will be better.

The application or control of range ability is superior to other cone meter devices since the area ratio can be changed to suit the operating flow rate.

Data comparisons (next) shows the enhanced range ability for such a machined device versus non-machined fabricated single beta cone meters

Typical Welded Cone Meters

The coefficient of discharge curve shown next is for a fabricated welded design the differences between the C.d.'s per subsequent production meters can be circa 7% due to the issue of keeping the manufacturing tolerances tight and control of the surface roughness which is difficult with a welded piece that is not machined.

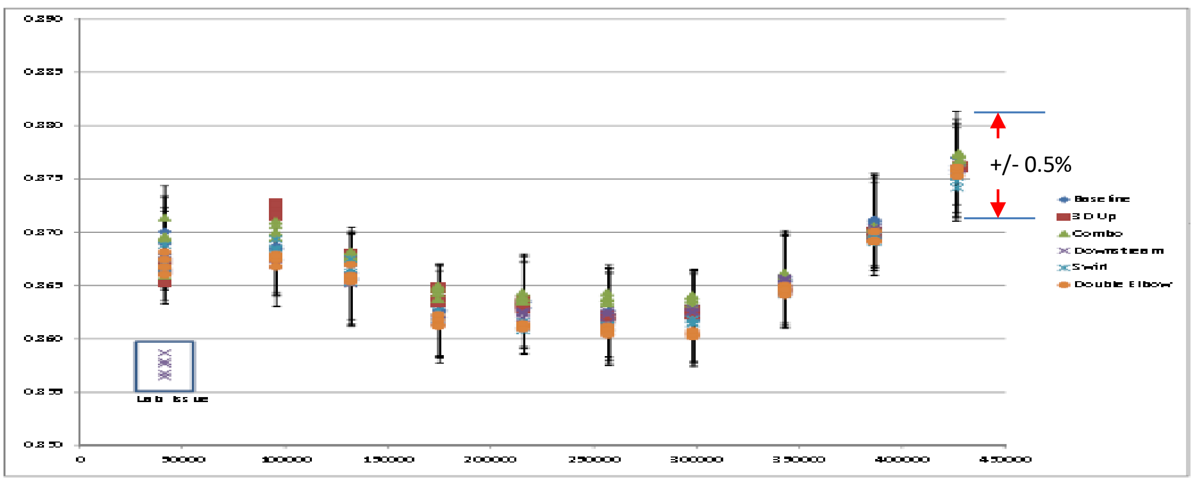

Fig 3 - 2 inch Generic Cone Meter (Welded) Tested 2009 et al Davis & Lawrence (0.45 β)

The calibrated points show good resistance to disturbance issues upstream as do most cone type meters as the base line for this meter and all disturbance parameters fall within +/-0.5% at each point.

If this 2 inch meter where to be used with the point inputted into a flow computer the performance would be very good, One cautionary issueis that of the calibrated Reynolds number (*ReD*) ranges.

As previously mentioned the normal situation regarding cone type meters is to calibrate each one to overcome geometric similarity issues. If the test loop uses a water medium then the high *ReD* range is limited to a velocity achievable in the medium (water as opposed to gas).

It is preferable to test the meters with similar viscosities and Reynolds No's (ReD's) to obtain a Cd in the correct flow range

Test Loop Flow Ranges

An example is shown next highlighting a calibration range issue, this shows a typical generic meter test report with flows over a large range based on air and water, a water rig cannot reach the high ReD's seen in an air rig therefore it would be impossible to fix the true C.d. points with good certitude above the limit of the water rig for some flow-rates**.** The testing at the maximum water flow range can be seen to be well below the gas /air test lab range-ability.

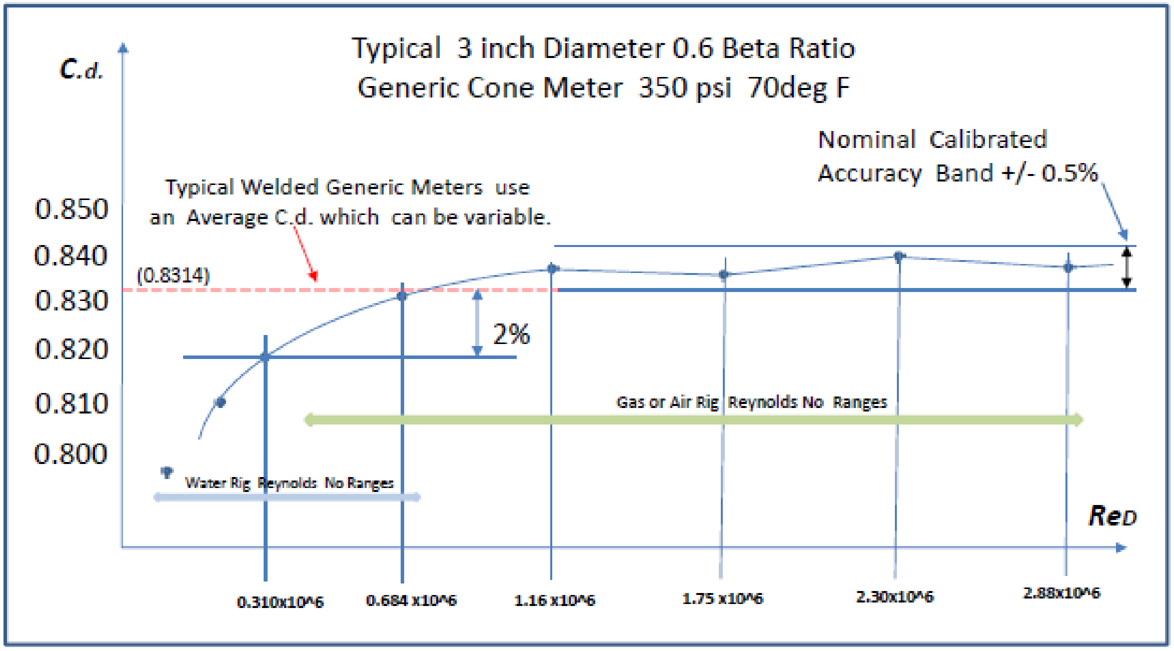

Fig 4 Typical Flow (ReD) Ranges (water versus an air rig)

Artifact Calibrated Meters

The use of interchangeable artifact calibrated beta/area ratio changers (Arc's) opens up the possibility to use the said meter inthe field application with a certain size of beta and then as the field condition changes over time a different ARC (beta) element could be installed thus reducing the need to change out an old meter for a new one, which may even cause pipe diameter changes to be necessary.

The next figure (5) shows a 2 inch artifact calibrated device with 3 beta ratios plotted on the one calibration chart , this shows that you can tighten up the uncertainty over the Reynolds number ranges by doing a change of area at the bottom range of each ARC (beta).

This improves the cone meter linearity and performance by negating the drop at the low Red range thus extending the linear range from the high to the low without a pre-determined calibration.

The Geometric, Dynamic, and Kinematic, Similarity being satisfied by a precision machining and manufacturing process.

If further proof would be needed sample production devices can be taken randomly from production and tested over a large manufactured batch therefore spreading any air/gas calibration cost over a few units which is a very economical checking method and provides proof of application.

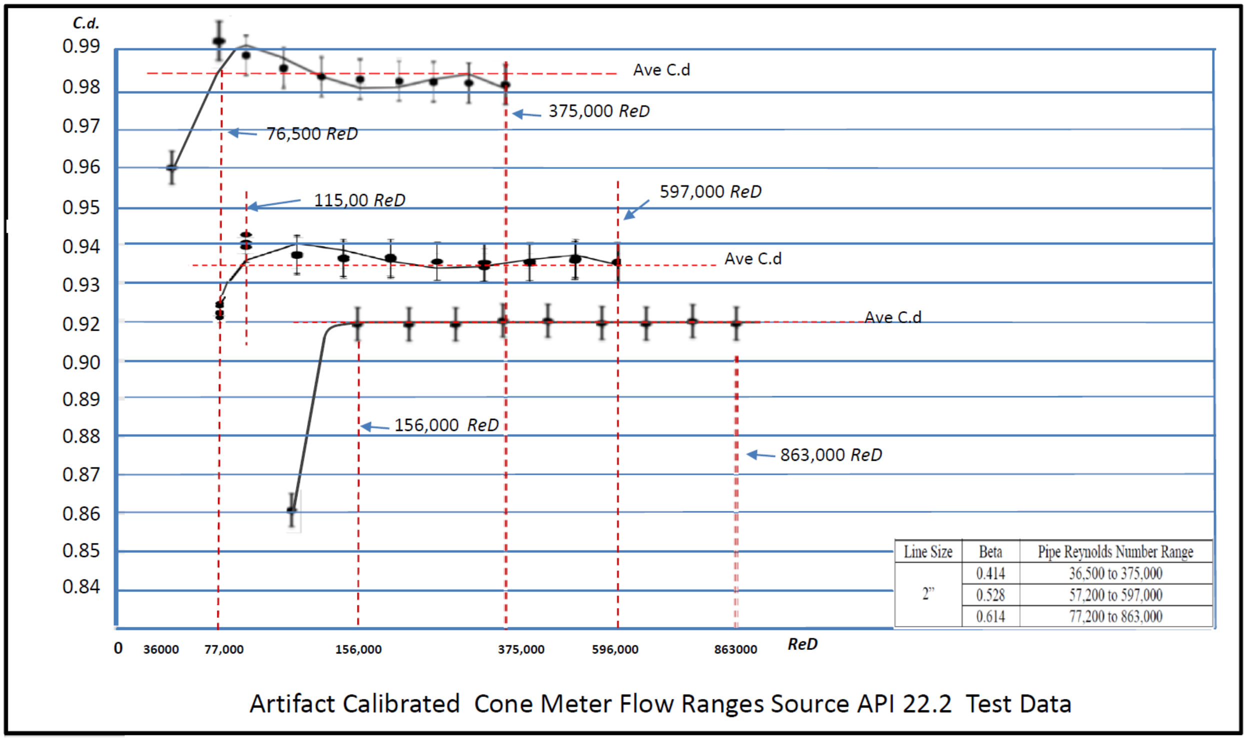

Fig 5.0 - Calibration Ranges for Different Arcs (Beta's) 2 inch meter

The meter in figure 5 has very good linearity for each beta changer (ARC) the data shows the average C.d. is constant over a +/- 0.5% between ranges of 375000 to 76000 *ReD* for the largest beta ratio changer or (ARC) 0.41Beta, from 597,000 to 115,000 *ReD* for the mid-size ARC @0.52beta ratio and a range of 863,000 to 156,000 *ReD* for the smallest diameter ARC tested at 0.61Beta

The real advantage for this type of area ratio change (ARC) type meter is that you can operate the meter at its optimum D.p through-out its life and to help to reduce transmitter uncertainties at the lower D.p.'s which can occur over time as a gas well depletes.

The meter can be re ranged using a beta ratio changer (ARC) that has inherent accuracy over a predetermined and defined range using the geometric shape (artifact) as the means to be sure its accurate.

The following data shown next from the API 22.1 testing that was performed at the CEESI facility in 2011.

The flow perturbation effects test on the meter can be seen graphically in the next figures.

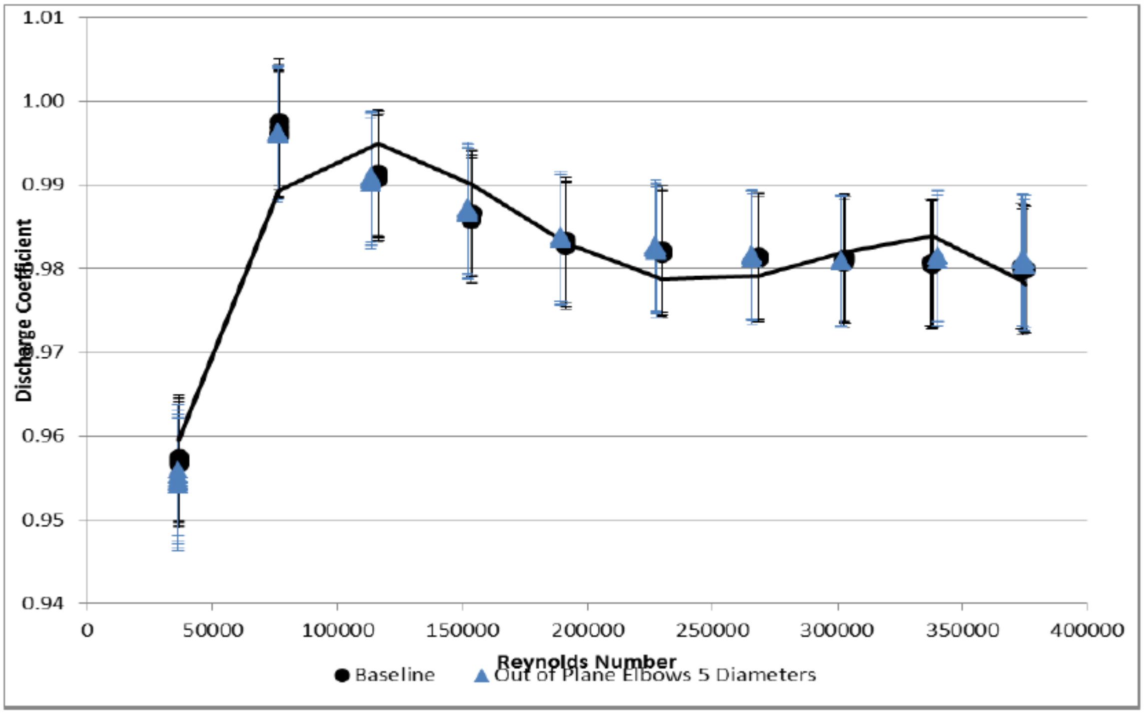

Fig 6.0 - 0.41 Beta base line with superimposed out of plane elbows testing (blue) @ 5D's

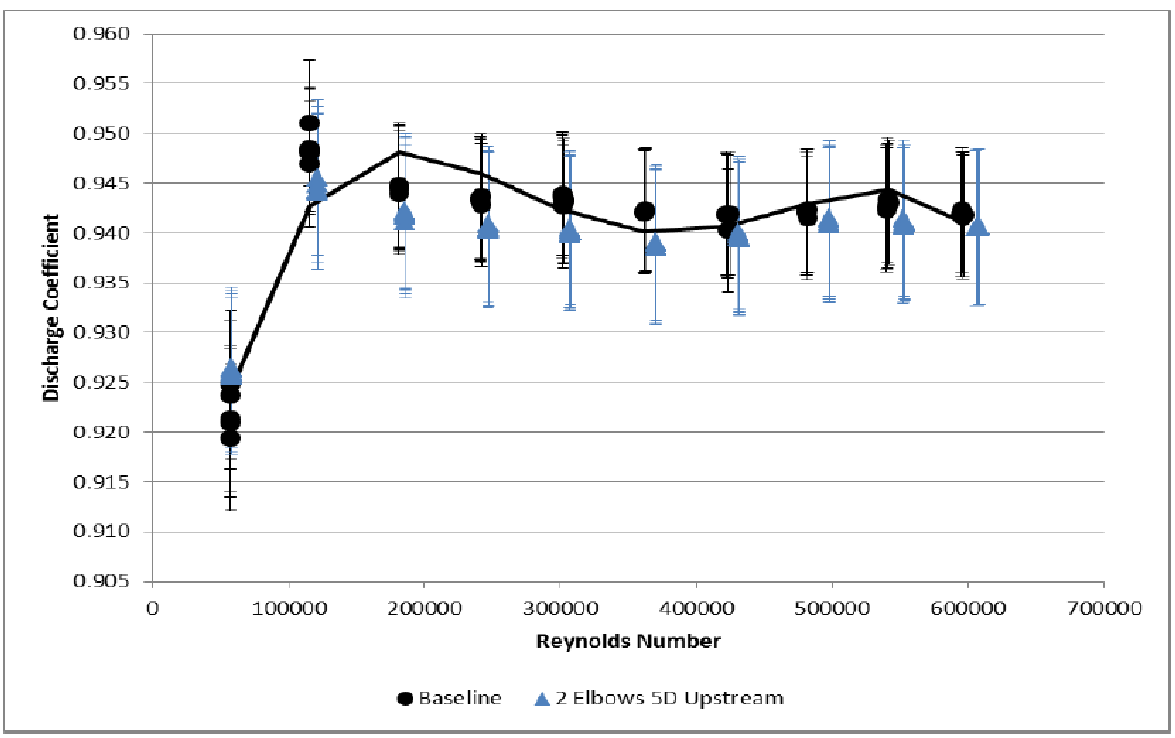

Fig 7.0 - 0.52 Beta base line with superimposed out of plane elbows testing (blue) @ 5D's

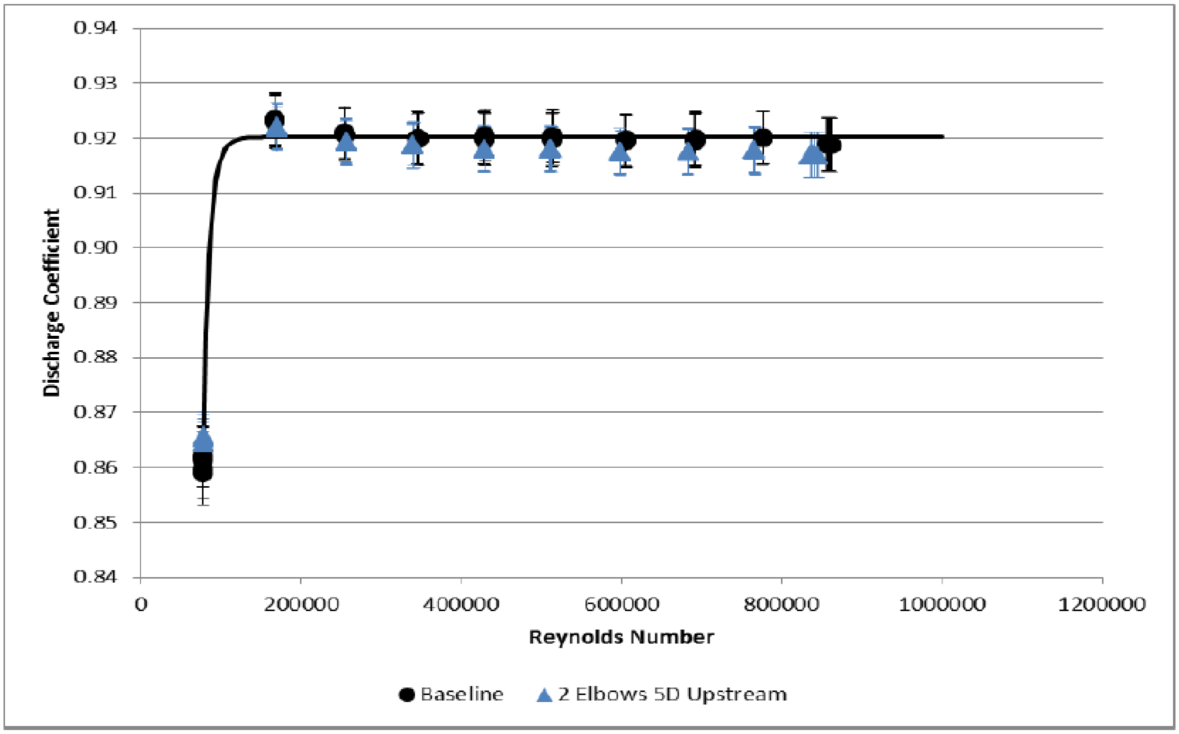

Fig 7.0 - 0.61 Beta base line with superimposed out of plane elbows testing (blue) @ 5D's

Conclusion

From the research data that has been produced over 35 years regarding cone meter type devices it seems that claims regarding the robustness of its perturbation resistance are well founded and provided a proper calibration is performed their use in custody transfer measurement is not an issue.

The calibration as pointed out must be on equivalent Reynolds Number Ranges, unless the device can repeatability demonstrate geometric similarity and machined accuracy between subsequently manufactured devices thus allowing artifact principles to be applied.

The use of artifact calibration techniques and control of the manufacturing process may be a key driver in the next evolution of these meter types.

Control of surface roughness and machining a meter together with tight quality control in the dimensional tolerance appear to enhance these meter types performance, and this also has an effect on the energy efficiency/recovery across the meter , C.d.'s of circa >+0.92 have been rarely seen with cone type meters.

It will be interesting to see future data sets for meters using an artifact calibration principle in a wet gas systems and how changing beta ratios is the same body will help in these applications

References

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2) Stewart D., Reader Harris M., Peters R., "Derivation of an Expansibility Factor for the V-Cone Meter", Flow Measurement International Conference, Peebles, Scotland, UK, June 2001
3) Hodges, Britton, Johansen & Steven 15th Flow Measurement Conference (FLOMEKO)Cone DP Meter Calibration Issues 2010
4) Lawrence /Sung HITROL & CAMERON , API 22.2 testing Part 1 IFFS 2009
5) Lawrence /Davis Field Comparison of a 4 Holed Orifice Plate and Cone Meter IFFS 2009
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7) CEESI - Expansibility coefficient derivation for a Dynamic Smart-Cone™ 2011
8) CEESI API 22.2 Data set for Dynamic Flow Computers USA June Release 2012

Author Biography

Mr. Philip Lawrence is the current Chairman of **ISO TC193 SC3** Natural Gas Standards Committee (Upstream Area) he has been working in the oil and gas industry for 30 years producing many technical white papers on various flow measurement topics such as - differential pressure meters , ultrasonic metering, and turbine meters.

Phil published 2 patents for flow metering and related devices, is a member of the Institute of Measurement and Control in the UK, and also works within in the API as a committee member and lead on the CPMA.

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Recent Publications

Testing of Differential Pressure Cone Type Flow Meters to Various International Standards – 8th International Flow Measurement Conference Colorado Springs (CEESI) - June 2012

The Effect of Geometry on Differential Pressure Meter Performance Zanker & Lawrence, The Americas Flow Measurement Workshop Houston 2011 - **[1]**

Lawrence /Sung (Hitrol & Cameron), API 22.2 testing Part 1 IFFS Alaska 2009 - **[2]**

Lawrence /Davis (Shell E&P & Cameron) Field Comparison of a 4 Holed Orifice Plate and Cone Meter IFFS 2009 - **[4]**