THE DANIEL SENIORSONIC MULTIPATH GAS FLOWMETER

GENERAL OVERVIEW
1. INTRODUCTION

Using Daniel’s four path SeniorSonic gas flow meter is a practical solution for the accurate measurement of gas flow applications. This multipath meter offers a number of very important advantages over conventional meter types including improved accuracy, reduced footprint size and installation and operation cost savings.

The prototypes for the Daniel meter originated from a British Gas Research and Development project lasting nine years. Their goal was to develop an accurate and reliable meter for fiscal and custody transfer purposes that would not require flow calibration or produce a pressure loss. Successful testing and evaluation were performed on meters in the 100mm to 1050mm sizes in actual operational sites.

In 1985, British Gas granted Daniel an exclusive license to develop the meter as a commercial product. Daniel’s continuing efforts to improve meter performance have resulted in a totally digital meter with expanded operational range and reduced operator dependence.

To date Daniel has supplied over one thousand multipath meters world-wide.

2. MEASUREMENT PRINCIPLE

The Daniel SeniorSonic Gas Flow meter measures the transit times of ultrasonic waves passing through the gas on four parallel planes to accurately determine the mean velocity of the gas flow through the meter. These four planes have been chosen to optimise the accuracy of the measurement regardless of the flow profile. The measurement paths are angled with respect to the pipe axis;

The transducers are mounted on the meter body at defined locations. The dimensions X and L are precisely determined during the meter fabrication. These measurements together with the electronic characteristics of each transducer pair characterise the ultrasonic flowmeter, without the need for a flow calibration. The transit time for a signal travelling with the flow is less than that for a signal travelling against the flow. The difference in these times determines flow velocity.

The measurement principle is described analytically as follows;

For each path;
Time from transducer U to D \[ t_{ud} = \frac{L}{C + V_m \frac{X}{L}} \] (1)

Time from transducer U to D \[ t_{du} = \frac{L}{C - V_m \frac{X}{L}} \] (2)

Solving (1) and (2) simultaneously and eliminating C

\[ V_i = \frac{L^2}{2X} \frac{t_{du} - t_{ud}}{t_{ud} t_{du}} \] (3)

Actual volume flowrate is; \[ Q = V_i \cdot \frac{\pi D^2}{4} \] (4)

This simple theory demonstrates that flow rate is a function of the physical dimensions of the meter body and the measured transient times. It does not include the local acoustic velocity and consequently does not rely on any other measurements such as pressure, temperature, density or gas composition.

When using a multipath meter, these individual chord velocities have to be averaged to give a mean gas velocity for the entire cross section of the flow. The averaging or integration technique varies from one manufacturer to the next. The complete Daniel algorithm is presented in the following section.

3. THE COMPLETE DANIEL ALGORITHM

Although there are various guidance documents available for ultrasonic metering (see section three), as yet there is no International Standard for USMs. Consequently Daniel believe it is absolutely crucial that the entire calculation algorithm for the meter is in the public domain. This means there are no hidden calculations or ‘fudge factors’.

The complete Daniel algorithm for the SeniorSonic Fiscal Meter is given below.

In Chapter 2 above, it is shown that for an individual chord, the local velocity can be calculated using:

\[ V_i(\tau) = \frac{L^2}{2X} \frac{t_{du} - t_{ud}}{t_{ud} t_{du}} \] (3)

In a multipath meter, \( V_i(\tau) \) is the average flow velocity along a chord having a lateral position \( \tau \). By applying a suitable integration technique, the mean fluid velocity, \( V \),
can be calculated based on the individual chord velocities. In the Daniel meter, this is done using the widely accepted Gauss-Jacobi technique with:

$$\bar{V} = \sum_{i=1}^{4} V_i(r_i)W_i$$

(5)

The chord positions, $r_i$ are shown in Figure 2.

The meter is symmetrical about the centre line with chords A and D positioned 0.809R from the centre line and chords B and C being positioned 0.309R from the centreline. These locations are fixed such that each meter size is geometrically similar.

For these locations, using the Gauss Jacobi technique, the weighting factors are:

$W_A = 0.1382$
$W_B = 0.3618$
$W_C = 0.3618$
$W_D = 0.1382$

These numbers are fixed and remain constant for every multipath meter.

These chord locations and subsequent weighting factors are recognised as the optimum solution for a multipath arrangement. Unlike other USMs, The SeniorSonic samples the flow profile; this minimises the effect of disturbed flow profiles on meter accuracy. In addition it gives the meter excellent through life stability as changes in wall roughness do not influence the meter performance. In addition, the meter is completely immune to symmetrical bulk swirl. This is why many independent metering consultants state that the SeniorSonic meter has the best flow profile independence of any meter on the market. (Grimley 1998)

In summary, individual chord velocities are calculated using equation 3 and the measured transit times and meter body geometry. These are then averaged using equation 5 and the weighting factors given above. This average velocity is then
multiplied by the British Gas Factor to give the final mean flow velocity. This velocity is multiplied by the cross sectional area of the meter spool to give an actual flow rate. This actual flow rate is converted to standard conditions using AGA8 or some other equivalent.

This is the complete algorithm of how the SeniorSonic calculates flow rate.

4. BENEFITS OF THE DANIEL SENIORSONIC

Field proven reliability

British Gas invested 10 years in the design, development and field testing of these meters before giving a license to Daniel in 1986. Daniel has continued to develop the meter, in particular: going from analogue to digital signal detection electronics; introducing Automatic Gain Control (AGC); using Digital Signal Processing (DSP) and producing a smart flow transmitter. There are now over 400 Daniel SeniorSonics operating successfully in Europe and the USA.

Standardisation efforts are under way in ISO/TC 30/WG 20 and with the IGE/GM/4 high-pressure gas flow measurement recommendations. Recently AGA report No 9 was released in The US. This report gives guidelines to manufacturers and customers on multipath meters. The SeniorSonic far exceeds the requirements of this document.

The meters are field proven in many arduous applications to the satisfaction of various government bodies such as NMI, PTB, SDM, DTI and NPD among others.

No line obstruction - No pressure loss

The hydraulic profile of the ultrasonic flow meter is almost identical to the pipeline with the only difference being recessed ports for the ultrasonic transducers. As a result there is no additional pressure loss caused by the meter. In addition, it is capable of passing a pig.

No moving parts - No lubrication or periodic maintenance

The only parts in contact with the gas are the ultrasonic transducers, which are solid state devices. There is no moving parts, no bearings to lubricate and therefore no component wear (unlike turbine meters). In the unlikely event of chord failure, it is possible to repair or clean a transducer while the line is under pressure. This is highly convenient and cost effective.

Over ranging other meters can cause damage e.g. buckling of orifice plates and bent blades or worn bearings of turbine meters. With ultrasonic meters no such damage can occur.

Reduced recalibration requirements
Since there are no moving parts in the meter, there is no reason for the meter performance to shift and hence a greatly reduced requirement for recalibration.

**Bi-directional capability**

The transit time measurement technique employed is intrinsically bi-directional with the transit time difference changing sign when the flow direction reverses. This results in the meter having the same calibration in both directions. This is quite unusual, as most other meters require special adaptation to cope with bi-directional flow. However, the normal practice of specifying upstream (10D) and downstream (3D) pipe lengths has to be modified to consider both sides of the meter as potentially upstream (10D).

**High capacity means fewer meter runs**

The Daniel ultrasonic meter is available in sizes from 4”NB to 42”NB and each meter has a normal flow range of 30:1 with an extended minimum flowrate which gives a 100:1 turndown. Typical, an ultrasonic meter can pass three times as much gas as the same size of orifice plate with a better accuracy. This allows a single ultrasonic meter to be utilised in applications where multiple orifice meter runs would be required to meet the flowrange.

**Measurement is not affected by gas properties**

The theory shows that the fluid velocity measurement is independent of the local acoustic velocity, VOS and is only depend on geometry and time measurements. The theory assumes that the VOS is constant along each acoustic path. This is normally a good assumption due the highly turbulent nature of industrial flow.

**Multiple paths cope with non-uniform flow profiles**

Each pair of ultrasonic transducers measures the velocity along the individual acoustic paths. The velocity on all four chords is then integrated to give the mean velocity of the gas and hence the actual volume flow. The chord location, orientation and number, together with the numerical integration technique, were derived to give the maximum immunity to disturbed velocity profiles. The ultrasonic paths criss-crossing on four planes measure asymmetric and swirling flow better than other meters. It is this ability that allows minimal installation requirements of straight pipe, 10D upstream and 3D downstream.

This minimal installation translates into considerable saving in space, weight and cost. Add to this the large turndown ratio of ultrasonic meters and they can make even greater savings on multiple-meter run systems, by reducing the number of runs required.

**High availability high integrity flow measurement**

The meter has no line obstruction, no moving parts and needs no lubrication or periodic maintenance. The only component in the gas line that can fail is an
ultrasonic transducer. There are however 8 transducers and 4 chords, thus the meter can be considered to have 3 spare chords. When the meter is working on all 4 chords it continuously stores the velocity profile, thus if a chord fails, a historical statistic is substituted from memory. Tests have shown that when a chord fails the additional error incurred by substitution can be as little as 0.1%.

If a chord fails this is indicated by an alarm and status, which gives an indication of the fault and allows repairs to be effected. As mentioned earlier, the extractable transducers allow transducers to be removed for inspection, repair or replacement, without interrupting either the meter operation or the gas flow.

5. APPLICATIONS

Natural gas transmission

This is the original application British Gas targeted. The main incentive was to find an alternative to the orifice plate that did not require flow calibration (unlike the turbine meter) but could achieve fiscal accuracy. The added advantages of no moving parts, no pressure loss and large turn down ratio has led to success in this market and indeed to much wider use of the ultrasonic meter.

Gas storage schemes

The function of a storage scheme is to import gas during periods of low demand and export gas to meet high demands. The natural bi-directional ability of the ultrasonic meter is essential. The lack of pressure loss is another bonus, as it is normal to compress the gas into storage and thus save energy over the whole life of the plant.

If the storage is in a salt dome, the gas is far from clean and dry. Water, methanol against hydrate formation, oil from the compressor and grease from the production wellhead are all present. The meter developed for wet gas is ideal for this application.

The high pressures (240 Bar) associated with storage results in a high gas density and very good coupling of the ultrasonic signal, making signal detection very reliable and accurate. If the gas company owns the storage facility, the measurement is for control, but with separate companies it becomes fiscal measurement in and out of storage.

Check metering

The idea is to have two meters in series to check one another. The normal task is to check an orifice or turbine meter. The main advantage of the ultrasonic meter is that it works on a completely different physical principle and thus will not be affected by disturbances in the same way as the meter being checked. The fact that the ultrasonic meter has no pressure loss means that it can be retrofitted to an existing metering system without requiring any additional power. With no line obstruction, the ultrasonic meter does not disturb the flow and can be placed upstream of the meter to
be checked without any detrimental interference. This would not be the case if orifice and turbine meters were used to check one another.

The ultrasonic meter can be used to check the accuracy of the other meter, but more important is the long term agreement between the two meters. If this consistency is disturbed, an alarm can be raised and the cause investigated.

**Offshore installations**

The main incentive is to save space and weight, which are at a premium on an offshore platform. The minimal installation requirements and high turn down ratio lead to a very compact metering skid. In addition, the high availability high integrity measurement reduces the need for spare meter runs, reducing the skid further.

The offshore environment is much harsher than the original transmission application, with much wider ranges of pressure, temperature and gas impurities. Extended range meters that can cope with wet gas, up to a few % liquid fraction by volume and high process temperatures, are now available for allocation measurements.

These meters can reduce the cost of measurement and make marginal field developments feasible.

**Pipeline monitoring and control**

In complex piping systems, gas transmission, distribution, offshore gathering, storage and treatment, it is quite difficult to predict how the system will react to differing conditions of supply and demand. Ultrasonic meters located strategically throughout the system can help monitor, control and balance the system. It is quite often not even obvious in which direction the gas is flowing let alone the flow rate, making the bi-directional ability of the meter most valuable. The lack of obstruction and pressure loss allows easy installation of the meter in existing systems. The accuracy of the un-calibrated meter is certainly sufficient for monitoring and control. The availability and integrity of the ultrasonic measurement results in a very reliable system.

6. SYSTEM OVERVIEW

The Daniel SeniorSonic multipath meter is comprised of the following;

- A high precision flanged meter spool piece
- Eight intrinsically safe piezoelectric transducers
- Fully digital electronics units (MKII DFI)

The ultrasonic meter body is mounted in the gas pipeline with the transducers fitted directly onto the meter body. The electronic drive unit is also mounted directly onto the meter body. The drive unit provides eight individual cables, with plugs, to connect to the transducers.
In simplistic terms, the drive unit is used to fire the ultrasonic transducers, it is also used to digitise and process the received signals from the transducers. It then calculates gas flow velocity and hence actual volumetric flowrate through the meter body. There is an option with the drive unit to accept pressure and temperature inputs so that corrected volume flowrates can be output.

The drive unit has the facility to communicate to a flow computer, using an RS232/RS485 serial communication link. Additional output capability (i.e. frequency or analogue) is available as an option. Analogue inputs for pressure and temperature can be taken by the drive unit. For a fixed composition, a standard volume flowrate output can be achieved. Alternatively, the flow computer uses this actual flowrate and other external inputs such as pressure, temperature and density transducers to calculate standard volume flowrate and mass flowrate of the gas.

A comprehensive diagnostics package is available with the metering system. This Windows based package, called Diagnostic Utilities Interface, DUI, facilitates easy routine checking and troubleshooting of the meter. DUI also allows monitoring of the gas flow both during normal and abnormal conditions. Such is the quality and quantity of diagnostic data that it is possible to “SEE” the behaviour of the gas within the pipeline.

7. RELIABILITY / AVAILABILITY

Overview

The ultrasonic meter, although now becoming much more established, is relatively new and hence there is much less historic data to review, compared with orifice plates for example, in order to quantify the availability for a particular meter. In order to give an indication of the reliability / availability of the Daniel multi-path ultrasonic meter, the main components of the installation must be considered individually.

The meter consists primarily of an accurately machined meter body into which eight transducers are fixed. The meter body is purely a piece of steel with no moving parts and hence does not affect availability.

The ultrasonic transducers are located in pairs at strategic points across the meter body to provide a velocity profile for the flowing gas. Transducer failure would affect availability however the intrinsic redundancy of the meter should be borne in mind when quantifying this availability.

The electronic drive unit is now smart enough to alarm when internal quality checks are not satisfied. In the unlikely event that a chord does fail, the meter will substitute a value based upon the remaining chords and historical values. Substituting historic data is a very accurate alternative since the pipework installation upstream of the meter is fixed and hence the flow profile is constant with time. The ultrasonic transducers are extractable under pressure, thus faults can be corrected with minimal inconvenience and no loss in accuracy.
Quantifying the Reliability / Availability

An MTBF analysis was carried out for 21 Daniel multi-path Ultrasonic meters between 1990 and 1995. These meters were installed on the major gas export stations in Central Europe. In the five and a half years in the field, the meters performed very well with an uncertainty better than the stated accuracy of +/- 0.5%. The reliability on these meters was also excellent with the following availability data for the five and a half years in use:

- Hours in service = 5.5 years = 48100 hours
- Transducers in 21 meters = 8 x 21 = 168 transducers
- Operational transducer hours in field = 8 094 240 hours
- Transducer failures = 13 failures
- Operational hours per transducer failure = 622 633 hours per failure
- Operational years per transducer failure = 71 years per failure

In addition to the fact that only 13 transducers failed in the five and a half years in service, these failures were confined to 7 of the meters. This suggests external effects such as lightning strikes or power surges as the cause for these failures.

8. CONCLUSION

The Daniel SeniorSonic meter is a proven solution to high accuracy metering for gas systems. This document has fully detailed the complete calculation algorithm ensuring total transparency for the user. This is considered vital since there are currently no standards on the use of multipath meters.

Benefits offered to users have been given together with typical applications. Reliability data is presented together with performance data from recently calibrated meters.