Kuwait 4th Flow Measurement Technology Conference

3-5 December 2019
Hilton Kuwait Resort

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Kuwait Oil Company

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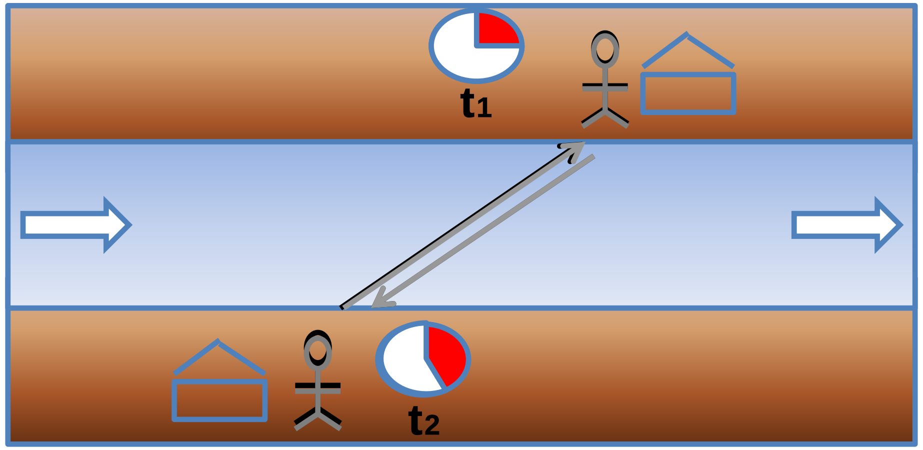
Ultrasonic Principal of Measurement

Consider a man standing beside a flowing river in a jungle, who wishes to visit a neighbour house on other side of the river, and decides to swim.

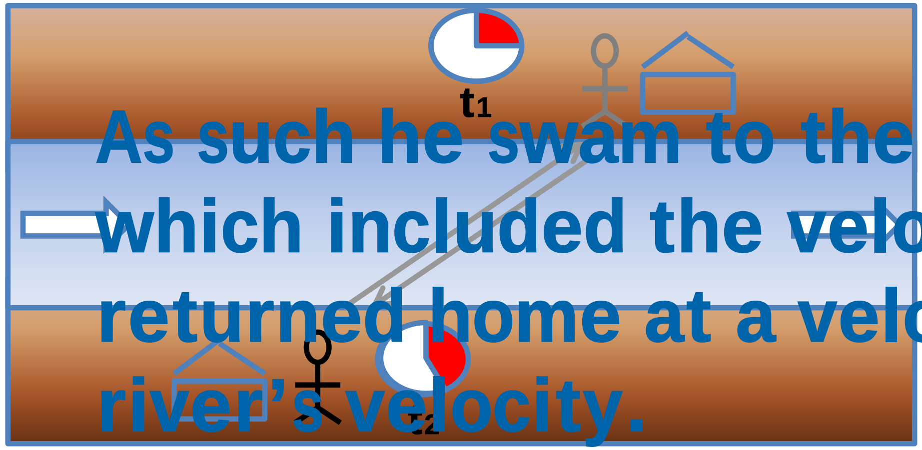


He swims with the flow of the river and arrives on other side in time t_1

He then swims back, and since now against flow of the river arrives on other side in time t_2

Ultrasonic Principal of Measurement

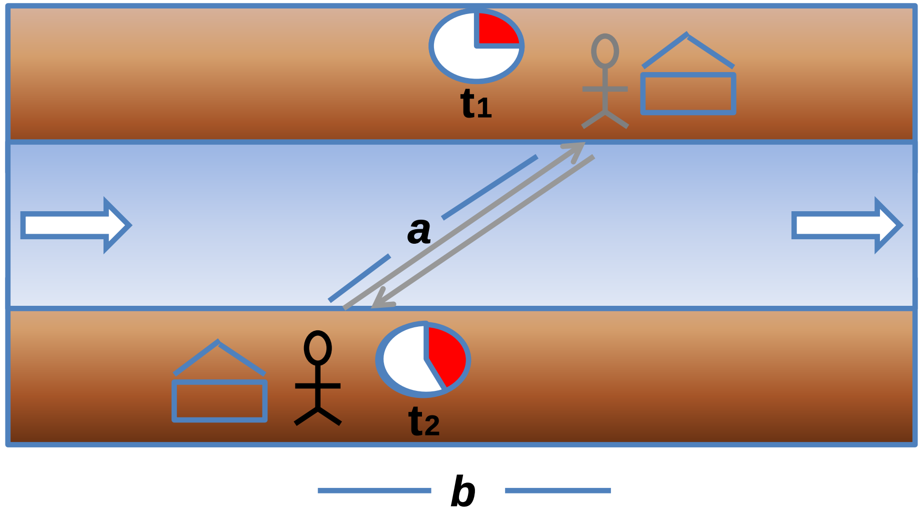
The man took longer to swim back home because he was swimming against the river's flow.



As such he swam to the neighbour house at a velocity which included the velocity due to the river's flow, and returned home at a velocity which was reduced by the river's velocity.

As such we can calculate the average velocity of the swimmer and the velocity of the rivers's flow

Ultrasonic Principal of Measurement

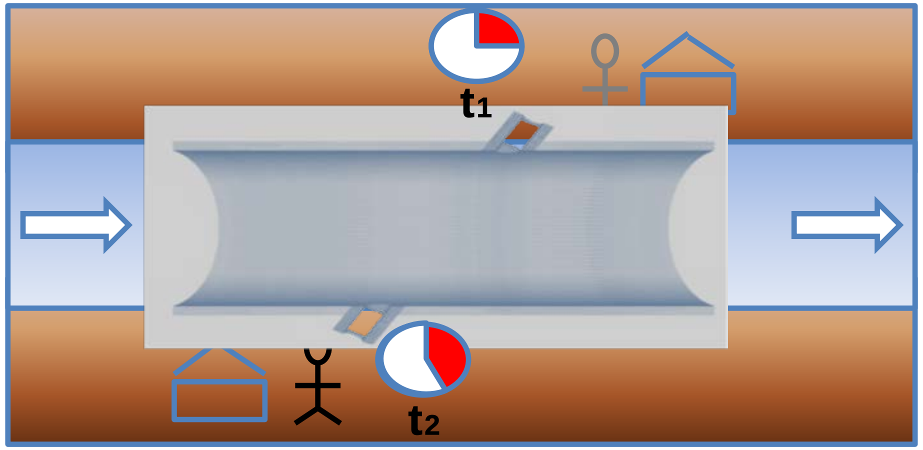


velocity = distance / time

If distance *a* is known, we can use the time taken to travel both directions to calculate the the swimmer’s average velocity and if distance b is known we can also calculate the river’s flowing velocity using transit time difference.

This principal is used as the ultrasonic measurement and is independent of fluid properties.

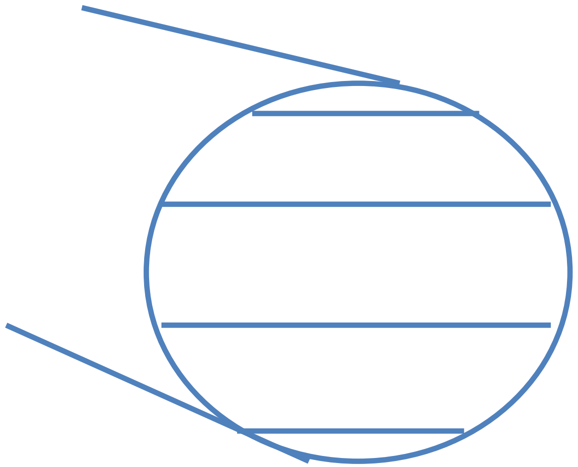
Ultrasonic Principal of Measurement



However, still considering a river, we know that we are warned that the river may be flowing more at the centre than at the banks, due to frictional effects etc

This holds true when we consider a pipe rather than a river. Flow shall be more through the centre of the pipe, rather than at pipe wall. Additionally making assumptions that the whole pipe area is flowing with same velocity as measured at one single location of pipe would be a significant assumption.

Ultrasonic Principal of Measurement



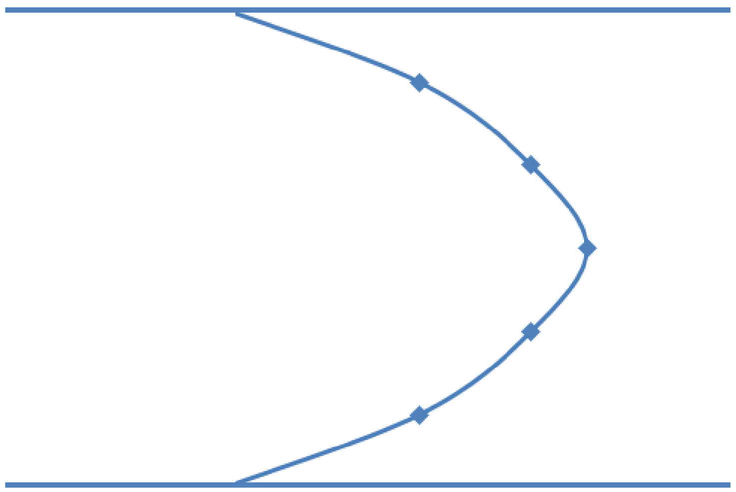
Consequently, ultrasonic meters generally measure the velocity at multiple horizontal points in the pipe, with each called a path, and as such the meter is multipath.

Based on standard mathematical principals of interpolation and integration, the velocity of the pipe is determined. The more paths, the better the interpolation/integration and the better the representation of the average velocity of the pipe is understood. It is generally accepted that at least 4 such paths is required for Custody Transfer accuracy.

Ultrasonic Principal of Measurement

Each path has a transducer pair, which is generally piezo-electic, which when a voltage is applied makes a sound wave, and when it receives a sound it creates a small Voltage and as such each transducer is both the sound emitting and receiving device. The ultrasonic electronics sequences the individual path transducers timing receipt of sound wave, and knowing the distance for each path.

Ultrasonic Principal of Measurement



This allows the velocity at each point in the pipe to be measured, and the overall velocity for the overall pipe determined through general mathematic principals.

The paths are optimally arranged by manufacturer, to allow better understanding of the velocity in the pipe, which is typically more pronounced in the centre of the pipe. The Velocity or Flow Profile is better measured where more paths are employed, and can allow better understanding of flow at pipe wall.

Key Ultrasonic Diagnostics

The ultrasonic is an intelligent device and offers some key diagnostics which include:-

Velocity Profile (Symmetry, Swirl, Cross Flow)
Individual Path and Overall Performance
Individual Path and Average Liquid/Gas and Sound Velocity
Individual Path Turbulence
Individual Transducer Gains
Individual Transducer Signal-Noise Ratio

Meters may be designed incorporating additional diagnostics or even path which can provide further key diagnostics e.g detecting liquids or gas

Pros and Cons

Pros

- High Accuracy (Fiscal / Custody Transfer standard)
- Meter Has Large Turndown
- No Moving Parts
- Reduced Compression/Pumping Costs (Non-Intrusive)
- Intelligent Device which can identify changes in meter behaviour, process or process conditions.
- Can assist with identifying causes of concern for measurement such as installation affects, stratification etc
- Can be used as part of overall station condition based monitoring system, indicating health of overall metering.

Pros and Cons

Cons

- **Difficult to prove (manufactured pulses, size and turbulence).**
- **Expensive to dispatch for 3rd party calibration**
- **Technology not understood in detail by users**
- **Needs specialist for repair.**

Are the Diagnostics Useful?

While the diagnostics are useful, the use of the diagnostics is not widespread since:-

- Diagnostics not understood by users whereas proving/ flow lab calibration is widely understood and accepted.
- Diagnostics often only examined once a problem has been identified.
- Diagnostics qualitative rather than quantative in nature
- Published work in understanding diagnostics has been more focused on gas ultrasonics rather than liquid due to availability of prover on liquids.
- Little or no guidance, standards or empirical data available and multiple diagnostic changes may be triggered associated with a single issue/change.

Are the Diagnostics Useful?

However, while changes in diagnostic may not be fully understood by users, it is clear that by simple regime of noting diagnostics after calibration (benchmark), and then looking for change, this can assist in identifying where further examination is required which may include a need for recalibration. Suitable thresholds for deviation of diagnostic can be established, using trends / control charts, such that maintenance and calibration (proving or flow calibration) can become more reactive than schedule based, with documentary evidence to justify mitigation of these activities, since the meter is seen to be similar in behaviour as when last calibrated.

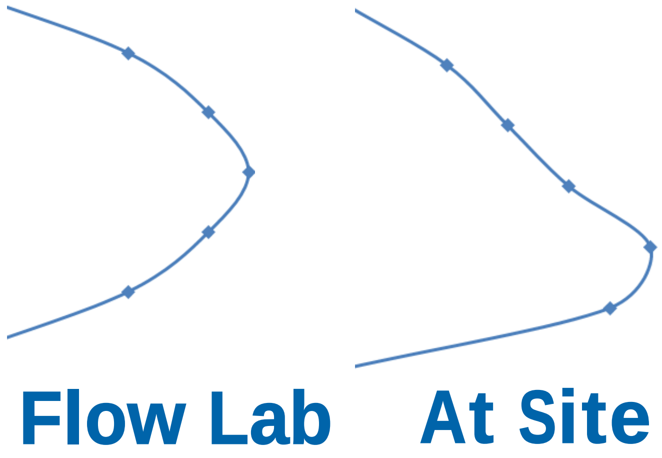
Calibration Requirements, Results & Initial Benchmark

The use of diagnostics does not mitigate the need for initial calibration, and indeed requires that in addition to the routine calibration, that an initial benchmark of the ultrasonic diagnostics be taken during this calibration such that the diagnostic values associated with this calibration are known.

Where this calibration is performed in a flow laboratory, prior to site, this allows installation affects to be identified at commissioning, and provides a better basis of transposition of flow laboratory results where the meter can be demonstrated to behave in a similar fashion to benchmark at the flow laboratory. Benchmarks can be used to observe changes in meter behaviour

Site Installation and Transfer of Flow Calibration Results

Current practice recommends site re-calibration on actual process for oil, and for gas it is common practice to "assume" the result of the flow lab calibration is transferrable to site. The use of Benchmarks can help justify such transfer, but can also flag up concerns. Consider the following flow profiles:-



Is it justified to assume cal lab result OK? The standard flow calibration used the average velocity which weighted the middle paths more, but with benchmark it can be demonstrated that outer transducer were just as accurate at time of calibration. Of course site flow profile needs investigated !

Proving, Master Meter & Check Meter and Recalibration

For oil, conventional proving can be problematic both due to manufactured pulses, and large turndown of meter. Since the meter is more sensitive, turbulence can affect proving whereas a traditional turbine rotational inertia tends to smooth this out. Statistical Proving techniques can be used, with population statistics to achieve 95% confidence over a far larger number of passes/trials or master meters can be considered. Check metering allowing arrangement of meters in series can assist in determining when a meter needs recalibrated to offset costs where no fixed proving facility or for gas applications.

Periodic Manual Monitoring of Diagnostics

But can the diagnostics also assist to move from schedule based to reactive based recalibration?

Manually checking diagnostics periodically requires specialists conversant with the meaning of the diagnostics when a change is observed, and only checks the meter at an instant in time, and as such is better for looking for gradual changes in behaviour such as transducers failing.

Automated Monitoring of Diagnostics

By introducing trends and control charts, this allows better monitoring of the diagnostics and with appropriate thresholds, especially as experience with the actual process is gained can allow refinement of these thresholds for the site, and with recalibration/reprove results can provide data to better understand when recalibration/reprove is required.

This can assist in identifying when there is a need to reprove, and as such immediately react to issue, rather than await next prove or recalibration and associated retrospective mismeasurement calculations, and also identifies when any observed change in meter performance may have occurred for any such calculations

Online Condition Based Monitoring

A further enhancement is one in which multiple instrumentation is compared against each other, and where deviation exceeds a limit alarms initiate appropriate reaction.

For gas, a combination of ultrasonic, online GC, temperature and a pair of redundant pressure devices allows check of all station instrumentation, since the VOS measured by USM can be checked against the GC calculated VOS, the temperature checked against expected (using VOS and Composition), and redundant pressure checked against each other. Where all devices agree everything is fine, where they do not, simple devices can be recalibrated to eliminate less expensive recalibrations first.

Online Condition Based Monitoring

For refined product, a similar approach could be conceived with VOS established at different operating temperatures at laboratory, or using NIST tables, and ultrasonic measured VOS checked against VOS derived based on operating temperature, with redundant pressure devices to allow an overall station solution.

For crude oil, the addition of viscometer and densitometer could be anticipated in allowing a station conditioned based monitoring approach.

Online Condition Based Monitoring

Such approaches are easier for users to understand, and provide more meaningful use of the diagnostics and measurements, to indicate concern for mismeasurement, and allow reactive maintenance.

However, such approaches needs understanding at design phase of the need for such data, and its interpretation and correct application to achieve the required outcome, and the author is not aware of any work for such liquid solutions due to the capability to prove in-situ.

Online Condition Based Monitoring

Further, there is a need for industry to drive manufacturers to provide similar emphasis for liquid as is provided for gas, to allow mitigation of proving, and early detection of mis-measurement which otherwise is only found at next prove. With approprate use of diagnostics, it is anticipated that mismeasurement, and need for retrospective mismeasurement calculations could be reduced, and move to a more reactive rather than scheduled proving regime with associated reduction of OPEX costs

Some Examples detectable through Diagnostics

Examples using diagnostics for Oil Application:-

Gas Present: Gain, SNR, VOS, Performance can be affected on upper transducers. Fitment of vertical diagnostic path assists detection
Water Present: VOS, SNR variations, again vertical diagnostic path can be of benefit.

Sediment: VOS, SNR, Gain

Transducer Faults: Gain, Performance, VOS

Some Examples detectable through Diagnostics

Upstream Fouling: Profile, Symmetry, CrossFlow, Swirl, Turbulence

Cavitation: SNR, Gain, Performance

Water Present: VOS, SNR variations, again vertical diagnostic path can be of benefit.

Sediment: VOS, SNR, Gain

Transducer Faults: Gain, Performance, VOS

Determination of Quantitative vs Qualitative Impacts

A lot of the diagnostics are of a quality nature. ie as long as nothing changes, then we have confidence, but as soon as something changes, what increased uncertainty does this introduce. It is only with better understanding of these diagnostics that decisions can be sensibly taken.

Does a shift in diagnostics require immediate action, does it increase uncertainty, or can it be scheduled for next planned shutdown?

Determination of Quantitative vs Qualitative Impacts

Chordal substitution from known benchmark can assist with indication of possible impact for example in case of profile shift, on the assumption that profile shift is not real, but due to transducer problems, but again requires expert understanding and expertise by the user, and based on current knowledge will not replace proving which provides definitive results. However it can aide in determination of when to prove where no fixed proving facilities or to reduce frequency of proving with associated OPEX savings

Conclusion

Better understanding of the technology and its existing diagnostic features and capabilities is required by users.

Understanding by users of proving techniques for ultrasonic (and indeed other intelligent devices), due to manufactured pulses and also their high accuracy and as a result sensitivity to factors such as turbulence, which had previously been masked from users through "smoothing" affects of rotational inertia of the measurement device

Conclusion

Better traceability on transfer of flow lab calibrations, through the acquisition during calibration of flow characteristics and diagnostics and better understanding by the flow lab of these diagnostics, and their benefit for traceability and transferabilty (especially for gas applications)

Simplification by meter manufacturer of diagnostics, such that they are better understood by the non-expert user

Incorporation of more intelligent monitoring functions for intelligent meters within the Metering Computer Systems

Conclusion

Ensure Company/National/International Standards

- Reflect latest understanding, and encourage manufacturers to invest in developing better refinement in their diagnostics / design, to allow movement from a scheduled to a better combination of scheduled and reactive proving / calibration regime at time of mismeasurement, which both reduces OPEX and reduces the likelihood of retrospective detection of mismeasurement at next scheduled prove or calibration.
- Reflect predictive maintenance as an acceptable basis for the justification of the reduction in frequency for scheduled maintenance to encourage advancement in this field.

THANK YOU