Paper 28

Multibeam Ultrasonic Liquid Flow Meter for Fiscal Metering and Custody Transfer Applications

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18 ULTRASONIC PATHS FOR LIQUID FLOW MEASUREMENT

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INTRODUCTION

Turbine and Positive Displacement meters have been successfully used in the oil industry for many years. Both technologies provide accurate flow measurement for custody transfer applications in compliance with international standards and recommendations such as OIML and API.

Over the last ten years, significant improvements in electronics and acoustics gave access to high accuracy liquid flow measurements based on ultrasonic technology.

The ultrasonic technology has been first efficiently used in the natural gas industry for several years. The development of the technology for the gas custody transfer applications has quickly shown that a multi-path geometry was the only way to cover a large range of flow velocity profiles.

Several suppliers have developed ultrasonic flowmeters for liquid applications based on the multi-path technology. During the last years, acknowledging the actual potential of the ultrasonic technology, API decided to create a working group to release a new API draft standard related to the ultrasonic technology for liquid flow measurement. Based on field test results performed under the API responsibility on crude oil and refined products, a draft standard has been issued end of the year 2002.

Today everyone agrees that ultrasonic technology creates values for end-users by simplifying metering installations and reducing their ownership cost. Indeed, the very low pressure drop through the metering system decreases the power consumption drastically and the lack of moving parts reduces the maintenance cost of the flowmeter.

Among all the advantages of the ultrasonic technology, the main end-users concern remains the flow measurement accuracy. To cover all applications and installation conditions, an ultrasonic flowmeter must be able to perform accurate measurement with uncontrolled flow conditions such as swirls, asymmetric, laminar, and turbulent flows.

In the oil industry, the range of Reynolds Number is significantly larger than those encountered in the natural gas industry. Considering both viscosity and turndown ratio ranges from 0.2 cSt to 1000 cSt and 10:1 respectively, the Reynolds Number covers a range from 100 to 10^7.

Hereafter FAURE HERMAN presents the main characteristics of its new ultrasonic flowmeter, the FH8500. This is the only 18 beams ultrasonic flowmeter available on the market. After a brief presentation of both the ultrasonic measurement principle and the main characteristics of the FH8500, more attention will be paid to overcoming the key issues to perform accurate flow measurements, swirls, asymmetric flows, and the laminar-turbulent transition.

ULTRASONIC FLOW MEASUREMENT PRINCIPLE

The measurement of the volumetric flow rate with the FAURE HERMAN FH8500 ultrasonic flowmeter is based on the principle of the ultrasonic transit time measurement. Considering a pair of transducers A and B located upstream and downstream of the flow respectively, the difference of the ultrasonic transit times T_{AB} and T_{BA} from A to B and B to A gives access to the average flow velocity of the liquid V_{AB} between A and B, see figure 1.

$$V_{AB} \propto \frac{L_{AB}}{2\cos\theta} \times \frac{T_{BA} - T_{AB}}{T_{AB} \times T_{BA}}$$

The volumetric flow rate Q_V is proportional to the average flow velocity V_{AB}, a hydraulic coefficient K is defined.

$$Q_V = K \times V_{AB}$$

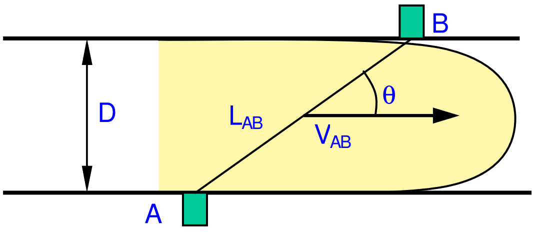


Figure 1: Ultrasonic transit time principle

At this stage, it is very important to mention the spatial information available using the transit time measurement principle.

1. The transit time measurement principle provides an indirect measurement of the volumetric flow rate.

2. The average flow velocity V_{AB} provides local information along the ultrasonic path only.
3. The relationship between the volumetric flow rate Q_v and the average flow velocity depend on the flow velocity profiles.

A first statement can be made. In order to perform an accurate volumetric flowrate measurement with an ultrasonic flowmeter a clear understanding of the 3D flow velocity profile is required. This is the only way to correctly compensate swirls, asymmetric flows, and laminar to turbulent flow velocity profile changes.

THE FAURE HERMAN FH8500

The FH8500 is the only ultrasonic flowmeter available on the market with 18 ultrasonic paths. These latter are generated by 12 transducers located upstream and downstream from the flow. An electronic box provides a fully integrated and compact metering solution (see figure 2).

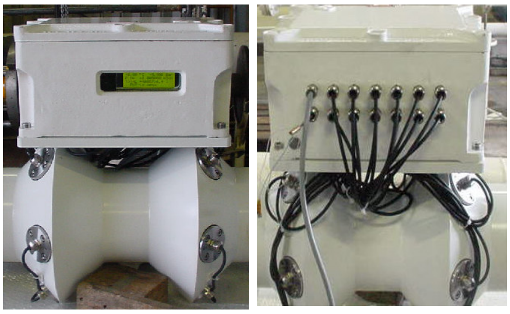


Figure 2: Front and rear sides of the FH8500

Figures 3 and 4 represent the FH8500 geometrical configuration with 18 ultrasonic beams.

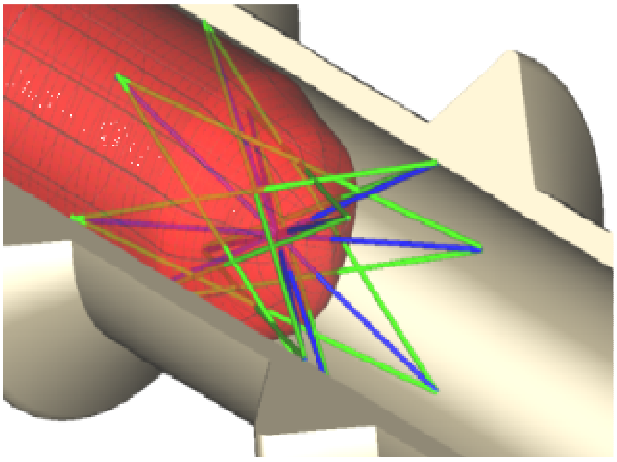


Figure 3: 18 ultrasonic beams geometry

The generation of 18 beams in 9 different physical plans covering the pipe cross section very well is the main characteristic.

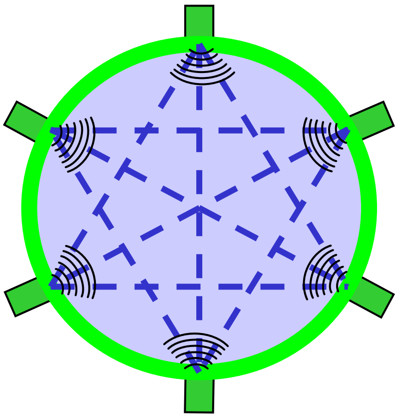


Figure 4: 18 ultrasonic beams geometry, cross section view

The advantages of this configuration which are described hereafter reside in its capacity to objectively analyze the flow regimes.

SWIRLS COMPENSATION

With swirl, the flow velocity of the liquid is no longer parallel to the axis of the pipe. The flow velocity has a perpendicular component that generates an inaccuracy of the flowrates measurement.

Swirls are usually generated by single or double bends located upstream from the meter. Figure 5 shows typical swirls created by a double bends configuration.

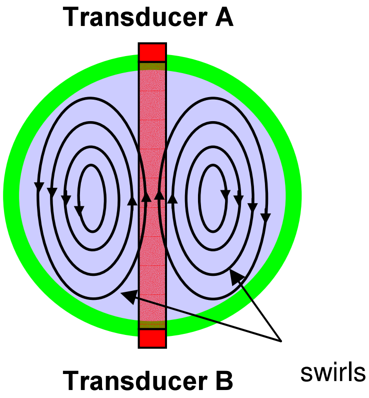


Figure 5: Swirls generated downstream from bends.

In this case, with only one ultrasonic path, the flowrates measurement is either over or under estimated. The only way to compensate the swirl effect is to use a symmetric ultrasonic path crossing the pipe in the opposite direction (Figure 6).

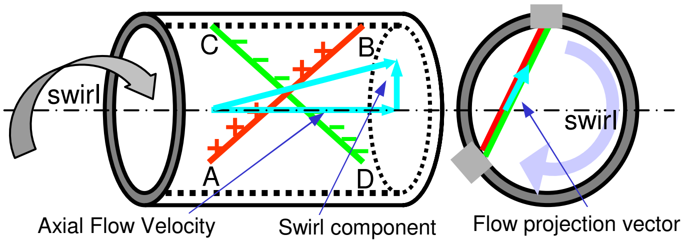
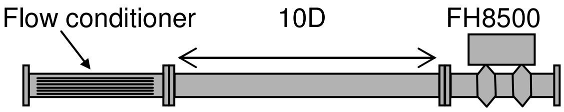


Figure 6: Crossed paths configuration for swirl compensation.

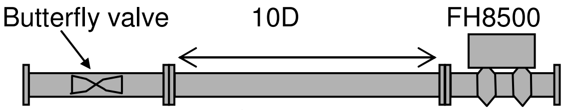
Figure 6 presents a part of the FH8500 configuration including only four transducers A, B, C, and D. These transducers generate 2 crossing ultrasonic paths in the same plan, the axis of the pipe being parallel to the plan. If you consider a swirl component, the flow velocity measurements through the ultrasonic paths AB and CD are higher and lower than the actual axial flow velocity respectively. The sum of the two flow measurements then suppresses the perpendicular component of the flow. This is the only geometrical configuration fully compensating swirls. The subtraction of the two measurements provides the percentage of swirl present in the pipe on the same plan.

Experimental results

The experiment has been carried out with a 6” FH8500. Two installation conditions have been considered to point out the effectiveness of the FH8500 to compensate swirls. In configuration 1, a flow straightener was located 10D upstream from the flowmeter. In the second case, the flow straightener was replaced by a butterfly valve 50% closed.



Configuration 1



Configuration 2

The swirl levels of the two configurations are shown in Figure 7. The measurements of the swirl components were based on the calculation principle mentioned above. The subtraction of the flow velocity measurement has been done for each couple of symmetric ultrasonic paths. This way, we are able to calculate the swirl contribution in six different physical plans.

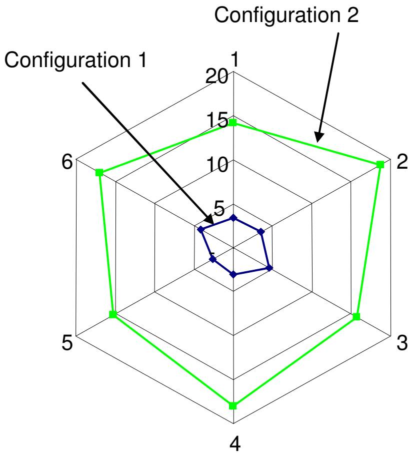


Figure 7: Swirl levels determined with the FH8500.

The configuration 1 creates a very low level of swirl, less than 5%. With the butterfly valve upstream from the meter, the swirl levels are between 15% and 20%.

For the two configurations, Figure 8 shows the meter factor over a flowrate range from 600 to 2400 BPH. A refined product with a viscosity of 1.6 cSt has been used for this experiment.

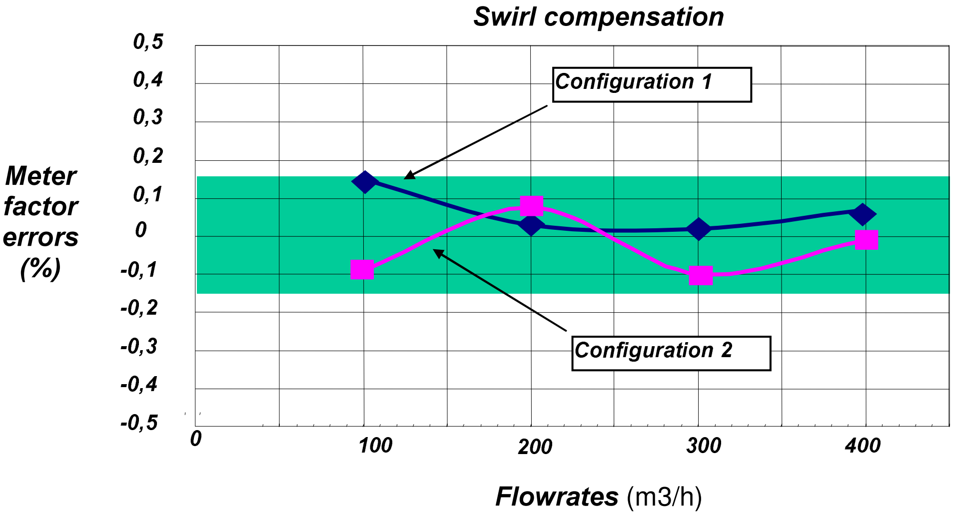


Figure 8: Meter factor errors as a function of the flowrates for the both configurations.

In spite of the high level of swirls generated by the butterfly valve, the meter factor accuracy remains inside the ±0.15%. Without using the swirl compensation procedure, the meter factor shift would be more than 1%. These results point out the capacity and the effectiveness of such a geometrical ultrasonic beam configuration to suppress the swirl disturbances of the flowrate measurement.

ASYMMETRIC FLOW COMPENSATION

In addition to the swirl generation, the location of bend, tee or valve upstream from the meter creates asymmetric flow velocity profile (Figure 9). In this case the maximum flow velocity is no longer at the center of the pipe.

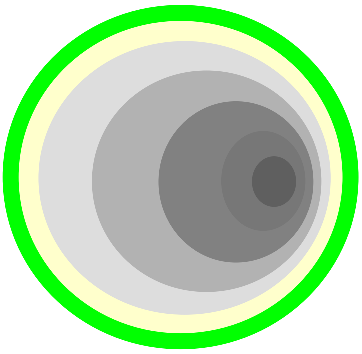


Figure 9: Asymmetric flow velocity profile

Figure 10 represents two multi-path configurations with parallel beams in the same plan. In both cases the measurement is affected by the flow asymmetry. The correction is difficult due to the lack of information about the level and location of the flowrate asymmetry.

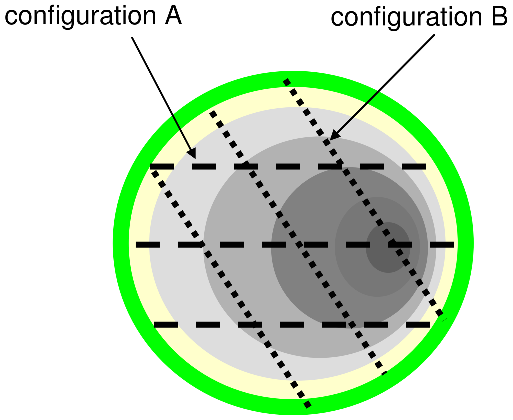


Figure 10: Asymmetric flow velocity profile with parallel ultrasonic beams.

In the case of the 18 beams configuration, the velocity flow profile can be characterized and the asymmetry determined (Figure 11). Thanks to this information a correction can be carried out when asymmetric profiles occur.

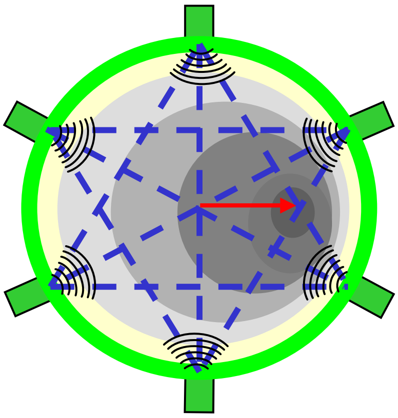
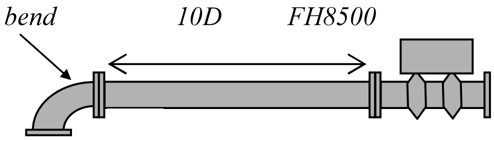


Figure 11: Cross section of the asymmetric flow velocity profile superimposed with the FH8500 ultrasonic beam configuration.

Experimental results

A configuration with a bend at 10D upstream from the meter has been used. This configuration generates asymmetric velocity profiles with a shift of the flow velocity barycentre of about 2%.



This experiment has been carried out with a 6” FH8500. Four refined products with viscosities contain between 0.5 cSt to 300 cSt have been used.

Figure 12 shows the meter factor evolution as a function of the Reynolds Number before and after asymmetric flow correction. Over the full dynamic range the error has been reduced by a factor 2. With and without asymmetric flow compensation the accuracy was ±0,3% and ±0,16% respectively.

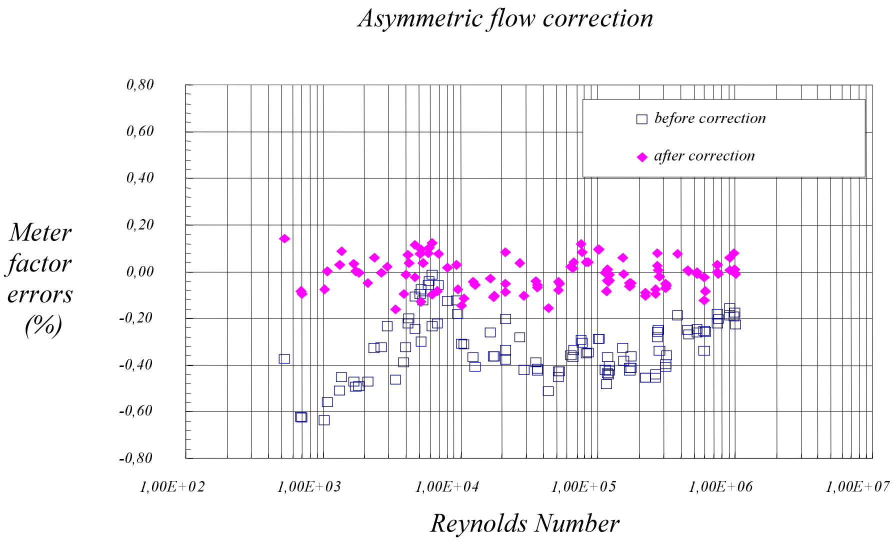


Figure 12: Meter factor vs. Reynolds Number with and without asymmetric compensation.

Figure 13 presents the off-centring of the flow velocity barycentre calculated by the FH8500 as function of the Reynolds Number. This measurement provides a first straight forward evaluation of the flow velocity profile asymmetry. The curve shows very interesting results. Indeed, the flow asymmetry is minimum for a Reynolds Numbers between 3000 and 6000 which is the range where the turbulent to laminar transition occurs and the uncorrected meter factors were at the right level before any correction (Figure 12).

The ability of the 18 beams configuration to compensate asymmetric flow velocity profile has been demonstrated. These set of results confirms that even with a multi-path ultrasonic technology the flow condition can affect the accuracy of the measurement.

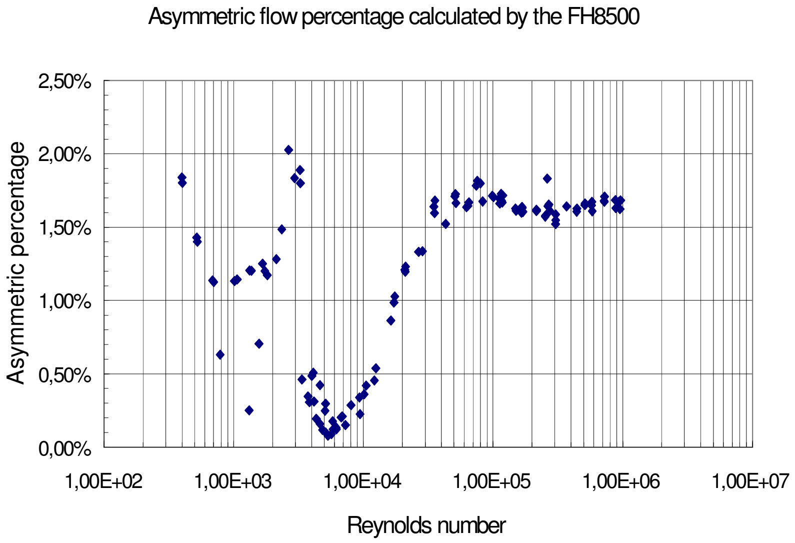


Figure 13: FH8500 Calculation of the flow velocity barycentre off-centring vs. Reynolds Number.

LAMINAR-TURBULENT TRANSITION

The viscosity range of crude oil and refined products is very wide from 0.2cSt to 1000 cSt involving a flow rate measurement over a wide Reynolds Number range from 100 to 10^7.

Therefore, the flow velocity profile is changing significantly from laminar to turbulent flow with a transition region between 2000 and 5000 Reynolds Number. In this region the flow profile is unstable swapping from laminar to turbulent flow profiles with a frequency dependant of both Reynolds Number and installation conditions.

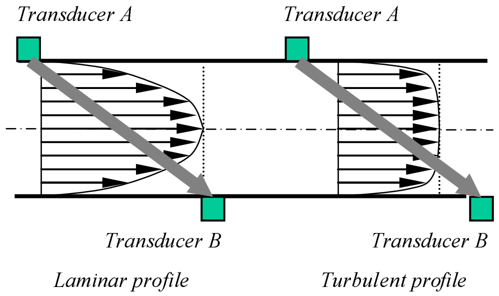


Figure 14: Laminar and turbulent profiles.

In the case of laminar and turbulent flow the flow velocity profile is parabolic and flat respectively (Figure 14). The first consequence is that the hydraulic coefficient K is different in both cases. Figure 15 shows the meter factor variations Vs. Reynolds Number in the case of a conventional one-path ultrasonic flowmeter. Keeping the same hydraulic coefficient the variation increases significantly when the profile becomes laminar. One-path technology doesn't provide enough information to adjust the hydraulic coefficient as a function of the flow profile. In this case, the meter factor variation increases significantly as the flow profile becomes parabolic.

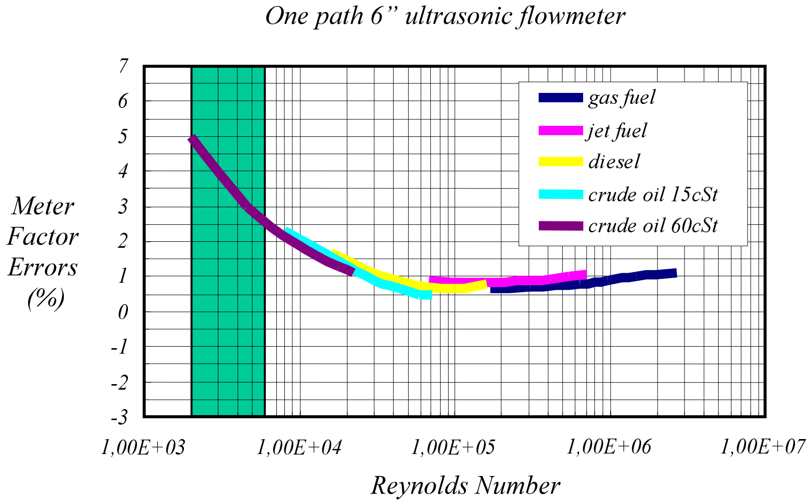


Figure 15: Meter factor Vs. Reynolds Number fir a one path configuration.

For Reynolds Number over 10^4, one-path ultrasonic technology can provide a flowrate measurement accuracy of ±1% under certain installation conditions. In order to improve the accuracy by one order of magnitude (±0.1%) a flow velocity profile correction is required involving the use of a multi-path technology.

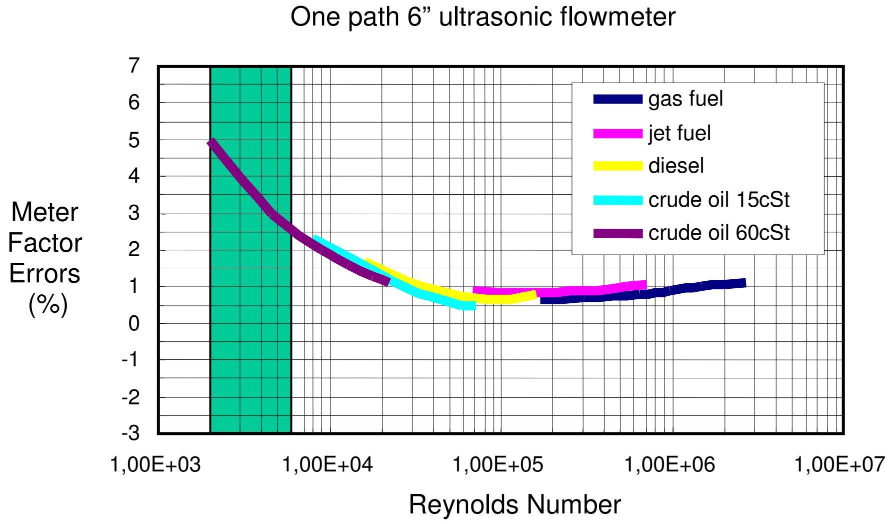


Figure 16: Meter factor vs. Reynolds Number for a 18 paths configuration.

Figure 16 shows the meter factor evolution Vs. Reynolds Number for a 6” FH8500. These results have been obtained on the FAURE HERMAN test benches. Accuracy better than ±0.15% can be reached over a wide range of Reynolds Number covering laminar and turbulent flows and the transition region. The Reynolds Number range has been obtained using four products covering a viscosity range from 1.6 cSt to 100 cSt and a flowrate turndown ratio for each product of 25:1.

With a multi-path ultrasonic flowmeter the adjustment of the hydraulic coefficient to the flow velocity profile is effective. Nevertheless, some installation conditions must be respected to reach this goal. Under certain specific conditions such as very compact installations with limited straight line upstream of the meter, less than 10D, an in-situ calibration might be needed.

Calibration tests in TRAPIL

To complement the results obtained with the FAURE HERMAN internal test benches, a series of calibration tests have been performed at the TRAPIL test facilities.
Three FH8500 sizes have been tested, 6", 10", and 12". For each of them, calibrations have been carried out with two products covering a range of viscosities from 0.6cSt to 18cSt.

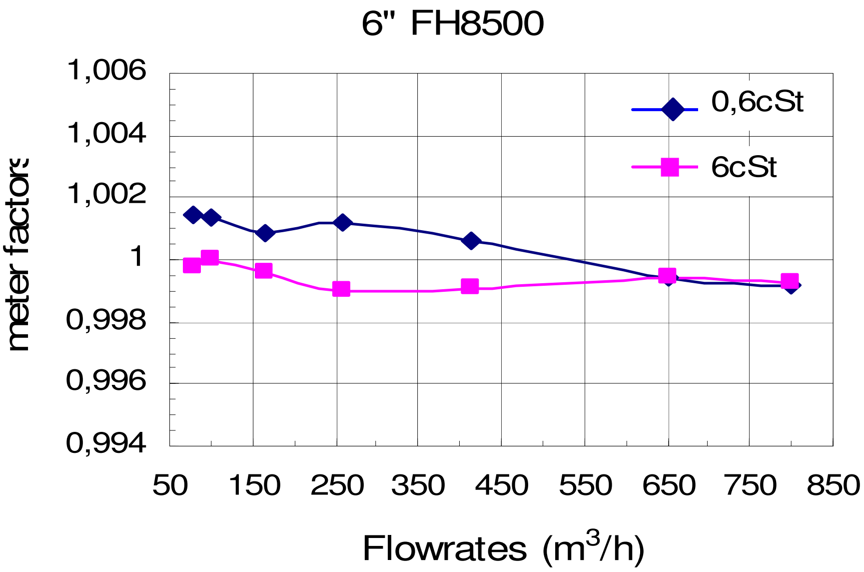


Figure 17: Meter factor vs. flowrates.

The figures 17, 18, and 19 show the calibration curves of the FH8500 6", 10", and 12" respectively. The experimental conditions were 10D straight line upstream from the meter.

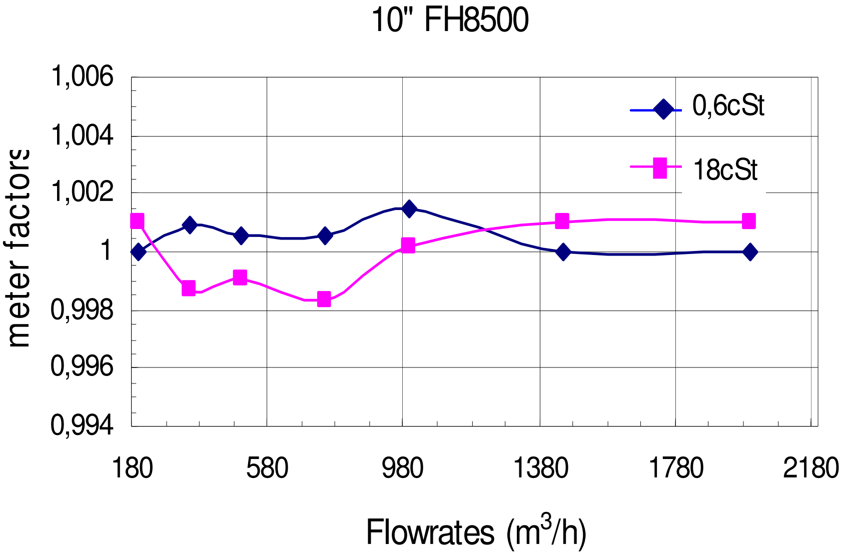


Figure 18: Meter factor vs. flowrates.

For all meter sizes and both products, the measurement accuracy is maintained between ±0.15% over a turndown ratio of 10:1. These results confirm the initial results obtained in the FAURE

HERMAN laboratory and the ability of the 18 path utrasonic technology to meet the custody transfer rquirement.

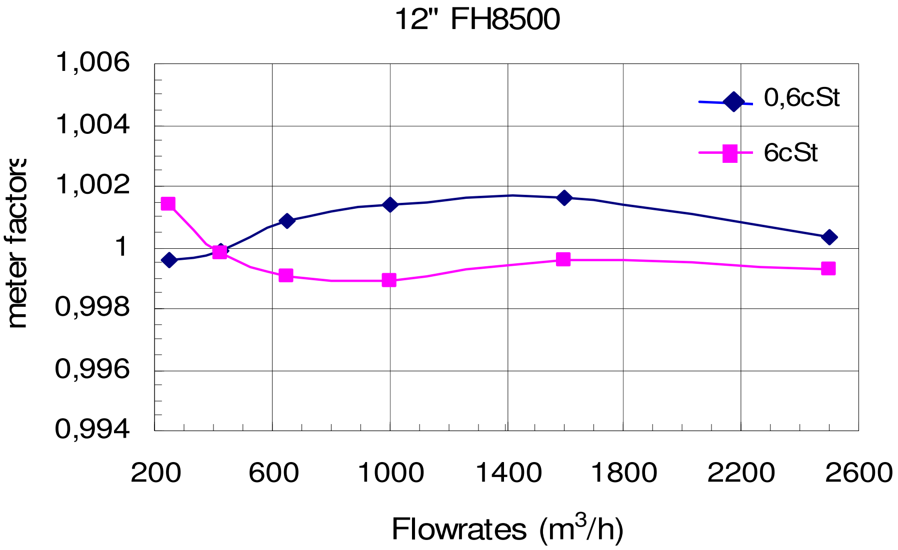


Figure 19: Meter factor vs. flowrates.

TRANSDUCER REDUNDANCY PRINCIPLE

Thanks to the 3 dimensional 18 paths configuration, the FH8500 provides redundant information and maintains custody transfer accuracy even if one set of transducers failed.
Although, FAURE HERMAN never experiment transducer failures, tests have been carried out in TRAPIL to simulate the failure of one and two sets of transducers. Hereafter the curves performed with low viscosity product shows that the meter factor is maintained inside the custody transfer accuracy when 1/6th of ultrasonic beams are missing. The meter factor variation starts when 1/3rd of the ultrasonic beams are missing.
In the field, this result is very important to ensure the measurement accuracy of the metering point and secure end-user revenues.
The replacement of the failed transducer can be made during the maintenance period with out interrupting the line in the meantime.

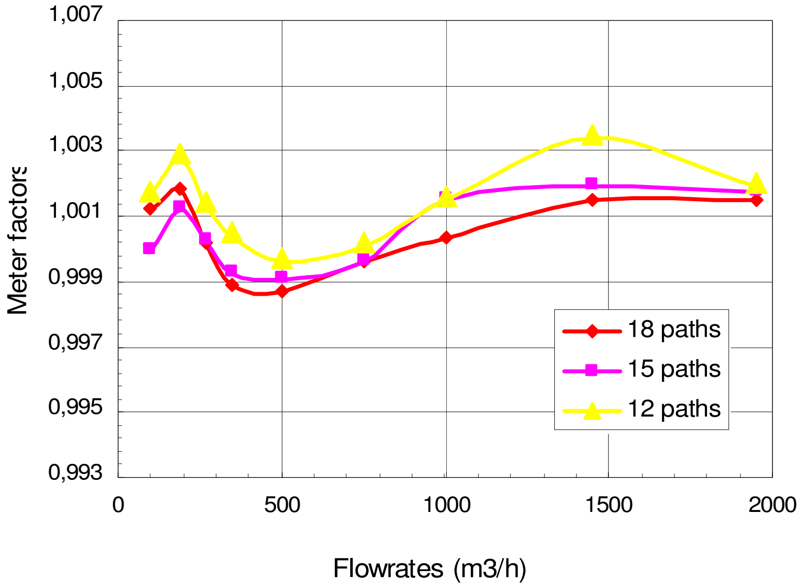


Figure 20: Meter factor vs. flowrates.

CONCLUSION

The purpose of this paper was to point out the capacity of the multi-path ultrasonic technology to deal with different installation conditions and to compensate the flow velocity profile perturbations.

The main results concern the ability of such an 18 beam configuration to analyze and to correct flow perturbations generated by the in-situ installation conditions. This geometrical configuration gives information on swirl, flow asymmetry, and flow regime.

Thanks to better knowledge of the flow profile, compact installations and severe flow conditions can be managed using this technology which is mainly characterized by the generation of ultrasonic paths in 9 different physical plans covering the whole flow profile. The future of the technology looks very promising. And will bring value to end-users. On the medium term, compact metering installations could be made using ultrasonic technology reducing the installation cost and providing predictive maintenance tools to minimize the cost of ownership.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.