COMPACT LARGE BORE DIRECT MASS FLOWMETERS

by

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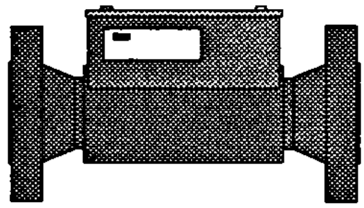

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SUMMARY

Although suitable for the measurement of hydrocarbons, few large bore direct mass flow meters are available, and these are generally limited in their application by their large size.

This paper presents a compact direct mass flow meter that uses a novel concept to sense the flow. A resonating tuning fork is used which enables the size to be kept similar to that of a turbine meter for bore sizes of 4 inch and above. The meter provides outputs of mass flow, density and temperature. Its naturally rugged design offers very high pressure containment.

The research has been performed by Schlumberger Industries in collaboration with Statoil. Tests results from Norsk Hydro, Porsgrunn are presented showing repeatability of ± 0.05 % and linearity of ± 0.25 % for a 4 inch bore meter at flow rates up to 350 tonnes/hr.

CONTENTS

1.0 INTRODUCTION

Direct mass flow meters are rapidly being accepted as a good method of measuring mass flow rate to custody transfer standards. Meter sizes are available from a variety of manufacturers in sizes from 3 mm bore up to 6 inch. All of these meters work on the principle of passing the fluid to be measured through the inside of one or two resonating tubes. These tubes can be configured in straight or bent configuration dependent on the manufacturer. Only one meter is currently available in 6 inch bore and this has a shipping weight of 636 Kg and is 1m x 0.3m x 2m in size. This generic physical size, which creates difficulties both for the manufacturer and the user, seems to be the major limitation on these meters.

For the Schlumberger Industries single straight tube design the problem was even more severe. In order to achieve the required pressure ratings combined with suitable mass flow sensitivity, a 4 inch meter would be 3 meters in length and weigh 300 Kg and a 6 inch meter would be 4.5 meters in length and weigh 1100 Kg. This was believed to be impractical and so an alternative solution was required.

2.0 METER DESIGN

In order to overcome the pressure and mass flow sensitivity limitations connected with passing the fluid through a resonating tube, this meter turns the problem inside out and inserts the resonating sensor into the flow. This means that the pressure rating in not limited by the sensor itself and the mass flow sensitivity can be adjusted as desired.

The meter takes the form of a stretched tuning fork either cast or wire eroded from a solid billet of stainless steel. The configuration is shown in fig 2.0.1.

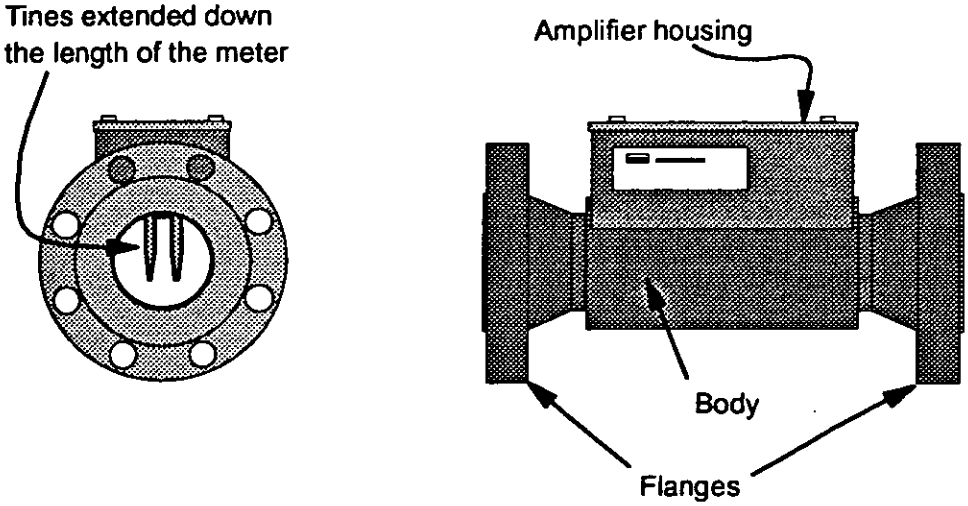


Fig 2.0.1 Mass Meter Tine Configuration

2.1 THEORY OF OPERATION

The operation of this meter is similar in theory to that of the tube type Coriolis meters, although the mathematics is a little more complicated. The tube wall defines a volume of fluid that acts on the resonant tines. The resonant frequency of the tines is dependent on the combined resonant mass of the tines and the fluid surrounding them. Thus the resonant frequency is dependant on the fluid density, which enables an accurate density output (±0.5 Kg/m3) to be computed. As fluid flow occurs Coriolis forces are generated which distort the tines' resonant mode shape. The magnitude of this distortion is proportional to the mass flow rate of the fluid flowing past the tines. This distortion can be detected as a phase shift in detectors mounted at each end of the tines.

It should be remembered that the tine movement is only micrometers in amplitude, and hence cannot be seen. All diagrams of the tine mode shapes are grossly magnified.

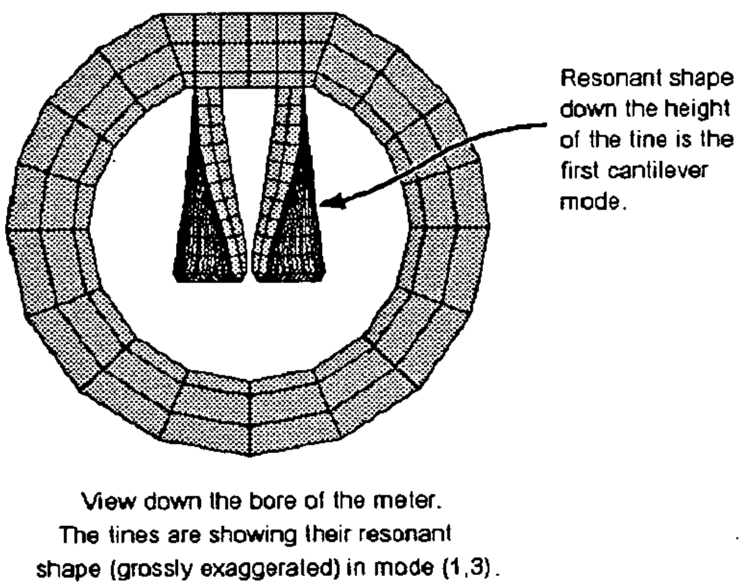
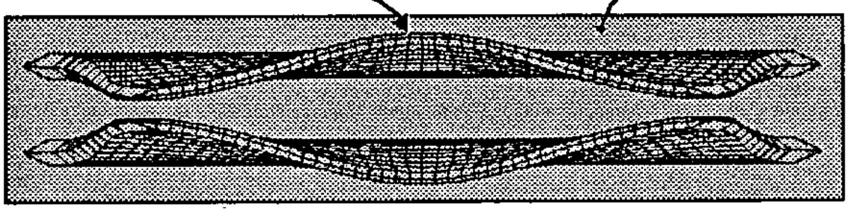


Fig 2.1.1 End View of Tine Resonance.

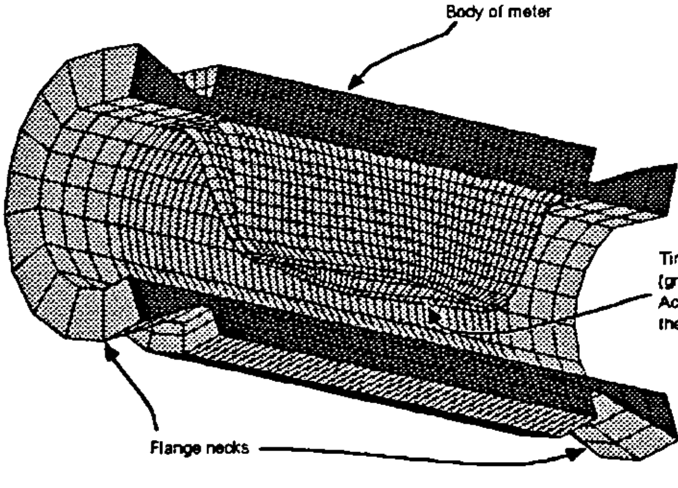
One significant advantage of this design is that the magnitude of the phase shift can be designed to be as high as required by controlling the relative positions of the operating mode and the associated twisting modes. In practice, operating phase shifts above 15 degrees create practical problems with linearity and density effects on the meter factor. This phase compares to tube meters which have a full flow phase shift of about 4 degrees.



Cutaway view from underneath the tines
The tines are showing their resonant
shape (grossly exaggerated) in mode (1,3).

Fig 2.1.2 View of Resonance from Underneath Tines.

The resonant mode chosen is a combination of the first tuning fork mode shape with the third longitudinal mode shape. This can be denoted as mode (1,3) and was found to be the most suitable mode due to a combination of physical characteristics. The discussion of such effects is beyond the scope of this paper.



Cutaway 3-dimensional view of the Massmaster400
showing the meter's resonant sensors.

Fig 2.1.3 Three-Dimensional View of Tine Resonance.

2.2 PICK-UP AND DRIVE MECHANISM

The mechanism for maintaining the tuning fork in resonance is similar to other Coriolis meters in principle: a single drive transducer translates electrical energy into tine movement, and two pick-up transducers detect the movement, developing electrical signals which are fed back into the drive circuit.

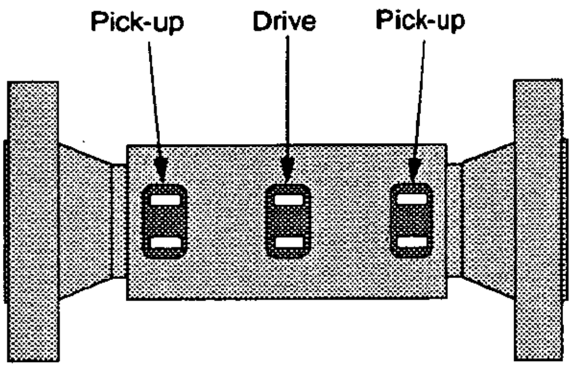


Fig 2.2.1 Pick-up and Drive Arrangement

Since the pick-ups are displaced up- and down-stream of each other, a phase diffence is detected between the two signals during flow. This is the prime measurement for the mass flow calculation.

2.3 MECHANICAL CONFIGURATION

The meter has an extremely high pressure containment ability as can be seen from the wall thickness in figure 2.1.1. The one inch thick wall is thinned only over very small areas, visible in figures 2.2.1 and 2.2.2. The wall thickness in the base of each area is still 5mm.

TINE SHAPE

The shape of the resonating tines has been chosen with a view to optimising Coriolis performance whilst avoiding cavitation, minimising erosion and preventing the build up of fibrous particles. The taper and profile of the tines are shown.

The existing design has been designed for oil/condensate applications although some generality of application can be assumed. For other specific applications such as gas mass flow a different tine profile may be used to optimise performance.

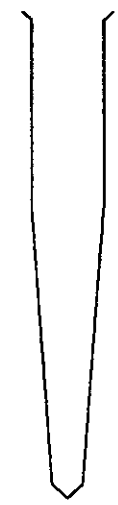


Fig 2.3.1 Tine X-section

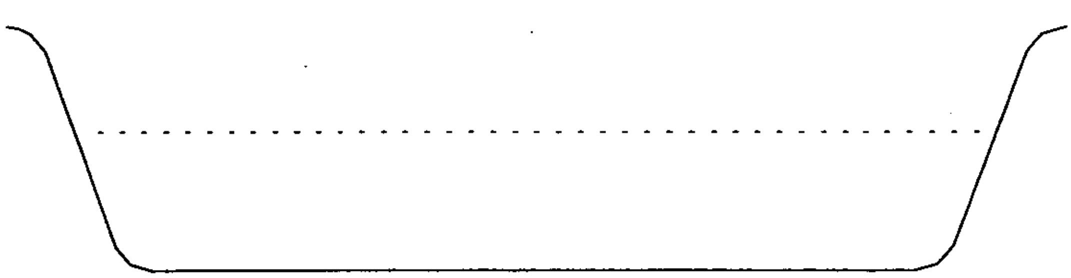


Fig 2.3.2 Tine Side View

3.0 METER PERFORMANCE

The meter produces outputs of phase shift, resonant frequency and line temperature in identical fashion to most other Coriolis mass flow meters. Also the factors that affect the meter's performance are very similar to those that affect traditional tube type Coriolis meters.

Accordingly the output can be compensated for all the characterised systematic effects using a flow computer.

3.1 EFFECTS ON METER PERFORMANCE (THEORY)

EFFECT OF TEMPERATURE

Changes in temperature affect the meter output primarily due to changes in the material modulus and to a lesser extent due to dimensional changes. The magnitude of these effects are;

Effect on mass flow sensitivity	+0.04% / deg C (for 316 st. steel)
Effect on density output	+0.6 Kg/m3 / deg C (for 316)

It is easy to compensate for these effects, which are characteristic of the material composition. They are of the same magnitude as for tube type meters.

EFFECT OF PRESSURE

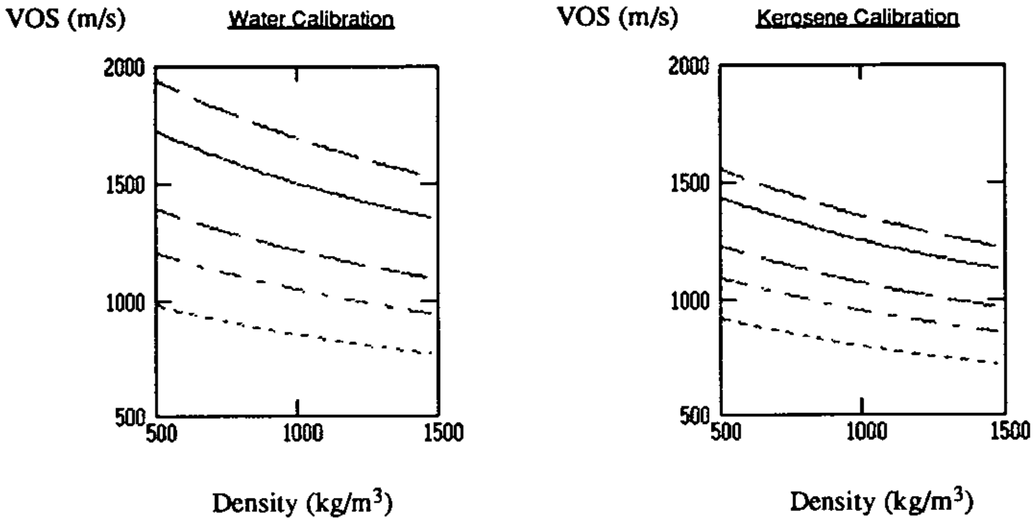
Because the tines are completely surrounded by fluid and no stress or dimensional changes occur in the tines, there is NO PRESSURE EFFECT on this type of meter on either density or massflow measurement.

EFFECT OF VISCOSITY

Homogeneous viscous fluids should have little effect on meter accuracy. High viscosity will damp the tine movement and the effective viscous range of the meter will depend upon the power setting of the drive. The present drive levels have been chosen to comply with intrinsic safety approval limits, but the useful viscous range has yet to be determined on these prototypes.

EFFECT OF FLUID VELOCITY OF SOUND (VOS)

The VOS of a fluid causes the resonant weight to be heavier than the static mass of a volume of fluid. Hence Coriolis meters always 'overread'. However since all meters are calibrated on real fluids the effect is automatically compensated for the calibration fluid. Subsequent use on a different fluid produces VOS errors.



Offsets -0.2%; 0; +0.5%; +1%; +2% respectively (top to bottom)

Fig. 3.1.1 Graphs of constant Massflow VOS offset.

EFFECT OF FLOW PROFILE

The meter could conceivably be sensitive to some types of flow profile within the pipeline. However no such effect has yet been identified and the sensitivity could be negligible. Through symmetry, swirl is not expected to create any systematic offset. Initial installations could use the same flow conditioning that is used for turbine meters, although tests may oneday prove that this level of conditioning is unnecessary.

3.2 TEST RESULTS

In collaboration with Statoil, a development program of tests has been planned and started. The results displayed herein are from the initial prototype, tested at Norsk Hydro, Porsgrunn, Norway on 3-4 October 1991.

NOTE ON FIG. 3.2.1

On the first day of testing, an attempt was made to find the flow range of the meter. Linearity was lost above 350 t/h due to the onset of cavitation. At low flow a zero error caused the percentage error to veer positive.

Developments both in streamlining to minimise cavitation and optimising zero stability are continuing at Schlumberger.

NOTE ON FIG. 3.2.2

On the second day of testing, the repeatability was assessed at three flow rates. The results at 170t/h and 300t/h were within the ±0.05% specification of the volumetric flow rig at Norsk Hydro.

NOTE ON FIG. 3.2.3

Loose wiring was identified as the source of the zero instability causing the 50t/h repeatability to appear worse than that at higher flows. After refitting the results in Fig. 3.2.3 were taken, showing 50t/h repeatability now under ±0.05% as well.

Naturally, repeatability is the first quality required of mass flow meter prototypes, but eventually tests on different fluids and flow conditions are intended. Testing on full simulated North Sea conditions is planned as soon as possible and off-shore experience anticipated soon after.

HYDRO

Porsgrunn

Automatiseringsavdelingen

Kalibreringsbevis for gjennomstrømningsmålere

Bevis nr.: F-2046

Oppdragsgiver: FIMAS

Produsent: Schlumberger

Dimensjon: 4"

Serienr: 001

Måleområde: 40-400 m3/h

Mass flow — Prototype

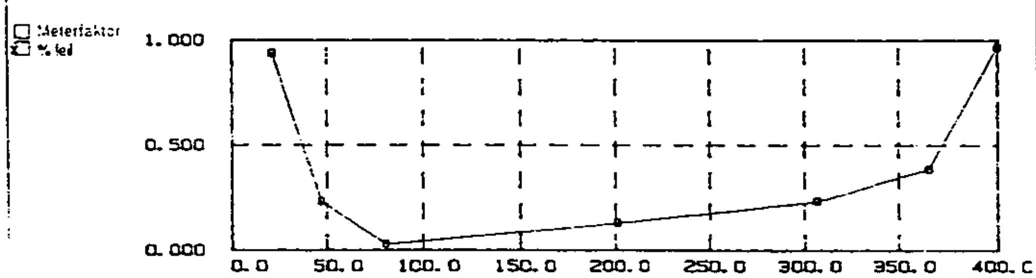
Væskestrøm m3/h	Avlest volum	Normal	Temperatur °C	Korrigert volum		Væskestrømsindik.	Indikert volum Kg	Pulser	Meterfaktor	Feil %
400.00	12092.00	H	22.2	12077.80			12194.80			0.97
365.00	12074.00	H	22.5	12059.20			12106.00			0.39
306.00	12098.00	H	22.5	12090.20			12118.60			0.23
201.00	12041.00	H	22.8	12025.50			12041.20			0.13
80.00	5928.00	H	22.0	5921.30			5923.10			0.03
47.00	6004.00	H	23.0	5996.10			6009.98			0.23
21.00	2012.00	H	23.0	2009.34			2028.20			0.94

H: Hulmålnormal. Nøyaktighet ± 0.05%. Temperaturkorreksjonsfaktor: 1-0.00005 · T (°C)

R: Referansemåler. Nøyaktighet volum: ± %. Nøyaktighet væskestrøm: ± %

Korrigert etter kalibrering mot hulmålnormal.

Gj.snitts meterfaktor



Væskestrøm: m3/h [x] % av FS ms

Kalibreringsvæske: Vann DN 100 mm Rett rørstrekk foran

Anmerkninger: OMGJORT VOLUMETRISK TIL MASSE.

Porsgrunn, den 3/10 91 Utført av: Hans Drage Ansvarshavende: [signature]

Fig.3.2.1 Test Results: Day 1.

HYDRO
Porsgrunn
Automatiseringsavdelingen

Kalibreringsbevis for gjennomstrømningsmålere

Bevis nr: E-2047

Oppdragsgiver: FIMAS.

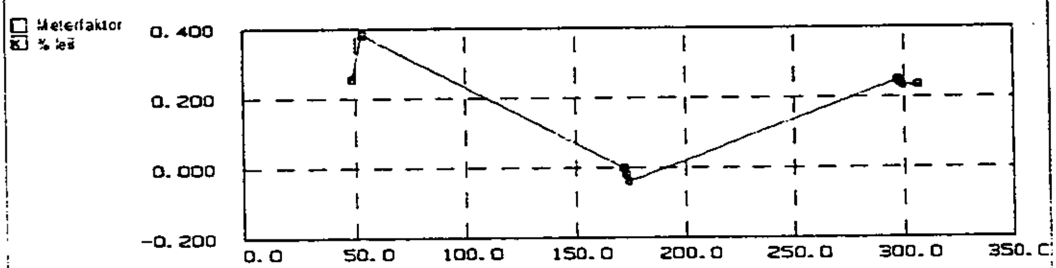
Målertype: Massflow | Produsent: Schlumberger | Dimensjon: 4"

Typebetegnelse: Prototype | Serienr: 001 | Måleområde: 40-400 m3/h

Væskestrøm m3/h	Avlest volum	Normal	Temperatur °C	Korrigert volum		Væskestrømindik.	Indikert volum Kg	Pulser	Meterfaktor	Feil %
306.00	12098.00	H	22.5	12090.20			12118.60			0.23
297.00	12085.00	H	22.2	12070.80			12100.90			0.25
298.00	12079.00	H	22.5	12064.20			12093.20			0.24
299.00	12094.00	H	22.5	12079.20			12107.40			0.23
172.00	12052.00	H	22.7	12036.80			12036.60			-0.00
173.00	12039.00	H	22.9	12023.40			12021.00			-0.02
174.00	12027.00	H	23.0	12011.10			12006.40			-0.04
48.00	6009.80	H	23.0	6001.88			6017.19			0.26
53.00	6040.20	H	23.6	6031.55			6054.59			0.38

* H: Hulmålnormal. Nøyaktighet ± 0.05%. Temperaturkorreksjonsfaktor: 1-0.00005 · T (°C).
* R: Referansemåler. Nøyaktighet volum: ± %. Nøyaktighet væskestrøm: ± %
Korrigert etter kalibrering mot hulmålnormal.

Gj.snitts meterfaktor



Væskestrøm: [ ] l/min [x] m3/h [ ] % av FS [ ] m/s

Kalibreringsvæske: Vann | DN 100 mm | Rett rørstrekk foran

Anmerkninger: OMGJORT VOLUMETRISK TIL MASSE.

Porsgrunn, den 7/10 91 | Utført av: Hans E. Drage | Ansvarshavende: [signature]

Fig.3.2.2 Test Results: Day 2.

HYDRO
Porsgrunn
Automatiseringsavdelingen

Kalibreringsbevis for gjennomstrømningsmålere

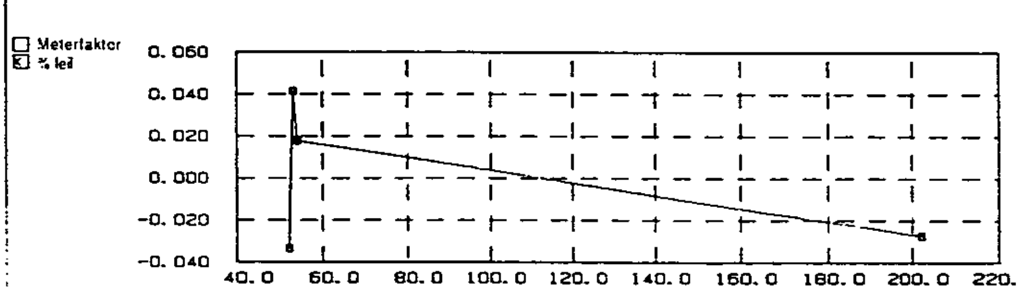
Bevis nr: E-2048

Oppdragsgiver: FIMAS.		
Målertype: Mossflow	Produsent: Schlumberger	Dimensjon: 4"
Typebetegnelse: Prototype	Serienr: 001	Måleområde: 40-400 m3/h

Norsk Hydro's normaler						Måler til kalibrering				
Væskestrøm ☐ l/min ☒ m3/h ☐	Avlest volum ☒ l ☐	Normal	Temperatur °C	Korrigert volum ☒ l ☐		Væskestrømsindik. ☐ Hz ☐ mA ☐	Indikert volum ☐ Telleverk ☐ NH integ. ☒ Kg	Pulser	Meterfaktor ☐ p/m 3 ☐ p/l ☐	Feil %
52.00	6054.00	H	24.0	6044.52			6042.49			-0.03
54.00	6049.80	H	24.0	6040.66			6041.73			0.02
53.00	6045.00	H	24.2	6035.63			6038.13			0.04
202.00	12046.00	H	24.0	12027.90			12024.60			-0.03

* H: Huimålnormal. Nøyaktighet ± 0.05%. Temperaturkorreksjonsfaktor: 1-0.00005 . T (°C)
* R: Referansemåler: Nøyaktighet volum: ± %. Nøyaktighet væskestrøm: ± %.
Korrigert etter kalibrering mot hulmålnormal.

Gj.snitts meterfaktor



Væskestrøm ☐ l/min ☒ m3/h ☐ % av FS ☐ m/s

Kalibreringsvæske: Vann Rør | DN | DN 100 | D mm | Rett forstrekk foran | xD

Anmerkninger: Omgjort volumetrisk til masse.

Porsgrunn, den 7/5 91 | Utført av: [signature] | Ansvarshavende: [signature]

78 5 93

Fig.3.2.3 Test Results: Day 2 cont.

3.3 SECONDARY OUTPUTS

The meter can be calibrated to compute **density** from the resonant time period, in a similar fashion to other Schlumberger 'Solartron' densitometers. A 3 liquid calibration with temperature calibration should achieve accuracies of ±0.5kg/m^3. Knowledge of the generic characteristics of VOS, flow and viscous effects will then permit accurate density measurement of the full 4" flow stream. As previously mentioned, there is no pressure effect on this meter. Knowing the mass rate and line density enables the **volume** rate to be derived.

A PT100 embedded into a tine gives an accurate measurement of **Temperature** for density referral calculations. Hence **referred density, standard volume,** and **nett mass** can easily be computed.

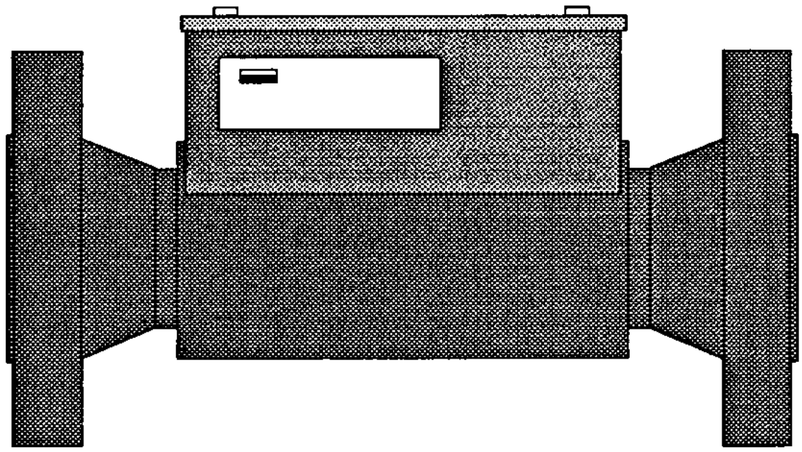
Despite the radical mechanical differences between this new meter and the standard Coriolis meter, the information output is identical. Hence the meter interfaces directly to a Schlumberger flow computer in which secondary calculations can be performed.

4.0 CONCLUSIONS

This meter places the sensing resonator within the fluid, instead of surrounding the fluid with a resonating tube. Thus it overcomes the problems of scale by turning the problem inside out. Large bore coriolis meters of only 3 diameters length will soon be commercially available.

Initial test results show that this design of meter can achieve similar performance to that of existing mass meters, yet have the advantages of compact size, rugged design and high pressure capabilities.

Work is planned to continue in optimising the design of a 4 inch meter and to produce 6 and 8 inch versions during 1993. Initial applications are expected to be on refined single phase products, LPGs and gases.



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.