A NEW MASS FLOWMETER AND ITS APPLICATION TO CRUDE OIL METERING

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Paper 2.1

NORTH SEA FLOW METERING WORKSHOP 1988
18-20 October 1988

National Engineering Laboratory
East Kilbride, Glasgow

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S U M M A R Y

The paper describes a new mass flow meter development by Schlumberger in collaboration with Shell aimed at crude oil metering. The meter is based on the Coriolis principle and is unique in that the flow path is a single straight tube. This is particularly advantageous in the measurement of crude oils which contain erosive sand particles, scale or wax. The current meter is for liquid/liquid mixtures whether clean or not.

The accurate determination of density also means that the instrument can be used directly as a net-oil meter in liquid/liquid flow without additional mixing or the usual sampling problems.

1 INTRODUCTION

Today, in the oil industry, there are two trends that are promoting the development of accurate and robust mass flow meters: the reduction in field size and the trend towards accounting in mass terms. Both these factors increase the need for a flow meter capable of accurately metering the flows near the wellheads in an oil production station. Traditional flow measurements require fluids that are cleaner than those anticipated from the future production stations and few instruments have been engineered with this application in mind. The mass flow meter development by Schlumberger in collaboration with Shell is aimed ultimately at this environment. The meter is based on the Coriolis principle, and is unique in that the fluid flow path is a single straight tube. This is particularly advantageous in the measurement of crude oils which contain erosive sand particles, scale or wax.

The current meter is for liquid/liquid mixtures whether clean or not. It provides both accurate mass flow metering and density measurement making it uniquely suitable for the net-oil measurement of wet crudes.

2 THE APPLICATION

Traditionally mass flow has been measured by combining a density measurement with either a volume or a differential pressure measurement. With these methods, it is impossible to measure crude-oil flow accurately near the wellhead since they require clean, single phase fluids of well-known, or easily measurable properties. The future smaller production stations, will not have the facilities to produce clean single-phase fluids. Therefore, there is a need to develop a meter that does not require an accurate knowledge of the fluid properties and that tolerates both non-homogeneous mixtures of oil and water and small amounts of entrained solids.

An obvious contender is a Coriolis-based mass flow meter because, in principle, this measures true mass flow independently of fluid properties. A number of these instruments are now available each with different configurations which benefit particular applications. All are similar however, in that they either have split flow paths and/or bends that need relatively high fluid velocities. These characteristics coupled with the need to use thin-walled tubing are drawbacks for measuring the flow of wellhead crude-oil which will contain erosive particles.

The Schlumberger meter has no bends and is suitable for use with liquid/liquid phases whether homogeneously mixed or not. It is the first stage of a joint Shell/Schlumberger development programme aimed at the accurate measurement of flow near the wellhead.

The meter is particularly suitable for measuring net-oil because it also provides an accurate measurement of fluid density. This eliminates all the sampling problems normally associated with this measurement. The computation of net-oil flow from density and mass flow are included in the mass flow computer. Thus a single instrument can make the complete net-oil measurement.

3 GENERAL DESCRIPTION

The mass flow meter (7860) consists of a hermetically sealed housing containing the sensing element which is a straight tube approximately 50 mm in diameter and which vibrates in a lateral mode at its resonant frequency.

As fluid passes through the tube, Coriolis forces produce a phase difference between the vibration at one point in the tube with respect to another. This phase difference divided by the resonant frequency is directly related to the mass flow rate. In addition, a measurement of the resonant frequency provides an accurate determination of the fluid density.

The sensing element is manufactured from a highly stable steel (Ni Span C) which provides good instrument stability for both the mass flow and density measurements. In order to prevent external forces from influencing the vibration pattern, the sensing tube is coupled to the housing and process pipework via flexible couplings.

Sensitive electromagnetic detectors monitor the vibrations of the tube with their signals being fed to a special signal processor. For accurate measurements under noisy pipeline conditions, the dedicated flow computer (7960) subjects the input signals to comprehensive digital filtering techniques. In addition to mass flow rate, this electronic unit also generates values for density and flow totals in both mass and volume units.

4 THEORY OF OPERATION

The sensing element consists of a simple straight tube, vibrating in a lateral manner at its natural resonant frequency. Consider a tube A-B vibrating in the fundamental lateral mode as shown in Figure 1. Let the tube vibrate in an upwards direction; with no fluid flow the tube is displaced symmetrically about the line CD. Sensors (of displacement, velocity or acceleration) positioned at X and Y will monitor signals that are in phase.

Now consider fluid flowing through the tube with a velocity V, and let us examine the forces on the tube due to this flow. The Coriolis force, Fc, on a body of mass M, is defined as

$$Fc = 2M\omega V \qquad (1)$$

where ω = the angular rotation velocity and the force acts in a direction perpendicular to the plane containing the velocity vector V and the angular velocity vector ω .

Consider the forces on the tube due to a small element flowing at position X. This element rotates anti-clockwise about A, with an angular velocity ω , where

$$\omega = 2 \Pi F \qquad (2)$$

where F = the resonant frequency of the tube.

Combining this angular velocity, ω , and the fluid velocity, V, results in a Coriolis force acting in an upwards direction. Now consider an element at position Y. The element now rotates clockwise about B; this results in a Coriolis force acting in a downwards direction. The net result of these additional forces due to the fluid velocity is that the tube displacement is no longer symmetrical about line CD but is asymmetric. This asymmetry manifests itself as a phase difference between the sensors at X and Y.

Furthermore, the phase difference, which is a measure of the asymmetry of the Coriolis force along the pipe is proportional to the mass flow rate (MV) multiplied by the angular velocity ($2 \pi F$).

In reality the situation is more complex than in this simplified model. Sophisticated mathematical models of the instrument have been developed which correlate very well with experimental results.

5 CONCLUSIONS

The Schlumberger mass flow meter development enables simple and accurate metering to be moved nearer the wellhead. The straight through configuration makes it particularly suitable for applications where the bends and thin wall tubing of most Coriolis meters are a drawback. The accurate determination of density also means that the instrument can be used directly as a net-oil meter in liquid/liquid flow without additional mixing or the usual sampling problems.

****APPENDIX****

SPECIFICATION

The specifications of the instrument are as follows:-

MASS FLOW SENSOR 7860

A sensor for liquid/liquid mixtures

Flow rate	100 metric tonnes/h
Pressure Drop	2 bar maximum
Turndown	10:1
Pressure	150 bar maximum
Temperature Range	0 - 100 Deg.C
Length	2100 mm
Weight	95 kg
Materials	Suitable for oil pipeline services
Wetted Parts	Ni Span C, 316 Stainless Steel
Safety	Zone 1, Gases IIB, Temp. T4

SIGNAL PROCESSOR 7960

Mounting	Panel Mount
Weight	4 kg

Surface Mount Technology

Maximum Distance from Meter	250 m
INPUTS	
Mass Flow	2
User Selectable (Analogue)	4 3 4-20 mA, 1 PRT
Status	4
OUTPUTS	
Analogue	3
Pulse (User Selectable)	4
Status/Alarms	4
COMMUNICATIONS	
Number of Lines	2
Port 1	RS 232C
Port 2	RS 232C or RS 485
Bi-directional	
INTERNAL TOTALISERS	4

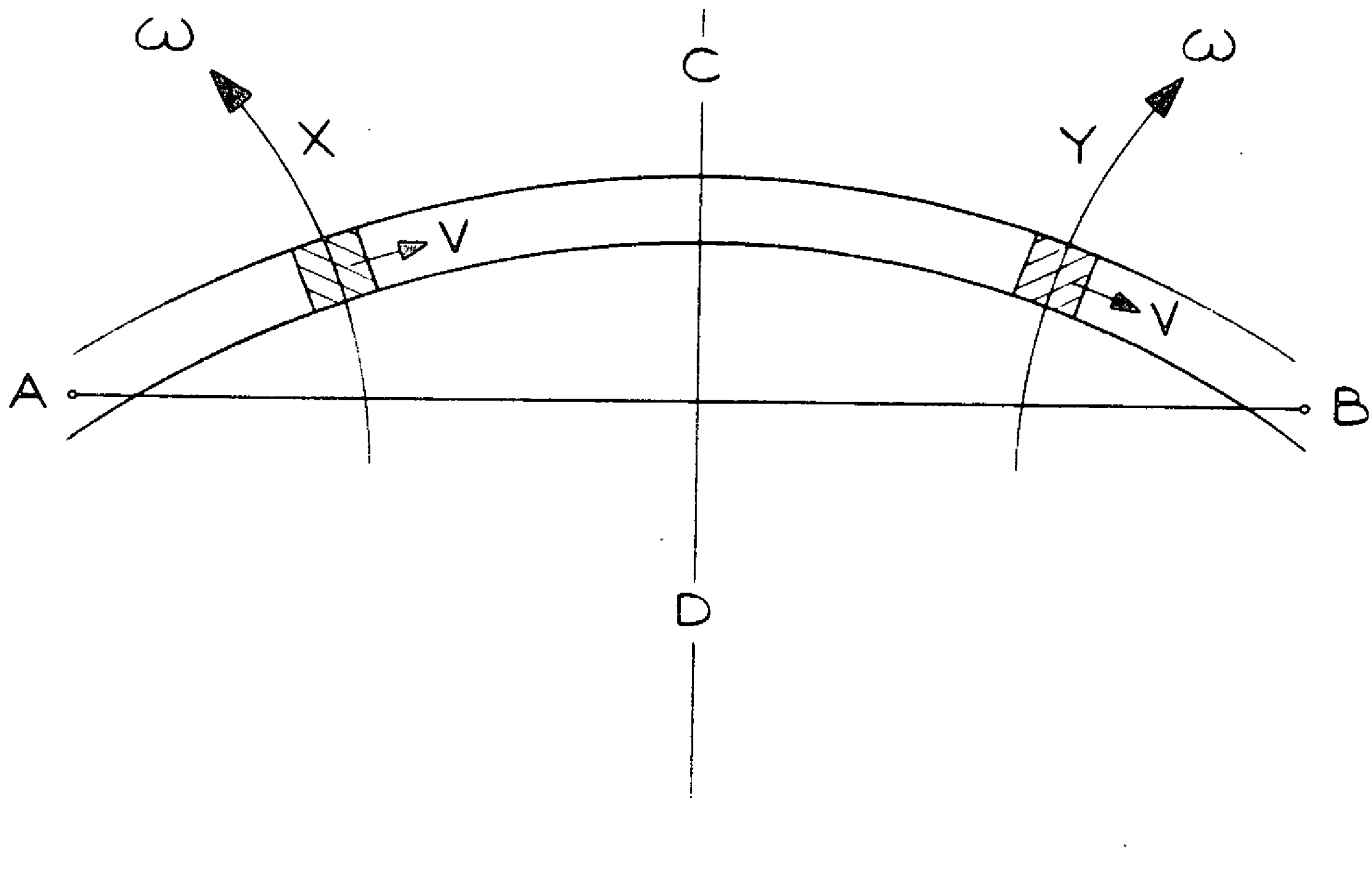

FIGURE 1: SCHEMATIC DIAGRAM OF VIBRATING TUBE

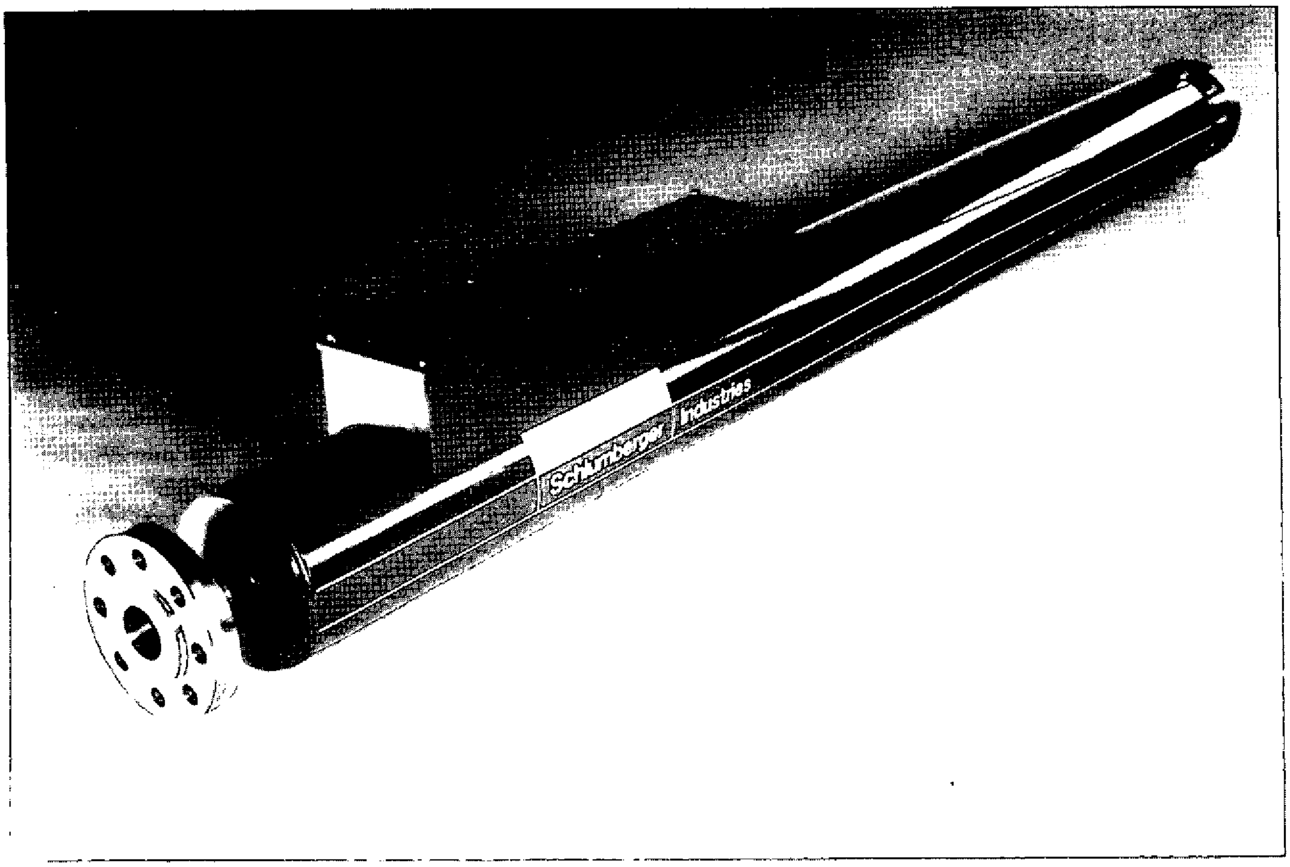

FIGURE 2: 7860 MASS FLOW METER

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.