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Flare Gas Metering by Ultrasonic Measurement

by

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INTRODUCTION

The ideal flaregas meter should be capable of measuring the complete range of velocities occurring in the flare pipe. It should be non-intrusive to avoid errosion or clogging of the sensor elements, thus reducing the necessity for frequent calibrations.

All of these objectives can be obtained by using an ultrasonic meter, but there are many technical difficulties which have to be solved to obtain a reliable and accurate instrument installed in a flaregas pipe.

A reliable flaregas meter has been developed by Chr. Michelsen Institute which is capable of measuring the flaregas flow in large diameter flare pipes with a velocity range of 0 m/sec. to 100 m/sec. It has a fast dynamic response to changes in flow conditions which can abruptly occur during shut-down condition.

This instrument has been developed over a period of 4 years and has been sponsored by Mobil Exploration Norway Inc., Statoil and Fluenta a/s. This instrument, the FGM-100 gas flowmeter is now produced by Fluenta a/s.

SYSTEM DESCRIPTION

The FGM-100 is a one-beam gas flowmeter designed to measure the complete range of flow velocities of potentially explosive gases flowing at low pressure in flare pipes.

Basic measurement principle

The FGM-100 is a transit time difference flowmeter. The transit time difference principle, also known as the time of flight principle, is the most common used measurement principle in industrial ultrasonic flowmeters and is based upon the fact that an ultrasonic pulse travelling between two transducers in the flow will have higher velocity downstream than upstream (Figure 1).

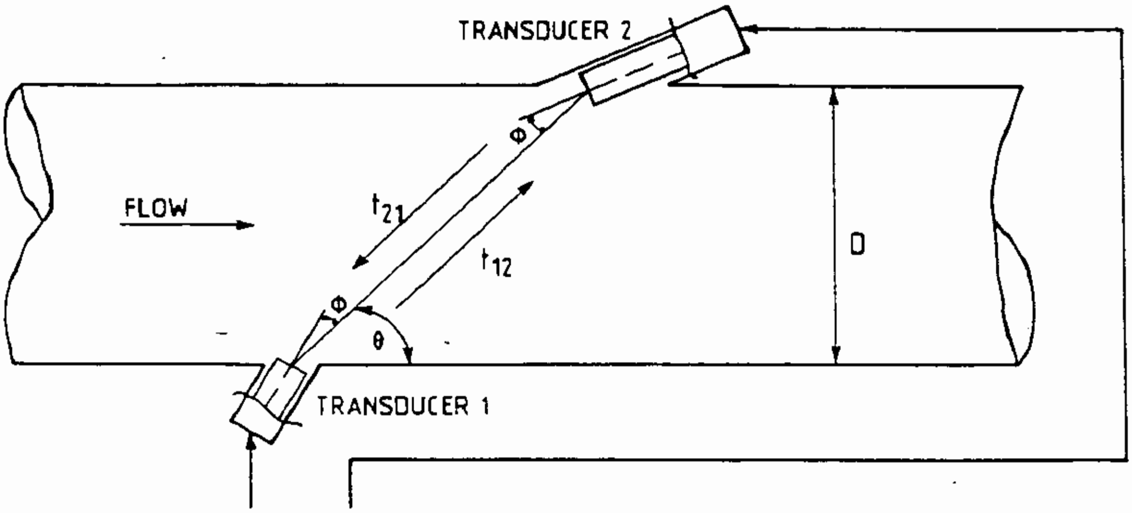

Figure 1. Transducer arrangement for FGM-100.

This measurement principle can therefore be used for flow measurement in homogeneous fluids and can measure the flowrate in both gases and liquids.

The difference in travelling times between the two transducers, upstream and downstream the moving medium, will be direct proportional to the flow velocity of the medium and can be expressed by the following formula:

$$\bar{v} = \frac{4D\,(t_{21} - t_{12})}{\sin 2\Theta\,(t_{12} + t_{21})^2} = \frac{D\,(t_{21} - t_{12})}{t_{12} \bullet t_{21} \sin 2\Theta}$$

where

$\bar{v}$ = Mean flow velocity

D = Pipe diameter

Θ = Angle of intertransducer centre line to axis of the pipe

t_{12} = Transit time from transducer 1 to transducer 2 (downstream)

t_{21} = Transit time from transducer 2 to transducer 1 (upstream).

As we can see from the formula, the mean flow velocity is independent of the sound velocity in the medium. This means that changes in sound velocity in the medium due to changes in temperature, gas composition, etc. do not influence the measurement results.

As shown in Figure 1 the two transducers are positioned facing each other at an angle Φ between the inter-transducer centre line and the transducer centre lines. The reason for this arrangement is that at high gas velocities the ultrasonic beam will be moved or 'blown away' from its initial transmitted direction along the direction of the flow, resulting in a curved path. The position of the transducers has been determined by means of theoretical investigations and verified during elaborated tests at the SINTEF wind tunnel. The transducer angle Φ has been determined in such a way that optimum signal condition has been obtained for the entire velocity range.

It can be shown that the formula given for the mean flow velocity also is valid even if the sound path, due to the 'blow away' effect, is unlinear. It is, however, important to be aware of that by positioning the transducers for compensation of the 'blow away' effect we have lost the possibility to use the meter for bi-directional measurements if only one pair of transducers is applied.

Transit time measurement techniques

The most common technique is the direct transit time measurement based on time measurement between thr transmitted and received ultrasound signal. This technique can not be used in a flaregas meter because of the low resonance frequency of the transducers and the high level of transmission noise at high gas velocities.

It has therefore been necessary to use two different measurement techniques:

a) For high and medium flow velocities:
   - A chirp signal technique with correlation detection to overcome high noise levels.

b) For low velocities:
   - Continuous wave phase measurement technique in combination with the chirp technique.

The chirp measurement technique

To determine t_{12} and t_{21} the two transducers are used sequentially as transmitters and receivers. This technique utilizes a special excitation signal of a continuous varying frequency going from f_1 to f_2 during the duration of the pulse. This signal is called the chirp signal and has a constant amplitude.

At the receiver the transmitted signal contains the sum of the chirp signal and the noise generated signal which are totally uncorrelated to each other. This signal is now fed to the pulse compression block that contains a real time CCD-correlator which performs in principle a cross-correlation between the received signal and the incident chirp signal.

Figure 2 shows the autocorrelation function of a linear frequency modulated chirp with amplitude A which is a sinc-function with amplitude $A \bullet \sqrt{B\tau}$, where τ is the duration and B is the bandwidth $(f_2 - f_1)$ of the chirp signal. The received chirp signal is now compressed and has a peak amplitude which is equal to the received signal multiplied by $\sqrt{B\tau}$. The FGM-100 uses a more elaborate function than the linear FM chirp, carefully selected with respect to the overall transmission path characteristics.

The maximum point of the compressed signal represents the time from the moment the chirp transmission started to the arrival of the entire chirp pulse. This time is detected by the chirp transit time detector block using a peak detector and a timer/counter circuit and is stored in the chirp transit time latch, to be read by the flow computer.

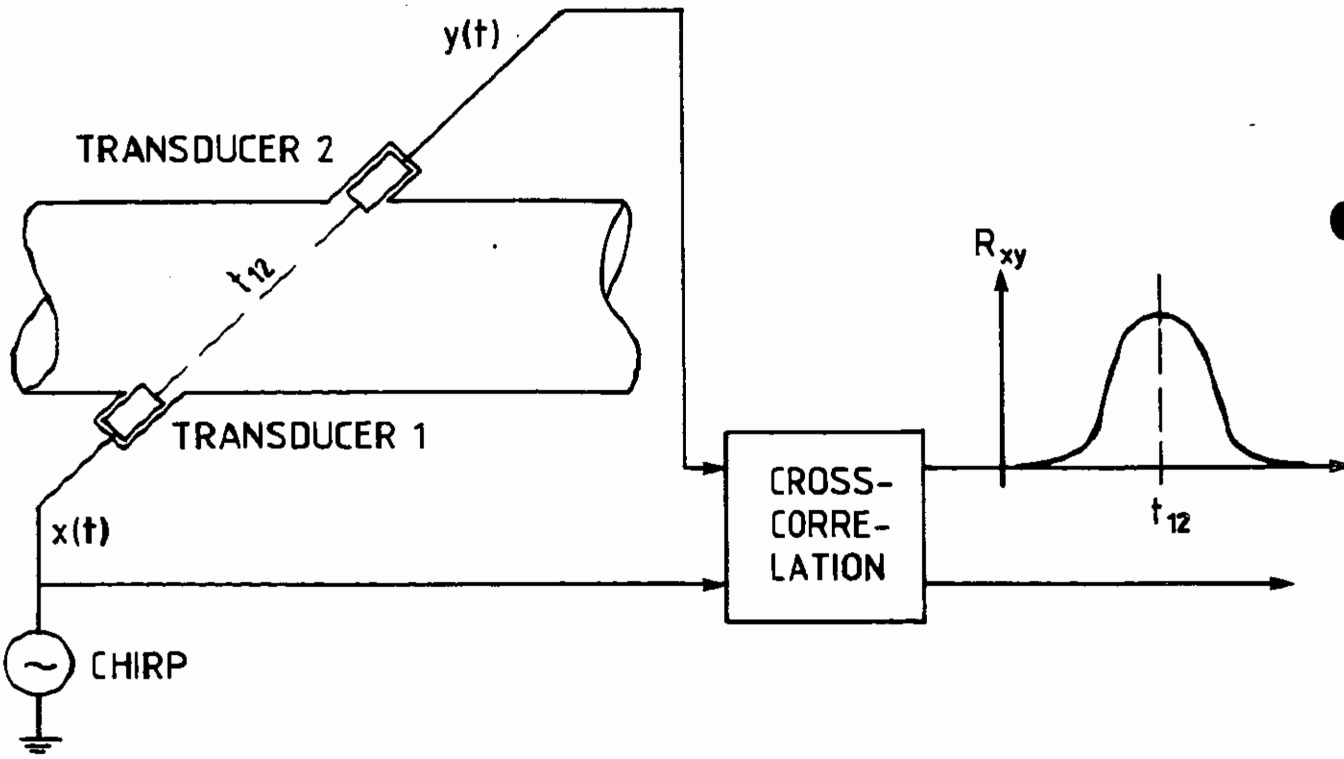

Figure 2. Principle of cross-correlation transit time measurement.

The improvement will increase with increasing duration and bandwidth of the chirp pulse and decreasing cut-off frequency of the generated noise. This implies that it is important to use transducers with high bandwidths. Due to the lack of high resonance peak in high bandwidth transducers the transmitted sound amplitude will be low compared with narrow band transducers. A compromise between those two characteristics must therefore be done.

The maximum point of the compressed received signal represents the time from the moment the chirp transmission started to the arrival of the entire chirp pulse. This maximum point is detected by a peak detector and a timer/counter and thus t_{12} and t_{21} can be measured.

Continuous wave (CW) phase measurement

For low velocities the CW-phase detection technique will represent a more accurate transit time measurement technique than the chirp technique. The CW-phase transit time measurement technique has therefore been chosen for velocities less than 10 m/s.

The inherent problem with CW-phase measurements is that for large variations in transit time the phase detector output will repeat itself at intervals equal to one CW-period. Hence, to ensure an unambiguous measure- ment it is necessary to know the number of whole CW-periods in the transit time. The chirp measurement is used to determine this number, while the CW-phase measurement gives the fraction. While this 'correction' to the CW-measurement could be done for each transit time, the FGM-100 only correct the transit time difference in this way.

A block diagram of the transit time measurement system is shown in Figure 3.

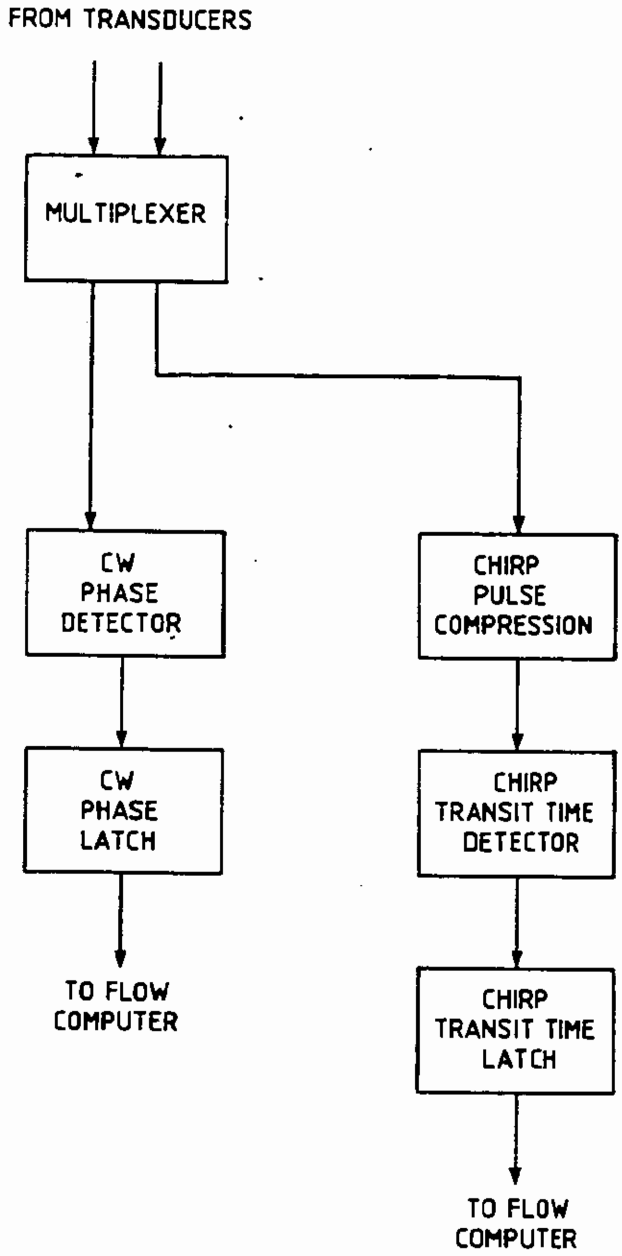

Figure 3. The transit time measurement system.

THE FLOW COMPUTER

The measured transit time is read into the Flow Computer from the CW-phase latch and the chirp transit time latch. In addition temperature, pressure and specific gravity (optional) are measured and read into the Flow Computer.

In the data filtering and evaluation block the transit time data are evaluated and 'noise measurements' are filtered out.

From the filtered data, the gas flow velocity is calculated from the formula given above. The velocity is then compensated for pressure and flow-profile variations along the section of the pipe. Then, standardized volume flow is calculated from the evaluated velocity using the measured temperature and pressure values obtained from the sensors placed on the pipe.

Mass flow is calculated from the standardized volume flow and measured or calculated specific gravity.

Totalized volume flow and mass are also calculated.

General layout of the complete signal processing system is shown in Figure 4.

THE ULTRASONIC TRANSDUCERS

Measuring flaregas flow we get into the difficulty that the gas pressure is low and hence, the acoustic impedance of the gas is low.
Due to safety reason the ultrasonic transducer should be encapsulated in steel or other strong resilient materials which will have a high acoustic impedance. The large difference in acoustic impedances will result in a poor acoustic coupling between the transducer and the gas at low pressure. Ordinary piston mode transducers can therefore not be used.

CMI has, however, succeeded in developing a new type of transducers which has a much better acoustic coupling to the gas than the piston mode types, even at low gas pressure. These transducers are made out of titanium, operate in flexure mode and are tuned to transmit and receive in the vicinity of the frequency of 80 kHz.

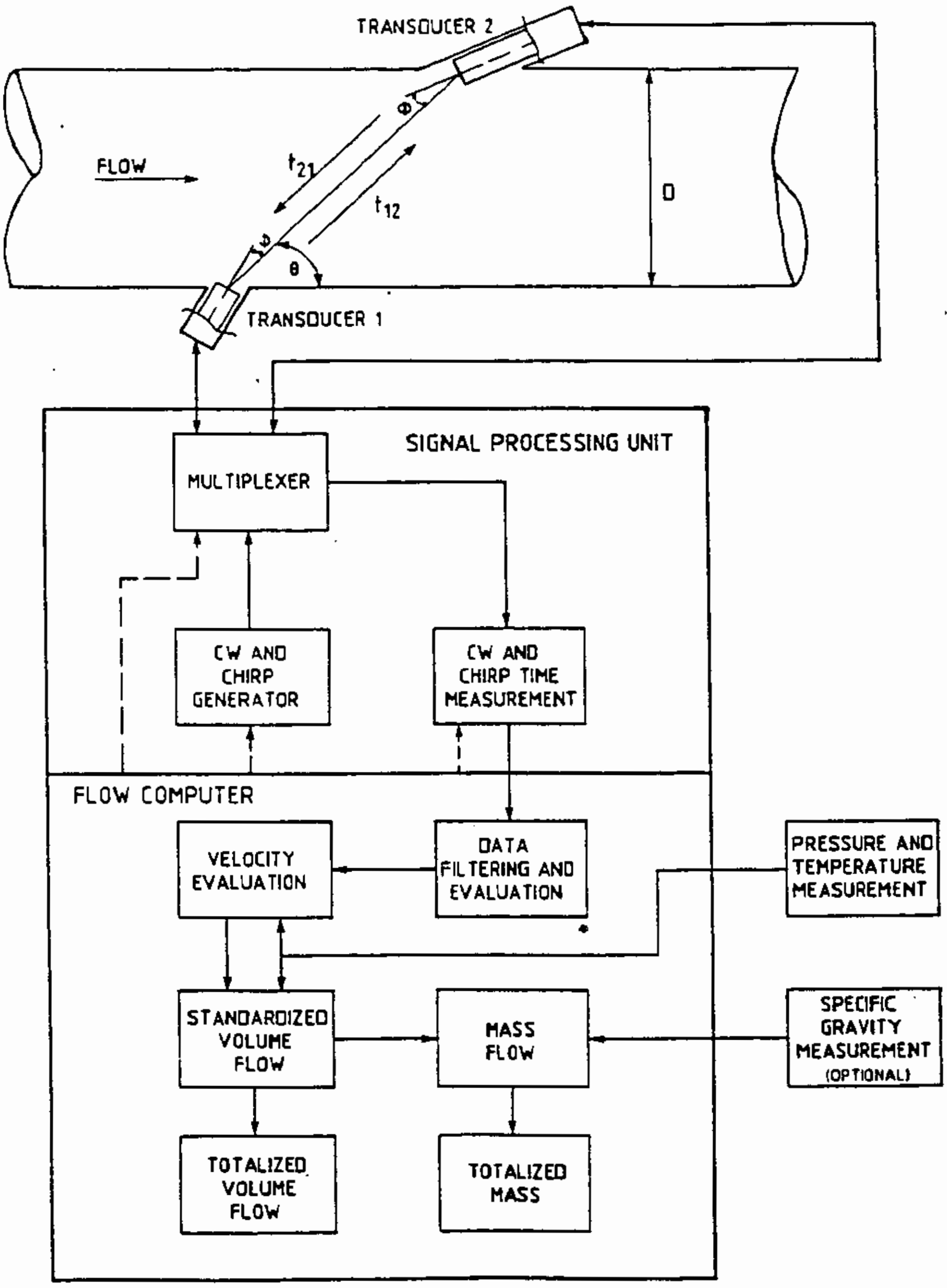

Figure 4. General layout of the signal processing system in FGM-100.

Due to safety considerations, the mandatory certification required for electronic and electrical systems has been obtained for these transducers from BASEEFA of the Health and Safety Executive of the United Kingdom.

In addition, the system placed in the flowpipe has a BASEEFA system certificate.

Elaborated tests and investigations of the transducer housing and type of damping materials hve resulted in a transducer with sufficient band-width to be used in an efficient chirp system.

THE SIGNAL TRANSMISSION SYSTEM

One unique feature in the FGM-100 flowmeter is the usage of optical fibres for transmission of signals between the ultrasonic transducers and the signal processing unit. The usage of optical fibres improves the resistance of the system to EMI-noise considerably.

The type of fibre used in the FGM-100 Ultrasonic Gas Flowmeter is shown in Figure 5.

The sheet containing the optical fibre is flame resistant and has been used in fibres used on offshore installations. The non-metallic 4-fibre cable of NEK Kabel A/S is specially designed for data communication and can withstand temperatures upto 125°C.

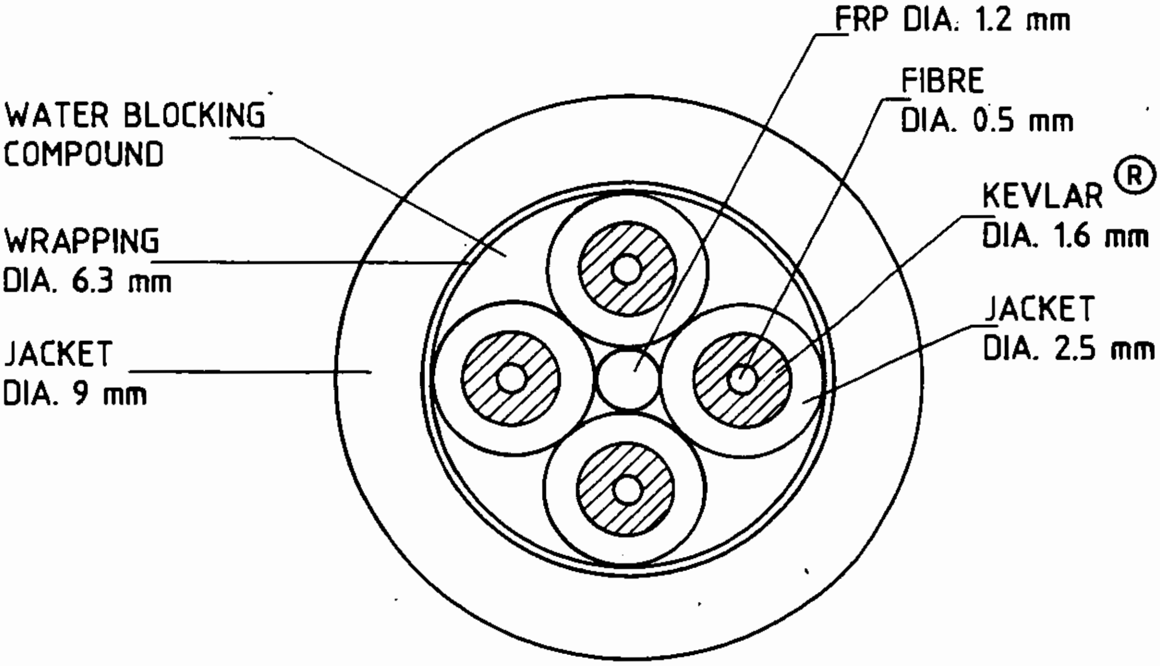

Figure 5. Optical fibre signal transmission cable.

SYSTEM LAYOUT

The system layout is shown with the principal units in Figure 6. The principal units are the following:

- CMI-Ultrasonic transducers
- Certified power supplies
- Two pairs of optical cables
- Signal processing unit
- Flow Computer
- Sensors for monitoring certain state variables of the gas
- Recording unit
- Key Board with alpha-numerical display.

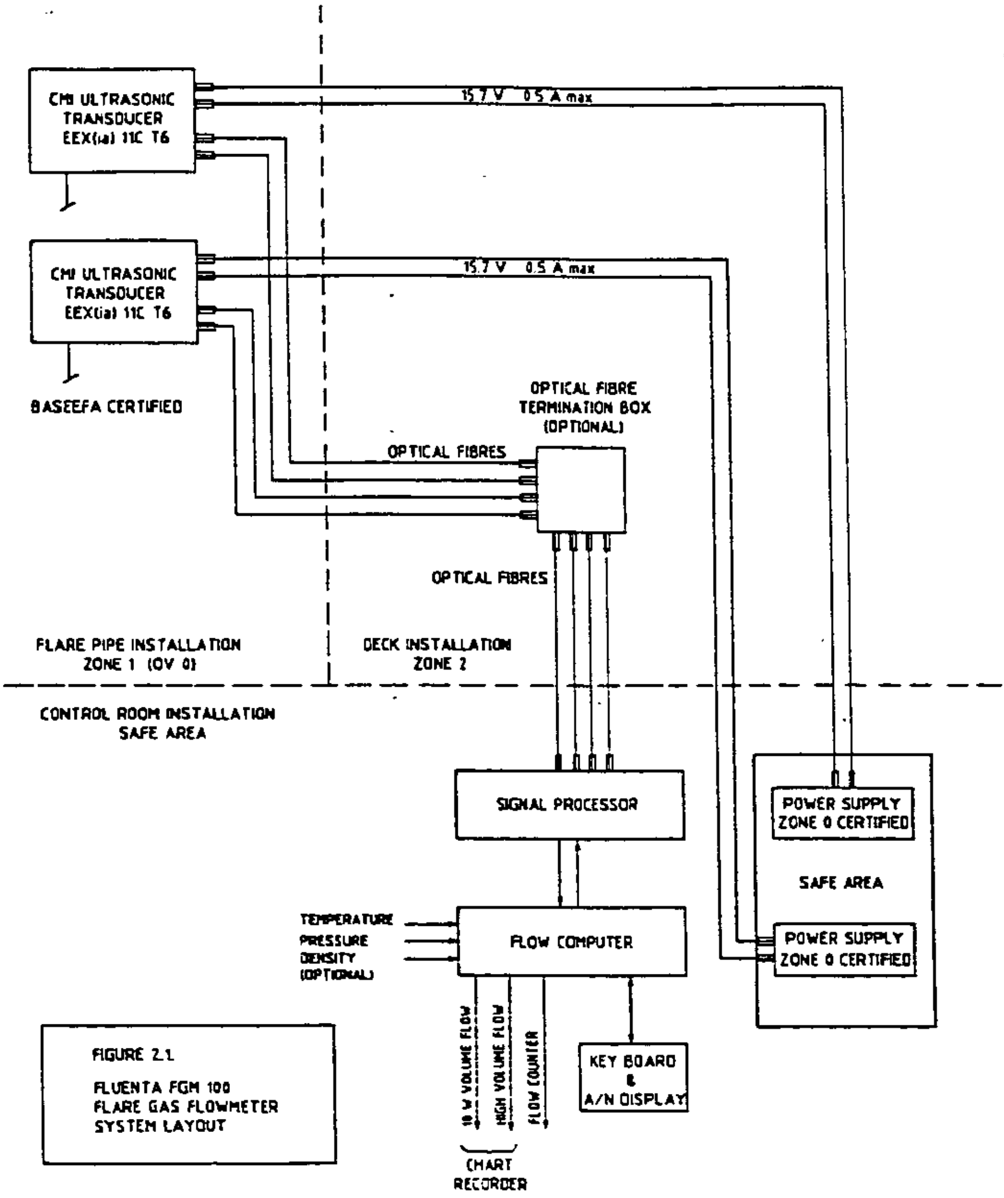

Figure 6. The system layout of FGM-100 Flare Gas Flowmeter.

As can be seen in Figure 6, these units are placed in various safety zones during actual installation. The zones specified in Figure 6 are:

- Zone associated with the transducers in the pipe in which the gas to be monitored is flowing. This is usually Zone 1 on offshore installations.

- Zone associated with the installations direct on the deck serving the transducers. This is usually Zone 2 on offshore installations.

- Control room, in which the signal processing unit and the flow computer are placed with the peripheral units for communication to the personnel in the control room. This is a 'safe area' according to the zonal classifications. The optical fibres carrying the signals associated with the ultrasonic interrogation of the flow are terminated in the terminal box with fibres of fixed length connected to the ultrasonic transducers. The rest of the fibres going to the control room can be of varying length, depending on the application.

TRANSDUCER MOUNTING

The transducers can be mounted on the flare pipe using specially designed rigs for accurate transducer orientation. The transducer mounting tubes are fitted with ball walves arranged in such a way that the transducers can be removed from the flare pipe without shut down of the flare. This is shown in Figure 7.

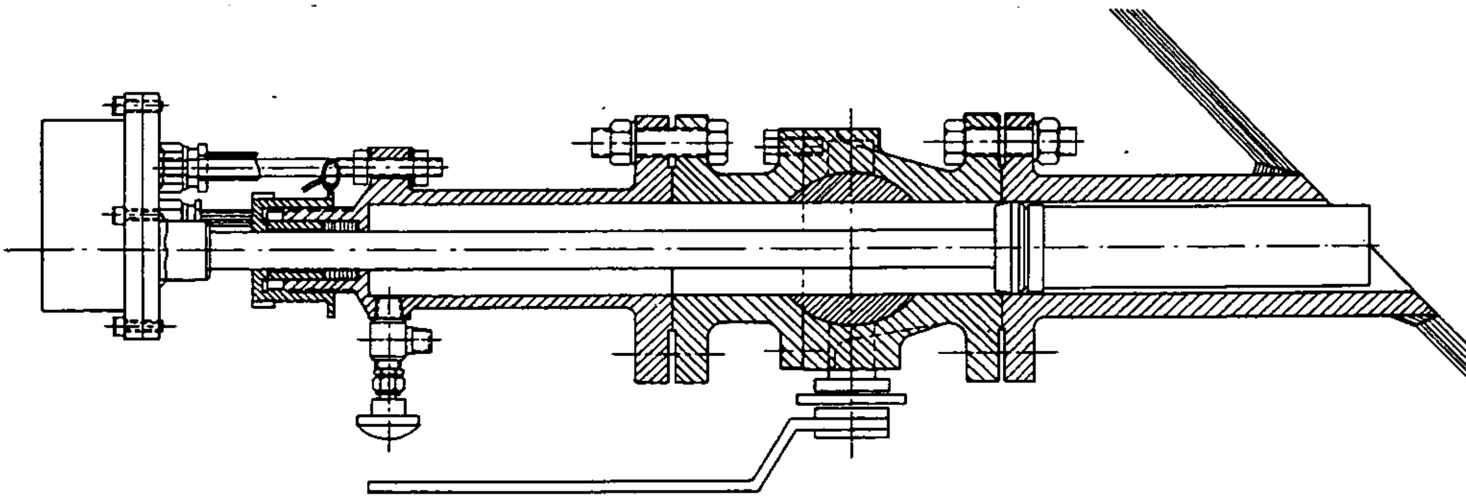

Figure 7. Transducer carrier unit.

SYSTEM PERFORMANCE

The FGM-100 Ultrasonic Gas Flowmeter has been designed to deal with difficult flaregas flow-metering problems; high turn-down ratio, and rapidly varying flow-rates and strict safety standards for devices utilized in explosive or potentially explosive environments.

As a result of extensive R&D, the meter has the Veritas certificate for mechanical stability for usage on Statfjord B platform, and BASEEFA certificates for intrinsic safety of the ultrasonic transducers and for the whole system. The model has undergone extensive tests in wind tunnel facilities in Norway. The BASEEFA certificates are for safety class EEXiaIICT6 and have the following numbers: EX 86B2411 and EX 872089.

The special transducer design and unique signal trains, containing unusual signal forms not found in other ultrasonic flowmeters, make it possible for the model FGM-100 to monitor flow velocities of gases at high turn-down ratios.

In addition, the frequent interrogation of the flow and advanced real time filtering of data make the meter an accurate device which combines robustness and easy installation with intrinsic safety.

The flowmeter has been tested between 0.05 m/s and 100 m/s in pipes with diameter of 36" (about 1 m). The overall uncertainty at 95% confidence level was found, from the wind tunnel tests, to be around 5% of measured value at fully developed turbulent conditions in the range 0.3-70 m/s. The restricted velocity range of 0.3-70 m/s for the confidence level was determined by the windtunnel and reference flowmeters and not by the FGM-100.

The uncertainty was found to be around 3% of measured value for velocities around 20 m/s. The resolution is 0.01 m/s in 36" diameter pipes. The repeatability of the meter was found to be 1% of volume flow for velocities from 0.3 m/s - 70 m/s in 36" diameter pipes.

ACKNOWLEDGEMENT

The author of this paper would like to express his sincere thanks to the project group at Chr. Michelsen Institute who has performed the development of this instrument and to Statoil and Mobil who have had the encouragement and patient to sponsor the introduction of a new measurement technique for offshore use.

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.