DETAILS OF THE TOMOFLOW TECHNOLOGY

1 INTRODUCTION

Tomoflow's new flow measurement technology is based on techniques which are superficially similar to those used in medical body scanners to produce cross-sectional density images of the human body. However, instead of using complex X-ray, isotope or magnetic resonance techniques, simpler (and more cost-effective) electrical capacitance measurements are used to obtain the density (concentration) image profiles at two separate locations on the pipe. Mathematical cross-correlation techniques are then used to calculate the velocity profile of the fluids inside the sensor from the two concentration profiles. The product of the concentration and velocity profiles of the fluid mixtures are integrated over the pipe cross-section to yield the flow data.

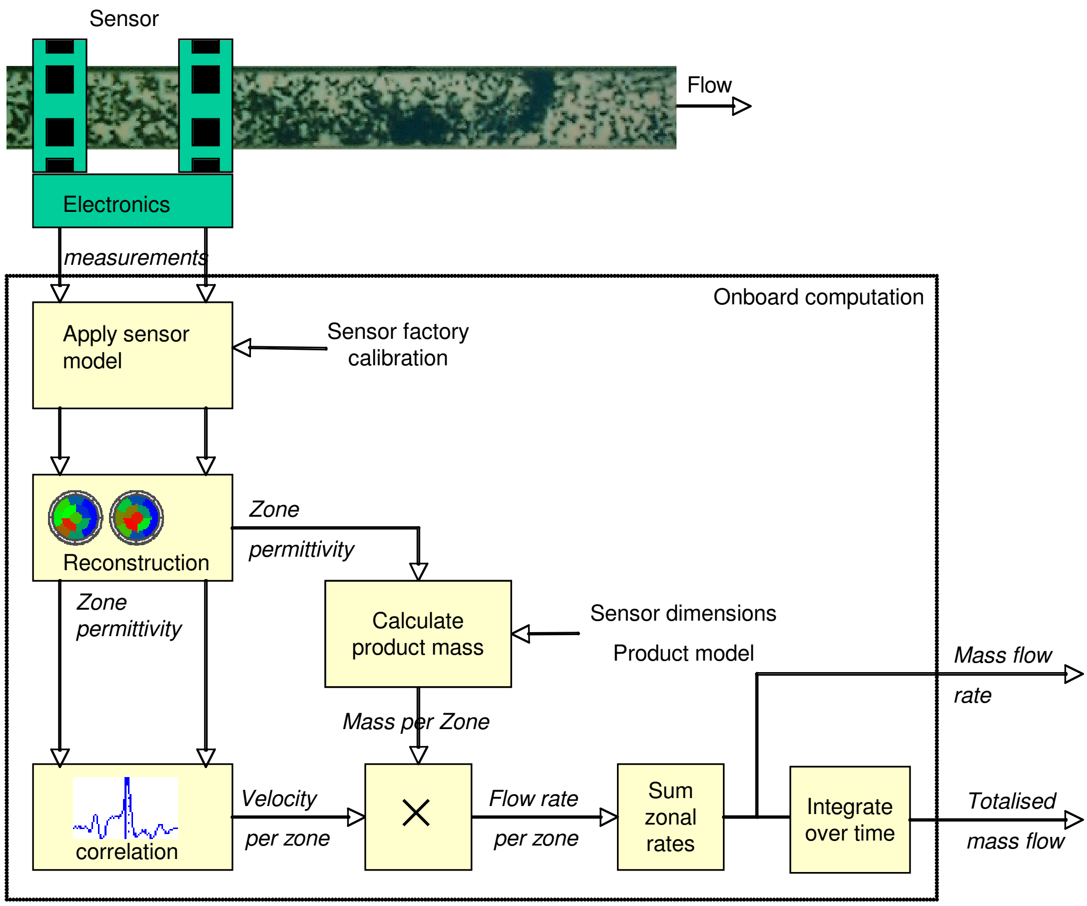


Fig 1 Tomoflow measurement principle

A simplified diagram of the Tomoflow measurement system is shown in figure 1. A twin-plane, multi-electrode capacitance sensor is located on the flow pipe or vessel and capacitance measurements are made at high speed between all combinations of electrode pairs at each measurement plane. These two sets of capacitance measurements are converted (reconstructed) into a pair of concentration profiles at the two measurement planes using Electical Capacitance Tomography (ECT)*.

* Some basic information about Electrical Capacitance Tomography is given in section 4.

The concentration values of similar cross-sectional zones at the two pipe locations are correlated to extract the average velocity in each zone and the volumetric flow profile across the sensor is then calculated from the concentration and velocity flow profiles and the sensor dimensions. This measurement and computation process is carried out on-line and in real-time.

The Tomoflow Technology has a number of unique advantages:

- Multiphase flows can be measured provided the imaging system can distinguish between the two phases. Most other measurement techniques require the two flow components to be separated before measurements can be made.
- It can be non-invasive and therefore will not disturb the flow pattern. Consequently it can be used where abrasive flows would destroy other flow sensors.
- The lack of internal features or moving parts means that there is no extra pressure drop across the sensor and also results in low maintenance costs.
- As the velocity is calculated in each zone across the flow cross-section, the measurement does not suffer from the gross errors exhibited by multiphase flow meters which rely on calculating an average velocity figure over the pipe cross-section.

Further information, including a number of technical papers can be found on the PTL web site **www.tomography.com**.

2 CURRENT DEVELOPMENT STATUS

The Tomoflow technology is currently available in 2 formats:

1. A multi-channel capacitance measurement instrument (**TFLR5000**), controlled by a standard PC via an ethernet link which connects to a remote multi-electrode capacitance sensor using RG174 coaxial connecting leads. This equipment is suitable for use in laboratory applications. Details of this instrument are given in a separate document.

2. An integrated flow sensor controlled by a standard PC. This system is suitable for use in light industrial environments. Details of a first prototype constructed on a 130mm OD PET tube are given in section 3. Similar devices can be fabricated on tubes of different diameters.

3. PROTOTYPE INTEGRATED TOMOGRAPHIC FLOW METER

(a) Internal View (b) External view

Figure 2. Prototype Tomographic Flow Meter.

The first practical realisation of this new technology to be developed is a fully-engineered prototype Tomographic Flow Meter (TFM), which can measure both overall product flow and which can also be used to analyse and optimise the flow of a mixture of 2 materials.

The prototype TFM is constructed on a plastic (PET) pipe of internal diameter 120mm and uses sets of 8 electrodes located around the circumference of the tube. All of the sensor electrodes and the electronic measurement circuitry are housed within a cylindrical metallic screened can. An internal view of the flow or electrodes and the meter is shown in figure 2(a) and the completed flow meter with the external screen fitted is shown in figure 2(b).

The sensing electrodes are fabricated on a flexible copper-clad plastic laminate using photolithographic techniques and this laminate is wrapped around the outside of the PET tube as shown in figure 3 to form the measurement electrode assembly.

This design approach allows a common set of measurement electronics to be used with pipe diameters in the range 50 to 300mm, so that only the sensing electrodes need be changed for different pipe diameters.

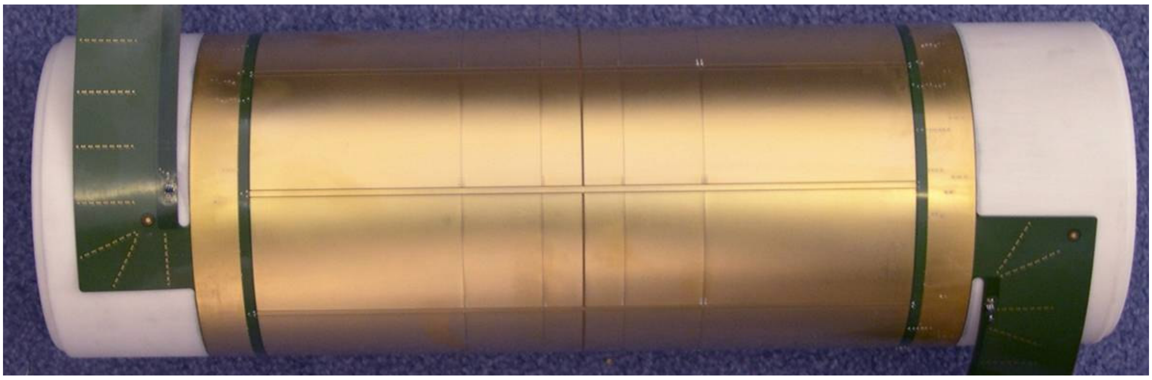


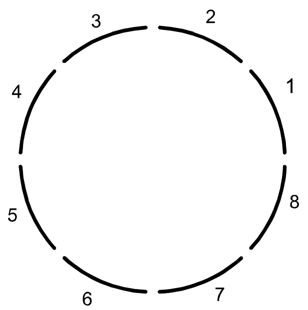
Figure 3. Electrodes mounted on PET Tube

The inter-electrode capacitance measurements are carried out using two analogue circuit boards, each of which contain 8 identical measurement channels (1 per electrode) and these analogue boards are controlled by embedded software which runs on a common digital circuit board which contains a Digital Signal Processor (DSP). One of the analogue circuit boards can be seen on the RHS of figure 2(a) and the DSP board is on the LHS of the same figure. The DSP board has a number of interface ports, including a high-speed ethernet link and an industry-standard serial port.

The existing prototype is currently controlled by a standard laptop computer via the ethernet link, although the internal Digital Signal Processor (DSP) chip is capable of fully controlling the unit instead of the PC if required. Real time flow information etc. is available either via the ethernet link or the serial port.

4. ELECTRICAL CAPACITANCE TOMOGRAPHY (ECT)

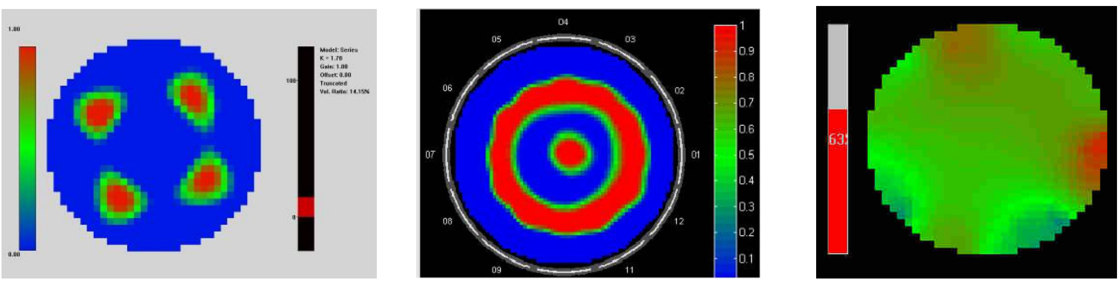
ECT is a technique for measuring and displaying the concentration distribution of a mixture of two insulating (dielectric) fluids, such as oil, gas, plastic, glass and some minerals, located inside a vessel. The measurement can be completely non-invasive if the vessel walls are non-conducting. The basic idea is to surround the vessel with a set of electrodes (metallic plates) and to take capacitance measurements between each unique pair of electrodes. From these measurements, the permittivity distribution of the mixture (which is related to the concentration of one of the fluids) can be deduced. In principle, vessels of any cross-section can be imaged and an example of a simple cylindical 8-electrode sensor is shown below.



Typical electrode arrangement

Practical ECT sensor

The concentration distribution, which can be derived from the permittivity distribution, is normally plotted on a fairly coarse pixel grid, because the relatively small number of available measurements limits the possible image resolution. In the sample images shown below, a red/green/blue colour scale shows areas of high concentration as red and areas of low concentration as blue.



(a) 4 plastic rods (b) Plastic rod inside plastic tube (c) fluidised sand

Sample ECT images

Although the resolution of ECT images is relatively low, they can be captured at high speeds, typically 5000 frames (images) per second for an 8-electrode sensor. If the fluid is in motion and images are captured at 2 axial locations, correlation techniques can be used to calculate the velocity profile across the vessel cross-section as well as the concentration profile. This enables the flow profile and overall flow rate in two-phase flow systems to be calculated. ECT can be used in a wide range of applications, including monitoring fluidised beds, flow rate measurement in pneumatic conveying systems, flame and combustion imaging, product uniformity monitoring and sensing, high-speed check-weighing and the monitoring of oil-gas flows. Further information on ECT and flow measurement applications can be found on the following web sites:

5. SOME COMMON QUESTIONS AND ANSWERS ABOUT THE TOMOFLOW TECHNOLOGY

Why does the world need another Flowmeter?
Most existing flowmeters work with a single fluid only, such as a liquid or a gas. These types of meter are widely used in industrial applications, particularly in the process and chemical sectors. Other common flowmeter applications include measuring the quantity of fuel supplied to vehicles in service stations and metering the supply of water and gas in domestic and commercial buildings. In all these cases, the fluid completely fills the pipe or vessel and they are examples of "single phase flows".

However, there are many other situations where it is either difficult or impossible to measure flows, particularly where there is a mixture of two different fluids inside the pipe. This situation occurs, for example, in oil production pipelines, which may contain a mixture of oil and gas. Another example is where solid particles (such as plastic pellets, sand, cement, coal or grain) are mixed with air and either flow under gravity or are pneumatically-conveyed inside pipes. These types of flow are known as "two-phase flows".

So what is new about the Tomoflow Technology?
The Tomoflow Technology offers a practical solution for measuring flows of mixtures of two insulating materials such as in pneumatic conveying of solids or the mixed flow of oil and gas. It works by measuring both the fluid mixture concentration and velocity at a range of locations over the pipe cross-section and calculates the overall flow from these measurements.

Does that mean there are lots of complicated sensors inside the pipe?
No. All of the sensing is done from the outside the pipe envelope, usually through an insulating liner, so that there are no physical obstructions inside the pipe and the Bühler-Tomoflow Technology is completely non-invasive.

How does it work?
The Tomoflow Technology is based on taking a large number of measurements between electrodes located on the outside of the pipe or vessel. Changes in the distribution of the fluids inside the pipe cause changes to the values of electrical capacitance measured between pairs of electrodes. From these measurements, it is possible to construct a map or image of the concentration distribution of the fluid mixture over the pipe cross-section.

This is done at high speed (500 images per second or more) and at two separate pipe positions. The 2 concentration images are then compared using a mathematical technique called cross-correlation, which allows a further map or image of the fluid velocity to be calculated. The concentration and velocity images are then processed to yield the accurate fluid flow rate.

Measurement Accuracy
Most existing flowmeters measure volumetric flow (eg. in litres per minute) and have accuracies in the range 1% to 10%.
The measurement accuracy of the Tomoflow Technology (in the range 1% to 5% depending on flow conditions) is already comparable with that of many existing flow meters and is likely to improved with further development.

What are its advantages?
Most flowmeters require the fluid concentration and velocity to be constant over the pipe cross-section. The Tomoflow Technology gives accurate results even when the fluid concentration and velocity varies over the pipe cross-section and can be calibrated to give results in either volumetric form, as a mass flowrate (eg. Kg per second) or totalised mass flow over a period (eg. in Kg).

Many flow meters contain internal components which disrupt the flow and are vulnerable to wear or damage by the flowing fluid. The Bühler-Tomoflow Technology contains no components inside the pipe and so is completely non-invasive.

And what are its limitations?
It is only possible to use electrodes located outside the pipe if the pipe wall is an insulating material such as plastic, glass or ceramic. In the case of a metal pipe, an insulated liner containing the electrodes is used. The Tomoflow Technology can only measure materials which are themselves electrical insulators (or predominantly so). This normally rules out its use with any form of aqueous fluid mixture.

Any other problems?
The Tomoflow Technology actually measures the permittivity distribution inside the sensor. Permittivity is an electrical property of insulating materials and is related to the volumetric concentration distribution of a mixture of 2 fluids by a set of well-established mathematical models. It is very important to select the correct physical model to obtain accurate flow measurements. If the product mass flow is required, the product density must be known or measured separately.

If a third fluid (eg small quantities of water in the form of moisture) is present, variations in the moisture content will also affect the sensor accuracy. However, in some cases, the sensor can be made to measure the product moisture content under flow conditions and compensate for this automatically.

What is the current state of development?
A working prototype, currently controlled by a laptop computer, has been developed and tests on this prototype show that it is possible to achieve measurement accuracies in the 1-5% range. This allows mass-flow measurements to be made with accuracies comparable to a loss-in-weight feeder system, but with the extra advantages of no interruption to the flow and with far greater dynamic response. This offers new measurement and control opportunities in process control. It can also be used for balancing flows between branches in a flow system and for detecting pipe blockages and other abnormal flow conditions.

For further information, please visit the PTL website www.tomography.com or contact us by email (enquiries@tomography.com).

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