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Solids Mass Flow Measurement in Pneumatic Pipelines

by F.M. Transducer and Microcomputer

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Summary

The paper outlines the basic design of the frequency modulated capacitance transducer which has been successfully used to measure mass flow rates of materials ranging from conducting metal particles to non-conducting solids with a wide range of permittivities.

The sensing electrode used offers no obstruction to the flow of the material and there are no moving parts to wear out. Parameters involved in the optimum design of the electrode are mentioned and their applications to different types of flow system shown.

Two capacitance transducers, axially spread along a pipe, sense the instantaneous concentration of the air-borne particles using turbulence flow noise techniques. The flow noise signals from the two transducers are cross-correlated to obtain the mean powder velocity. Also available from the transducer is the rectified and averaged signal which is related to concentration.

The velocity and concentration signals are then input into a PET microcomputer from which the mass flow rate is calculated and displayed. The computer also provides output signals suitable for controlling the feed rates or for triggering alarms if plant is not operating near the required set point.

1. Introduction

The chemical industry is automating and an important aspect of this introduces the need to measure quantitatively and qualitatively the state of the plant. One branch of this involves solids flow metering.

The mass flow rate of solids in a pneumatic conveyor is related to the product of the solids velocity and concentration. These two parameters are measured and a system using a microcomputer calculates the flow rate.

The microcomputer-based solids flow meter is simple, reliable and low in cost. It is intended for flow indication and alarm in automatic plant and machines handling solids materials. It is suitable for flow measurement and control in the majority of process situations where accuracies of a low percentage, together with continuous flow measurement, are required.

A block diagram of the system is shown in Fig. 1. It consists of two capacitance transducers, a cross-correlator, an interface unit and a microcomputer.

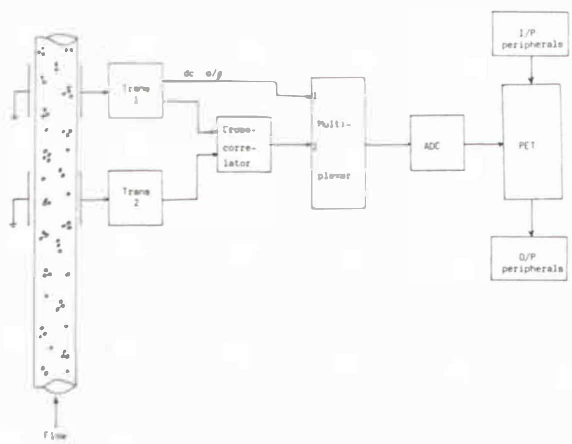

Fig. 1: System block diagram

2. Principle of the Transducer

A capacitor, termed the electrode, is formed in the walls of a pneumatic conveyor. The mass flow of particles in the conveyor may be measured by relating the mass in a section of the pipe to the change in capacitance of the electrode.

The dielectric constant of the air in the field of the electrode increases with the presence of solids in the conveyor. However, the flow of particles in a pneumatic conveyor is not completely regular. This may be due to variations in the feed rate of the material into the conveyor because of load changes in the storage feed hopper. Also particles moving in the conduit strike rough parts of the walls and generate components of velocity normal to the flow axis. These changes in velocity are observed in the form of turbulence with particles colliding with each other causing local variations in the concentrations of the solid in the pipeline.

The flow may be regarded as a mixture of an average flow and a superimposed smaller irregular flow termed the flow noise. It is found, experimentally, that there is a direct correlation between flow noise and the mass flow.

Capacitance changes dependent on both the average flow and the flow noise are produced when particles flow through the electrode. The instrument converts the capacitance flow noise into an electrical signal which depends on the mass flow rate. The instrument consists of two main sections namely the electrode and the transducer proper.

The electrode shape and size depend upon the specific application, but basically it consists of a capacitor formed flush with the walls of the conveyor so that there is no obstruction to restrict the flow. This capacitor is connected in parallel with an inductance inside the transducer to form a tuned circuit for a transistor oscilloscope (Fig. 2). The frequency of oscillation varies with changes in electrode capacitance. An integrated F. M. demodulator circuit converts these changes in frequency to voltage changes which contain components due to the average flow, the flow noise, capacitance changes due to deposits or wear of the conveyor wall and drift in the working parts of electrical components. Of these only the flow noise is required in the final electrical signal. An AC amplifier effectively removes the rather slow voltage changes and its output is passed in an AC voltmeter to produce a current output of 4—20 mA. The output of the AC amplifier is also available for cross-correlation. A refinement of the instrument is made by feeding the slow voltage changes into a voltage to capacitance converter, which in turn regulates the oscillator frequency so that optimum electronic working points are maintained (Fig. 2) [1].

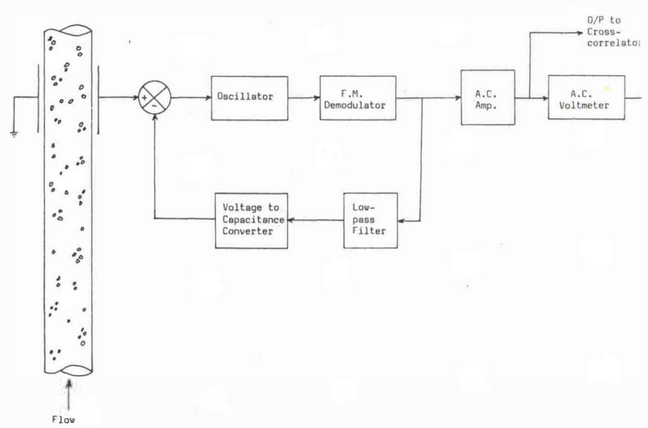

Fig. 2: Transducer block diagram

2.1 Application to Flow Measurement

In pneumatic systems the gas velocity is usually sufficiently high to cause turbulent flow, because these conditions minimise blockage due to settling out of the conveyed solids. In such a system the solids tend to be uniformly distributed throughout the conveyor and the high level of turbulence produces relatively large amounts of flow noise. For these applications the electrode design is relatively simple and several designs are available, the actual design is decided mainly by the shape, conveying gas pressure and size of the ducting. The positioning of the electrode must be considered and it should be placed several pipe diameters away from bends in the conveyor.

Ring electrodes are the most convenient for pipes up to 100 mm in diameter. For larger diameter pipes and rectangular ducts better results are obtained by removing a section of the duct wall and replacing it by the electrode plate. However, in one particular application it is found that the ring electrode is required even though the pipe diameter is 370 mm (14 $^1/_2$ in). This is in the transporting of pulverised fuel (pf) into a coal fired burner where severe 'roping' of the solids flow causes an extremely irregular solids distribution as described below.

2.2 The Ring Electrode

In this electrode a complete section of the conveyor is isolated from both up and down stream sections. The central section is about 15 mm wide and is spaced using materials with low dielectric coefficients (e. g. PTFE) resulting in a physical gap of 4 mm between the two pieces of metal (Fig. 3).

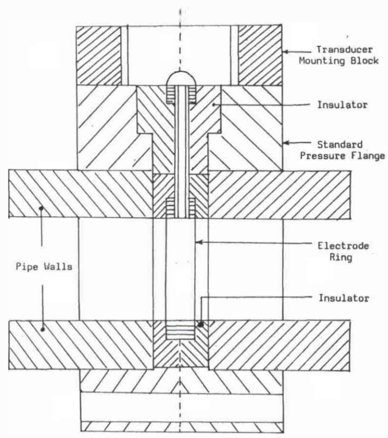

Fig. 3: Section through a typical ring electrode

The sensing electrode is a ring all round the circumference of the pipe wall enabling it to detect all round the conveyor. This gives it an advantage over localised electrodes. Furthermore, the electrode sensing zone has good penetration into the centre of the conveyor. A phenomenon termed the 'roping' effect occurs in pf flow in the feed pipes to a coal fired burner. A 'rope' is a band of fuel formed by the segregation of pf and air. This travels as a helix along the pipelines resulting in a very irregular distribution of pf in the pipe. The shape and position of the helix depends upon the flow conditions. All these suggest that the electrode used should be equally sensitive over the whole cross-section of the conveyor because a localised electrode could unfortunately be positioned diametrically opposite to the rope under certain flow conditions or even having the rope precess near it periodically under other flow conditions. The ring electrode is hence ideal for this particular situation because flow signals will be detected irrespective of the shape and position of the rope or the regularities of the flow distribution [3].

3. The Cross Correlator

The measurement of the transit time of a lagging signal or disturbance in the flow between two axially separated sensors is termed cross-correlation. Basically, this means that the passage of some disturbance in the flow is followed and the time it takes to travel to a downstream point measured. The transducer senses this disturbance in the flow and the correlator computes the transit time from the AC signal of two transducers.

The cross correlation function is defined by:

$$R\,x\,y\,(\tau) = \frac{1}{T}\int_0^T x\,(t-\tau)\,y\,(t)\,d\,t$$

It can be shown that this function has a maximum value when the cross-correlation lag, τ, is equal to the transit time τ^* of the lagging signals. Hence if l is the transducer spacing then the flow velocity, $\mu = l/\tau^*$ [2].

By studying the shape of the correlograms, the cross-correlator can also be used to detect incipient blockage. This is especially important in processes like the pf flow to coal-fired boilers in which the feed pipe may be blocked due to the 'roping' effect. In the horizontal section of the feed pipe the 'rope' travels along the bottom of the pipe and slows down under the influence of the frictional forces with the pipe wall. This may result in a blockage which is very dangerous because a blocked pipe may ignite back causing an explosion. It is, hence, vital that incipient blockages be detected.

A set of curves made under laboratory conditions are shown in Fig. 4. Curve (i) shows a sharp peak, indicating

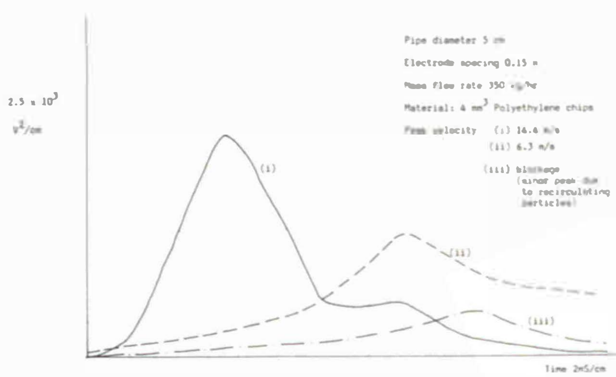

Fig. 4: Typical correlograms

that all the particles are travelling at approximately the same velocity. As particles start to separate out from the flow the width of the peak widens and the height falls due to the increasing spread in the particle velocities. Curve (ii) shows the pipe when separation is just commencing and curve (iii) represents the virtually blocked pipe condition. So by studying the shapes of the correlograms a warning signal can be generated for any predetermined set of flow conditions [4].

4. The PET Microcomputer and its Interface

The PET microcomputer gathers data from the capacitance transducer and the cross-correlator via its interface. Together with the inputs and specification from the keyboard, the computer with the help of the algorithm stored in its memory then calculates the required parameters. It will display the parameters the software commanded for and, if necessary, send out warning and control signals.

The data coming into the PET are the concentration signal from the transducer and the transit time signal from the correlator. The concentration signal is in current whilst the transit time signal in voltage. They are both analogue signals and have to be converted to digital signals suitable for the computer. The conversions are done by the interface unit, which consists of a 16 channel, 8 bit analogue to digital converter. A POKE instruction from the software of the PET will enable the converter and start the conversion of the selected channel from analogue to digital form. A PEEK instruction will then read the data into the computer.

The transit time signal is used to calculate the mean particle velocity, μ (Section 3). This, together with the concentration signal and the algorithms (Section 4.1) stored in the computer, is then used to calculate the instantaneous mass flow rate continuously. The calculated parameter will be displayed on the VDU.

For warning and control purposes, that is if the process is not operating within the preset values, output signals can be sent from the PET through digital to analogue converters to the device such as a valve or directly to alarms.

The shape of the correlograms can also be closely monitored so that any incipient blockage can be detected and the appropriate action taken.

4.1 The Computer Algorithms

The air velocity in many pneumatic conveying systems may have to be increased to prevent saltation at high solids flow rates. It is hence essential that solid velocities be measured so that a relationship between mass flow rate and velocity may be determined.

An experiment was carried out using 4 mm cube PVC chips pneumatically conveyed along a 80 mm diameter pipe. The experiment consists of runs in which the air pressure in kept constant and the solids feed varied. The transducer output, solids velocity (from cross-correlation) and mass flow rate (by weighing and timing) were recorded. The procedure is repeated for different air pressure. The results are plotted in graphs shown in Fig. 5, where

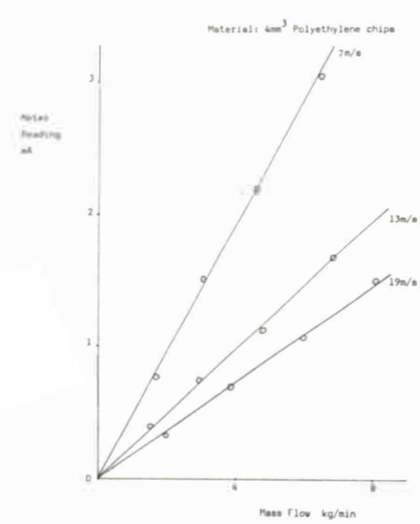

Fig. 5: Experimental results

linear relationships were obtained for each solids velocity, that is

$$Y = M_l X \quad (1)$$

where Y = transducer output (in mA) and solids concentration, X = mass flow rate. If the gradient, M_l can be related to μ, the solids velocity, then mass flow rate may be determined from μ and X. A graph of M_l versus μ is then plotted and this is linearised by using linear regression resulting in Fig. 6 where

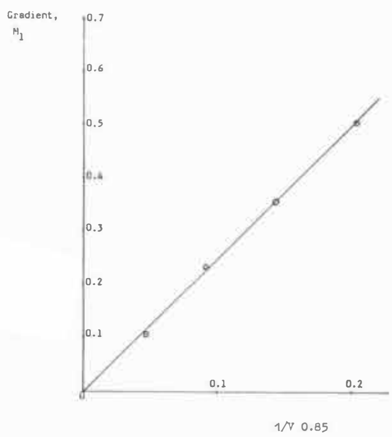

Fig. 6: Result of linear regression

$$M_l = \frac{2.5}{V^{0.85}} \quad (2)$$

substituting (2) into (1) and rearranging gives

$$X = \frac{YV^{0.85}}{2.5} \text{ that is}$$

$$\text{Mass flow rate} = \frac{\text{solids concentration} \times \text{velocity}^{0.85}}{2.5} \quad (3)$$

This equation is stored in the PET to enable the mass flow rate to be calculated from the concentration and transit time data.

The above equation applies to 4 mm cube PVC chips in an 80 mm conveyor. The measured solids signals is a function of the dynamic properties of the particle movement in a turbulent field and their permittivity, hence the numerical parameters in Equation (3) will vary with different applications.

5. Conclusion

A low-cost microcomputer based system for measuring mass flow rate over a wide range of conditions has been described. Mass flow of solids in the temperature range 0—70 °C presents no problem but special design of the electrode and positioning of the transducer is required for higher temperatures up to 400 °C.

The flexibility of the system means that it can be modified to cater for different applications. Special tasks like detecting incipient blockages, giving alarm signals and controlling valves to maintain the desired set points, can be performed.

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