# Fluid Velocity Profile Meters Using FeSiB Glass Covered Wires

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***Abstract -*** In this paper we present a fluid flow-meter based on the inductive response of glass covered FeSiB amorphous wires, arranged as vertical active cores with respect to the flow of a liquid in a pipe of circular or rectangular diameter. Arrays of parallel FeSiB glass covered wires, fixed at the one end and free at the other are set normal to the fluid flow inside of an array of thin coils, thus covering the whole cross section of the fluid conduit. An excitation coil is also used for static flow measurements. The displacement of each glass covered wire corresponds to the local velocity of the fluid. It has been determined that the uncertainty of the voltage output dependence on the fluid flow is better than 1%. So, the profile of the fluid velocity along the cross section of the fluid conduit can be determined.

## I. Introduction

A number of flow rate meters in closed conduits have been presented in the past [1- 6] based on destructive [7] or non destructive techniques.

In destructive techniques, the flow is affected by causing a secondary effect in order to measure it indirectly, or additives are used to create the secondary effect required to measure the flow in question. Differential pressure devices, weighing and volumetric methods, instability methods, variable area method, cross correlation method, turbine flow meter and tracer method are among the destructive techniques used for flow sensing and measurement.

On the other hand, non destructive techniques do affect neither the flow nor the flowing element. Such techniques or devices are the Coriollis flow meter [8-12], the electromagnetic method [13-17] and the Doppler technique.

Low flow rates are difficult to measure, especially with destructive techniques, due to the undesirable pressure drops introduced by these techniques.

An almost non – destructive technique [13] is presented in this paper, based on the measurement of the bending process of glass covered FeSiB amorphous wires fixed at one of their ends, arranged as vertical active cores of Linear Variable Transformers [18-19] with respect to the flow of a fluid in a pipe of circular or rectangular diameter. This technique allows the measurement of low flow rates, as well as the determination of the velocity profile into fluid conduits.

## II. Sensor description

The basic sensor arrangement is presented in figure 1. An array of parallel FeSiB glass covered amorphous wires (1), fixed at the one end and free at the other end is set normal to the fluid flow and are used as the active cores of especially designed Linear Variable Differential Transformers (LVDTs).

The wires are equally spaced in booth x and y directions and placed in a way covering the whole cross section of the fluid conduit (Figure 1a). The x - spacing is determined by the number of wires, while y - spacing depends on the width of the corresponding LVDT windings. Since this width is very small (of the order of mm), the y spacing between the first and the last used wire is very small, thus allowing assuming that the plane defined by these wires is perpendicular to the conduit axis.

The wires diameter is of the order of 100 μm, making their presence in the flowing fluid almost non-destructive because their surface is negligible in comparison with the diameter of the fluid conduit. The ratio between the wire surface and the cross section of the fluid conduit is 100/R (R expressed in micrometers}, where R is the active diameter of the fluid conduit.

The primary coils (2) of the LVDTs can be considered as rings placed out and along the length of the fluid conduit and surrounding it. The secondary windings (3) of each LVDT are set symmetrically with respect to the glass covered amorphous wire used as its active core and are connected in series opposition (Figures 1b, 2).

The operation of the sensor is illustrated in Figure 2 which presents a longitudinal section of the fluid conduit and one LVDT with its corresponding active core.

When the fluid flow equals zero, the output voltage of the LVDT equals zero, since no magnetic material appears inside the secondary windings of the LVDT.

When the fluid is flowing, the free end of the wire is displaced the glass covered amorphous wire is bent and curved, thus entering the secondary winding of the LVDT and an output voltage $V_o$ is developed at the LVDT secondary coil. This voltage is proportional to the amount of the magnetic material entering the secondary windings of the LVDT, i.e. the displacement of the glass covered wire acting as its core.

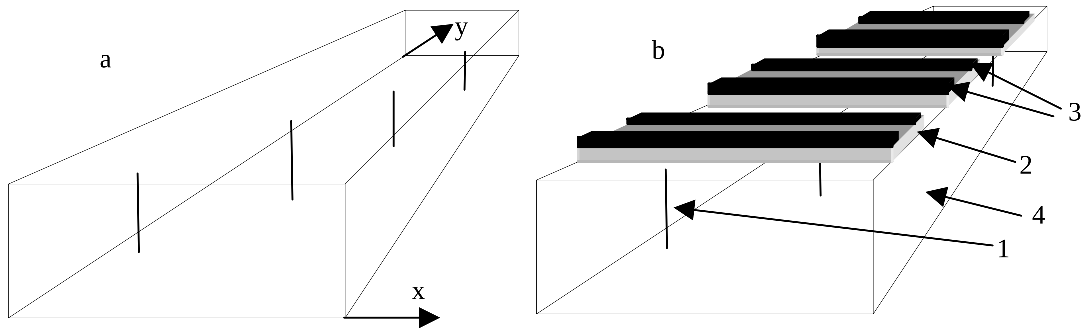


Figure 1: Schematic diagram of the sensor. (1) Glass covered wire used as active core, (2) primary LVDT winding, (3) secondary LVDT windings, (4) fluid conduit.

Since this displacement is proportional to the fluid velocity at the corresponding point, the output voltage of the LVDT can be used to determine the local fluid velocity at this point. The output voltage of the LVDT is reversed if the fluid flow direction is opposite to the one indicated in figure 2.

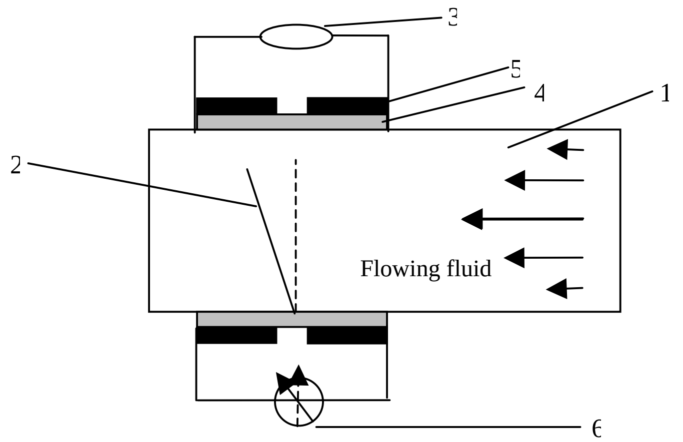


Figure 2**:** Sensor operation principle. (1) flowing fluid conduit; (2) amorphous wire fixed at the one end; (3) ac current source; (4) primary coil of the LVDT; (5) secondary coil of the LVDT; (6) ac rms voltmeter.

Using the above described procedure, the fluid velocity can be determined at the position of each wire. Since the array of glass covered wires covers the whole cross section of the fluid conduit, this sensor arrangement can serve to determine the fluid velocity profile into the fluid conduit.

### III. Experimental results and discussion

The sensor used for experiments comprises 10 LVDTs and 10 FeSiB glass covered amorphous wires of 120μm diameter as active cores (marked as ac1, ac2, …, ac10). This sensor was used to determine the fluid velocity into a pipe, using the experimental set-up of Figure 3, which is described in detail in [13].
Figure 4 presents the voltage output of the LVDTs with active cores ac1, ac2, ac3, ac4 and ac5. The outputs of the LVDTs with active cores ac6, ac7, ac8, ac9 and ac10 are identical to the outputs of the LVDTs with active cores ac4, ac3, ac2 and ac1, due to the fact that they are symmetrically placed to them with respect to ac5 which is placed at the middle of the conduit cross section.
Measurements made for flows up to 70 l/min indicate a monotonic response of the described sensor. However, the resulting voltage output is not linear; therefore, a computer controlled look-up table correction is required.

The experimental results obtained for various conditions of flow indicate a repeatable and monotonic dependence of the LVDTs outputs on the fluid flow. The resulting sensor uncertainty [20 - 23] is illustrated in Figure 5. As can be seen from this Figure, it never exceeds 1%.

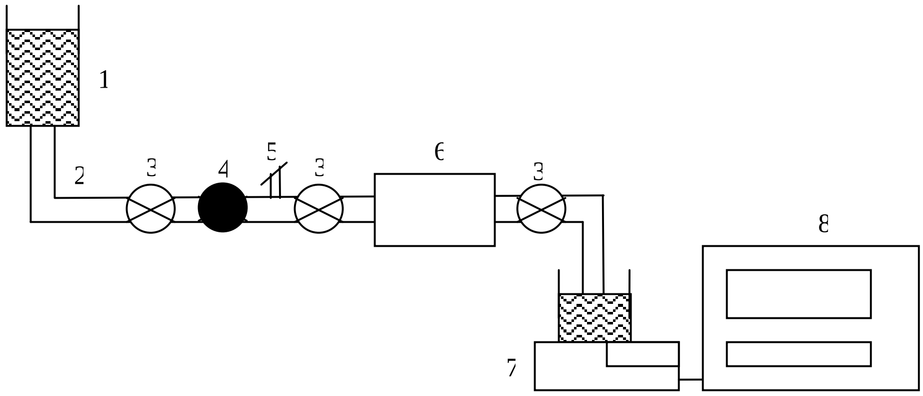


Figure 3. Experimental set-up: (1) liquid tank; (2) piping; (3) electric vanes; (4) controlled pump; (5) relief valve; (6) flowmeter; (7) real time reading electronic balance; (8) computer.

The simplicity of construction of the described sensor, the ability of using low cost electronics as well as the ability of modular construction ensures a relatively low and therefore competitive cost.

In conclusion, the presented sensor is a relatively low cost device offering good accuracy for industrial applications where the measurement of low flow rates is required.

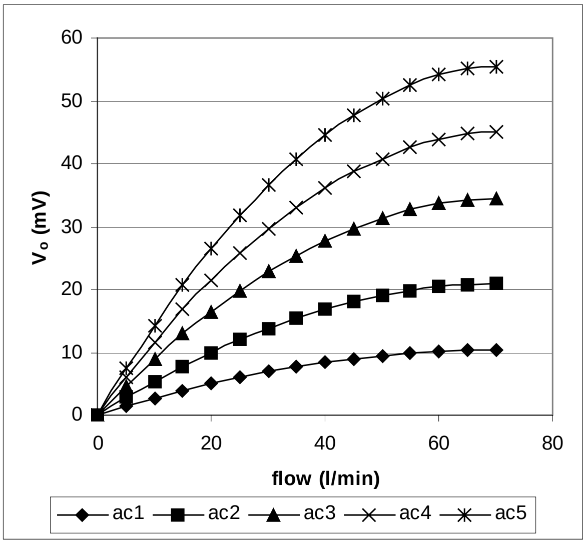


Figure 4: Dependence of the voltage output of the LVDTs on the fluid flow.

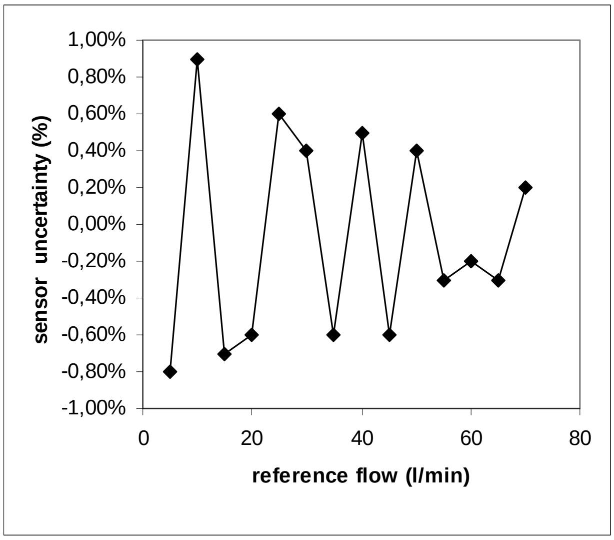


Figure 5: Sensor uncertainty

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