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Efficient and Low Cost Flow Measurement Using Bend Sensor Flowmeter

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Abstract

This paper presents a new, innovative and accurate approach to the measurement of flow which would give continuous and digital output. This paper deduces linear relationship between flow pressure measurement and the change in resistance of the bend sensor used in the setup. Finite element analysis of the sensor is also done and desired outputs are obtained. Low cost and good stability makes the sensor ideal for industrial as well as house hold applications.

Keywords— Flow measurement, MATLAB Curve fitting, ANSYS Finite Element Analysis, Bend sensor, Flow meter.

Introduction

Flow measurement is the process of measurement of bulk flow of fluid in open channels or inside close conduits. Measurements are generally done with respect to either pressure related to the flow of fluid or velocity associated to the fluid. Flow can be measured as volumetric or mass flow with units such as litres per second or kilogram per seconds. Flow measurement is used almost every industrial sector. From gas flow measurement at gas stations to measurement of slurry at sewage treatment plants, flow measurement plays an important role.

Flow measurement of fluid (a generalised term for both liquids and gases) in industries require great accuracy. For example, accuracy in flow measurement of petrol at a gas station is a primary requirement and devices with least error is the one best suitable for the application. On the other hand, at a flow measurement station measuring the flow through a pipe in a petrochemical plant requires repeatability and precision. Hence the measurement of bulk fluid requires consideration of a lot of system parameters related to the plant, the flowmeter is installed in.

The described model of flow sensor given below accurately gives out the reading of low pressure associated to fluid measurement for both low and high viscous fluids.

BEND SENSOR

Bend sensor, also known as flex sensor is a sensor that changes resistance depending on the amount of bend on the sensor. It is a passive resistance device fabricated by laying strips of carbon resistive elements within a thin flexible substrate. More carbon elements means less nominal resistance. These carbon elements are sandwiched by layers of thin copper and plastic films. When the substrate is bent the sensor produces a resistance output relative to the bend radius.

The bend sensor can be directly read as a potentiometer with a resistance output or across a voltage divider to get voltage output that is proportional to the bend applied. The sensor is immune to degradation through mechanical contacts, thus presents a long application life. In this work, commercially available 4.5 inch bend sensor by spectra symbol (www.spectralsymbol.com) has been used.

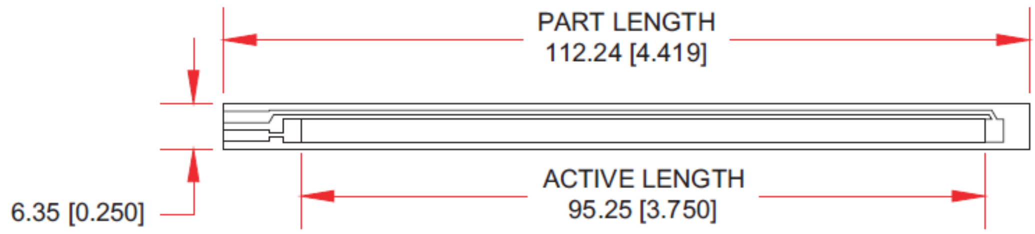

Fig. 1 Dimensional Diagram of Bend sensor in mm[inches].

Under no bend condition the output resistance of the sensor is 9.12 Kohms (flat resistance) and increases upon bending in one direction. The output resistance decreases if the sensor is bent in the opposite direction.

Fluid Flow Induced bending concept

A Flow instrument using a bend sensor utilises the basic principle wherein a fluid flowing inside a pipe bends the sensor toward the direction of fluid flow. The bulk flow of fluid can be quantised by the bending moment on the bend sensor that is caused by the drag associated to the flowing fluid. The basic model of the flow sensor is measurement of this bending moment in terms of the resistance and comparing it to the pressure and displacement curve for the same element found out by the finite element analysis using ANSYS software considering the main constituent of the sensor as Plastic (vinyl acetate).

The Flow instrument is placed inside the pipe housed inside Stainless Steel tubing that houses the bend sensor and the signal readout circuit with an insulated as well as water proofed cross-section. This is inserted inside the pipe whose fluid flow is to be measured by attaching T-joint tube fixture in between the pipe flow as illustrated in the fig 2.

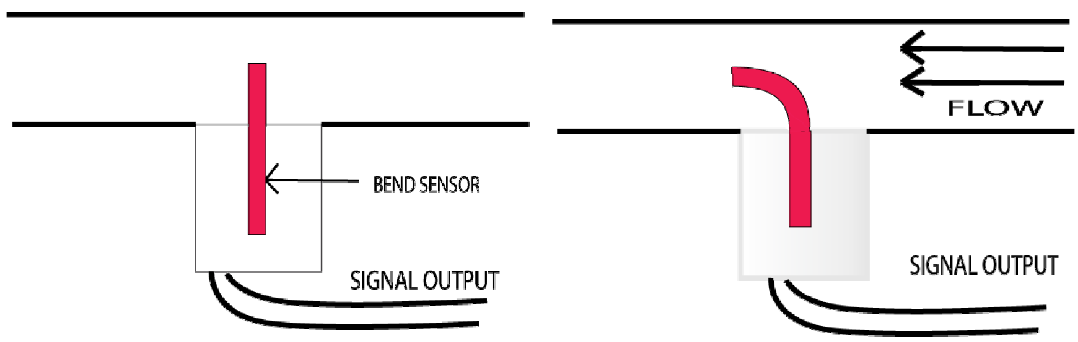

Fig. 2 (TOP) Flow Instrument field implementation illustration(Bottom) Bend sensor displacement due to fluid flow illustration.

Resistance Profiling

Resistance profiling operation is done to find the characteristics electrical resistance variation of the sensor versus displacement of the sensor from one tip while the other tip is kept stationary. A tapping point (hinged) of 6 cm from base is made, thus only 4.3 cm of the sensor is free to bend. The 6cm tapping increases the range of the device and reduces drag vibrations in the sensor strip while it is being use as a flow sensor in order to measure fluid flow inside a tube.

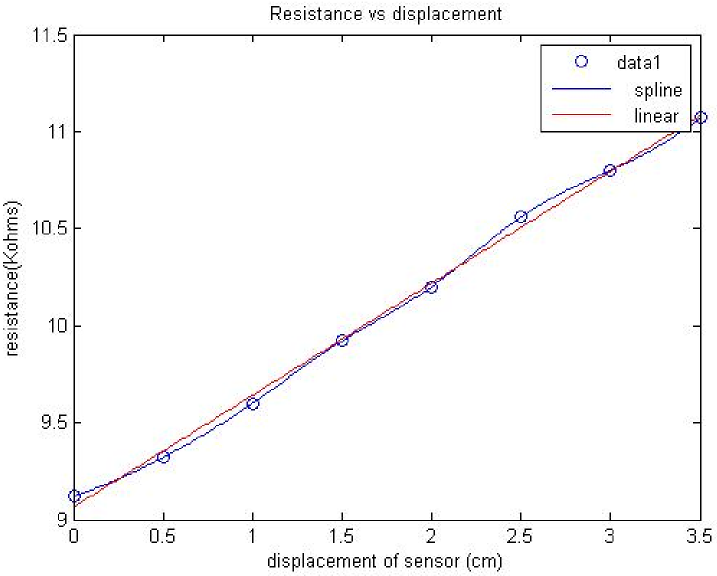

Fig. 3 Positive flow displacement vs resistance variation graph.

The above graph is a plot of the displacement of the sensor on a single axis and the consequent resistance variation produces by the sensor. The relation is a linear function for a maximum displacement of 3.5cms after which it has an exponential function.

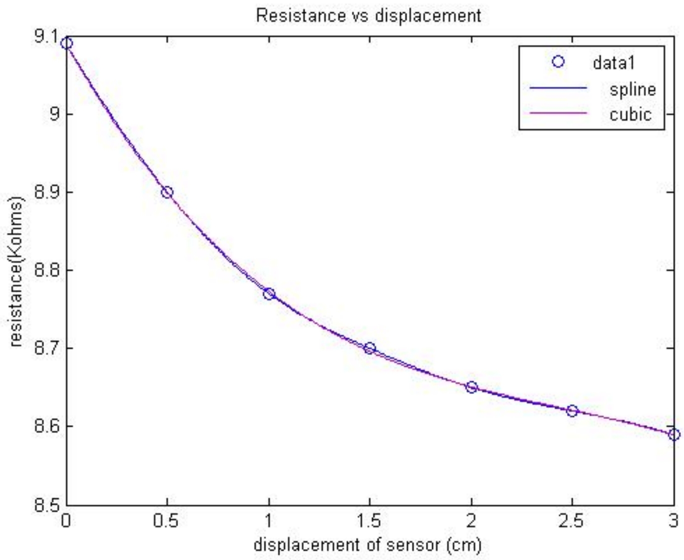

Fig. 4 Reverse flow displacement vs resistance variation graph.

The Bend sensor used is bidirectional. It gives inversely proportional resistance variation when it is bend in the opposite direction. Above graph (Fig3) is plot of sensor resistance variation and displacement of the sensor in opposite direction of the fig1 graph mimicking a reverse fluid flow inside a pipe.

ELEMENT DISPLACEMENT ANALYSIS

When the Bend sensor is under a fluid flow, the experiences a force or pressure which causes bending. The displacement of the non-stationary tip of the bend sensor from the initial flat condition can be calculated using Finite Element Analysis (FEM) using ANSYS software for various pressure values. Hence a relation between the resistance variation output and pressure applied is obtained.

TABLE I ANSYS FEM analysis

Sr. No.	ANSYS FEM RESULTS		
	Pressure (Pa)	Force (N)	Displacement (cm)
1	500	1.290	1.59
2	600	1.548	1.92
3	700	1.806	2.23

4	800	2.064	2.55
5	900	2.322	2.87
6	1000	2.580	3.19
7	1200	3.096	3.83

The element considered as bend sensor material is plastic with a coefficient of drag as 1 and a density of 1.04 g/cc.

Young's modulus is taken as 3.6 Gpa and a poison ratio of 0.35.

The pressure values are converted into velocity by using the following Drag Force Equation:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

where

F_D is the drag force, which is by definition the force component in the direction of the flow velocity,[1]

ρ is the mass density of the fluid, [2]

v is the velocity of the object relative to the fluid,

A is the reference area, and

C_D is the drag coefficient.

Therefore, a relation between the flow velocity and output resistance variation is obtained.

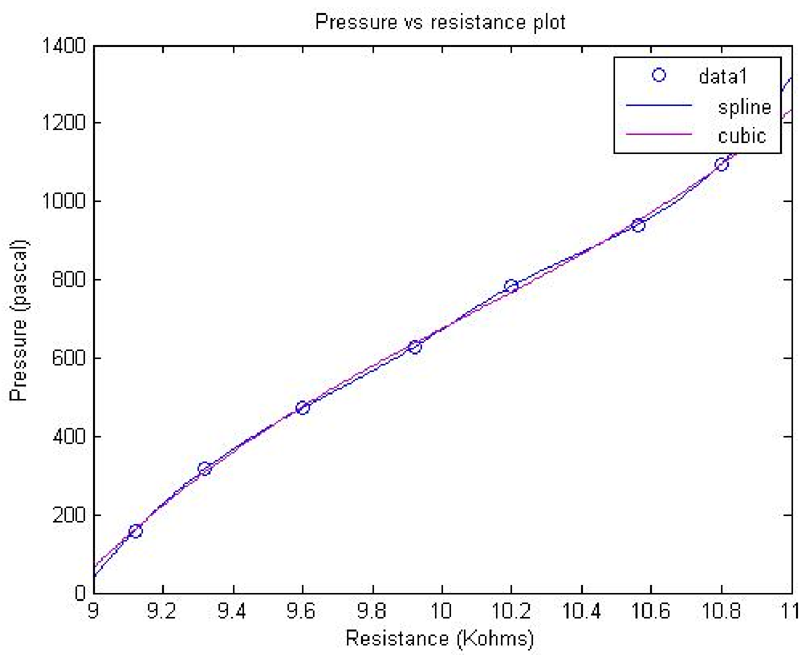

Fig. 5 Positive flow displacement vs resistance variation graph.

From the above graph, it is observe that the relation between the applied pressure on the bend sensor strip and output resistance variation is linear across a wide range.

Hence it can be concluded that by knowing the output resistance of the bend sensor, the unknown pressure applied or velocity of the fluid associated with the fluid flow in the pipe.

Signal readout circuit

The signal readout circuit measures the variation in output resistance of the bend sensor. Unknown resistance is found using 4 wire Wheatstone bridge circuit which is read by an gain amplifier, whose analog output is converted into digital form using PIC 18F microcontroller. The program in the microcontroller gives the corresponding pressure output which is then displayed.

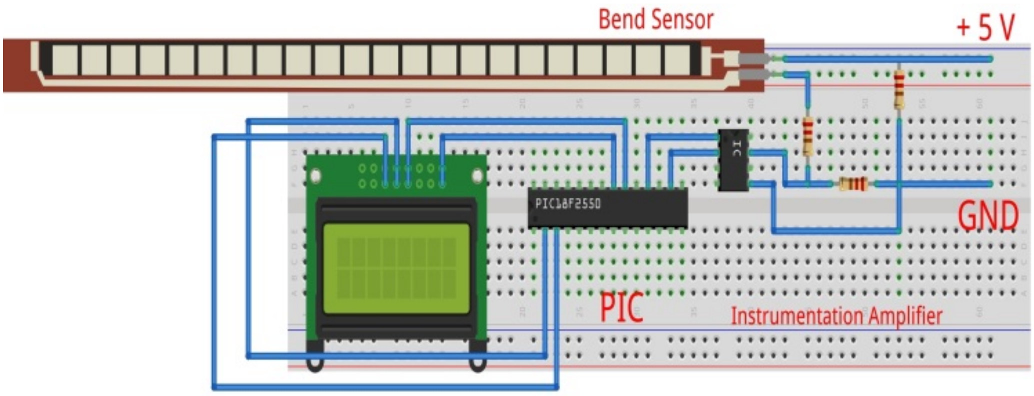

Fig. 6 Block representation of signal readout circuit.

Conclusion

From the result graphs it can be deduced that for a specific range of displacement, corresponds to a specific pressure across the cross section of the conduit. This is verified by the linear graph obtained from the experimental setup as well as the finite element analysis of the element. Hence this model can be used successfully used for flow measurement for a given range. The range will in turn depend on the type of coating of the bend sensor. The range, repeatability and several different factors can be varied by changing the coating element.

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