Design and Realization of Sensor System for Flow Measurement

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Abstract: - The article describes design and realization of an airflow structure for measurement. There are structure and electronic circuits design in the paper are described The principle of a flowmeter sensor operation is based on the mechanism of a fluidic oscillator. It uses fluidic paths in feedback. Oscillator samples have been made using different technologies and materials. Micromechanical shaping, etching and sticking as basic operations have been used. Further there is described design, construction and measured results of the developed flowmeter with a fluidic oscillator for measurement of fluid flow. Measured fluid flow is displayed on a digital or analog measuring device calibrated in values of immediate flow amount or flow velocity. A CoventorWare software was used for design of mechanical behaviour and CADENCE software was used for electronic circuits design.

Key-Words: - Design, Microsystems , Sensor, Microelectronics, Fluidic

1 Introduction

For measurement of fluid flow velocity or volume flow of liquids and gases, there exist many methods, starting from the oldest ones, which are purely mechanical, over combined - mechanical and electronic, to present methods making use of the third generation sensors - optical fibre sensors. Each method has a certain optimal range of measured values. Flowmeters with fluidic oscillators enable to measure flow of liquids and gases without necessity to re-adjust for various substances. The core of the fluidic oscillator is made of a fluidic bistable amplifier, completed with a feedback. This feedback is created by connecting output and control channels - Fig. 1.

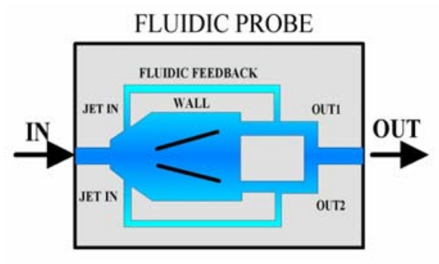

Fig.1 Principle of the fluidic oscillator

In the feedback circuit, oscillations of fluid emerge. In injection jets the pressure energy of the fluid is changed to kinetic energy. In collectors the fluid flows in the direction of opening enlargement and kinetic energy of captured fluid changes into pressure energy there. Effect of Coandon phenomenon causes adhesion of liquid/gas flow from the input jet IN to one or another holding wall. It is possible to turn over the flow from one wall to another one by impulses led to injection jets JET IN. Connection of output fluid paths OUT1 and OUT2 with injection jets creates feedback that constitutes an astable flip-flop system with turn-over of the fluid flow alternately to one or another wall. In the feedback the signal is delayed - shifted in phase. This phenomenon arises because the accummulation chamber is filled through the resistance (narrowing path). Further there is utilized fluid inertia that causes spreading of the signal in the form of a pressure wave. In the channels it is manifested by pulsating fluid. The signal has an impulse character. In this way a fluidic system is created that is similar in its behaviour to an electric astable flip-flop circuit with pulse shaped output signal. With respect to the analogy with the electric astable system it is called „fluidic oscillator“. The output flow from the fluidic oscillator is marked OUT and it is composed of the outputs OUT1 and OUT2.

Frequency of these oscillations is dependent only on fluid flow velocity and diameter of feeding pipes. It does not depend on properties of the flowing fluid in a certain range of Reynold's numbers. Sensor systems with fluidic oscillators can be used for measurement of liquid and gas flow with temperatures ranging from -20 to +120 ^{o}C. The conversion characteristic is a linear function for big Reynold's numbers. The output signal is electrical or pneumatic with impulse or analog shape.

The fluidic oscillator does not contain any moving parts, it is suitable for gases and liquids with different properties without necessity of readjustment (air, water), its operation is independent on temperature in a wide range. However, it requires to be installed directly in the pipes, it is sensitive to increase of viscosity, coarse impurities influence precision of measurement considerably [1].

2 Design of signal processing circuits

Information about flow velocity or measured flow volume is evaluated by means of measurement of fluid oscillation frequency in the oscillator. Frequency is a linear function of the flow velocity. Fluid oscillations can be sensed by an appropriate sensor placed in the feedback channel of the oscillator. A pressure sensor can sense pressure changes, or a temperature sensor can be used. Then the signal is sensed from a heated resistance sensor (special thermistor), which is cooled by the fluid with oscillation frequency of the oscillator. Sensed information about fluid flow from the oscillator has impulse characteristic with impulse frequency f. The signal can be modified to a form suitable for digital indication of results or processed by an analog frequency measuring device with analog indication. The basic requirement laid on a sensor for sensing fluid oscillations in an oscillator is its sufficient response rate with regard to the rate of fluid oscillation changes.

The cooling principle of heated resistance sensor has been chosen as the measurement method. A special microthermistor marked NR506E (Pramet comp.) has been chosen as a heated resistance temperature sensor. This thermistor has a special surface treatment and therefore it is suitable for measurement of water as a fluidic medium as well.

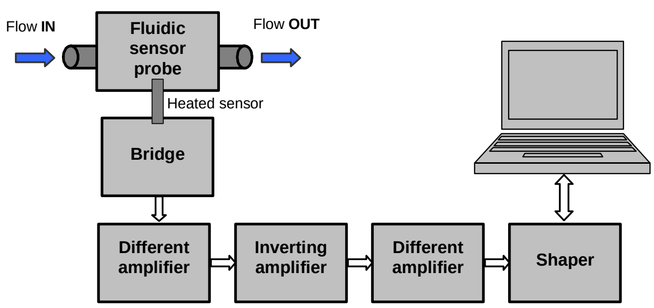

Fig.2 Sensor system with analog signal processing

The fluidic oscillator with the heated resistance temperature sensor has been completed with an electronic connection for impulse processing from the sensor. Oscillating fluid is cooling the sensor in oscillation rhythm, which causes periodical changes of sensor resistance. A block diagram of the whole sensor system is on the Fig.2.

The heated resistance sensor R_S is connected to a resistor bridge. The bridge is fed through a control transistor. To the bridge diagonal, input of differential amplifier with amplification of the input difference signal approximately 80 is connected. Output of this amplifier controls operation of the transistor. If the resistance of the sensor R_S (greater cooling) is decreasing, the amplified difference signal opens the transistor, voltage on the bridge is increasing, current flowing through the sensor R_S is increasing and begins to heat the sensor, its resistance is then increasing. Balance on the bridge is injured and the transistor is closing. For measurement, the absolute magnitude of sensor resistance depending on flow velocity is not substantial, but only changes of the resistance caused by oscillating fluid are of importance. This alternating component of frequency, being in the range of units or tens of Hz, is sensed and further processed by alternating inverting amplifier with amplification approximately 1200. On its output there is direct voltage with superposed alternating component which is amplified in a two-stage amplifier so that on its output there is an alternating signal with amplitude of 1.5 to 2 V.

A counter has been used for frequency measurement. There has been realized direct connection of a PC for measured data processing.

3 Design and realization of sensor probe

For development of this sensor probe, various materials and technologies have been used. First samples have been made by precise microshaping of polymethylmetaacrylate. Individual middle reliefs of the probe have been made by precise microshaping. Then the outer walls have been sticked precisely to individual reliefs. Various relief shapes with different dimensions have been designed and realized. Afterwards simulation has been performed and subsequent measurements for optimal setup of mutual position of individual relief parts have been done so that optimal parameters could be obtained. One of these parameters is reaching maximum possible oscillation amplitude at minimum possible volume of higher harmonics. The ratio height/width of input jet IN has been chosen 3/1. The angle between holding wall and oscillator axis is 11° or 12°. On Fig.3

photographies of several realized structures of fluidic oscillators are shown..

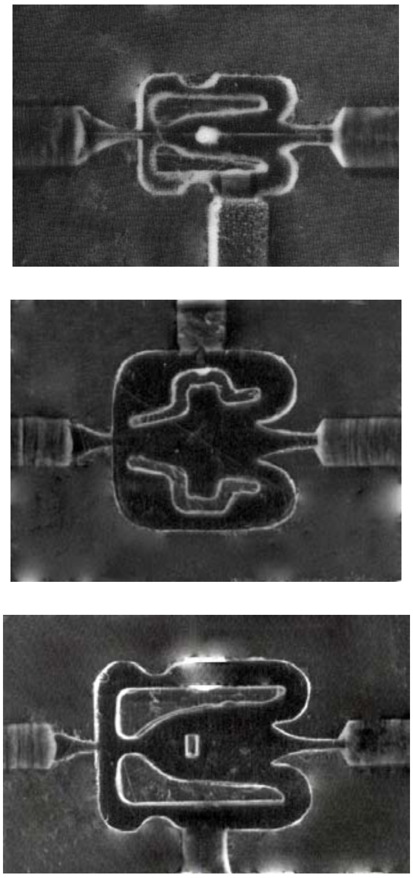

Fig.3 Different shape and dimensions of realized samples

4 Use of Models with Software Support

During design and modelling of properties of designed structure, the system of models can be simplified when considering concrete properties and purpose of microsystems. This approach is suitable for microsystems education at university as well. The design of microsystems can be realized in several forms with corresponding time series.

Ideative model of microsystems can be created. The model has input information, output functions, and inner logical functions.

Further step is realization of the SOFT model of microsystems using PC and libraries of electronic components and blocks. For special microsystems blocks it is necessary to use either existing blocks or to define these special blocks. In this model it is possible to simulate simple functions using means for analysis of electronic circuits and systems. Realization of micromechanical elements in this model is based on electrical and mechanical, or possibly further analogies. For realization of the SOFT model in this phase simplified electrical and non/electrical functions are considered so that it is possible to realize them in a simple way [2].

Realization of HARD model is a successive step and is used for verification of basic functions of the designed SOFT model. It is possible to use available elements for realization of the HARD model. This model illustrates characteristics and behaviour of the designed microsystems model. It is instructive for education; it is possible to demonstrate its behaviour and basic characteristics. There are close connections between SOFT and HARD models.

Design of microsystems is the most difficult part and follows after previous steps. Micro-models are developed from these macro-models according to the rules for design of integrated microsystems (technology, materials, software, etc.). Macro-model properties are compared with simulated and modelled properties of real microsystems. For these purposes, suitable tools are utilized (MEMCAD, CADENCE, SPICE, etc.) [3].

It is necessary to use models on system level for correct complex functioning of the designed MST. On lower levels, further types of models can be used: models on the level of individual energy domains, physical models, etc.. In design process, there can be used equivalent models that operate with quantities from various energy domains. A number of design tools (ANSYS, CoventorWare, MEMCAP, etc.) exist for modelling of structures and further elements of MST. Modelling and simulation on various MST levels are utilizes for optima MST design [4].

Individual models and their interconnections are illustrated in Fig.4.

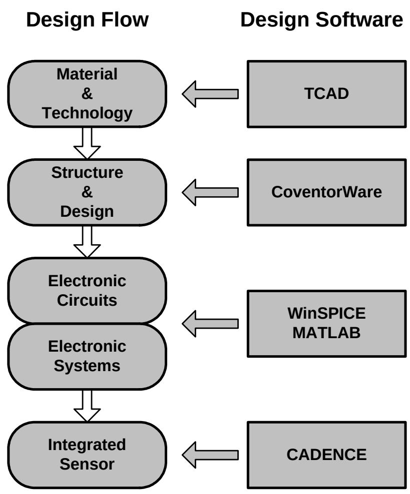

Fig.4 Design flow

The CoventorWare program was used for modelling of mechanical strain in the structure. The best way haw to proceed is to design 2D layout of the structure. By definition of deposition and etching steps properties we can simulate the technology process. Each etching step has assigned its masking layer from layout. Each deposited material has assigned its material properties as for instance: density, initial stress caused by deposition, specific heat, thermal conditioning, etc. Mechanical stresses can have a great influence on mechanical as well as electrical properties

Behaviour of a sensor or sensor block can be described by differential equations whose form is dependent on physical nature of corresponding sensor or sensor block activity. Three basic function types exist for description of this behaviour. Functions describe relation between input and output (zero-order, first-order, second-order). Mathematical modelling of a sensor is a powerful tool in assessing its performance. Mathematical models are utilized for equivalence generation. Physical laws are applied to these models. Results are models with simple lumped parameters. Mechanical and thermal elements can be converted in this way to equivalent electric connection. For solving this electric model, well-known and elaborated methods for electric circuits can be used.

4 Results of the work and conclusions

Several samples of sensor systems with fluidic oscillators with heated resistance temperature sensors have been made and measured. The differencies between samples have been in size and layout of the inner relief. For individual systems with fluidic oscillators, the oscillation frequency has been measured by a counter. The frequency has been measured in dependence on flow volume Q at different fluid temperatures in the range from 5 to 35 ^{o}C, namely both at increasing and decreasing fluid flow volume. Fluid temperature has no influence on measured values in the given range. Calibrating curves of three samples of the flowmeter are shown on Fig.5. Each curve has been acquired as medium value of several measurements on the same sample. Value dispersion has been approximately 5 per cent from the maximum measurement range.

Measured signal has been observed on an oscilloscope and it has turned out that for the smallest sample S_3 there has been significant signal distortion caused by higher harmonics and unstableness of oscillator oscillations has emerged. Both phenomena are probably caused by asymmetry and mechanical production imperfection of the device. At small size, even slight asymmetry causes above mentioned phenomena. Production asymmetry of the oscillator can be partially suppressed by differential layout, i.e. sensing oscillation frequency from both feedbacks and their comparison in time. Besides that, precision depends on fluid oscillation frequency in the oscillator. For presented operating frequencies the thermal inertia of used probe thermistor of the fluidic oscillator can be neglected.

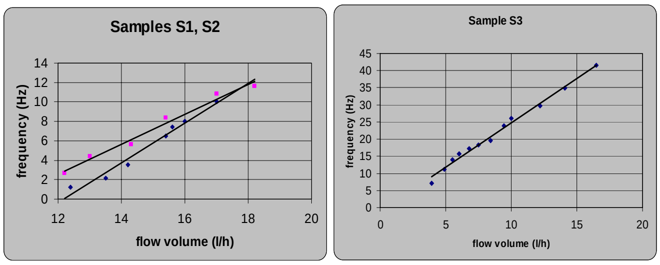

Fig.5 Calibration curves of sensor samples

7 Acknowledgements

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