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Design and Simulation of a Novel MEMS Bidirectional Anemometer

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ABSTRACT

In the present research, a novel MEMS bidirectional anemometer was designed and simulated based on drag force flow sensors and Piezoresistivity measurement with use of CoventorWare Software capabilities and Fluent 6.1. For achieving research objectives, first, anemometer geometry creation and mesh generation for ability of mechanical fluid analysis were done with use of Gambit Software. Furthermore, investigations have been carried out experimentally using wind tunnel with a 45 mm diameter, 50 mm length and speed range of 0 to 21 m/s. Finally, mean pressure exerted on plates and cantilevers of anemometer was used as input for MemMech and MemPZR analyzing tools of CoventorWare Software and output of Wheatstone bridge was obtained in two directions with 500mV supply voltage. The obtained results from study indicate sensor output is 2.61mV for 18m/s speed, which present 2.5 times sensitivity increased compared to a similar identified design. In addition, the obtained results from simulation show a slightest difference with obtained results from theoretical equations.

KEYWORDS: MEMS anemometer, cantilever, Piezoresistivity

1. INTRODUCTION

When a fluid flows, the quality of it is under question. The fluid can be gas or liquid. The subject of measurement can be amount of mass displaced, travelled distance, or displaced volume. Few traditional flow sensors are applicable in micro domain. Limited sensitivity, large size, high dead volume and connection problems with micro fluidic parts limit their application. However, micro fabrication has its particular advantages such as high resolution, fast time response, integrated signal processing circuits and lower fabrication cost. The first mechanical micro flow sensor was presented by Van Putten and Van Riet in 1980s. [1] This type of sensors benefits from thermal techniques for flow measurement. Later on the efficiency of sensors was improved and various fabrication systems changed from the macro-world to the micro-domain. One of the flow sensor applications is evaluation of wind speed. Micro electromechanical anemometers divide into two categories; thermal and mechanical. Thermal anemometers would be biased high in lower range, and respond well to light winds, but in higher speed, they are less accurate. In addition, humidity and debris in flowing air cause some difficulties for this type of sensors.

The mechanical anemometer mainly base on measuring force or pressure. One of these mechanical anemometers is a drag force anemometer. This type of sensors consists of cantilevers, plates, and a measuring instrument for quantifying strain change constructed in an integrated system. When the plates are immersed in the fluid, a tensile force exerts on it which cause deviation of cantilever. The deviation rate by Piezoresistivity measure applied on cantilever will be identified and evaluated. In this study, a novel design for this type of sensors will be scrutinized.

2. THEORY

Proposed anemometer consists of four plates attached to four cantilevers and measuring is done by Piezoresistors are located in cantilevers (

Fig.**1**). The anemometer also, has capability to measure wind velocity in two different directions. With air flow passage through anemometer, a pressure exerts on each plate which it calculates by Eq.Error! Reference source not found.. [2]

$$\boldsymbol{P = \frac{1}{2} C_D \rho V^2} \qquad (1)$$

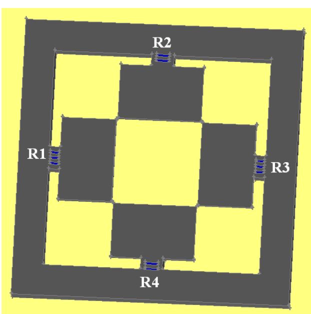

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Fig.1: The designed sensor model

In this equation, P is exerted pressure on plate, is drag coefficient, ρ is air density, and V is wind velocity. C_D is depending on Reynolds number and experimental measurements.

Reynolds number for proposed design denoted by

$$Re = \frac{V}{\upsilon} . \frac{4A}{S} \qquad (2)$$

Which V is wind velocity, u is kinetic air viscosity, A_{CH} and S are the area and perimeter of the flow channel. With substituting the relative numbers of the intended design, Reynolds number for 21m/s speed was around 1800, which with respect to it, C_D was around 0.4.

The stress for each cantilever illustrated by Eq.(3) [3]

$$\sigma(x) = \frac{M(x)c}{I} = \frac{6Fx}{bt^2} = \frac{Fx}{Z} \qquad (3)$$

In this equation, $\sigma(x)$ is cantilever stress for distance x of force exertion, $M(x)$ is bending moment in distance x, c=t/2 is the distance from neutral axis to cantilever surface, t is cantilever thickness, I is cantilever and plate inertia moment, X section modulus of cantilever, and b is cantilever width. Section modulus obtains from below

$$Z = \frac{bt^2}{6} \qquad (4)$$

Also, the applied force F on the plates is expressed by

$$F = P \times A \qquad (5)$$

Which A is total area of cantilever and plate.

Area of A is calculated by Eq.(6)

$$A = W \times L + a \times b \qquad (6)$$

In this equation, *W* is plate width, *L* is plate length, *a* is cantilever length and *b* is its width.

In

Fig. **2**, one of the designed cantilevers is shown which its dimensions are W=1500μm, L=1000μm, t=10μm, x=700μm, a=200μm and b=400μm. With substitution of the dimensions in above equations, the maximum stress was obtained from pressure exertion of 100Pa, which is equal to 16.5MPa, and it is compatible with the results of simulation.

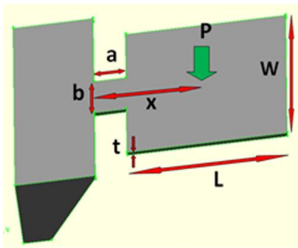


Fig. 2: One of the designed Cantilevers

3. ELECTRIC DESIGN

This sensor benefits from a Wheatstone bridge (Fig.3) with four P-type boron- doped piezoresistors near edges of cantilevers as shown in

Fig.**1**. Cantilevers and Piezoresistors are in crystalline direction of (110) and on crystalline surface of <100> .

Each pair of these Piezoresistors faces each other, so two Piezoresistors R1, R3 is parallel to normal stress $\sigma(x)$ and two Piezoresistors R2 and R4 are perpendicular to it.

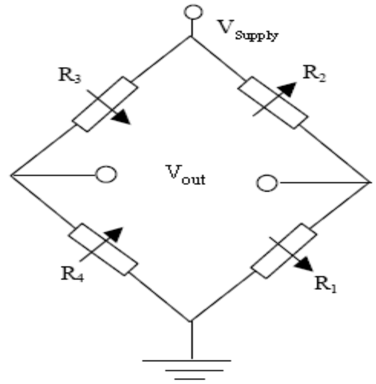


Fig.3: Wheatstone bridge of anemometer

The change in resistance R1 and R3 with $(\frac{\Delta R}{R})_l$ and the change in resistance of R2 and R4 with $(\frac{\Delta R}{R})_t$ have been shown which obtains from Eq.(7) and (8). [4]

$$(\frac{\Delta R}{R})_l = \pi_l \sigma_l + \pi_t \sigma_t$$

$$(\frac{\Delta R}{R})_t = \pi_l \sigma_t + \pi_t \sigma_l \quad (8)$$

In Eq.(7) and (8), for p-type Piezoresistors, π_l =71.8× $10^{-11} Pa^{-1}$ is Piezoresistive parallel coefficient and π_t= -66.3×$10^{-11} Pa^{-1}$ is Piezoresistive perpendicular coefficient. σ_l and σ_t are also show parallel and perpendicular stress components, respectively. Eq.(9) shows Wheatstone bridge output voltage for supply voltage V_{supply}.

$$\frac{V_{out}}{V_{supply}} = \frac{(\frac{\Delta R}{R})_l - (\frac{\Delta R}{R})_t}{2 + (\frac{\Delta R}{R})_l + (\frac{\Delta R}{R})_t} \quad (9)$$

4. SIMULATION

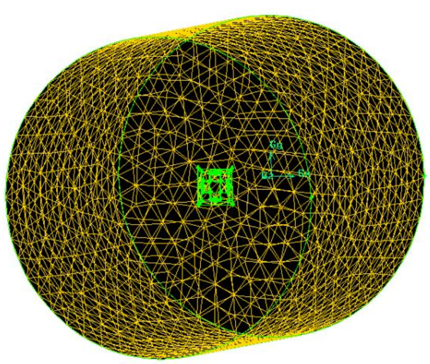
For achieving the research objectives, first the sensor model constructed by Gambit Software and for creating identical conditions with the field data of reference article [5], the sensor was placed in wind tunnel with 45mm diameter and 50mm length. In next step, mesh generation was done for whole system as an appropriate output file was obtained from it by Fluent Software.

Finally, mesh geometry was analysed by Fluent Software under atmospheric pressure and temperature of 300 degree Kelvin and the average pressure decrease on cantilevers for speed of wind from 0 to 21 m/s were recorded.

Fig. 4 shows mesh model and speed vectors in Fluent Software, and

Fig. 5 shows pressure contour of cantilevers for 18m/s.

Fig.6 also illustrates average pressure exerted on sensor as a function of wind velocity.



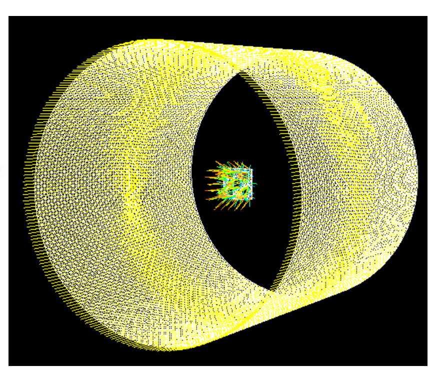


Fig. 4: Gambit mesh model and wind velocity vectors

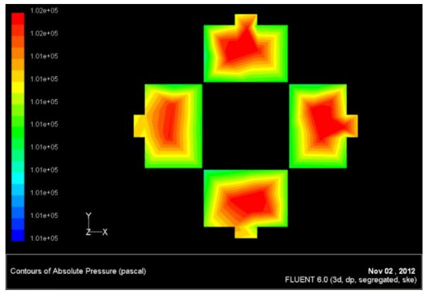


Fig. 5: Cantilevers pressure contour

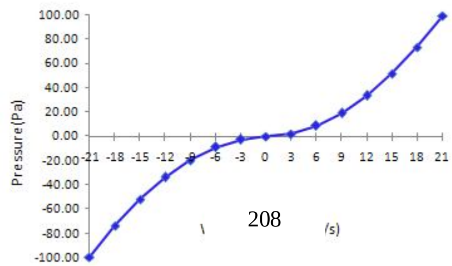


Fig.6: Pressure vs. wind velocity

After this step, the sensor was designed according to Fig.7 by CoventorWare Software.

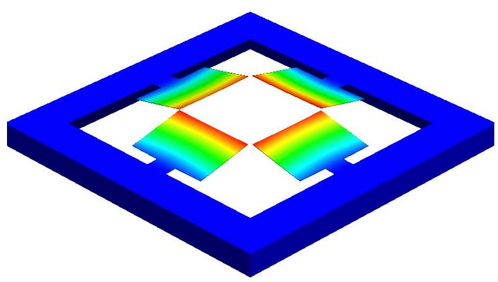


Fig.7: Designed sensor in CoventorWare

First, mechanical analysis of MemMech was obtained under provided pressure by Fluent Software in two directions, and results were used as input for MemPZR Piezoresistive analyser. For comparison with the results of reference article [5], Wheatstone bridge supply voltage was considered equal 500mV. Fig.8 illustrates sensor output vs. input pressure in two directions.

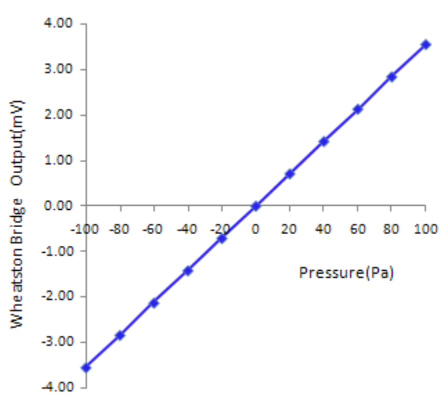


Fig.8: Sensor output vs. pressure

For assessment of simulation results with theoretical texts, the diagram for anemometer output voltage obtained from simulation and theoretical equations and were compared which expressed in

Fig.9. Overlaying of the results showed insignificant deviation.

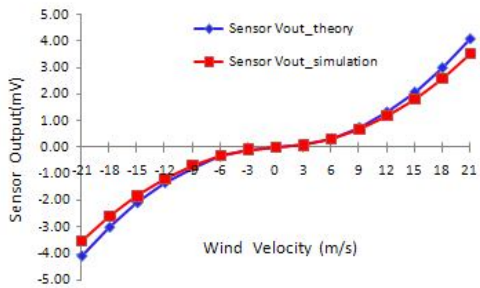


Fig.9: Sensor output Vs wind velocity

5. CONCLUSIONS

A novel micro electromechanical anemometer w[illegible] and simulated by use of four symmetrical cantilevers and plates, and obtained results were compared with th[illegible] of reference article [5]. With analysing the obtained results from simulation, it was identified that output sensitivity of the innovated design to wind velocity was approximately 2.5 times more than that belong to sensor of reference article [5]. Also the sensor output was not symmetrical for design of reference article [5], while, in the innovated design, the diagram looks totally symmetrical.

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