Design and Simulation of Piezorestive Pressure Sensor for AFM Probe the Displacement Measurement

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Abstract

investigating pressure applied in surface vertically that is done by use of mechanical procedures isn't efficient to measure pressure applied in inner surface of reservoir or pipes having gas due to entering pressure into whole walls and different surfaces. So, in order to measure this kind of pressure, several studies were conducted in past decades and also various procedures were proposed that some of them had a mistake, benefits and faults. At this paper, we designed and simulated structure titled as Piezo-resistor manometer by following proposed problem and employing Piezo's structures, then we investigated the effects of movement of this structure's probe to improve and linearize its output. The results showed that, in addition to physical parameters like screen dimensions of manometer, cantilever length, apparent shape, probe dimensions and quality of each probe, load resistance has main effect on linearization of probe performance considering output voltage too.

Keyword: AFM , Barometer , Piezo resistor , Prob , Cantilever

1. Introduction

This paper aims to describe how to design and simulate Piezo-resistor manometer in order to measure movement of probe Afm. It's worthy to mention that all results obtained of this paper that are being investigated and simulated in different forms of voltage and ohm, it is solely due to applying pressure on structure and movement of probe Afm.[1-2]

Diaphragm movement is measured by changing inductance. Inductive pressure sensor includes two windings coupled with a magnetic core. When the applied pressure moves diaphragm, this core moves too. Electronic circuits such as resonance circuits measure inductance function. Low cost and smaller size of semi-conductive pressure sensor by developing technology at different engineering fields such as precise measurement, biomedical and control systems are more being demanded.[1,3] Micro sensors are extensively used at modern machines and also micro pressure sensor is one of current discriminative machines and obtained popularity in biomedicine, aerospace and automotive industry. Such sensor is formed of one silicon wall and four resistance placed at wall sides along crystal (110). When pressure applies at one side of diaphragm, diaphragm is bended and tension is formed at whole structure.[4]

Changes obtained of tension shows changes at piezo electric resistance. In order to improve voltage sensitivity of such resistance- piezo sensor, Paul Watson configuration is carried out by piezo resistances. This paper aims to identify quality of these micro structures and simulate new proposed structure for conducting

applied goals. Also, it is worthy to mention that simulation of this sensor will be carried out by powerful software named COMSOL.

2. Materials and Methods Piezoelectric

Piezoelectric effect is employed at specific materials like Quartz to measure tension due to pressure. This technology is used to measure dynamic pressures. Some kinds of crystals called piezoelectric due to mechanical transformation create electric signals that voltage level of this signal is proportional to transformation level. Cristal has been connected to metal diaphragm. In order to measure pressure, one side of diaphragm is in contact with process signal and other side of diaphragm is mechanically connected to crystal. Output voltage signal of crystal has small extent. (at the extent of micro-volt).[4-7]

So, one booster with high input impedance should be employed. In order to avoid signal loss, booster should be installed near sensor. Crystal can sustain heat until degree 400 Fahrenheit. Temperature changes can affect crystal, so temperature compensation should be carried out. Pressure sensor has more application including pressure measurement, height measurement from sea level, measurement of venter effect-help current and also height/depth measurement.

3. Function modes

Contact mode: at this mode, microscope tip is in feeble contact with sample and picturing is carried out by measuring tip deviation (by repellent force between tip and sample).

Non-contact mode: at this mode, there is no contact between microscope and sample and picturing is carried out by gravity force between tip and sample.

Alternative contact mode (beating): This mode is like non-contact mode, but the difference is that at alternative contact mode, vibrating county leaver tip contacts with sample slowly and vibration extent is much more than non-contact mode. At this method, picturing is done by county leaver vibration extent.

4. Physical and electromechanical relationships

At this part, first, structure description, different parts and also the relationship between them has been investigated. Lastly, definition and the reasons to need portioning have been proposed.[8]

Simulated structure contains three parts. First part is pressure exertion plane. In fact, pressure exerted at structure applies the greatest force on this point. This part should be dry and hard in viewpoint of quality, such that it can transfer whole pressure. Resting place of this part is exactly on the first of second part. The second part is county leaver that has spring-like structure and can start vibrating after exerting pressure. County leaver which is the connection between first and third parts, transfer vibration caused by pressure exerted to itself leading important changes on electric parameters like frequency, voltage and ohm amount to third part. All of these changes are shown at the third part at maximum form.

The third part is probe Afm. This probe can have different size and shapes but when designing this probe, two point should be considered.

First point is that it must be smaller than pressure exertion plane, because at this way, it can transfer whole possible incidents. The second point is that it must be hard and dry from viewpoint of quality in order to transfer county leaver as it is possible and does not damp anything by itself. Structurally, when working with this sensor, we encounter electromechanical structure. So, all conditions should be investigated from both electronic and mechanical viewpoints. As was mentioned all equations are equations of mechanical and electronic forms. [8,9]

At such cases, all different parts of one structure change into several subparts and then theey are separately investigated. This work is called rationing. Different kinds of rationing are employed by considering different structures. But at the present paper, rationing based on structure and triangle shape has been used that its benefits are going to be discussed at chapter 4 by details.

Mathematical relations: at first, structure function figure is seen at different frequencies. Chapter 3 presents mathematical relations using at this simulation. So, presenting these relation here at this part in order to point suggested case appears to be useful.

V=abc(Rl_v)

Voltage relation

$$P_m = \frac{1}{2}\text{intopl}(\text{realdot.rho} * \text{g\_acc}, \text{solid.u\_tY})) * \text{w\_plate}$$

P_m : Mechanical power relation

$$P_E = \frac{1}{2}\text{realdot}(\text{cir.Rl\_i}, \text{cir.Rl\_v})$$

P_E : Electronical power relation

5. Software products:

The reason for designing structure, as depicted at figure 1 is that county leaver can easily move by exerting pressure with different frequencies.

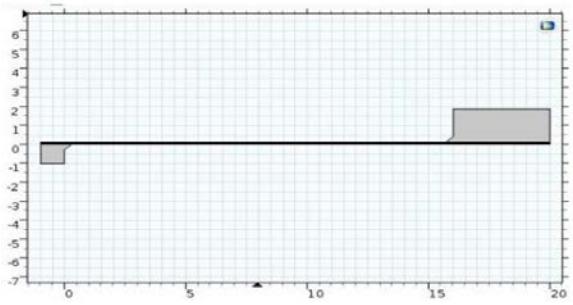

Fig.1. product of selecting mechanical structures at software

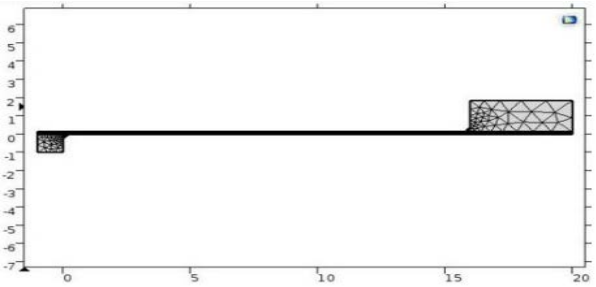

Fig.2. rationing product at software

As seen at figure 2, the best function of structure is at frequency 5/75 Hz. So, in order to take useful product, it needs to apply frequency 5/75 Hz on structure that it is called frequency response figure. This case has been shown at figure 3.

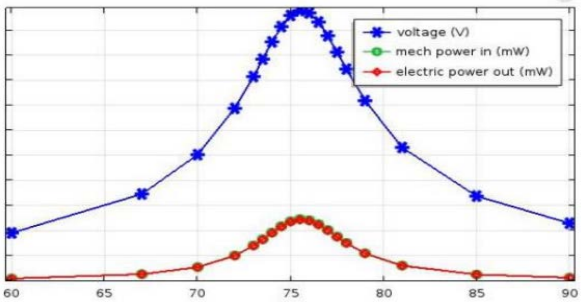

Fig.3. frequency response

Next step, pressure changes leading voltage changes, mechanical pressure and electronic pressure at frequency 5/75 Hz with high quality will be investigated.

Other parameter of this paper is load resistance with value 1 kΩ. This resistance has suitable linear increase at low pressure but it does not have high function at high pressure, nevertheless resistance 10 kΩ has suitable function pressure at calculation range.

The next important investigated parameter at this paper is maximum pressure point. This parameter is important mechanically, such that it can show where greatest curvature of structure occurs.

It can generally be said that this paper investigates system function at different frequencies, changes of mechanical and electric pressure, load resistance, maximum pressure point and apparent changes.

6. Results

This paper aims to design and simulate Piezo-resistor nanometer sensor for measuring replacement of probe Afm, such that it was done here by KOMSOL software.

Based on investigations, the following conclusion can be drawn:

Paul Watson model is the best model for integrating network including Piezo-resistor pressure. By considering widespread functions of Afm and exerting it easily, Piezo-resistor measurement method is much more suitable and undeniable.

The method for measuring Afm system suggested here is new and more useful method.

At this paper, related parameters will be optimized on the basis of definite element method . Circuit design at this paper is precise with high quality, such that it can measure pressure amount exerted on Piezo structure.

So it can be said that by exerting pressure on simulated Piezo-resistor structure, measuring its ohm value, replacing ohm values at Paul Watson circuit and also displacing Afm probes (which can be 12 modes), we can find the best point of function.[10]

As mentioned at section 4, one the most important parameters at this paper, was investigation on pressure changes led to changes on voltage, mechanical and electric pressure. This was depicted at figure 4.

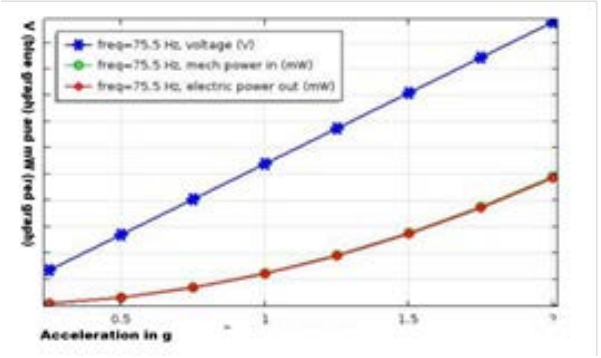

Fig.4. Pressure changes

Pressure exerted at structure was shown at figure 4. Pressure exerted at structure except exerting initial acceleration on sensor plane leads to form oscillation at county leaver that this one cause directly displacing Afm probe.

The reason for investigation acceleration at this figure is that exerting pressure on structure vertically leads to initial acceleration. blue, red and green line drawn at figure above indicate voltage in term of volt, output electric power in term of mW

and exerted mechanical power in term of mW respectively. It should be mentioned that by replacing value 1 to changes value, two figures of electric and mechanical powers are coincident to each other.

One more important parameters of this paper was 1 kΩ load resistance having linear increase at low pressures but it didn't happen at high pressures. (Figure 5). Nevertheless this increase is exponential increase but it is constant and consistent. So, 10 kΩ load resistance is reasonable load resistance value. In order to be sure of reasonable function point , that is, selecting 1 kΩ load resistance value, structure output is estimated by 100 kΩ load resistance too. As it is clear at figure, this resistance does not include reasonable and linear operation too.

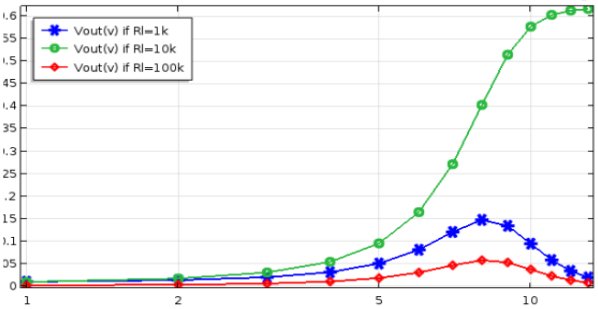

Fig.5. Load resistance

As seen at figure 5, output value is obtained in term of volt (V). This voltage results from exerting pressure on sensor area of pressure leading to displace Afm probe and change values.

Other parameter investigated here at figure 6 is maximum pressure point. It shows where maximum and minimum curvature occurs at structure. Orange line indicates maximum curvature and green line indicates minimum one.

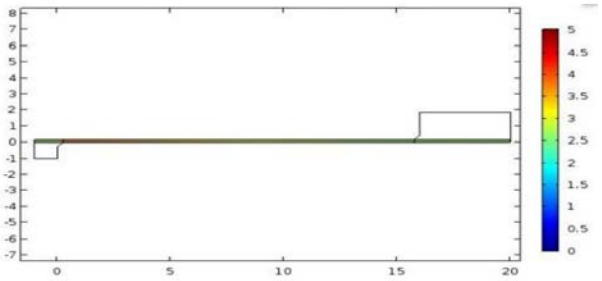

Fig.6. maximum pressure point

Pressure exerted at sensor plane has more effect on county leaver vibration movement. County leaver vibrations lead to move Afm probe. This displacement has significant change from viewpoint of electric factors that they were discussed before. As the last output of simulation, apparent changes of system have been depicted at figure 7.

This figure indicates apparent changes based on pressure. It is worth saying that Afm sub probe movements are being clearly shown at this figure.

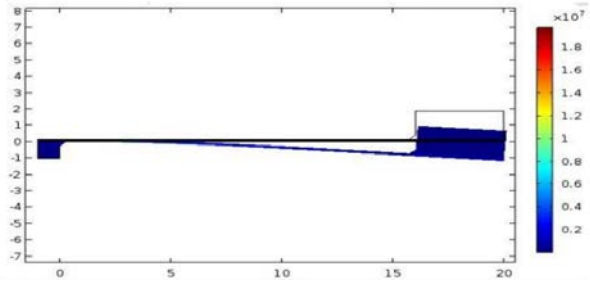

Fig.7. apparent changes

7. Comparison with previous researches

Ti Son Ling Chao et.al worked on studying pressure sensor with Silicone gel to protect shape surface and analyzing pressure sensor performance and also providing new and applied method which is reliable tool to design sensor performance. Parametric studies showed that gel thickness does not have output voltage limitation in different

temperatures. On the other hand, when environmental conditions of silicone gel are limited, thicker silicone gel leads to better consistency at sensor performance. Based on these results, it can be concluded that proper selection of sensor structure in geometry and mixture of silicone gel materials increase not only sensor sensitivity but also decrease thermal effects and penetration on packing.

Also Shang et.al designed sensor which has defined height of 30 micro meter on the basis of technological conditions and after exerting pressure 150 K Pascal, diaphragm height changes to value 1150 micro meter. In order to transfer maximum height from sensor viewpoint, ohm value of this Piezo-resistor has impedance coincidence with load and also it has linear output and desirable optimization. Making structure diaphragmatic helps increase maximum transfer of pressure and stress value.

Saloni Korasia et.al simulated and analyzed design and analytical models od low pressure sensor. Based on obtained output, maximum stress near diaphragm edge was identified. This area dimension is 400*70 nm. Piezo resistor is the sensor model evaluating low pressure of square-shaped diaphragm and also evaluating its performance is carried out by limited element simulation. Obtained sensor output is measured in widespread limitation and also its linear pressure is safe. Also, maximum stress place has been identified by limited element simulation. This activity is useful for designing low pressure sensor; this sensor is beneficial at biomedicine for measuring aggressive pressure.

Matus Gacha et.al researches are more precise and suitable at pressures more than 0.25 Mpa. At this model investigates pressure exerts at top surface of wall (membrane), exerted curvature and stress resulting from displacement of wall or membrane with maximum value of 0.49 micro meter. As expected, the greatest curvature occurs ta wall center. One of the most significant researches on measuring 0 to 300 KPa was done by G.H Kim and et.al. they concluded that we can use active silicone Nano-wire of pressure sensorcasing sensitivity increase and sensor size decrease. From viewpoint of performance, sensor output is nonlinear at limit lower than 150 KPa. Then by increasing sensitivity in exchange for one KPa, it increase 337/5.

8. Conclusions

Although Piezo has proper performance at alternative currents, it is worth to operate with alternative voltages. In Piezo structures, voltage changes are low, so it needs amplifiers. These changes happen in some cases including measurement of pressure amount, vibration rate, temperature measurement and sound produce.

Ohm change rate of Piezo has heterogeneous impedance at different conditions. For example, structure having load resistance 2.2 K has better performance than load resistance 22 K. this structure with resistance 220 K doesn’t have desirable output. So, finding proper load resistance to determine ohm change rates of one piezo structure is one of important and basic factors. One of other important parameters at Piezo structures is finding the best frequency,

because performance of piezo structures is different from each other at several frequencies.

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