International Journal of Instrumentation Control and Automation

Volume 2 | Issue 1 Article 13

April 2012

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A NOVEL DESIGN OF SERPENTINE STRUCTURE FOR ENHANCED PERFORMANCE OF MEMS BASED PRESSURE SENSORS

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Abstract- In this work an effective MEMS based capacitive pressure measurement system is proposed. Thepressure sensing element consists of two capacitorplates. Thebottom plate is mechanically fixed, whilethe upper plate is a flexible silicon membrane with flexures. The pressure acts on the upper plate. Avariable separation between the plates is introduced.Maximizing the deflection of the plate is a keyto improve the sensitivity of the sensor. In this paper various flexure designs are studied. A comparison of the flexure sensitivity is made for the automobile tire pressure range.

Keywords*- TPMS; MEMS capacitive pressure sensor; flexure; COMSOLmultiphysics.*

I. INTRODUCTION

A capacitive pressure sensor is composed of two platesthat serve as top and bottom electrodes. The bottom electrode is fixed while the top electrode is composed of a deformable diaphragm.

The deformation of the top diaphragm due to applied load pressure results in the variation or change in the capacitance, which can be measured with an interface circuit. The deformablediaphragm can either be circular or square. A square diaphragm is chosen here as it gives the maximum deflection for a given pressure.

A square diaphragm which is fixed along its sides gives maximum deflection at the centre whereas on introducing the flexures, theplate has a uniform deflection throughout. A study on fixed-fixed flexure and two models of serpentine flexures are done. It is found that the sinusoidal serpentine flexure gave the maximum deflection.

A TPMS(Tire Pressure Monitoring System) has a transmitter inside each tire to monitor tire pressure in real time, and to send out wireless RF signal about the tire data to display, and receiver inside the cabin. It will provide real-time monitoring of all tires, and will give warnings about abnormal conditions to make sure all yourtires are always under the correct condition.With the makeup of tire compounds today, spotting a tire low on pressure is much more difficult.

A vehicle with just one tire under-inflated canreduce the life of the tire and can increase the vehicle's fuel consumption.
Thus a TPMS plays an important role in enhancing the automobile performance and safety.
The structural parameters were designed for the maximumpressure to be measured by the pressure sensor in a car, which is equal to thestandard tire pressure of car i.e. 35psi or 241.29kPa.

II. BACKGROUND

Capacitive Pressure sensor converts the diaphragm deformation, corresponding to pressure, into a change of capacitance and which is finally converted into outputelectrical signal. To convert the capacitance into voltage, capacitance measurement circuit is used. The capacitance is proportional to the deflection of the capacitor plate.Hence for a particular pressure the design which gives the maximum deflection gives the maximum capacitance and thus improves the sensitivity of the sensor.The three different flexures studied here are the fixed-fixed flexure, the serpentine square flexure and the serpentine sinusoidal flexure. The load acts on the square plate.The deflection is uniform throughout the plate.Increasing the number of meanders and amplitude of the serpentine structure increases the deflection.

III. MODELING

Si (E=169GPa, υ=0.28) is chosen as the devicematerial here. Analytical equations for the deflections were derived using the energy methods. The plates are designed using COMSOLmultiphysics software such that themaximum deflectionis limited to 12µm.A comparison of the three flexure designs is done to find out the one that gives the maximum deflection.

A. Analytical modeling of deflection

The flexures taken here are geometrically symmetrical i.e. each of the flexures in the figure is made from four springs. Hence only one spring is analyzed. The flexure symmetry is important in determining the boundary conditions. For translation of the mass, the flexures impose a guided–end boundary condition. Displacement and rotation of the spring end are constrained to be zero except in the direction of applied force. The springs were separated into beam segments and the boundary conditions at the ends of each beam segment were determined by solving $\sum$ F=0, $\sum$ M=0 and $\sum$ T=0. Where F is the force, M is the moment and T is the torsion. Using energy methods, solving the set of simultaneous equations that describe the boundary conditions we get the displacement at the end of the spring.

In all the cases we assume small deflection theory.Castigilano's second theorem states that the partial derivative of the strain energy of a linear structure U with respect to a given load P is equal to the displacement δ at the point of application of the loadi.e.

$$\delta=\frac{\partial U}{\partial P} \quad (1)$$

a. Fixed-fixed flexure:

The fixed-fixed flexure is modeled as four guided-end beams. Residual stress and extension stress are neglected here. Thus the deflection when force is applied on the square plate is given by

$$\delta= \frac{FL^3}{4Ewt^3} \quad (2)$$

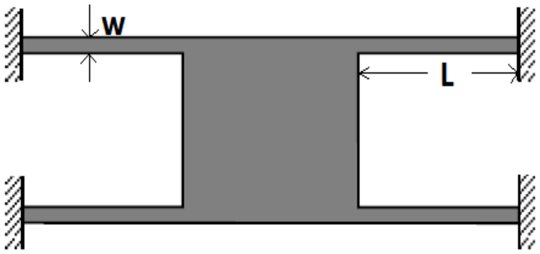

Figure 1: Fixed-fixed flexure

b. Serpentine flexures:

Two types of serpentine flexures are studied in this paper. Like the name itself they have a serpentine shape. The serpentine square flexure has the shape of a square wave and the serpentine sinusoidal flexure has the shape of a sine wave. The length, width and thickness of both the serpentine flexures are taken the same.The thickness of the flexure is t and w is the width.

i. Serpentine square flexure

Each meander is of length aand width b, except for the first and last meanders. The beam segments that span the meander width, called span beams or spans, are all considered equal in the deflection analysis here.

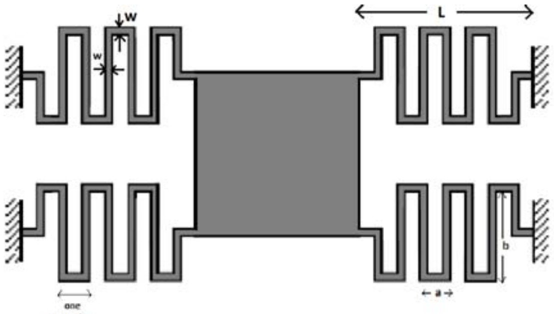

Figure 2: serpentine square flexure

ii. Serpentine sinusoidal flexure

Each meander is an arc of radius a/2 and width b, except for the first and last meanders. The beam segments that span the meander width, called span beams or spans, are all considered equal in the deflection analysis here.

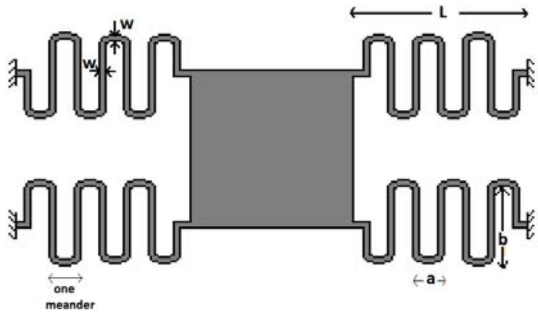

Figure 3: Serpentine sinusoidal flexure

The deflection of a serpentine flexure is given by

$$\delta\approx \frac{Fa^2\left(\left(\frac{GJ_b}{EI_{x,a}}\right)a+b\right)n^3}{48GJ_b} \quad (3)$$

$$\text{for } n>>\frac{3b}{\left(\left(\frac{GJ_b}{EI_{x,a}}\right)a+b\right)} \quad (4)$$

where n is the number of meanders in the serpentine flexure. G is the torsion modulus where

$$G=E/2(1+\upsilon). \quad (5)$$

For the serpentine square flexure$I_{x,a}$is the moment of inertia where

$$I_{x,a}=wt^3/12 \quad (6)$$

For the serpentine sinusoidal flexure $I_{x,a}$is the moment of inertia modified for curvature of the arc section.

$$I_{x,a}=\int_A \left(z^2/(1-2z/a)\right) dA \quad (7)$$

Where z is measured from centroid of the cross section and

A is the area of cross section

J is the torsion constant. The torsion constant is given by

$$J=\frac{1}{3}t^3w\left(1-\frac{192}{\pi^5}\frac{t}{w}\sum_{i=1,i\ odd}^{\infty}\frac{1}{i^5}tanh\left(\frac{i\pi w}{2t}\right)\right) \quad (8)$$

When t<w. If t>w, then the roles of t and w are switched.

B. COMSOLmultiphysics simulation

The COMSOLmultiphysics simulation software is used here. The MEMS module in it is used to design and analyze the deflection of the flexures. Following shows the simulated flexure designs. The serpentine flexures were simulated with four menders each. All the flexures had the same length, thickness and width. The load was applied on the square plate and the deflection was analyzed.

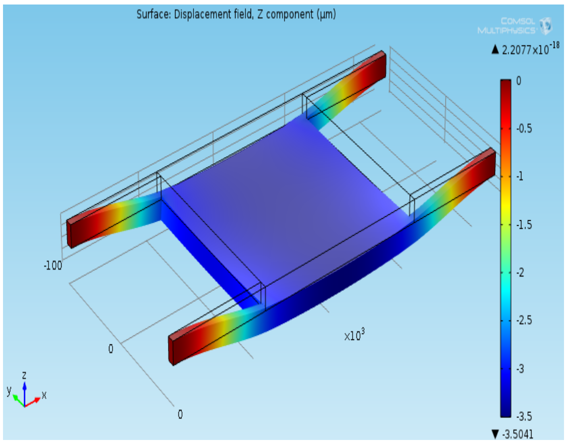

Figure 4: Total displacement contour for a fixed-fixed flexure

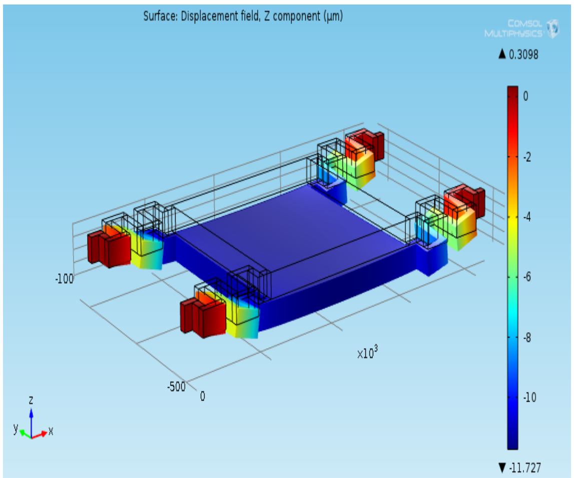

Figure 5: Total displacement contour for a serpentine square flexure

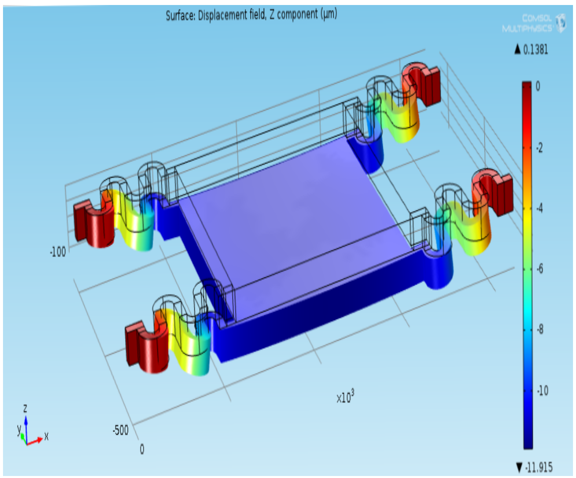

Figure 6: Total displacement contour for a serpentine sinusoidal flexure.

The load is made to act on the square plate and has uniform deflection throughout the plate. Of all the flexures the serpentine sinusoidal has the maximum deflection and the fixed-fixed has the minimum deflection.

IV. EXPERIMENT

The flexures were designed such that it can withstand the maximum tire pressure without breaking. The square plate is of side 1000µm. The other dimensions are t=100µm,a=150µm, b=250µm, and L=500µm. The pressure of 35psi (241317 Pa) is applied on the square plate. The deflections obtained, for n=4, by analytical method and by simulation are tabulated below.

TABLE I. DEFLECTION OF THE FLEXURES

Deflection for P=35psi	Flexures		
	Fixed-fixed (µm)	Serpentine square (µm)	Serpentine sinusoidal (µm)
Analytical	3.13	10.95	11.10
COMSOLmultiphysics simulation	3.50	11.72	11.91

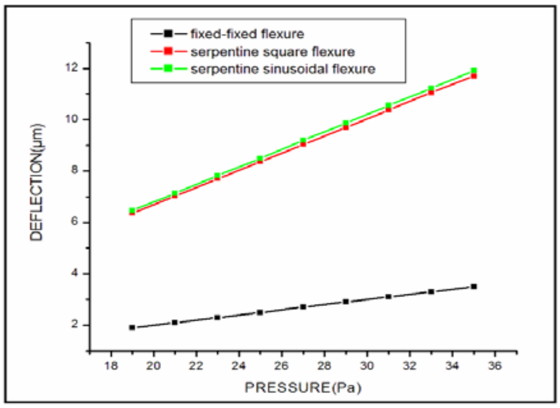

Figure 7: Deflection of the flexures w.r.t. varying load

V. CONCLUSION

As the capacitance is proportional to the deflection of the capacitor plate, for a particular pressure, the flexure which gives the maximum deflection gives the maximum capacitance and thus enhances the capacitive sensitivity of the sensor.The serpentine sinusoidal flexure gives the maximum deflection for a given pressure. Table I shows the deflection of the flexures both analytically and numerically. In the figure 7 the load vs. deflection is shown graphically. On introducing the flexures, the deflection is uniform throughout the plate. Increasing the number of meanders and amplitude of the serpentine structure, the deflection can be improved.Thus the proposed serpentine sinusoidal flexure is very appropriate for MEMS pressure sensor applications such as in TPMS.

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[5] Design Principle of Suspension of MEMS Gyroscope Qin Shi, Shourong Wang*, AnpingQiu ,YishenXu and XunshengJi(Dep t. ofInstrument Science and Engineering, Southeas t University, China)

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