COMPARATIVE ANALYSIS OF MEMS CAPACITIVE PRESSURE SENSOR FOR DETECTION OF TREMORS IN PARKINSON'S DISEASE

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ABSTRACT

In this paper, we are proposing a novel high sensitive, more reliable structure for an accelerometer sensor with silicon material which detects the resting tremor (continues tremor or Pill rolling tremor) of a patient suffering from Parkinson's Disease. The essential tremor frequency is from 3Hz to 7Hz. The Proposed structure is simulated using COMSOL Multi Physics 5.0 CAD tool and results are compared with the different shaped proof mass with different materials of a moving part of sensor. The minimum range of Eigen frequency that the proposed structure got 2.3572Hz and the maximum range is 8.679Hz with a displacements of 1.04µm to 2.74 µm. It is evident that now a days only the clinical based tests are the conventional tests to detect the severity of the tremor for Parkinson's Disease as per the UPDRS. In this paper we are proposing the new methodology to detect the resting tremor of Patient which is the initial symptom of the Parkinson's Disease. It is clear from the results that the Silicon material for proof mass gives the best sensitivity values when compared to all the materials of polymers. The capacitive actuation technique is proposed in this paper to identify the output capacitance and voltage because it gives high sensitivity and accuracy and reliability.

Keywords: *Essential Tremor, Proof Mass, Parkinson's Disease, UPDRS, Capacitive Actuation*

1. INTRODUCTION

MEMS have shown significant promise in the last decade for a variety of applications such as pressure sensors, positional sensors, actuators which are used in medical applications[1]. In the recent years, Parkinson's disease became a common disorder in the people throughout the world. Parkinson disease is a disorder of the central nervous system in the human body. It is a disorder that passes through genes. Most common and initial observablesymptoms of Parkinson's disease is Resting Tremor which can be identified when limb is fully supported against gravity and the muscles are not voluntarily activated this can be identified using this proposed structure which works under the desired frequency.

Piezo-resistance and variable capacitance are the two well-known techniques to calculate the sensitivity of the sensors and accelerometers. Most commercially available piezo-resistive sensors come with a disadvantage of limited operating temperature which requires an additional compensating temperature circuit[2]. Whereas the MEMS capacitive accelerometer has the advantage of smaller size, weight and relies on the variation of capacitance when the geometry of capacitor is changing. Modeling of the sensor at the device level allows the designers to examine the behavior of the structure on par with the physical conditions it is subjected to. In this paper, we present the performance of a pressure sensor modeled in different structures and with different proof mass materials where the response of every structure with its diversified materials is analyzed. Parkinson's Disease stood in the second place among all the Nero degenerative diseases. The main cause of the disease is yet not known, but it is due to the loss of dopamine in Central nervous system. The Clinical symptoms of PD includes tremor or shake of hands, small hand writing, loss of smell, trouble in sleeping, trouble in moving, constipation, soft or low voice, masked face, Dizzying, Fainting and stooping or hunching over[3],[4].

Various Experiments have done to detect the symptoms of Parkinson's Disease like application of some algorithm(Tian et.al) to the output signal extracted from the hand and they got very high noise in the signal and the accuracy

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percentage is in between 79%-81%[5]. Pavel et.al proposed the algorithms to access the neurological state of the people[6]. EI-Gohary worked with the inertial sensors for the assessment of neurological tremors[7]. Manto et.al worked with the wearable sensors[8]. Darvish et.al proposed wearable sensors and implantable sensors[9]. Ransong et,al experimented with Laser lines to detect the essential tremor of PD[10]. But above all have got the sensitivity not at a satisfactory range. Here we are proposing a novel methodology with the help of MEMS accelerometer based wearable sensors to detect the essential tremor of PD.

2. DESIGN PARAMETERS

The operation principle for the accelerometer that we study are based on the response of a movable finger with respect to physical stimulus and the electrical property that it generates, namely capacitance. In this section, we will review the operation principle of the accelerometer and determine the set of necessary measurements to characterize and calibrate the device. A spring-mass capacitive MEMS accelerometer structure is shown in Figure 1. The movable shuttle is connected by two springs with the spring constant, K. Two fixed plates, together with the movable plate, form two capacitors. If there is no acceleration, the movable plate is at the center of two fixed plates, so that both capacitors have the same capacitance value in Eqn.1.

$$C = \frac{\epsilon A}{D} \qquad (1)$$

where ε is the dielectric constant, A is the overlap area between movable and fixed plates and d is the gap between the plates.

If a vertical acceleration is applied to this system, the MEMS sensor will be activated by this stimulus which contributes to a certain amount of small displacement x, then C1 and C2 will be modified as given in Eqn.2 and Eqn.3 respectively

$$C1 = \varepsilon \frac{A}{d-x} \qquad (2)$$

$$C2 = \varepsilon \frac{A}{d+x} \qquad (3)$$

$$x \cong \frac{d^2}{2\varepsilon A} \Delta C \qquad (4)$$

$$A = \frac{k}{m} x \qquad (5)$$

The offset between the two capacitors is given by Eqn.3. This non-linear equation can be solved assuming x<<d. Thus, one can obtain a linear relation between capacitor offset and displacement, and hence, acceleration (Eqn.3-6).

$$\Delta C \cong \frac{2\varepsilon A m}{k d^2} \qquad (6)$$

$$S = \frac{\varepsilon A m}{kd\text{^}2} \qquad (7)$$

Where k is the spring constant and m is the mass, and S is the linear coefficient (sensitivity) between the measurable quantity (ΔC) and acceleration, which is also referred to as the untrimmed sensitivity of the system. Unfortunately, the sensitivity is a function of the internal parameters of the MEMS structure, namely, permittivity, mass, and spring constant, area, and gap. In order to facilitate accurate readings from the MEMS devices, it is essential that these devices are calibrated with respect to their internal parameters and is shown in analytical model of accelerometer shown in Figure1.

3. PROPOSED DESIGN

In this work, the proof mass structure is placed at the center surrounded by four axes on all sides with fixed constraints at the edges of all the axes. The axes are placed at the edges and their length is on par with adjacent axis limb. With all the limbs present it looks like a spiral structure in clock- wise direction. The proof mass is a general square structure with perforation added to it. The presence of perforation made the proposed design to achieve 5-10Hz frequency that identifies resting tremor. It is a type of tremor in Parkinson's disease that has the frequency range in 3-10Hz. Perforation reduces the deformation of the component drastically by observing the input strength through it holesThe perforated holes can be placed in any order and ofany size. Here, they are taken uniformly such as a plus symbol which is placed at the center of the square plate. The other structures with square, circular and rhombus proof masses without perforation has given frequencies in KHz which is of high frequency range.

A typical block diagram accelerometers shown in Figure 1.

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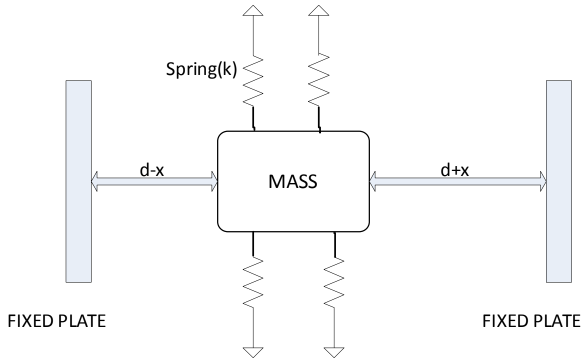

Figure 1.Analytical model of Accelerometer.

Different Shapes of Proofmass of the structures are shown in figure 2

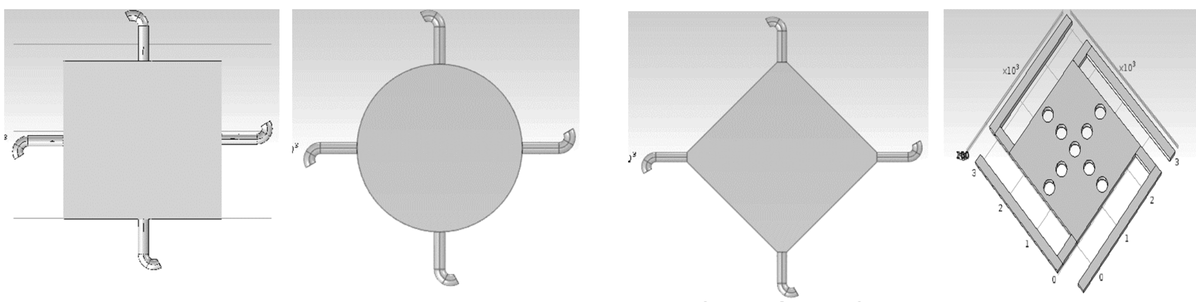

Figure 2. (a) Square Proof Mass (b) Circular Proof Mass (c)Rhombus Proof Mass (d)Perforated Proof Mass

Proposed Structure with Rectangular Proofmass is shown in figure 3

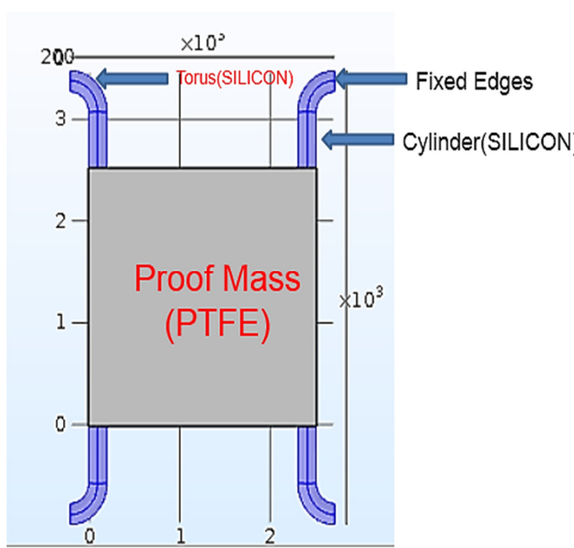

Figure 3. Proposed Structure with rectangular proof mass

3.1 Comparison Of Proposed Design With Existing Designs:

The perforated proof mass is added with the basic material silicon and the limbs are applied with poly-silicon material. Though the design is tested various material that are abundantly used in present days only silicon proved to be the best material in this case. Materials like PTFE, PMMA, Nylon are used. All the three materials are applied in all the

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shapes but none turned out to achieve the specified results.

To reduce the frequencies the thickness of the device is altered which increased the device size. But with the presence of perforation though the size is increased the mass of the system is reduced which plays a vital role in the calculation of natural frequency.

Normal tetrahedral meshing is done for all the structures by utilizing the software COMSOL Multi-physics 5.0. Manuscripts must be in English (all figures and text) and prepared on Letter size paper (8.5 X 11 inches) in two column-format with 1.3 margins from top and .6 from bottom, and 1.25cm from left and right, leaving a gutter width of 0.2 between columns.With variation of shapes and materials of proof mass similar results are achieved. So the presence of perforation and it's size matters a lot in the specified structure.

The properties of different materials used are specified in the Table 1 and the different Eigen frequency values obtained for each structure are in Table 2. Here only PTFE material values are only mentioned because out of the three materials PTFE has given low Eigen frequency values compared to others in extreme cases. The Eigen values obtained while silicon material used is shown in table:1.

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Table 1: Material Properties.

Material Property	Polysilicon	PTFE	Nylon	PMMA	Silicon
Young's Modulus(Pa)	169e9	0.4e9	2e9	3e9	179
Poisson's Ratio	0.22	0.46	0.40	0.40	0.26
Density(Kg/m3)	2320	2200	1150	1190	2329

4. RESULTS

From the Fig 4, 5, 6, 7 it can be inferred that with the usage of silicon material the device deformation is reduced at certain frequencies which concludes that the system is more stable and has more durability. It is also observed that rhombus and circular shaped proof masses are more sensitive and they easily get wear off. On the basis of squared proof mass Eigen

frequencies the proposed structure proof mass is also taken square and the limb lengths and axis are adjusted to achieve the frequency range. With the change of material and dimensions of the device

Eigen frequency is arrived at 5Hz which is suitable for the identification of resting tremor.

Fig 4(a) and 4(b) represent the square shaped proof mass with PTFEand Si. Here silicon gives Eigen frequency in the range of Eigen frequency of PD. It is also clear thatPTFE shows more deformation when compared to Silicon. So PTFE is not the suitable material for proof mass.

Fig 5(a) and 5(b) represent the circular shaped proof mass with PTFEand Si. In both of the structures the deformation is high. Hence circular shaped proof mass structures are not preferable for movable structures in accelerometers.

Fig 6(a) and 6(b) represent the Rhombus shaped proof mass with PTFEand Si. In both of the structures the deformation is high. Hence rhombus shaped proof mass structures are not preferable for movable structures in accelerometers.

Figure 7 is the most commonly used structure in accelerometers. Even it is giving high sensitivity, the Eigen frequency range of this type of sensors are not in the range of tremor frequency range of PD.

Figure 8 represents a structure with a silicon based proof-mas structure which is giving the Eigen

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frequency in the range of tremor frequency of PD. So we have proposed this structure to detect the frequency of PD in accelerometer sensor as movable component, it also shows the minimum deformation with normalization and without normalization is shown in fig4 and 5.

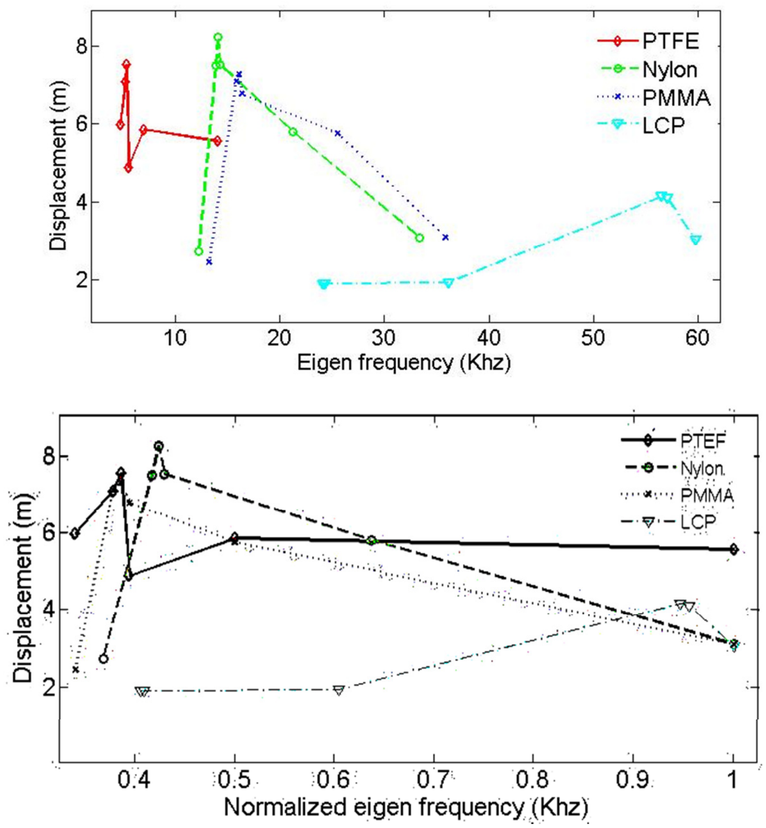

Fig 4: Graph for Eigen Frequency and displacement when different materials for proof-mass

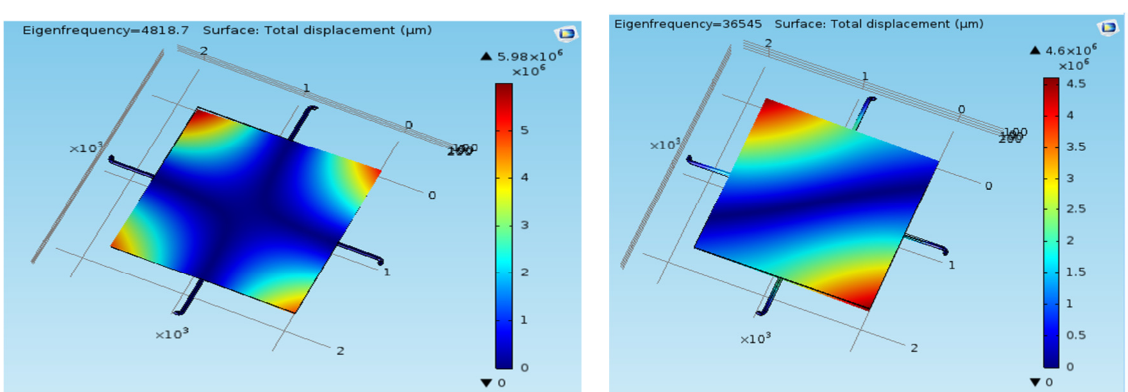

Fig 5: Square proof mass of (a)PTFE and (b)Si

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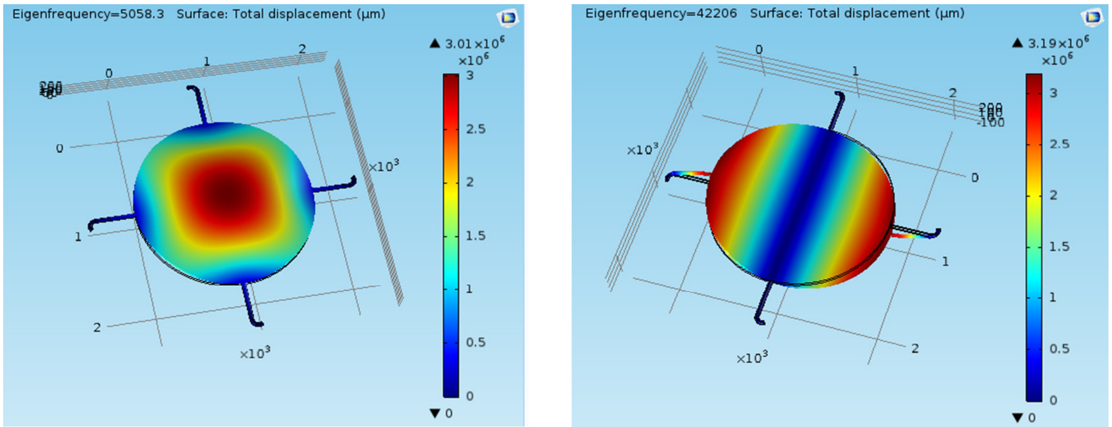

Fig 6:Circular proof mass of (a)PTFE and (b)S

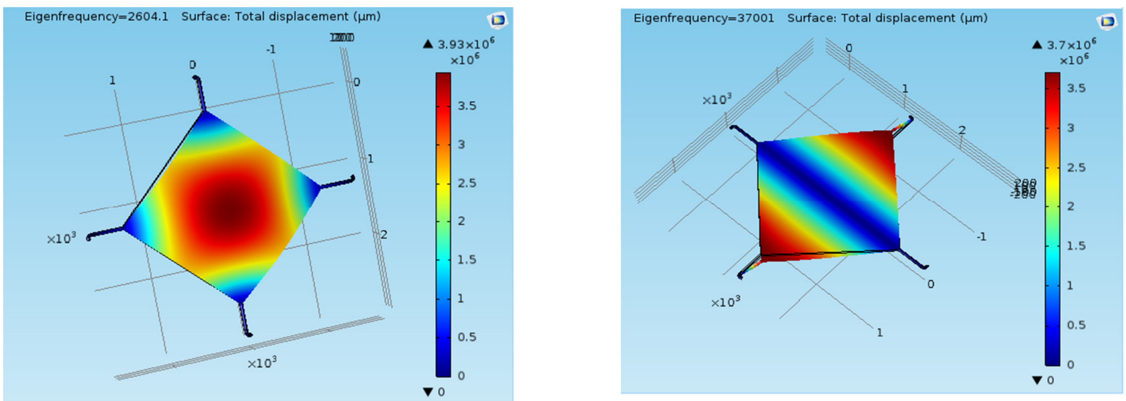

Fig 7: Rhombus proof mass of (a)PTFE and (b)Si

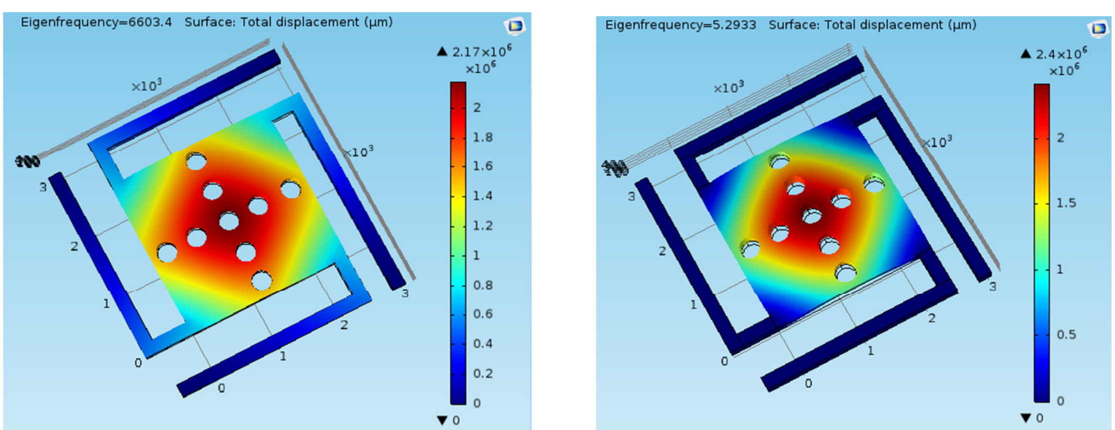

Fig 8: Perforated proof mass with (a)PTFE and (b)Si material

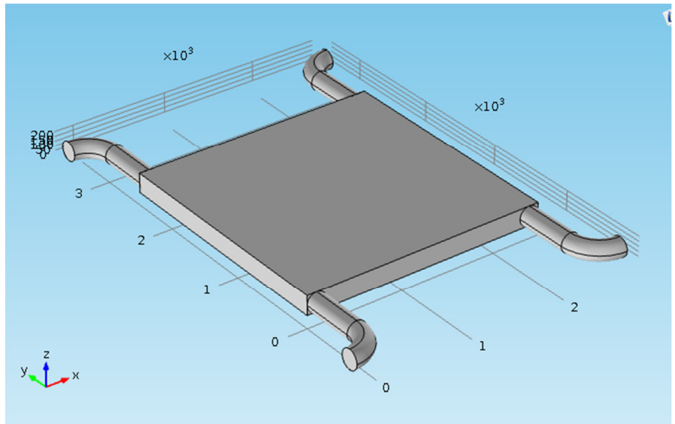

Fig. 9: Proof mass with Si material

5. CONCLUSION

In this paper, we have reported a novel structure accelerometer sensor with silicon material which detects the resting tremor of Patient

The essential tremor frequency is from 3Hz to 7Hz. The Proposed structure is simulated using COMSOL Multi Physics 5.0 CAD tool and results are compared with the different shaped proof mass with different materials of a moving part of sensor. The minimum range of Eigen frequency that the proposed structure got 2.3572Hz and the maximum range is 8.679Hz with a displacements of 1.04µm to 2.74 µm. It is evident that now a days only the clinical based tests are the conventional tests to detect the severity of the tremor for Parkinson's Disease as per the UPDRS. Here, we have proposed new methodology to detect the resting tremor of Patient which is the initial symptom of the Parkinson's Disease. It is clear from the results that the Silicon material for proof mass gives the best sensitivity values when compared to all the materials of polymers. The capacitive actuationtechnique is proposed in this paper to identify the output capacitance and voltage because it gives high sensitivity and accuracy and reliability

6. ACKNOWLEDGEMENTS

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