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Development of a Quantum Tunneling Composite based 1-DOF Tactile Sensor

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***Abstract*—Tactile Sensing is the measure of tactile parameters such as pressure, force, temperature, vibration, etc. by sense of touch. This paper presents the development of a novel one degree of Freedom (DOF) tactile sensor which can be used to measure the force applied at one direction. A novel composite material named as Quantum Tunneling Composite (QTC^{TM}) is used as the sensing element for the developed sensor. The sensor structure consists of a spring load mechanism to increase the sensing range of the QTC^{TM}. Thanks to the improved characteristics and cost effectiveness the sensor application in industry is promising.**

Keywords— Tactile Sensors, Composite Materials, Quantum Tunneling Composite

1.INTRODUCTION

Tactile sensors are devices which use tactile sensing principles to acquire data from the physical world. Tactile sensing basically involves with measuring tactile parameters such as pressure, torque, temperature, vibration, etc. with the aid of physical touch [1], [2]. Although importance of tactile sensing was identified in 1970s, developed technology or devices in that area were in a primitive stage. More advancements came for tactile sensing technology after 1980s. In this period various sensing principles were identified which can be incorporated with tactile sensors and more advanced devices were developed [2]. Several sensing principles can be identified which can be incorporated with tactile sensors.Measuring the resistance change induced from the resistive material squeezed between electrodes [3], measuring the resistance change of diffused resistors in silicon MEMS tactile sensors[4][5] , using a strain gauge to measure the deformation of a tactile cell [6], measuring the accumulation of charges and the resulting voltage build-up as a membrane is forced[7] and measuring the capacitance change induced by the change in the gap between the electrodes [8] are some of the popular sensing mechanisms. Apart from these, use of conductive polymers or composites is also gaining popularity at present[9]. Over the past decades tactile sensors are being used in robotics, medical and industrial applications where measuring the pressure variation of a surface is critical.

In this research, a tactile sensor with good performance and low manufacturing cost compared to other commercially available tactile sensors is presented. There are three major components in this tactile sensor, namely, sensing element, mechanical structure and electrode arrangement. A conductive composite is used as the sensing element of the proposed tactile sensor. The chosen conductive composite is a novel material called Quantum Tunneling Composite (QTC^{TM}). QTC^{TM} material changes its conductivity according to the mechanical deformation it undergoes[10]. Also the improved performance of this material will increase the performance of the proposed sensor. Amarasinghe, Kulasekara [11] have proposed use of QTC in MEMS tactile sensor for gripping force measurement due to the advantages of this material.

A novel mechanical structure was proposed to overcome the limitations of QTC^{TM} and to provide a platform for the application of force to the sensor. In this proposed sensor, electrodes are designed so that the contact points between sensing elements and electrodes are minimum. This would decrease the error occurred when a current passing through the contact point.

In this paper, we will discuss the sensing element and its properties, and limitations. Next, the designing of the mechanical structure and the structural analysis are performed to verify and optimize the structure. Then the electrode design and the electrical circuitry of the proposed sensor will be discussed. Finally, the experiments will be carried out to evaluate the developed sensor.

II. SENSING ELEMENT

Since sensing element is a major component in a sensor, it directly affects the cost and the performance of a sensor. For the proposed sensor, it is decided to be use electrical conductive composite as the sensing element. The principle of Electrical conductive composites is one of the most important finding in the past century. Despite the useful material properties that the polymers provide, they have been neglected by many applications because of their electrical insulation property. But by combining polymers with filler materials, it was found that the polymers can show electrical conductive property to some extent [12]. Electrical conductivity of these composites vary with the type and the amount of filler material used in the process. A polymer material become conductive if its filler content exceeds beyond the percolation threshold. Main mechanism behind such composites is that the fillers inside tend to form paths between them, so that the electrical current could flow [13]. Quantum tunneling composite is such a commercially available conductive composite which is developed by the Peratech Ltd., United of Kingdom [14].

This material shows extensive reversible increase in electrical conductivity when mechanically deformed. This is an improved property comparing to the other composite available. Also response to an applied voltage changes according to the amount of deformation from ohmic to nonlinear and hysteresis. Unlike Carbon particles which used in other composites QTC™ use Inco Nickel Powder. These powders contain sharp spikes like protrusions [15]. Under compression resistance of the QTC™ can fall from $10^{12} – 10^{13}$ Ohm to less than 1 Ohm. Also when the QTC™ compressed into low resistance state, it can carry a large current without damaging the element[10].

QTC™ comes in the form of pills of size 3 mm× 3 mm × 1 mm. So the maximum deflection that could obtain for the force applied is limited to under 0.8 mm. this affects the sensor range severely. It is suitable to use a force scaling down structure along with this material to increase the sensor range.

III. MECHANICAL STRUCTURE

A. Structural Design

Mechanical structure is used to decreases the amount of force applied to the sensing element. This will ensure the range of the sensor will increase according to the application. Design of such structures depend on the application and the sensing element using for the sensor. Proposed design contains piston cylinder system with a single spring. Force will be applied to the top face of the piston. Due to this, piston tend to move along the cylinder axis and transfer that force to the sensing element. Spring applied in this structure will decrease the magnitude of the force applied to the sensing element. Fig. 1 shows the conceptual design of the proposed structure.

Since almost all the parts have circular geometry, they could be manufactured easily with simple machining operations. Also because of the minimum number of parts and the geometry of the parts, alignment problems won'toccur at the assembling stage. This will also reduce the manufacturing cost of this design, which is an added advantage. Also because of the thread between the base cup and the lid, it is possible to give a pre compression to the sensing element which could be an advantage.

B. Structural Analysis

Since the resistance of QTC™ pills vary with the deflection of the pill, it is important to have a clear idea about the deflection of the pill for each force value. First, structure was analysed

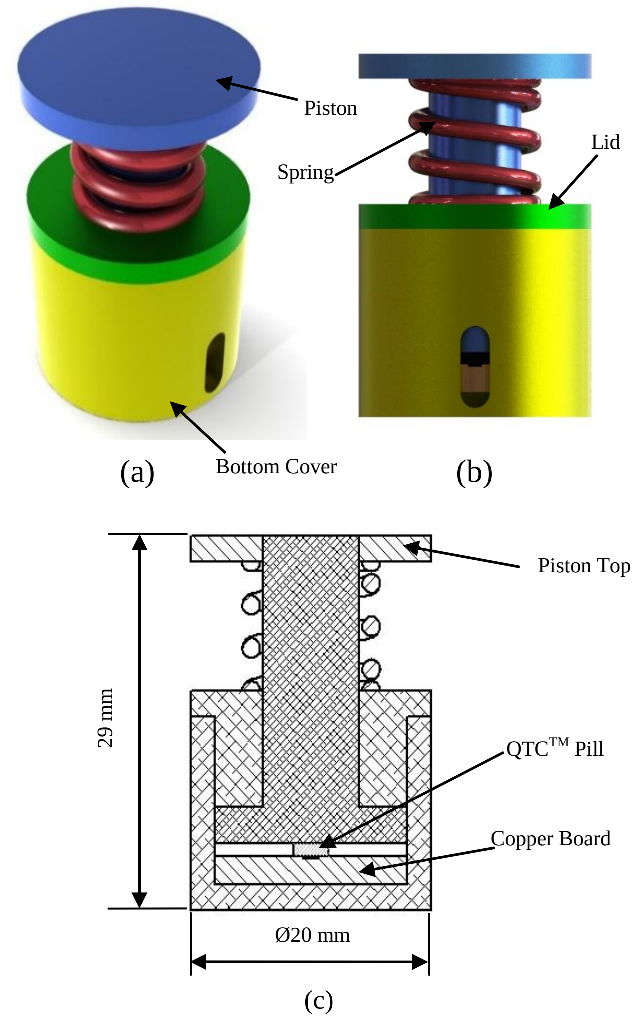


Fig. 1. Conceptual Design of the proposed structure; (a) Isometric view. (b) Front elevation. (c) Sectional front elevation

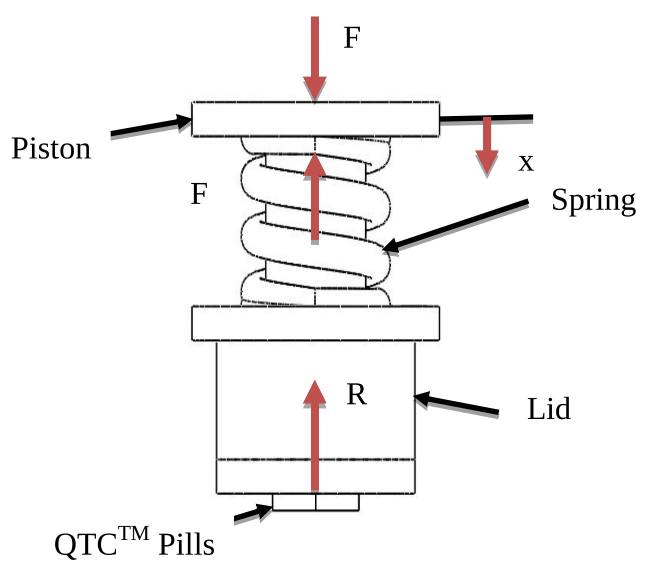


Fig. 2. Forces acting on the sensor structure

analytically to identify the forces acting on it. Fig 2 shows the free body diagram for the sensor structure. Here "*F*" denotes the force applied to the sensor, "F_1" denotes the spring force and "R" denotes the reaction force from the QTC™ pills. In the next stage, using the finite element analysis software ANSYS, a structural analysis is performed.

One of the major objective of performing a structural analysis is to forecast the behavior of the sensor for different spring gauges. ANSYS analysis performed here has the capability to indicate amount of deflection of the sensing element for each force value. Hence using this analysis following can be forecast for each spring gauge regarding the sensor,

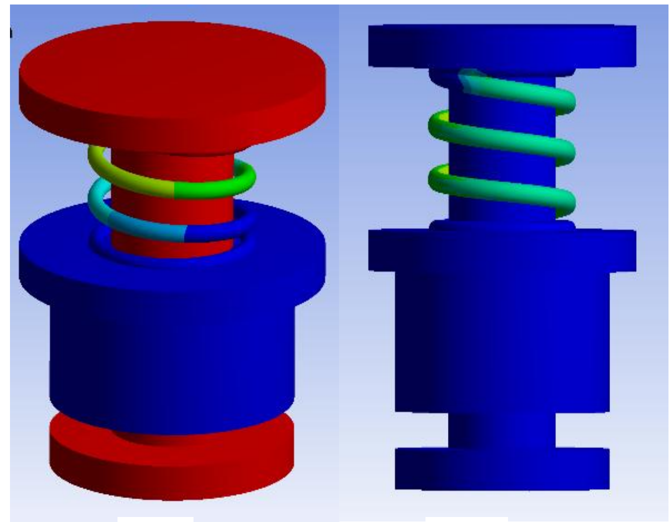
- Maximum force that can be applied
- Maximum deflection of the sensor when maximum load is applied.

Hence using this analysis, a spring gauge value for the sensor can be chosen which is compatible with the application of it. Also this can be used as an aid for calibrating the sensor for a specific application.Fig. 3 shows the shows the plot results for structural analysis performed for spring gauge 1.0 mm.Table 1 shows the maximum force range that can be applied for spring gauges 1.0 mm and 1.5 mm. Also it shows the maximum deflection of the sensor for each spring gauges at corresponding maximum force that can be applied.

Characteristic	Unit	Spring Gauge 1.0 mm	Spring Gauge 1.5 mm
Force Range	N	0-250	0-270
Total Deformation (Overall)	mm	0.72733	0.76049
Equivalent Stress (Overall)	MPa	315.74	305.42
Total Deformation (QTCTM pill)	mm	0.71784	0.74293
Equivalent Stress (QTCTM pill)	MPa	10.737	11.206

IV. Electrode Design

Electrode designing is critical for this sensor, as there is a possibility of a transmission loss of the output signal through the contact points between QTC™ pills and the electrode. Also noise could be added to the signal through these points. This will be a disadvantage when taking the sensor output for measurements. So an electrode was design to minimize the contact points between QTC™ pills and electrode. Fig. 4 shows the designed electrode. In this design a copper cladded board is used to create electrodes. As shown in Fig. 4 copper layer is separated to two regions so that it work as two separate electrodes. QTC™ pills are mounted on the copper clad board so that they are touching both these electrodes. Output signal can be taken out from those two electrodes. Using an electrical circuit as shown in Fig. 5 signal conditioning can be done for the output signal of this sensor. After the signal conditioning using a controller force applied to the sensor can be recorded according to the sensor output voltage.



(a) (b)

Fig. 3. Structural analysis plot results; (a) Total deformation (Overall). (b) Equivalent stress (Overall)

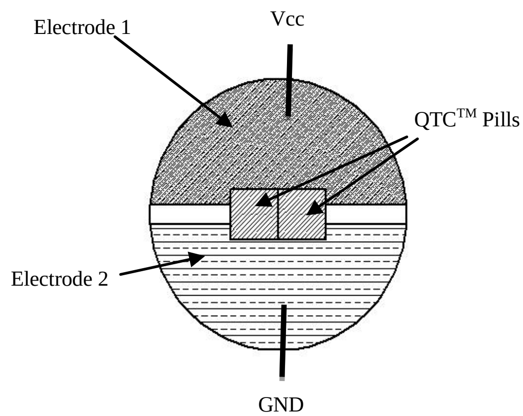


Fig. 4. Proposed electrode design

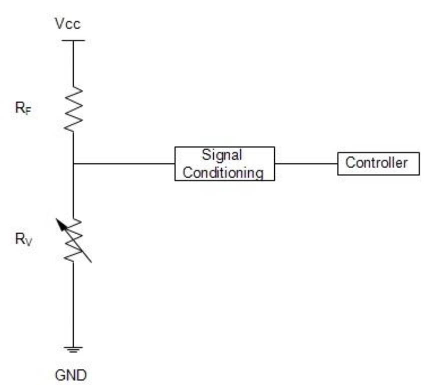


Fig. 5. Proposed electrical circuit diagram

V. Experiment and Results

Using avaialble manufacturing techniques, the proposed sensor structure is fabricated and assembled for later testing and calibration. Fig. 6 shows the fabricated sensor.

Experiments were carried out for the fabricate sensor to identify the variation of sensor deflection for each force applied. A gradually increasing force was applied to the fabricated sensor and deflection was recorded for each force value. Three sets of data were taken through this experiment and average of those data were taken to plot the graph between force vs. deflection as shown in Fig. 7. According to the results, proposed tactile sensor shows relatively linear relationship between the force applied and the deflection.

Another experiment was carried out to identify the sensor output variation for each force value. Output variation with regard to the input variation is important when calibrating a sensor. Calibration of sensor is done so that the performance of the sensor will be free of structural errors. Performance errors usually occurs when the sensor output is deviate from expected output for a corresponding sensor input. Usually structural errors are repeatable errors which consistently added to the output at each measurement. These errors can be calculated and compensated at the signal processing stage so that the sensor output is free of structural errors [16]. Fig. 8 shows the plotted results for this experiment.

According to the plot shown in Fig. 8, the fabricated tactile sensor shows slight hysteresis error. Also from the graph it can be seen that hysteresis error occur during the lower force values. So when measuring forces at high values, hysteresis shown by this sensor will be insignificant. Also by compensating the output with a well versed algorithm, hysteresis of this sensor can be avoided.

Fig. 6. Fabricated 1-DOF tactile sensor

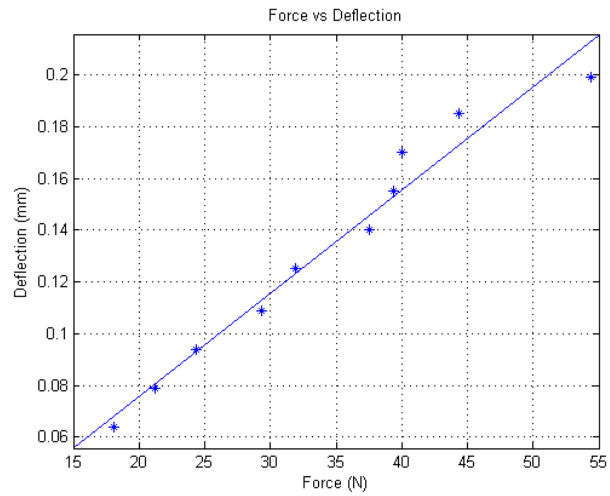


Fig. 7. Experiment Results; force vs. deflection plot

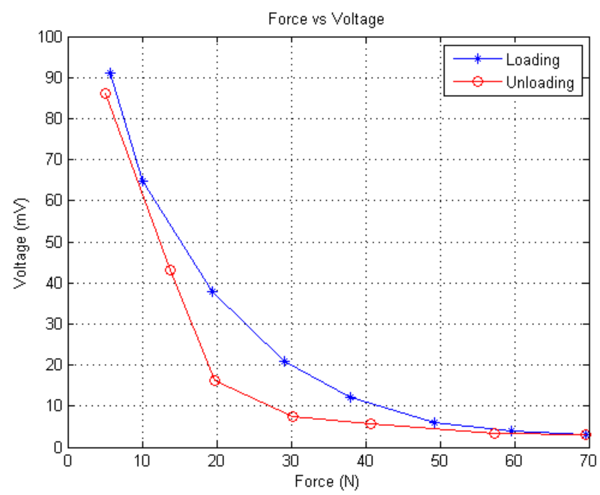


Fig. 8. Experiment Results; voltage vs. force plot

VI. Conclusion

A novel 1-DOF tactile sensor for industrial applications is proposed. Sensing mechanism proposed in this paper use QTC^{TM} pill as the sensing element. There would be some drawbacks when using QTC^{TM} as sensing element for a tactile sensor. The proposed mechanical structure for the sensor has been able to overcome those drawbacks successfully. Ability to change spring used in the structure according to the force applied will support to change the force range that the sensor can sense accordingly. The simulation was carried out to validate this phenomenon and the working principle of the sensor. Using QTC^{TM} and the proposed structure enhanced the ability to fabricate a low cost, high performance 1-DOF tactile sensors.

VII. Future Works

For some applications, hysteresis of this sensor can be neglected as hysteresis is negligible at higher forces. But for some applications error can be critical. So for those applications it is required to use an algorithm to compensate the hysteresis error occurred by this sensor. Although measurement of force applied at one direction is usable for industrial applications, a sensor with capability to measure force at multiple directions could be beneficial. So future works will involve with developing an algorithm to compensate hysteresis of this sensor and develop a mechanical structure which could be incorporated with QTC^{TM} so that the force at multiple directions can be measured through the sensor.

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