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A Model for Hypersensitive Airflow Sensor Concept

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ABSTRACT

From an engineering standpoint, automated reaction from the system is most important in fulfilling the requirement of the intelligent control system. Nevertheless, many related studies regarding in developing the hardware of the system such as high sensitivity of the airflow modelling in detecting the changes either in user or the environment is very crucial in produce high quality airflow model. Hence, this research aims to develop preliminary design for the high sensitivity of the airflow in macrofluidic control in detecting the changes of the airflow movement based on relative velocity motion theory and describe the deformation behaviour of model structure in detecting the slight changes of the airflow field. The consideration of the new design should cover few parameters such as the deformation which covers speed range from 0 km/h to 110 km/h indicates higher sensitivity of airflow model and 360° of the upcoming airflow coverage. The design stage will be divided into multiple section which are the main structure, the tip and inner support structure (shape memory alloy). Integration of shape memory alloy material and consideration of different shape will be implemented to enhance the performance of the dynamic airflow model sensor. Nevertheless, the design provided in this paper can provide idea *and fill the research gap in producing the airflow in macrofluidic model that can perform accurately in dynamic motion from the relative velocity.*

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Introduction

At present, there is no high sensitivity of the airflow model that can measures in dynamic motion with wide range of speed accurately. However, there are still no concept or reliable model in considering the relative motion to be integrated into the airflow model to achieve high sensitivity airflow model (dynamic). Previous research only focus static airflow model by presenting the three-dimensional model with simulation to improve the sensitivity of the airflow detection [1-2]. The suitability of vane meter approach sensor detect the airflow based on the bend angle of the bending portion elements [3-6]. Hence, integration of new technology is very important in covering wide range from 0 km/h to 110 km/h of the improved design model. In dynamic motion, the model should be able to cover 360° of airflow movement and corresponds with the relative velocity of the motion.

First parameter in designing of the strip structure where slight changes has been made at the tip of the structure. The tip structure is constructed by imitating the leaves structure in effectively detect low presence velocity in the airflow field. The middle section of the strip will be in rectangular shape to capture the upcoming high velocity.

Hence, the development of shape memory alloy may be integrated into the model to improve the capture range of bending moment for the strip of the airflow model. Integration of titanium-nickel alloy, Ti-51.3Ni (at%) [7-8] is required to enhance the strip strength during high velocity speed. The activation of the shape memory alloy is based on the thermal energy applied onto the structure .The martensitic transformation is detected by holding at fixed temperature and measure the electrical resistivity throughout the process as shown in Figure 1. The structure of the memory alloy will be in martensite phase in low temperature whereas austenite for high temperature. The material will undergo phase change from martensite to austenite and the material will return to its original state. The integrated structure of the proposed concept as shown in Figure 2.

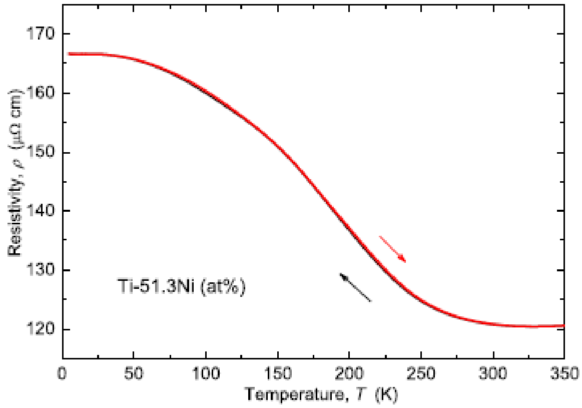

Figure 1: Temperature dependence of electrical resistivity measured in the cooling and subsequent heating process with a cooling and heating rate of 2 K/min [8].

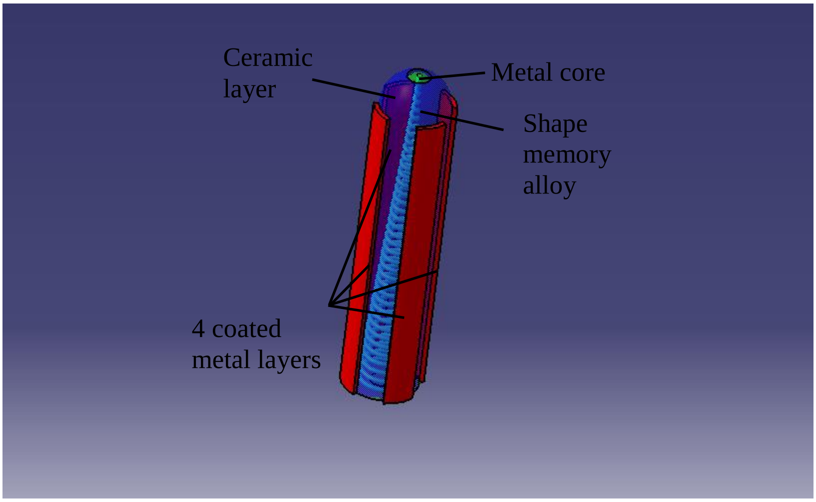

Figure 2: Integrated structure of the hypersensitivity airflow model concept

Key factors in developing hypersensitivity airflow model

Airflow intake area coverage

Most of the existing model only cover single direction based on the design where there is an exact location for the airflow intake for the airflow movement detection. The paper by H Kawaoka on Extraction of Heartbeat Signal from Airflow at Mouth by Flow Sensor implement single direction for the airflow intake as shown in Figure 3. This approach is very common applied to the hot wire application where detection is done by calculating the temperature difference in the airflow movement area. In contrary, the approach emits the limitation for the airflow coverage and reduce the performance and sensitivity of the airflow.

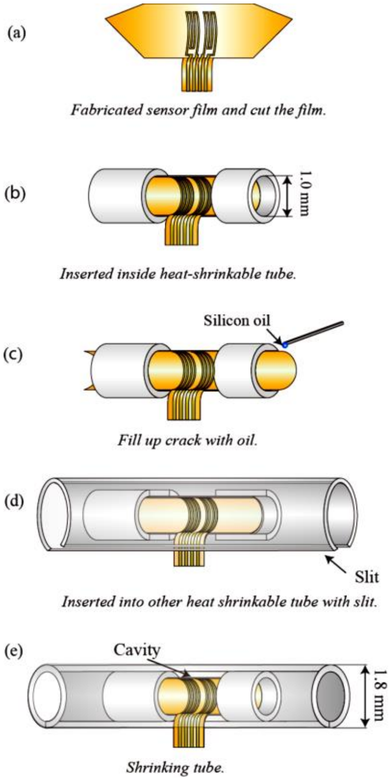

Figure 3: Components of the sensor during the installation inside the tube [9].

For this research, a huge concern is placed in covering 360° of airflow movement to achieve the hypersensitivity stage in developing the airflow model. Vane meter approach exhibits better incoming airflow coverage compared to hot wire approach. Bending moment method is implemented in order to calculate the air movement based on the resulted bending structure occurred during the changes in airflow movement. Previous research also shows that plane cantilever have been used to detect the changes of airflow by integrating multiple fingers to the sensors as shown in Figure 4. This will provide the gap for improvement to develop better performance airflow sensor.

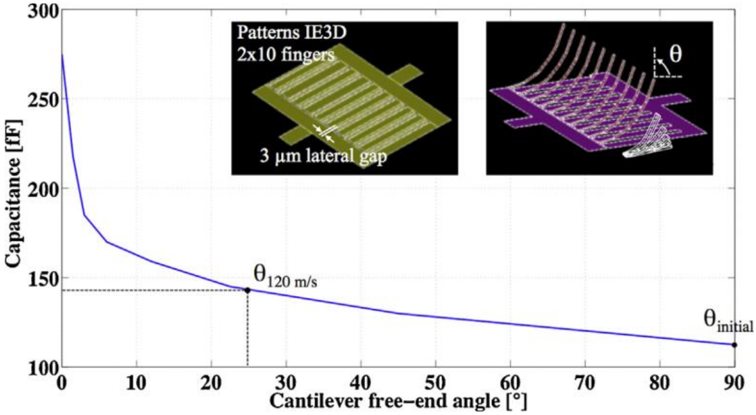

Figure 4: IE3D-simulated capacitance value with for 20 interdigitated fingers with different deflections [10].

Airflow intake speed coverage

Another key factor that contributes to the development of the hypersensitivity airflow sensor is the speed coverage. Most of the sensor developed only highly performed either in low speed or high speed velocity as shown in Table 1. In addition, this reduces the reliability of the existing sensor to perform in huge speed range.

Normally, hot wire approach has limitation in obtaining high accuracy of airflow changes in high speed due to inconsistency in maintaining the temperature. Hence, most of the design chose to redesign the model and create specific entrance for the upcoming airflow intake. In contrary, this solution reduce the coverage area in detecting the airflow movement which involuntarily affects the performance of the hot wire airflow sensor.

Vane meter approach also face the same problem as the hot wire approach. However, the limitation in covering the wide range of speed can be overcome by integrating new material that can enhance the material properties of the bending moment in the airflow sensor in specific time. Hence, this step will maintain the enhance performance of the sensor despite the changes done to these key factors.

Table 1. Existing type airflow sensors with different speed coverage.

Detection types	Speed range (m/s)	Sources
Bending moment	0 - 7 m/s	[11]
Light wavelength shift	Above 2.8m/s	[12]
Change of pressure at sensing plate	0.0002 m/s	[13]
Shear stress	0 - 6 m/s	[14]

Design concept of the hypersensitivity airflow model

Main structure of the MMPF

The overall structure of the strip is based on Multi-electrode Metal-core Piezoelectric Fiber (MMPF). The design structure enable to cover the detection range of 360° which is effective to meet the specification of high sensitivity airflow model sensor. The metal core is placed at the center which function as the electrode whereas the coated metal layer on the surface of the ceramic will act as the other electrode as shown in Figure 6. Number of 4 surface electrodes will be used where 2 of each electrodes will be symmetrical in position arrangement. The fabrication of the structure can be either using hydro-thermal method [15] or squeezing and pressing method [16]

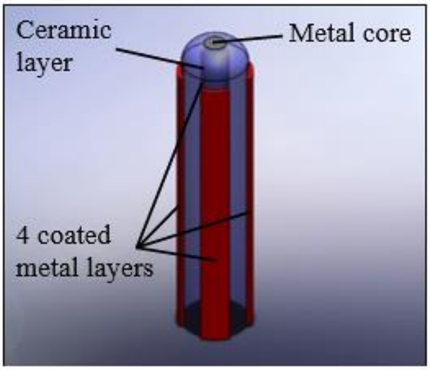

Figure 6: Preliminary design of the proposed MMPF structure.

End tip structure fiber strip

The design shape of the tip structure is based on the nature where a few designs have been produced based on the characteristic from the nature. Crickets which have high sensitivity sensory hairs located on the belly can detect changes of the airflow movement. The length of sensory hair range from 150 µm to 750 µm [17] as shown in Figure 7. Hence, the first preliminary shape design is based on this aspect has been produced as shown in Figure 8.

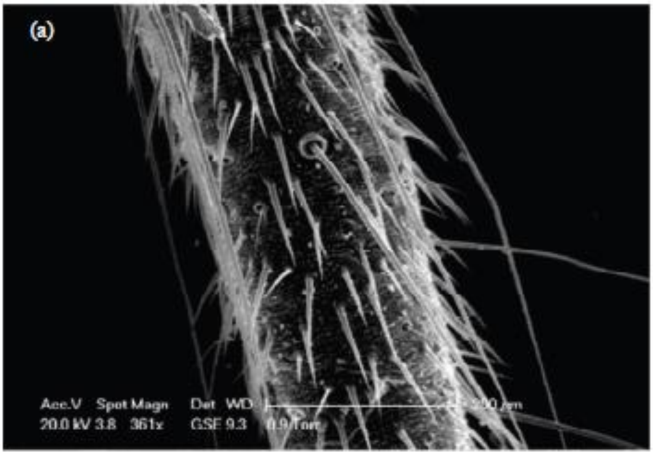

Figure 7: The amplified hair structure of the crickets [17].

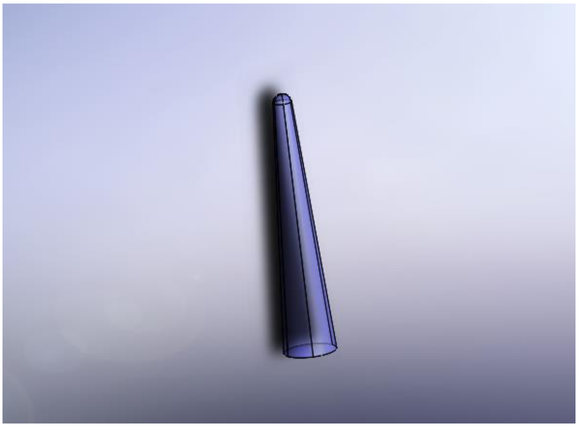
Figure 8: Preliminary design of the tips structure based on sensory hairs of the crickets.

Second approach used is based on the leave structure where the tip of the leaves are very thin and very fragile. This criteria comply with the needs in detecting low velocity changes in airflow movement for high sensitivity model. Figure 9 shows the examples of the computed geodesics between various plant leaves to from same species and across species [18]. This information will enable to obtain the most suitable shape that can be integrated together with the main structure of the high sensitivity airflow model.

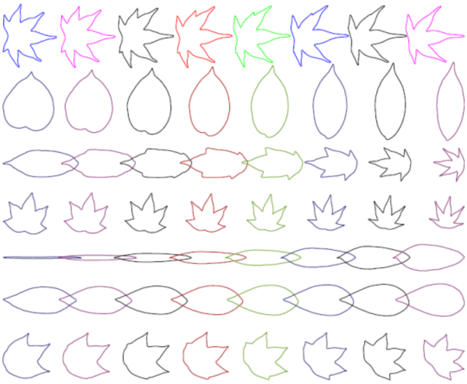

Figure 9: Examples of geodesics computed with the proposed approach [18].

Figure 10 shows the preliminary design of the tip structure for the high sensitivity airflow model. From this benchmark, the preliminary design of the tip structure has been chosen based on the suitability during the assembly of the airflow model where the leave structure is more significant to be integrated into the high sensitivity airflow sensor in covering wide range from 0 km/h to 110 km/h.

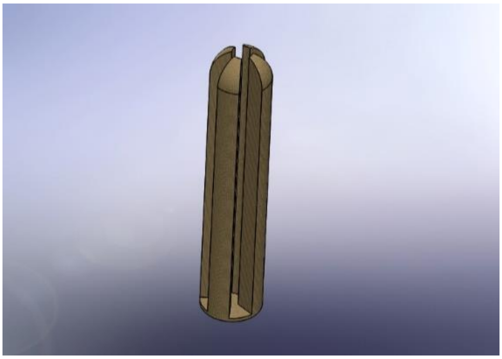

Figure 10: Preliminary design of the tips structure based on leaves shape

Wire structure shape memory alloy (Nickel-Titanium material)

For the design of the shape memory alloy, wire based structure will be used and attached onto the main structure. The material will help in regaining the original shape of the strip during high velocity stage where 2 transformation phase are involved in the process which are austenitic phase and martensitic phase [19] as shown in Figure 11. The transformation is based on the martensitic phase transformation where sufficient value of stress applied will change the microstructure of the shape memory alloy as shown in Figure 12.

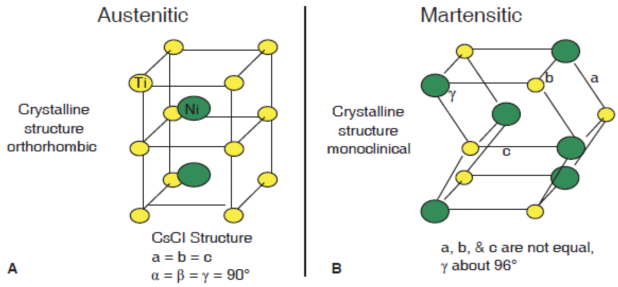

Figure 11: A) Austenitic phase and B) Martensitic phase [19].

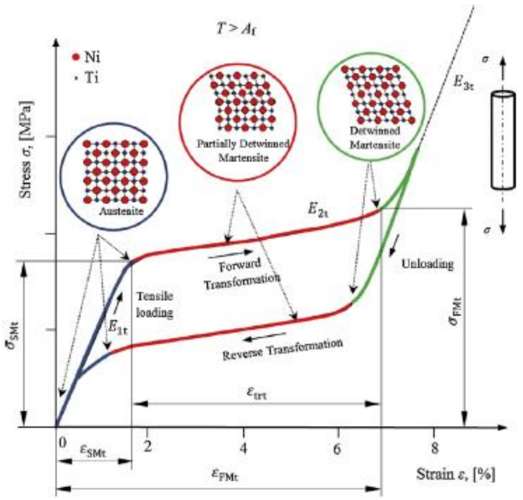

Figure 12: Stress strain curve under uni-axial loading for Nickel-Titanium material [19].

The wire design will be in helix around cone shape. The wire for the shape memory alloy be placed at the centre of the main structure of the airflow model. Bottom section will have wider coverage and become thinner towards the tip of the fiber strip. This is due to the factors in regaining the original state and retain the high sensitivity for each section of the fiber strip in covering wide range velocity from 0 km/h to 110 km/h.

The development of the wire shape memory also need to consider the aspect of the stress and strain that the structure can sustain to face low and high velocity speed. Hence, shear stress in Eq. (1), tension stress in Eq. (2) and compression stress in Eq. (3).

$$\tau_{cri} = Q_{\sigma crio}/\sqrt{2} \quad (1)$$

$$\sigma_{crit} = Q_{\sigma crio}/\,(1+\gamma_o)^{n_0} \quad (2)$$

$$\sigma_{crit} = Q_{\sigma crio}/\,(1-\gamma_o)^{n_0} \quad (3)$$

The 2 unknown which are γ_o and n_0 can be used with constant value respectively of 0.9 and 0.1 [20]. In the other hand, the modulus of elasticity for tension and compression are related by using Eq. (4)

$$E_c = E_t = 2\mu(1+v) \quad (4)$$

Therefore, the preliminary design for the wire shape memory alloy has been concluded as shown in Figure 13 below.

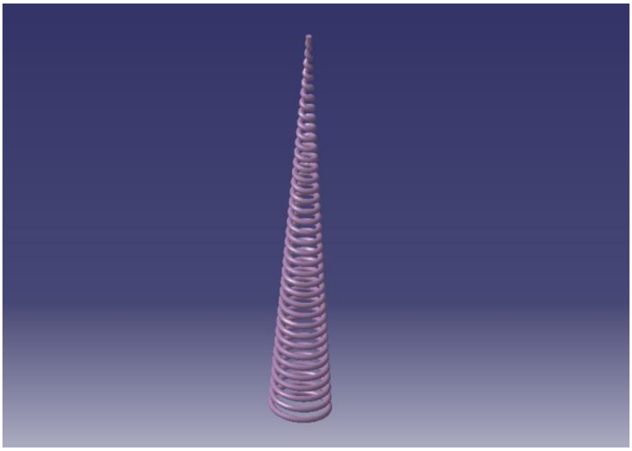

Figure 13: Preliminary design for the Nickel-Titanium wire alloy

Conclusion

This study intended to create the breakthrough in producing the airflow in macrofluidic model that can perform accurately in dynamic motion from the relative velocity. Improvement that have been done to the structure of the airflow model section may increase the performance of the sensor and manage to cover wide range of velocity from 0 km/h to 110 km/h. Integration of shape memory alloy structure will enable the structure to detect high velocity speed from the bending moment by enhancing the structure strength of the airflow model. The leaves shape pattern produced at the tip helps in improve in detection coverage for the low speed velocity in airflow field. Hence, the improvement in the structure specification and integration of the new components will increase the performance of the high sensitivity of the airflow model sensor.

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