Design of Micro-Ice Detection Sensor for Aerospace Application

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***Abstract* – MEMS (Micro Electro Mechanical System) design systems are used for the development of Micro Ice Detection Sensors, which give change in capacitance as output when ice is detected on aircraft body. Ice detection technique using Silicon diaphragm as sensing element by using Intellisuit is presented. The capacitive technique for ice detection is used. Finite element analysis (FEA) is done to optimize the sensor geometry for enhanced sensitivity to ice accretion. The sensor is simulated in 2 modes, Pressure Sensitive Mode and Stiffness mode. In pressure sensitive mode, the capacitance change obtained is proportional to the ice accretion on the diaphragm. In Stiffness mode, the capacitance obtained is inversely proportional to the ice film formed on the diaphragm. Thus ice present on the body of aircraft can be detected by using Micro capacitive Ice detection Sensor.**

Keywords – capacitance, MEMS, micro diaphragm, stiffness

I. INTRODUCTION

Aircraft ice detection systems have received a great deal of attention because of their importance in flight safety. In-flight icing is caused by the presence of metastable, super-cooled, water droplets in clouds usually between -10°C to 0°C[1,8]. When the aircraft encounters these droplets, they may either suddenly change phase from liquid to solid upon impact, or they may flow back as a thin film of water, collect into droplets due to surface tension, and then freeze[3]. The buildup of ice on the leading edges of fixed wings causes an increase in drag and a decrease in lift of the aircraft [3,4]. Ice formation can also result in the inability to retract moveable surfaces, such as slats and flaps. Furthermore, dislodged ice can damage the aircraft skin, antennas or other instrumentation, and cause catastrophic engine failure if ingested. Ice builds in flight where no heat or boots can reach engine, blocking the engine's air source. Ice accumulated on the wings, propeller, and windshield, can roll or pitch the aircraft uncontrollably. It can lead to a temporary loss of control.

These potentially severe problems have led to the need for reliable and robust sensors for the detection of ice. MEMS-based sensor system, with the inherent advantages like smaller size and microelectronics compatibility is particularly attractive for ice detection. MEMS pressure sensors based on capacitive technique are more popular in aerospace industry because of their high sensitivity and low pressure ranges.[6]

II. DESIGN OF SENSOR

The Sensor is designed in Intellisuit 3D Builder. The simulation of the sensor is done with the help of Intellisuite Thermoelectromechanical Module. The sensor geometry is developed in design module of Intellisuit-3D Builder. The layer by layer the geometry is formed.

The sensor is in the form of circular disk. The radius (R) is 0.42 µm. The thickness (h_1) of individual plate is 1.5µm. The air gap between the capacitor plates (h_2) is 1.5µm.

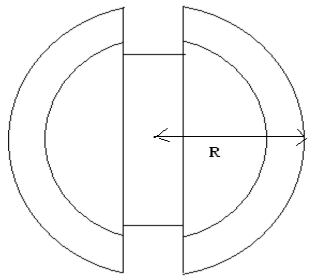


Fig.: Top view

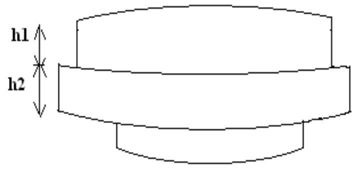


Fig. Front View

III. DESIGN PRICIPLE

The sensor uses capacitive technique for working. The capacitance can be given as follows [7]:

$$C = A\varepsilon/d \qquad (1)$$

Where, C=capacitance

A=area of contact of two plates

ε=permittivity of free space

d=distance of separation between two plates

In case of circular diaphragm sensor, the capacitance under deflection is as follows.

$$C= \iint \varepsilon/[d-w(r)]*rdrd\theta \qquad (2)$$

Where,

W(r)= deflection of diaphragm

r=radial distance from centre of diaphragm

Capacitive sensing utilizes the capacitance change induced by the deformation of the diaphragm to convert the sensory information (here pressure) into electrical signals.

IV. MODELING OF SENSOR

After the sensor is designed in Intellisuite, it is simulated for different conditions in the Intellisuite-TEM (Thermo-electro-mechanical) analysis module.

The sensor is simulated in two modes i.e. pressure sensitive mode and stiffness mode. In first mode, the icing occurs on aircraft body due to temperature fall below 0°C.Due to accumulation of ice, pressure on diaphragm increases and corresponding capacitance is obtained. So, by measuring the capacitance, ice can be detected.

In second mode, the metastable, super cooled water droplets in clouds collide with aircraft body and freeze to form ice layers causing diaphragm stiffness to increase. Then actuation forces are applied electro-statically to cause diaphragm deformation. Therefore, for a given actuation voltage, an ice-covered diaphragm exhibits a smaller deflection than a corresponding ice-free diaphragm. This deflection is measured in terms of capacitance change between diaphragm and bottom electrode.

V. SIMULATION

The sensor design is simulated in static mode for the increasing ice accretion. For the simulation, Following properties of diaphragm are used-

1) Density=2.3 kg/m^3
2) Young's modulus=160 GPa
3) Poisson's ratio=0.26

The sensor can be simulated in two ways-

a. Pressure Sensitive Mode

b. Stiffness Mode

a. Simulation of Sensor in Pressure Sensitive Mode

During the operation mode i.e. during flight, icing is occurred on the surface of the aircraft and eventually on the sensor diaphragm. The weight of ice exerts the static pressure on diaphragm and the diaphragm is deflected. The deflection of diaphragm causes the change in capacitance .By detecting the change in capacitance, the presence of ice can be detected.

For pressure sensitive mode, following settings are recommended:

Diaphragm voltage=0 volts

Bottom electrode voltage=0 volts

The pressure range is 0.1MPa to 1Mpa.In ice-free condition, nominal capacitance obtained is 26.731702 nf. And nominal displacement is 0.51254 μm.

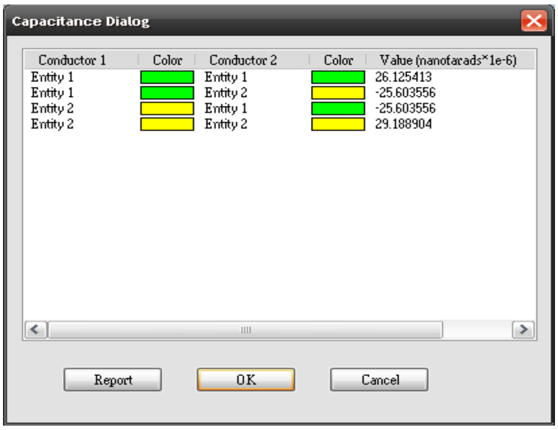


Fig. Capacitance=29.188 nf for Pressure=0.5 MPa

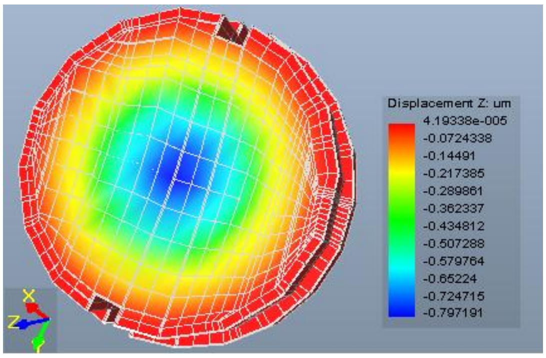


Fig. displacement=0.797191 μm for pressure=0.5 Mpa

Then sensor is then simulated for different values of pressure and the response of sensor is characterized .

Results are shown in 2 ways- the displacement and the capacitance:

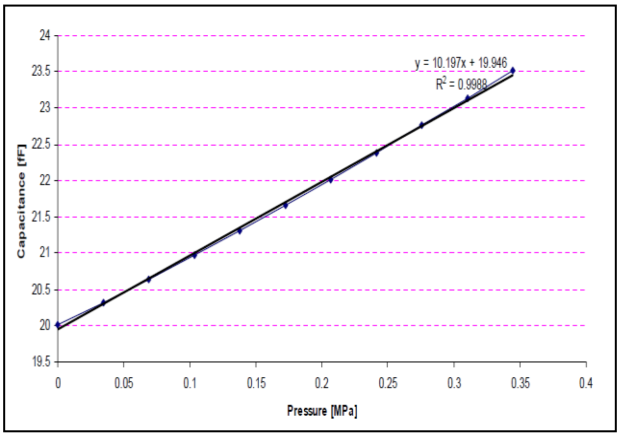


Fig. Capacitance vs. pressure

Results also give the displacement vs. pressure curve as shown in following figure.

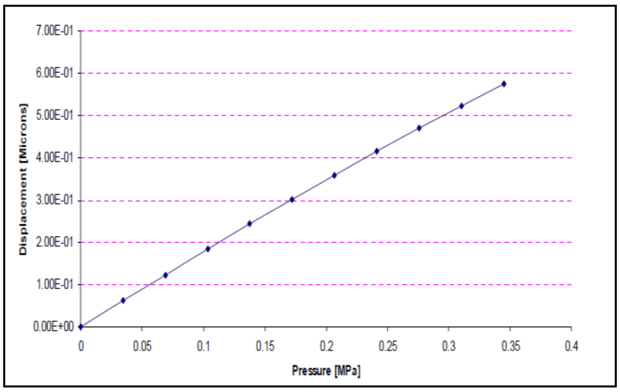


Fig. displacement vs. pressure

Results show the linear relationship between pressure due to ice accumulation and capacitance change. Second figure shows the relationship between pressure and displacement i.e. Center deflection of diaphragm.

b. Simulation of Sensor in Stiffness Mode

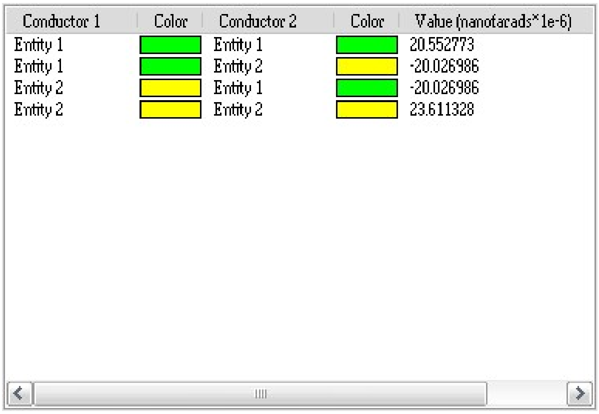
During operation, the meta stable , super-cooled droplets of water in clouds collide with aircraft and freezes on the surface. Thus, the layers of ice form on the surface of sensor i.e. diaphragm increasing the stiffness of diaphragm. The actuation voltage given to bottom electrode causes diaphragm to deflect in due to electrostatic force developed. Because of increasing stiffness, the deflection becomes lesser and capacitance decreases. Thus, inverse characteristic of increasing ice deposition and capacitance is obtained.

For stiffness mode, following settings are recommended-

Diaphragm voltage= 0 volts

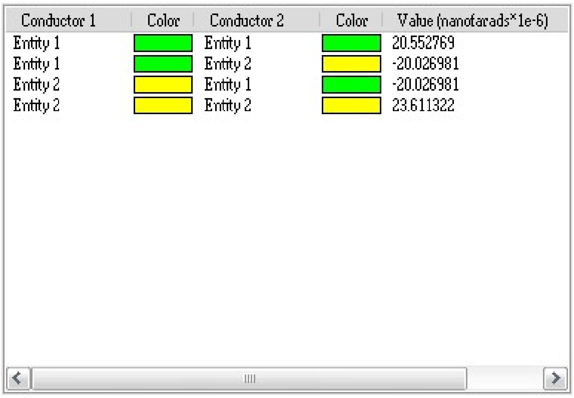
Bottom electrode voltage= 0.5 volts

Capacitance and diaphragm deflection results are shown below-



Conductor 1	Color	Conductor 2	Color	Value (nanofarads*1e-6)
Entity 1		Entity 1		20.552773
Entity 1		Entity 2		-20.026986
Entity 2		Entity 1		-20.026986
Entity 2		Entity 2		23.611328

Fig. Capacitance=23.611328 nf for Ice layer=0.1µm



Conductor 1	Color	Conductor 2	Color	Value (nanofarads*1e-6)
Entity 1		Entity 1		20.552769
Entity 1		Entity 2		-20.026981
Entity 2		Entity 1		-20.026981
Entity 2		Entity 2		23.611322

Fig. Capacitance=23.611322 nf for Ice layer=0.15µm

The Stiffness change of diaphragm can be simulated by changing the density of the diaphragm. The sensor is simulated for increasing stiffness and the response of sensor is characterized.

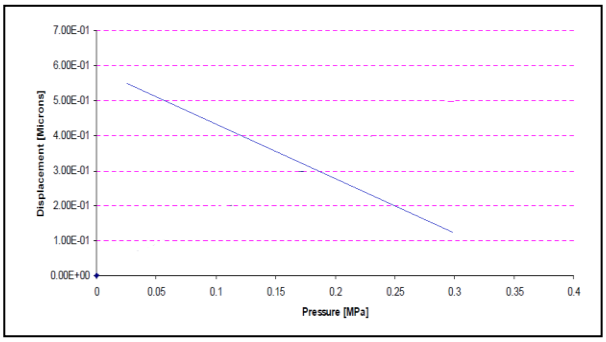


Fig. displacement vs. pressure

Results show the relationship between the deflection of diaphragm vs. pressure reduction due to the stiffness caused by ice accumulation.

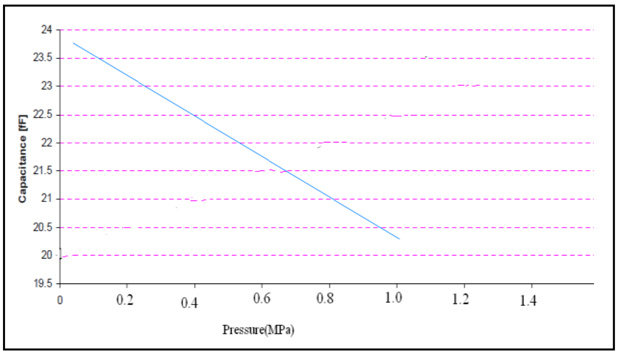


Fig. Capacitance vs. pressure

The graph shows the inverse characteristic of stiffness of diaphragm and the capacitance between the plates.

VI. CONCLUSION

This work presents the issues related to the ice accretion on the aircraft and also provides a solution in the form of micro Ice Detection Sensor. The feasibility of capacitive diaphragm type micro Ice Detection Sensor for the detection of the ice is demonstrated.

Results show that the diaphragm deflection is affected by the ice accretion and operates in two modes Pressure Sensitive Mode and Stiffness Mode. In Pressure Sensitive mode, the capacitance change is directly proportional to the ice accumulation. In Stiffness mode, the capacitance change is inversely proportional to the ice accretion due to the adhesion between ice and diaphragm.

VII. ACKNOWLEDGEMENT

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