MODELLING AND ANALYSIS OF AN ACCELEROMETER USING MSC/ARIES AND MSC/NASTRAN

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ABSTRACT

This paper presents the modeling and analysis of an accelerometer mounted on a jet engine block. The effects of some extreme thermal and vibratory conditions were examined. The finite element model of the accelerometer was modelled using the solid modeling and automatic meshing generation capabilities of MSC/ARIES. Normal modes and thermal analysis were then performed using MSC/NASTRAN Version 68.

INTRODUCTION

An accelerometer is a device which produces an electrical signal proportional to accelerometer. In short, it is a device for measuring shock and vibration. The particular accelerometer is made up of piezoelectric crystal element, electronics box and cable socket. In order to study the effect of piezoelectric crystal's temperature distribution and accelerometer's natural frequencies when mounted on jet engine, MSC/ARIES and MSC/NASTRAN are used to build up solid and finite element models and perform the heat transfer and normal modes analysis. The process is accomplished at three steps:

1. Solid model and finite element model
   A solid model and a finite element model are built up to best represent the physical conditions of the accelerometer and cable assembly. All dimensions are taken from actual shop drawing.

2. Normal modes analysis
   Constraints are applied along the edges of three mounting cylindrical holes to simulate the bolt mounting boundary conditions. The natural frequencies are compared with excitation frequencies from the environmental assumption.

3. Thermal analysis
   To examine the piezoelectric crystal temperature change under an assumed thermal environment condition.

The effect of design changes on thermal and modal analysis is studied then in order to optimize the performance of the accelerometer.

SOLID AND FE MODELING

MSC/ARIES is employed to generate the three dimensional geometric shape of the accelerometer. The geometric data is obtained by taking exact measurements of the accelerometer and the resulting solid model was used for generating the finite element model. In order to facilitate the operating procedure for building accelerometer solid model, the accelerometer assembly is divided into three major parts: Base & Cable, Electronic Box, and Piezoelectric Crystal Unit.

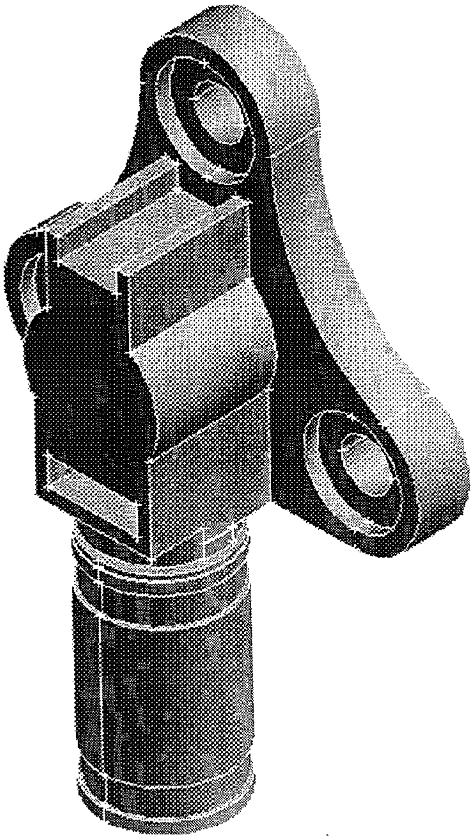

Fig. 1 The Base & Cable Part

For the Base & Cable part, shown in Fig. 1, it is built up as follows:

1: Start with a closed curve for the solid EXTRUSION of the base.
2: Construct three HOLES for bolts.
3: For the piezoelectric crystal unit's enclosure wall, we make several closed curves and develop the EXTRUSION.
4: Make a box for the connector between piezoelectric crystal unit's surrounding wall and cable and several curves; then EXTRUDE these curves into solid, SUBTRACT these curves from box and construct a HOLE on it.
5: Create a profile curve and center line for the solid REVOLUTION of cable.
6: Construct several HOLES on cable solid for placing cable wire.
7: UNION all solids.

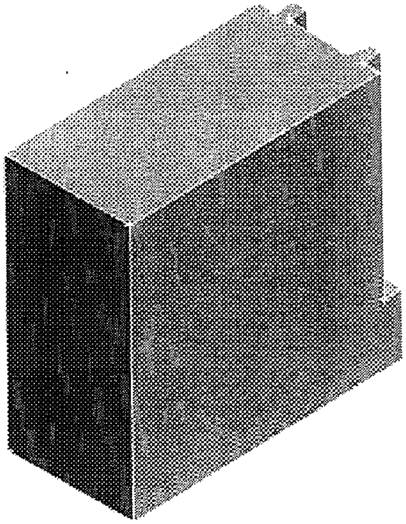

Fig. 2 The Electronic Box

For the Electronic Box, shown in Fig. 2, the operation process are as follows:

1: Make two boxes, exterior and interior geometry shape, and then SUBTRACT interior box from exterior box to get a electronic box solid.
2: For the connector between Base & Cable and Electronic Box, we create a 'H' shape closed curve and two boxes, smaller box and bigger box; then EXTRUDE this 'H' curve into solid, UNION 'H' solid, one bigger box, and Electronic box solid, and SUBTRACT smaller box from Electronic box solid.
3: Create four closed curves and then EXTRUDE as four screws inside electronic box solid.
4: Make two boxes as IC boxes and four cylinder as four screws.
5: UNION all solids.

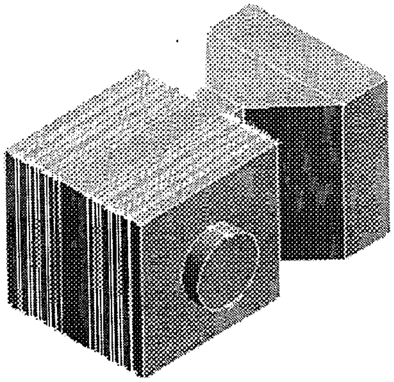

Fig. 3 The Piezoelectric Crystal Unit

For the Piezoelectric Crystal Unit, shown in Fig. 3, are as follows:

1: Create six closed curves to define a skinned solid and then loft a SKIN solid across these curves.
2: Make two HOLES on both side of piezoelectric crystal unit and use REGION to divide it into several small boxes in order to assign different material properties in FEM application.
3: Create two cylinders and UNION them to make a screw; then MIRROR it to get another copy screw.
4: UNION all solids.

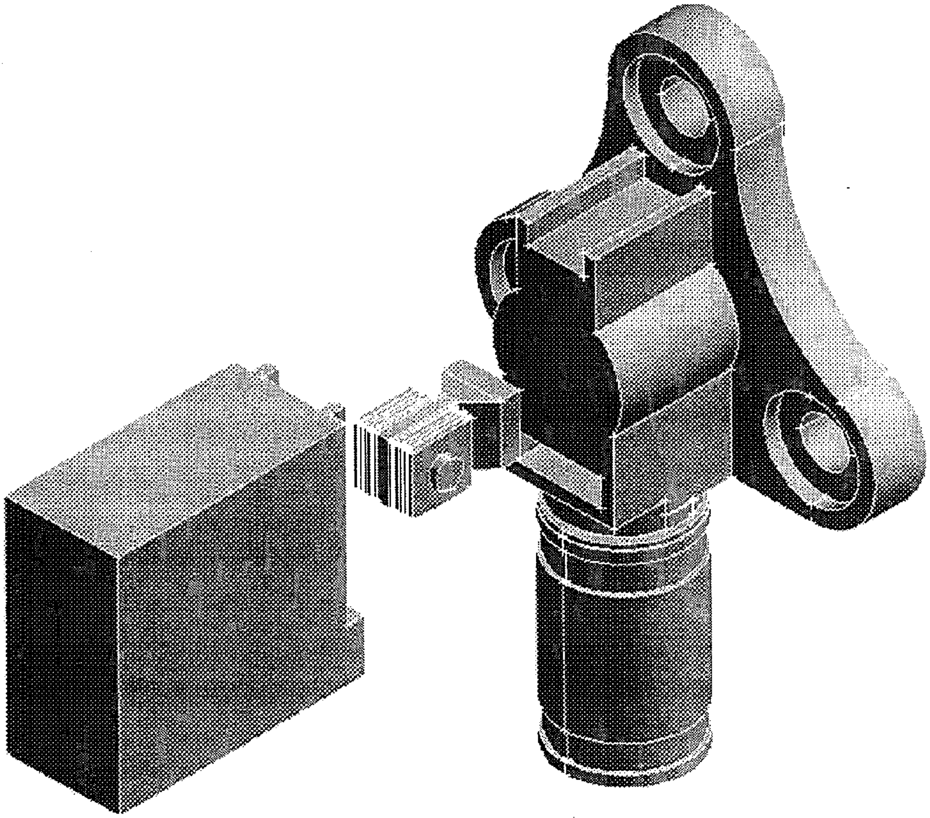

Fig. 4 Shaded Image Of Accelerometer Assembly

By UNION these three major parts of accelerometer, shown in Fig. 4, we get a solid model which is well prepared to be used in ENVIRONMENT, establishing restraints, and FEM application, creating finite element mesh.

In the normal modes analysis, restraints are applied on the cylindrical surfaces of the three bolt holes before using FEM to approximate the bolt mounting boundary condition. However, a finite element model is generated for both normal modes and heat transfer analysis.

In the FEM application, the piezoelectric crystal element and electronic box are meshed using mapped mesh generation techniques and the automatic mesh generator is used for meshing the exterior complex solid geometry. A 100g weight is attached to the end of the cable socket to approximately simulate the effect of hanging cable mass to the vibratory characteristics. The entire cable assembly weights about 190g.

Fig. 5 and 6 show the shaded images of the solid model and its half-sectional view respectively. Fig. 7 and 8 show the finite element model and its half-sectional view.

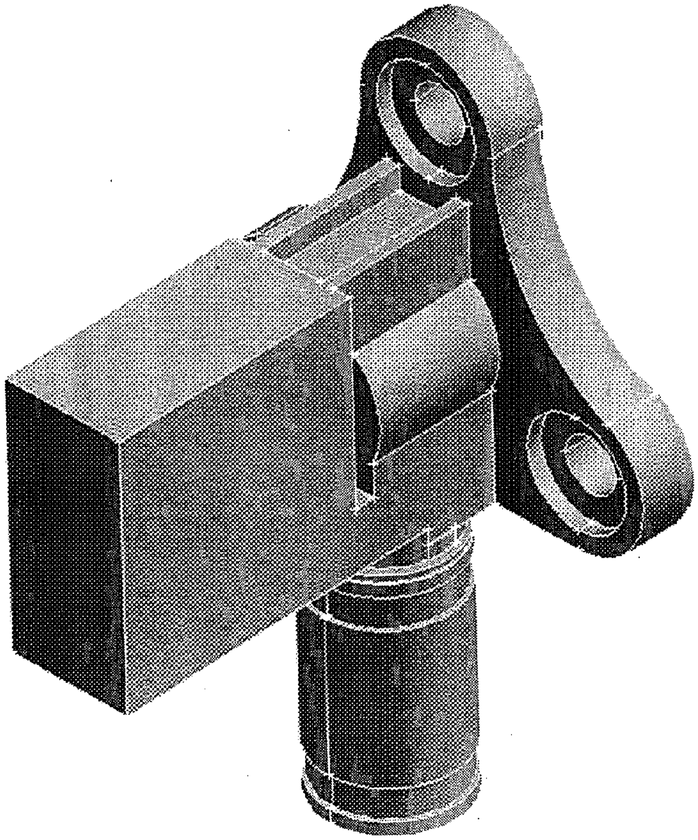

Fig. 5 Shaded Image Of Accelerometer Solid Model

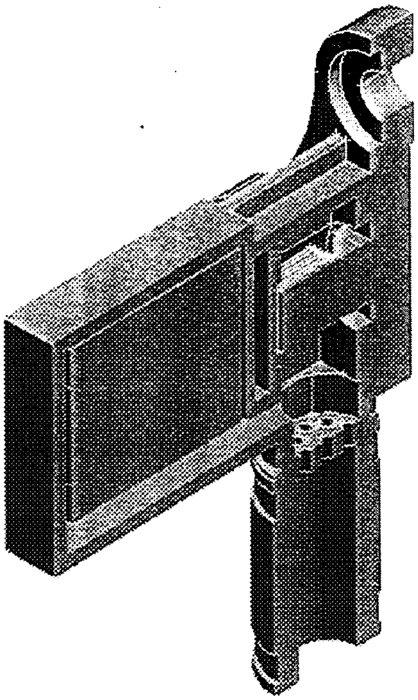

Fig. 6 Cross Section View Of Solid Model

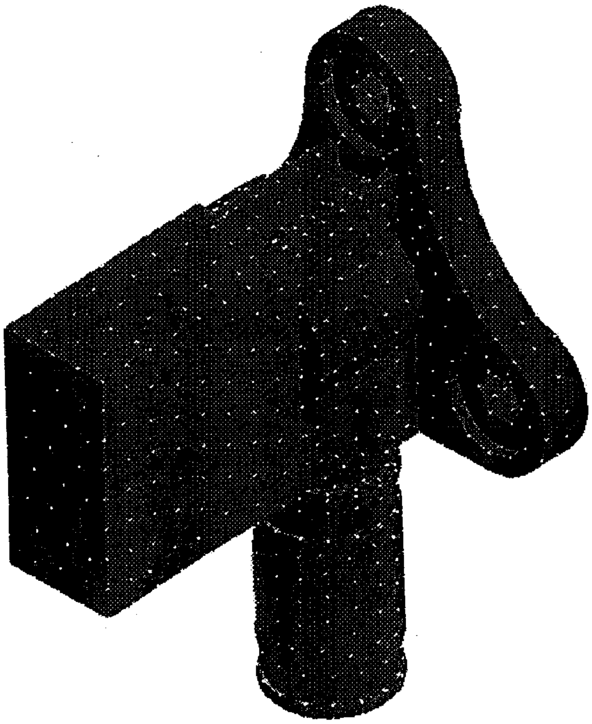

Fig. 7 Finite Element Model Of Accelerometer

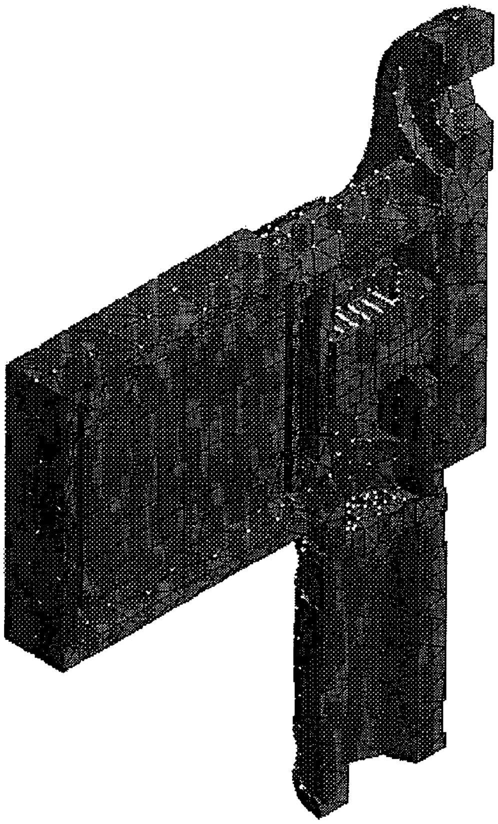

Fig. 8 Cross Section View Of Finite Element Model

NORMAL MODEs ANALYSIS

Case Study

This finite element model including cable mass contains approximately 1300 CHEXA and 8600 CTETRA solid elements. The material property at room temperature for all materials are used for normal modes calculations. SOL 103 is used to perform the normal modes analysis.

Results

The first three natural frequencies of the FE model with and without cable mass are obtained to justify that critical frequencies do not coincide with or near the excitation frequencies from the environmental assumptions. Table 1. shows the results. The corresponding mode shapes are shown in Fig. 9 through 11.

Table 1
Natural Frequencies of Normal Modes Analysis

MODE	w/o Cable Mass	w/ Cable Mass
1	3123.10 Hz	2036.11 Hz
2	4332.77 Hz	2209.00 Hz
3	4872.14 Hz	3106.67 Hz

The results show that all the natural frequencies are much higher than 360 Hz, the critical frequency for the accelerometer design specification. It can be concluded that the design of the sensor is dynamically sound and no natural frequencies fall in the range of excitation frequencies from the environment.

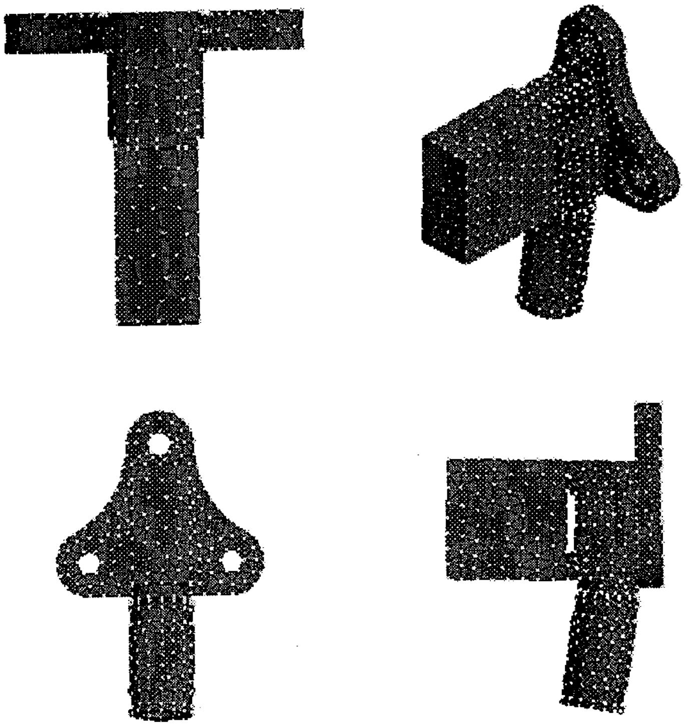

Fig. 9 First Model Mode-Shape (2036.11 Hz)

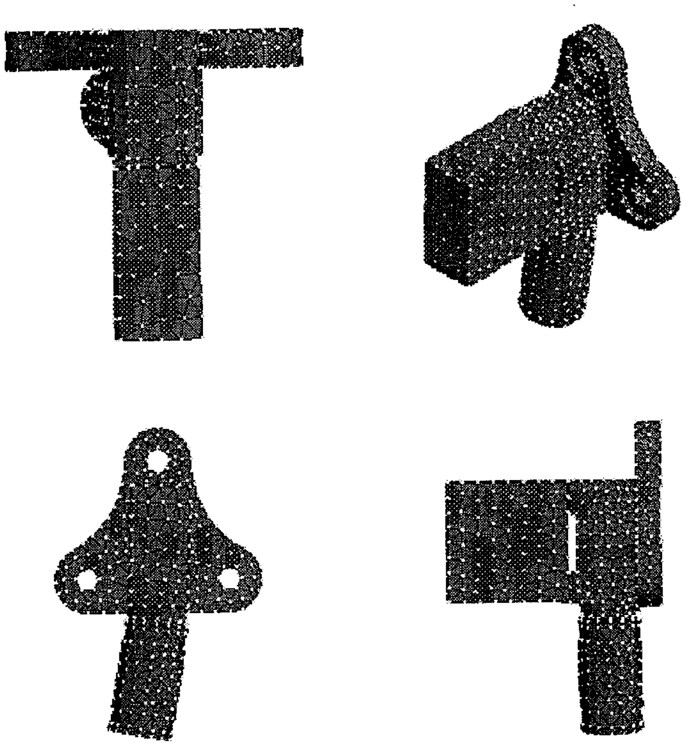

Fig. 10 Second Mode Mode-Shape (2209.00 Hz)

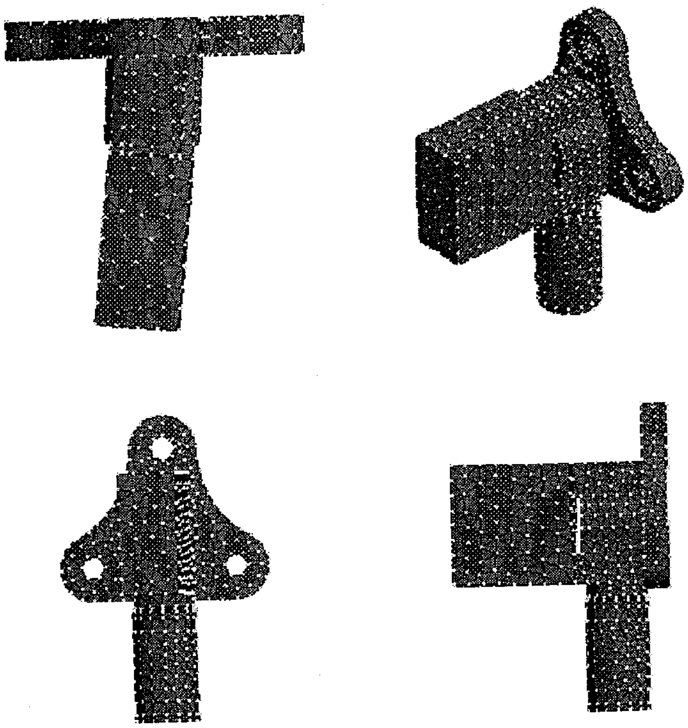

Fig. 11 Third Model Mode-Shape (3106.67 Hz)

THERMAL ANALYSIS

Case Study

The piezoelectric accelerometer is designed to be mounted on the surface of an jet engine. Hence the assumed thermal environment conditions are derived based on the engine operational conditions. In order to perform thermal analysis, the assumed thermal environment is used to determine the temperature distribution in the sensor. The temperature distribution at the two most temperature sensitive locations of the sensor, i.e., electronics and piezoelectric crystal, is examined to generate ideas for improving the temperature condition at piezoelectric crystal.

Thermal Environment Assumptions

The sensor shall be capable of continuous operation throughout the ambient temperature range of -40°F to 350°F and at 420°F for one five minute interval per flight. Furthermore, the sensor also subjected to an operational requirement throughout the engine case temperature range of -40°F to 425°F and at 660°F for one five minute interval per flight.

In order to ensure a proper operation of the sensor, it is necessary to thermally isolate the electronics and the piezoelectric crystal from the engine case, which can occasionally exceed the temperature limit of the components. Therefore, the sensor was so designed to minimize the thermal conduction from the engine case to the crystal and between the lower chamber, which houses the electronics. The geometry of the sensor was also designed to provide effective cooling of the sensor by utilizing the cooler Nacelle air stream.

Because there is convection boundary conditions imposed between the outside thermal surface elements of sensor housing and ambient environment, the following demonstrates the calculation of convection coefficient:

To determine the convection coefficient, h, air pressure and velocity are needed. It can be found from the design specifications that the air pressure and velocity at the highest engine and ambient temperature combination are

$P = 3$ psi
$V = 11$ ft/s

respectively.

From the perfect gas law, $\rho = p / RT$, it follows that the ratio of kinematic viscosities for a gas at the same temperature but at different pressures, p_1 and p_2, is $(\upsilon_1 / \upsilon_2) = (p_1 / p_2)$. Hence the kinematic viscosity and Thermal Conductivity of air are

$$\upsilon = 1.831 \times 10^{-4}\, m^2/s$$
$$k = 0.0399\ W/m^{\circ}K$$

respectively.

The convection coefficient, h, can be related to Nusselt number, Reynolds number, and Prandtl number

$$h = Nu_L K / L$$

Where Nu_L, Nusselt number is

$$Nu_L = 0.664\ Re_L^{1/2} Pr^{1/3}$$

where, in turn, Reynolds number and Prandtl number are

$$Re_L = VL / \upsilon$$
$$Pr = 0.6847$$

respectively.

By evaluating these numbers at 420°F, h can be determined for the horizontal and vertical walls and by averaging, and getting:

$$h \approx 10\ w/m^{2\circ}K$$

Discussions

Case 1 : This FE model contains approximately 1300 CHEXA and 8600 CTETRA solid elements, and 1600 thermal surface elements. The initial isothermal temperature of 350°F is specified on TEMP Bulk Data entries. A convection heat transfer condition (CONV) is imposed to allow thermal communication between accelerometer housing surface and the ambient environment (420°F) through a heat transfer coefficient (H ≈ 10) and a surface element (CHBDYE). Temperature constraints (SPC) of 660°F are applied to simulate the engine case temperature boundary conditions.

The thermal finite element model is analyzed with a transient heat transfer analysis (SOL 159) for a period of five minutes. The resulting temperature at representative grid points of piezoelectric crystal and electronics are listed in Table 2.

Table 2
Temperature Distribution of Accelerometer

Minute	Crystal	Electronics
0	350.00	350.00
1	578.63	352.71
2	615.44	359.22
3	630.18	371.76
4	646.22	387.88
5	648.89	404.45

Case 2 : Other than the applied thermal conditions in Case 1. the enclosure radiation boundary condition are included to account for the thermal radiation between piezoelectric crystal and inside wall surface of lower chamber. The Gaussian integration view factor calculation method is used for the radiant enclosure exchange process. The resulting temperatures are listed in Table 3.

Table 3
Temperature Distribution of Accelerometer w/
thermal radiation boundary condition

Minute	Crystal	Electronics
0	350.00	350.00
1	532.46	350.90
2	589.81	355.46
3	608.94	367.28
4	617.93	382.69
5	620.44	401.46

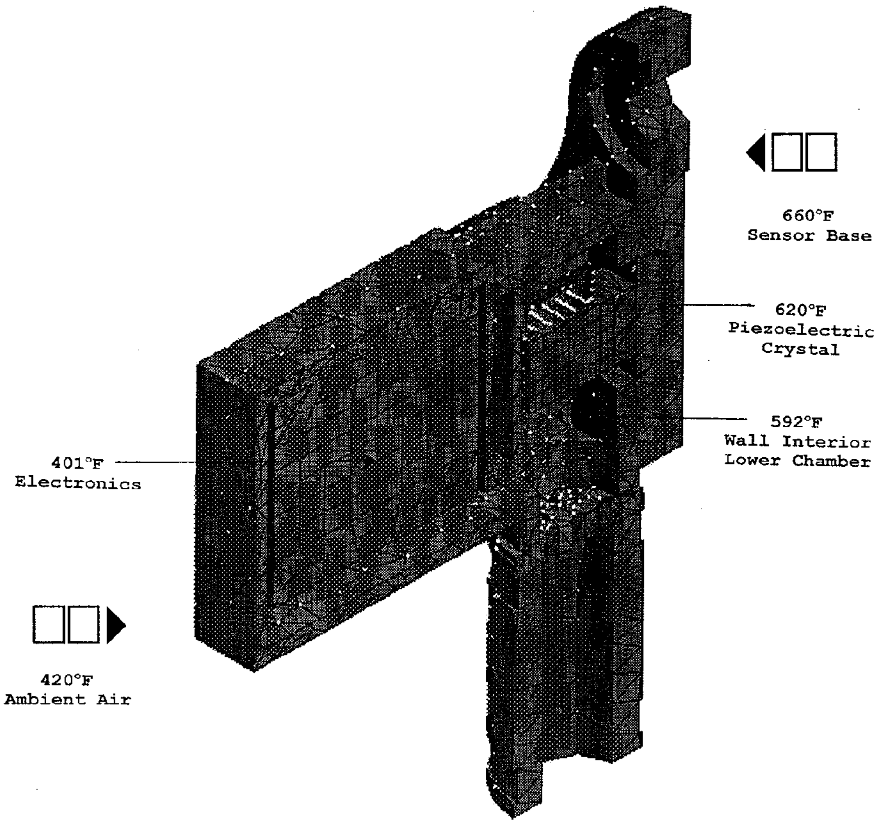

Fig. 12 Temperature Distribution At The End Of Five Minutes

Comparing the resulting temperature of Case 1 and Case 2, the piezoelectric crystal temperature of Case 2 is about 28°F lower than that Case 1. The temperature from transient heat transfer analysis in Case 1 does not agree with experimental conditions. The results indicate that Case 1 is not realistic to simulate the temperature distribution of piezoelectric crystal. The radiation boundary conditions need to be taken into account to find the accurate temperature distribution of accelerometer sensor. The resulting temperatures, at the end of the five-minute interval, at some representative points of the critical locations are illustrated in Fig. 12.

CONCLUSIONS

This paper presents a procedure for solid/finite element modeling using MSC/ARIES, and normal modes and heat transfer analysis using MSC/NASTRAN V68. Furthermore, the process in transient heat transfer analysis may serve as a general guideline to include all possible thermal conditions for obtaining an accurate result. The result of normal modes analysis shows that this design is dynamically sound. However, in the transient heat transfer analysis the temperature of piezoelectric crystal is close to the material's critical temperature, 660°F, which may affect the sensor's performance. It is recommended that the insulation of accelerometer be modified by adding some kinds of thermal insulation between the sensor base and crystal stack and/or by changing the materials of the accelerometer to a less heat conductive material than tungsten steel.

REFERENCES

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