VIBRATIONAL CHARACTERISTICS OF AIRCRAFT EXHAUST T50 THERMOCOUPLE

Siddesha T [1], Madhusudhana S[2], Lingaraj L[3]

[1, 2,3]*Assistant Professor, Department of Mechanical Engineering. TJIT, Bangalore.*
siddubavish@gmail.com

Abstract

A limiting factor in a gas turbine engine is the temperature of the turbine section. The temperature of a turbine section must be monitored closely to prevent overheating the turbine blades and other exhaust section components. One common way of monitoring the temperature of a turbine section is with an EGT gauge. The main focus of this project work is to analyse and validate the T50 thermocouple for static and fatigue load requirement using finite element analysis tool Ansys workbench14.5.Analysis results are correlated and validated using empherical relations. In case of static nonlinear analysis, bolt pretension has been validated using bolt stiffness relation. In case of dynamic analysis thermocouple response has been validated using harmonic sine equation. The proposed design meets the design guidelines of FAA for critical engine operating conditions.

Keywords: *Aerospace, FEM, Fatigue Strength, Nonlinear Static Analysis.*

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1. INTRODUCTION

Engineering machines and structure in service, experiences vibration, and their design generally requires consideration of their dynamic behaviour. The type of input forces experienced by different components of aerospace in service is dynamic. The progressive, localized and permanent structure change that occurs in a material subjected to repeated or fluctuating strains at nominal stresses that have maximum values less than the tensile strength of the material which may culminates in cracks and causes fracture after a sufficient number of fluctuations is known as fatigue. Fatigue and durability design of any component of an aerospace structure plays an important role to ensure reliability. The total damage and life of a structure is due to a combination of static and dynamic loads arising from engine vibrations, service load. The basic aim is to enable fatigue life calculations to be done at the design stage of a development process. It is necessary to clarify the term fatigue as the estimation of fatigue life when the stress or strain histories obtained from the structure or component.

1.1 Exhaust Gas Temperature Thermocouple

A limiting factor in a gas turbine engine is the temperature of the turbine section. The temperature of a turbine section must be Monitored closely to prevent overheating the turbine blades And other exhaust section components. One common way of monitoring the temperature of a turbine section is with an EGT gauge. EGT is an engine operating limit used to monitor overall engine operating conditions.

2. SCOPE OF WORK

The Main focus of this Project work is to evaluate the vibrational characteristics of aircraft exhaust T50 thermocouple. From Vibration analysis stress response output found.

3. MATERIAL PROPERTIES

Support tube and Simplex Element has been modeled with Inconnel 625.

Table 5.1 Mechanical properties of Inconnel 625 material

SI.No	Description	Value
1	Young's Modulus(E)	1.478 *10^5 N/mm^2
2	Poisson's Ratio(ϑ)	0.29
3	Density(ρ)	8.44*10^-6 Kg/mm^3
4	Yield Strength(σy)	262 N/mm^2
5	Ultimate Strength(σu)	675.6 N/mm^2

2. Housing, Lid and terminal has been modeled with AISI304 steel

Table 5.2 Mechanical properties of AISI304 steel material

SI.No	Description	Value
1	Young's Modulus(E)	1.79*10^5 N/mm^2
2	Poisson's Ratio(ϑ)	0.27
3	Density(ρ)	7.75*10^-6 Kg/mm^3
4	Yield Strength(σy)	99.7 N/mm^2
5	Ultimate Strength(σu)	310.2 N/mm^2

3. Bolt has been modeled with Inco 718.

SI.No	Description	Value
1	Young's Modulus(E)	1.79*10^5 N/mm^2
2	Poisson's Ratio(ϑ)	0.27
3	Density(ρ)	7.75*10^-6 Kg/mm^3
4	Yield Strength(σy)	99.7 N/mm^2
5	Ultimate Strength(σu)	310.2 N/mm^2

4. CATIA MODEL

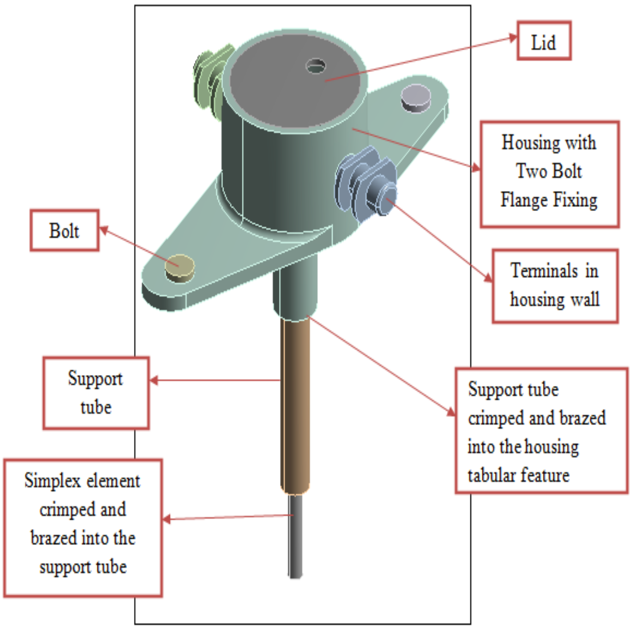


Fig 1 Representation of T50 thermocouple in 3d view

5. FINITE ELEMENTS MODEL

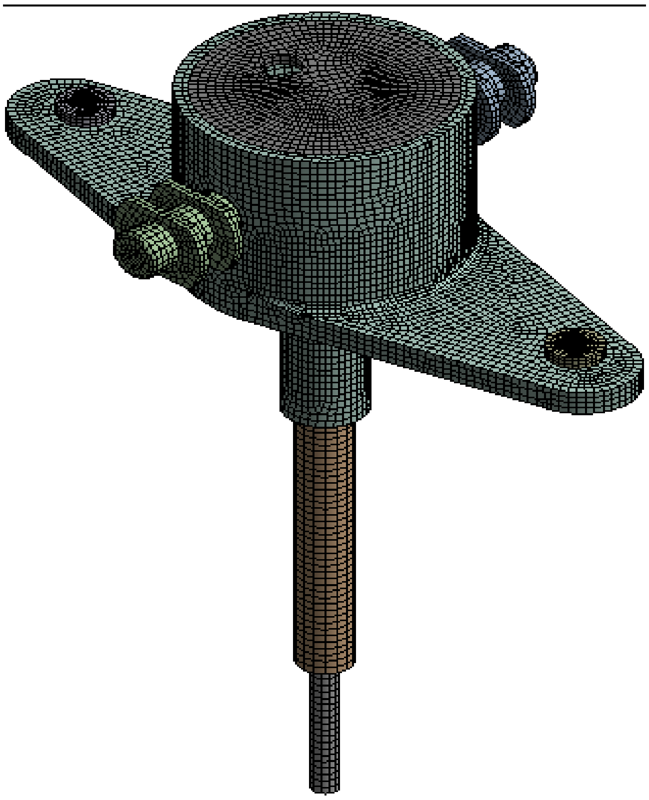


Fig 2. Finite element model of T50 thermocouple.

6. VIBRATION ANALYSIS OF T50 THERMOCOUPLE

The modal analysis has been performed for a frequency range of 0-2000 Hz and at 600 C.

BOUNDARY AND LOADING CONDITIONS

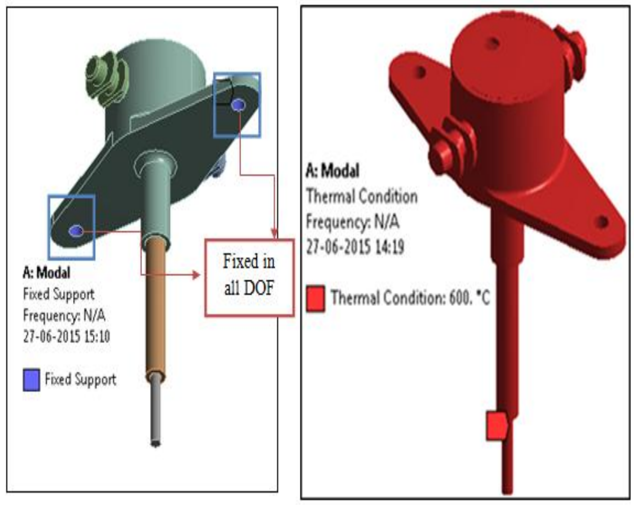


Fig 3 Boundary and Loading Conditions

RESULTS & DISCUSSION

Total 2 modes are observed in the frequency range of 0-2000 Hz

Table 1 Modal frequencies of T50 thermocouple

Mode no	Frequency (Hz)	Remarks
1	1168.3	Bending mode in X-direction
2	1605.5	Bending Mode in Y- direction

➢ **Mode Shapes**

Mode-1: Element bending mode in X-direction at 1168.3 Hz

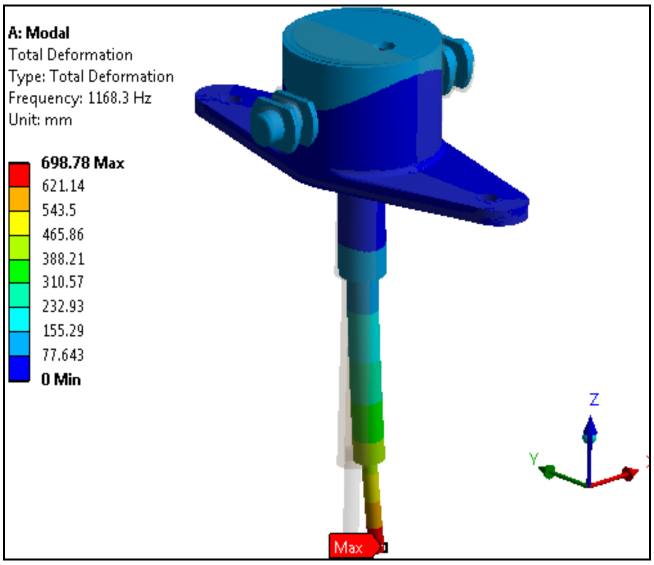


Fig 4 First Mode shape in T50 thermocouple

Mode-2: Element bending load in Y- direction at 1605.5 Hz

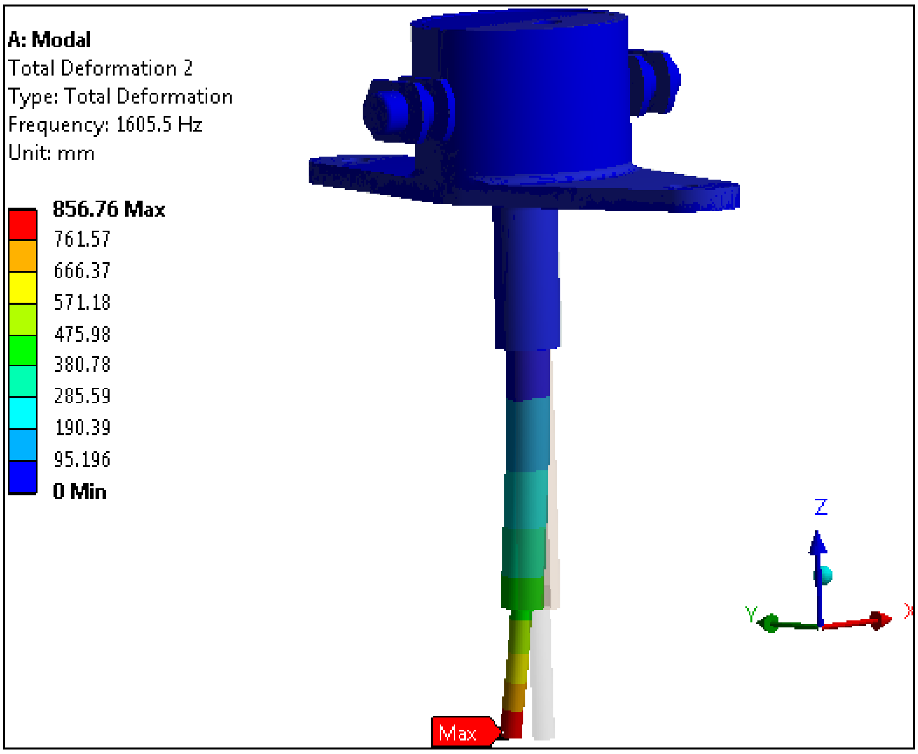


Fig 5 Second Mode shape in 50 thermocouple

MASS PARTICIPATION FACTOR

X-Direction mass participattion details

***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION
TOTAL MASS = 0.86615E-04

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	1168.26	0.85598E-03	0.42201E-03	1.000000	0.178092E-06	1.00000	0.205613E-02
2	1605.47	0.62287E-03	0.15345E-06	0.000364	0.235467E-13	1.00000	0.271855E-09
sum					0.178092E-06		0.205613E-02

Y- Direction participation details

***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION
TOTAL MASS = 0.86615E-04

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	1168.26	0.85598E-03	0.15520E-06	0.000094	0.240874E-13	0.890896E-08	0.278097E-09
2	1605.47	0.62287E-03	0.16443E-02	1.000000	0.270372E-05	1.00000	0.312155E-01
sum					0.270372E-05		0.312155E-01

Z- Direction participation details

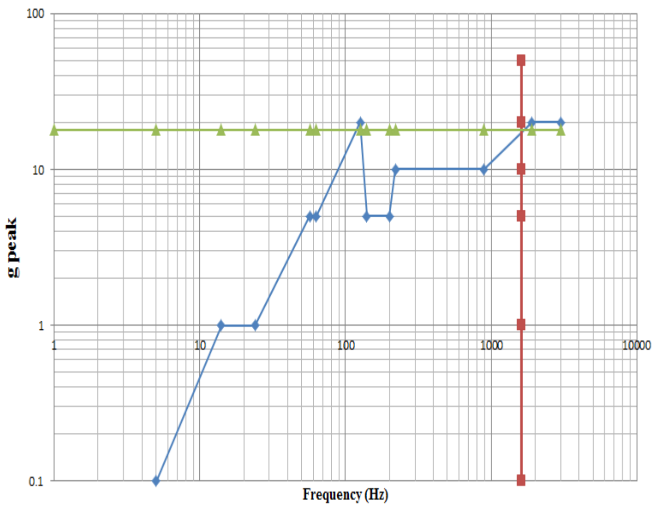
***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION
TOTAL MASS = 0.86615E-04

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	1168.26	0.85598E-03	0.13342E-03	1.000000	0.178020E-07	0.999989	0.205530E-03
2	1605.47	0.62287E-03	0.44914E-06	0.003366	0.201725E-12	1.00000	0.232899E-08
sum					0.178022E-07		0.205532E-03

Takeaway: by observing mass participation factor and effective mass contribution, we can concluded that Y-direction is having a dominant mass participation and hence Y-direction is selected for further vibration study.

B. Harmonic Response:

Harmonic analysis was carryout for the frequency range of 0-2000 Hz with damping ratio of 2% and in the harmonic analysis an acceleration load of 9814.56 mm/ s^2 is applied in Y-direction.



Graph 1. Response curves for scaling factor

From the above graph it is clear that, actual G at 1605.5 Hz is 18 G. So the scaling factor of 18 is used to get the actual response and stress results.

Fig 6 Acceleration load is applied to T50 thermocouple in Y-direction

RESULTS AND DISCUSSION – HARMONIC ANALYSIS

Frequency Response

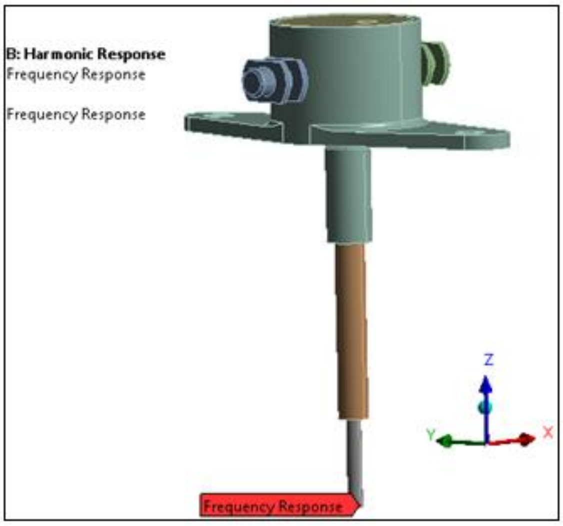
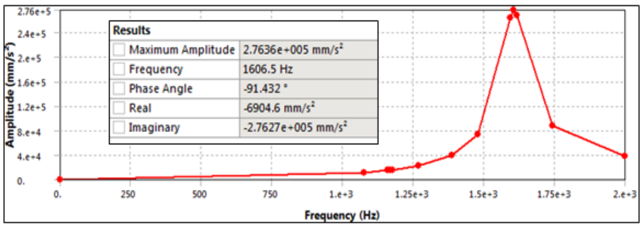


Fig 7 Acceleration response locations- Element



Graph 2 Acceleration response plot

	Acceleration (mm/s^2)
Output Response for 1G	**2.76E+05**
Output Response for 18G	**4.97E+06**
Amplification Factor (Output/Input)	$\frac{276360}{9814.6}$ **= 28.15**

Total Deformation

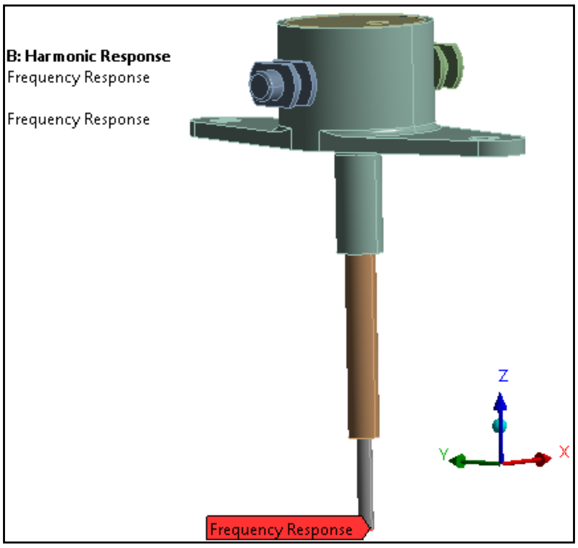
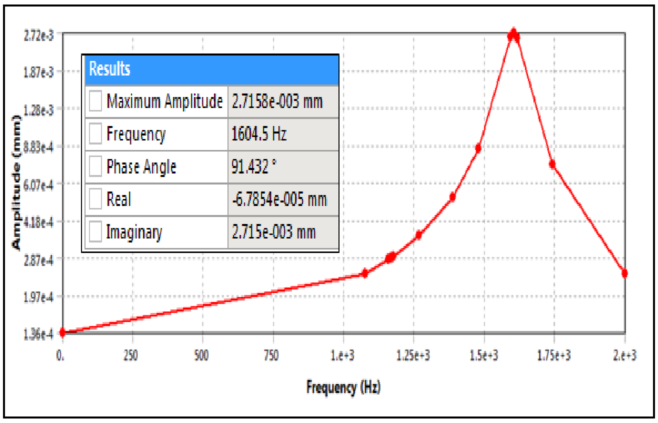


Fig 8 Deformation response locations- Element



Graph 3 Deformation Response Plot

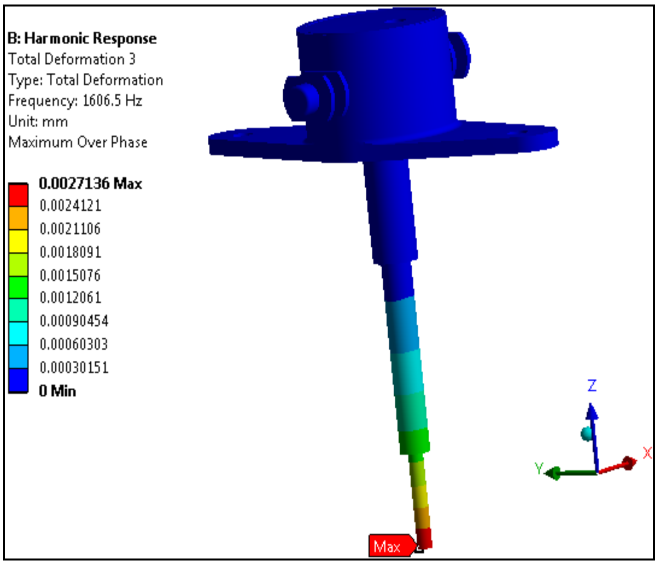


Fig 9 Deformation plot at 1605.5 Hz

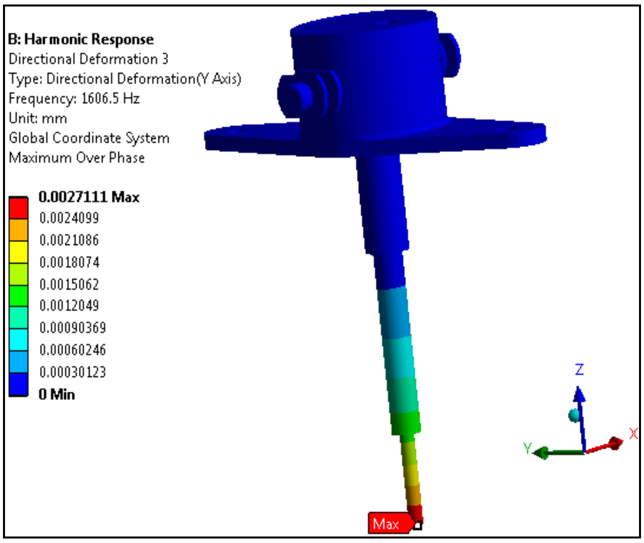


Fig 10 Directional deformation (Y-Axis) plots at 1605.5 Hz

	Deformation (mm)
Output Response for 1G	**2.72E-03**
Output Response for 18G	**4.90E-02**

Max Stress Plot – Element:

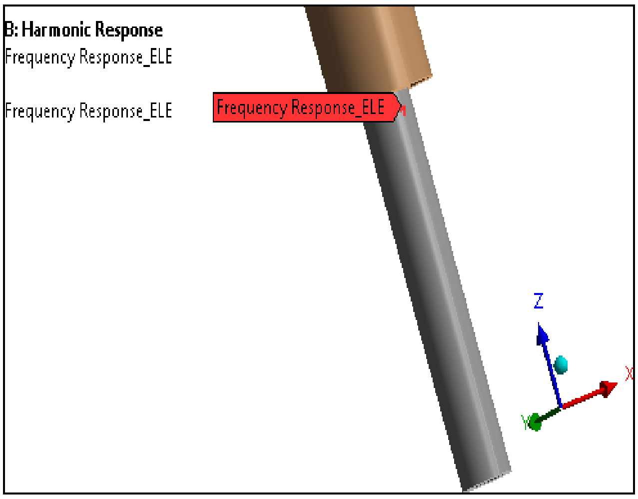
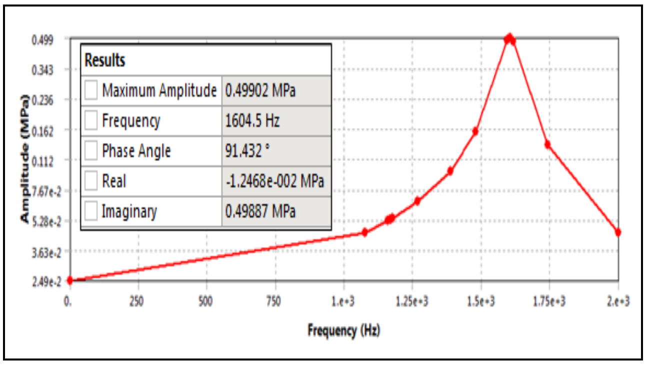


Fig 11 Frequency response locations- Element



Graph 4 Frequency response plot-Elements

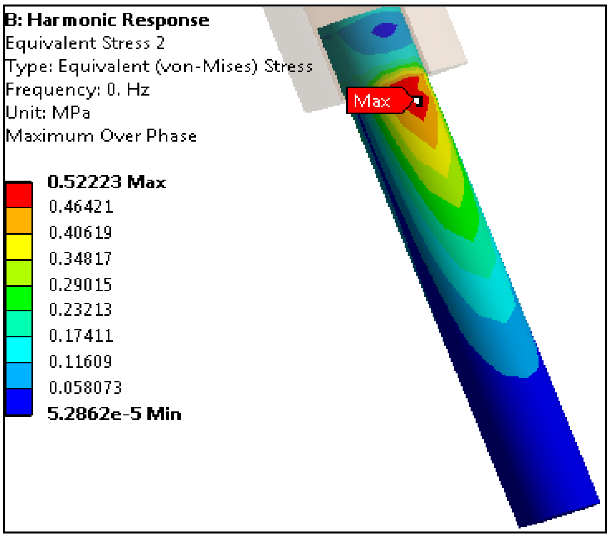


Fig 12 Equivalent (Von-Mises) Stress- Element

	Element Stress (MPa)
Output Response for 1G	**0.52**
Output Response for 18G	**9.36**

Max Stress Plot – Support Tube

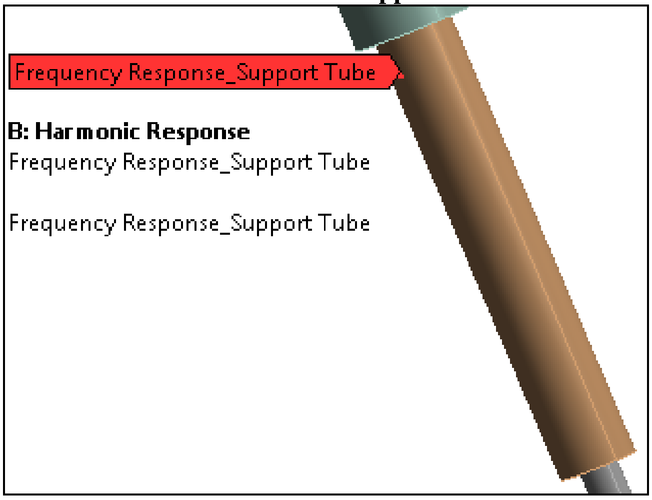
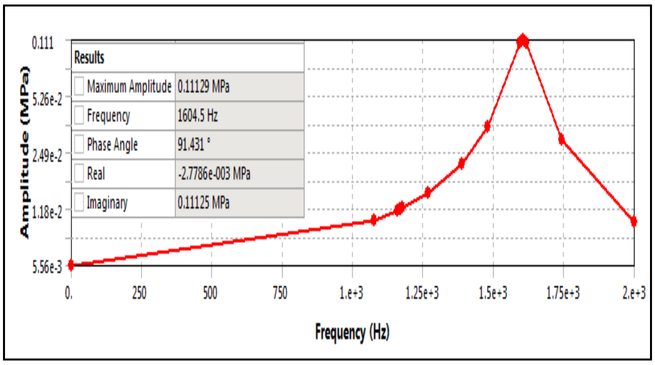


Fig 13 Frequency response locations- Support Tube



Graph 5 Frequency response plot-Supports Tube

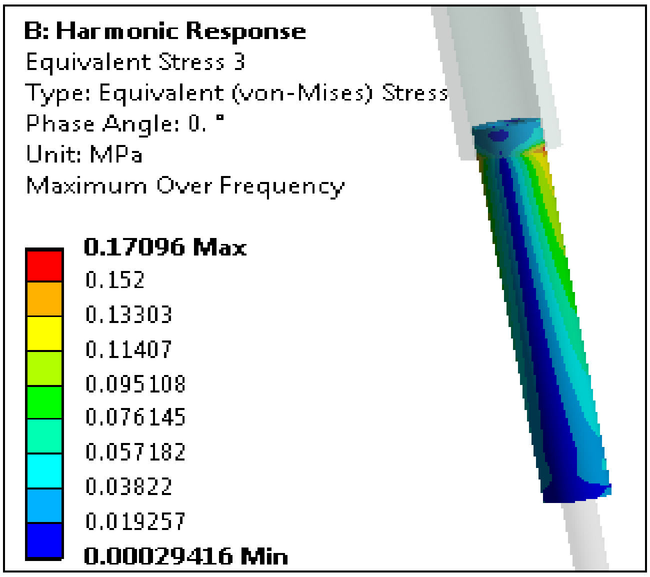


Fig 14 Equivalent (Von-Mises) Stress- Support Tube

	Support tube Stress (MPa)
Output Response for 1G	**0.17**
Output Response for 18G	**3.06**

Max Stress Plot – Housing:

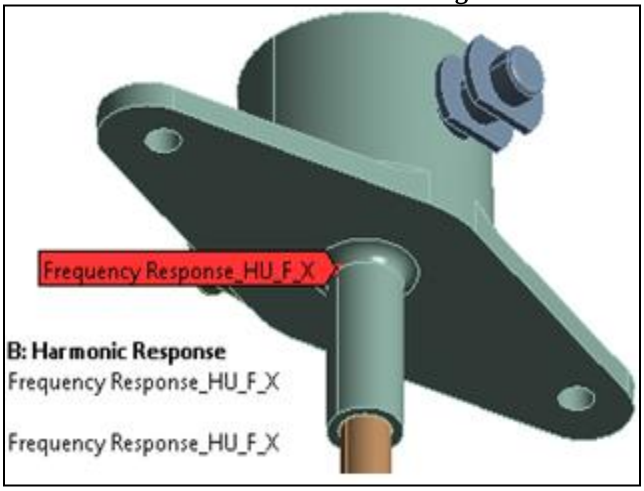
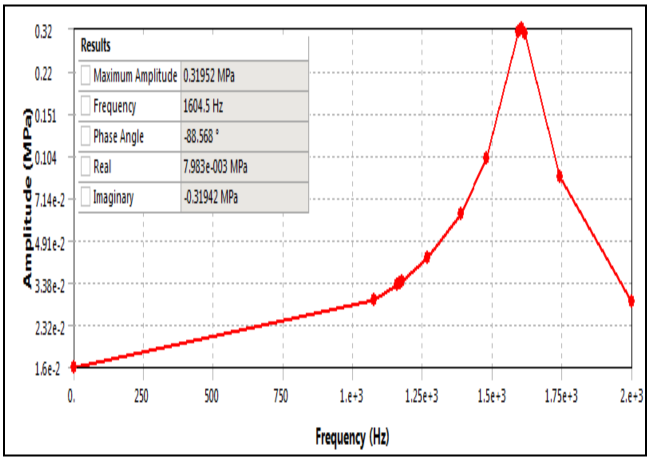


Fig 15 Frequency response locations- Housing



Graph 6 Frequency response plot-Housing

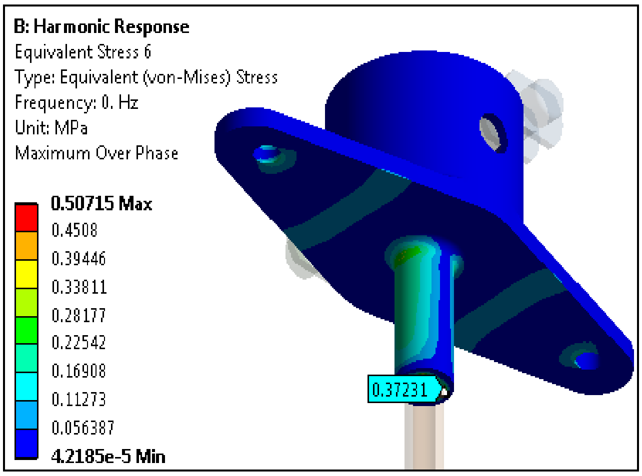


Fig 16 Equivalent (Von-Mises) Stress- Housing

	Housing Stress (MPa)
Output Response for 1G	**0.5**
Output Response for 18G	**9.0**

Max Stress Plot – Terminal

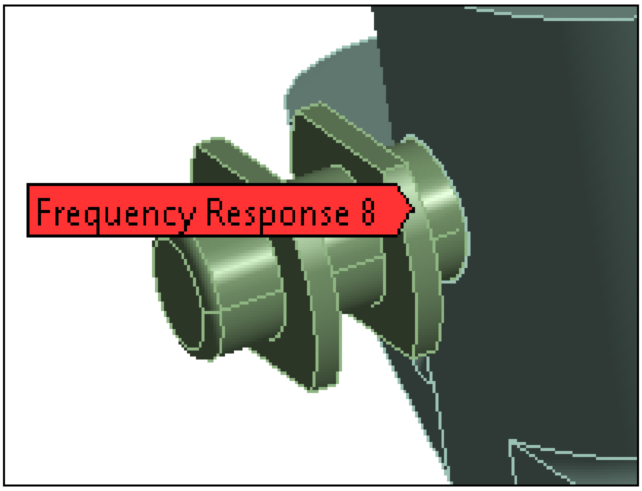
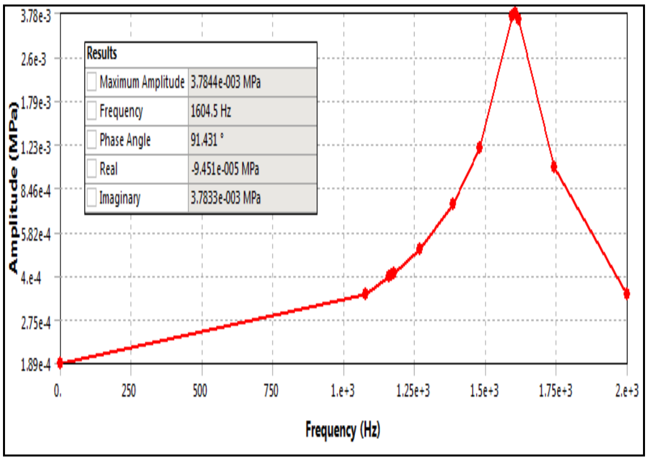


Fig 17 Frequency response location- Terminals



Graph 7 Frequency response plot-Terminals

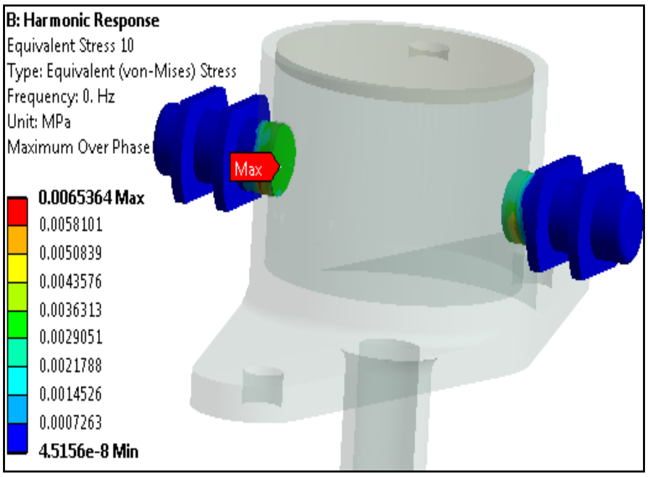


Fig 18 Equivalent (Von-Mises) Stress- Terminal

	Terminal Stress (MPa)
Output Response for 1G	**0.0065**
Output Response for 18G	**1.17**

CONCLUSION:

- Vibrational characteristics like natural frequency and mode shapes are obtained using modal analysis by this predict of resonance is possible.
- Mode-2 with natural frequency of 1605.5 Hz is considered as critical mode as it is having high effective mass in Y direction compared to X & Z direction and mass participation Ratio 1.
- Steady- state response of a T50 thermocouple is obtained using Harmonic response analysis.
- It is analysed for the critical frequency (mode-2) in Y-direction.
- Graph of displacement and stress is plotted against the frequency; by this peak stress is found. The obtained results are satisfactory and fall below the limit

SCOPE FOR FUTURE WORK

- Exploring other cost effective materials with minimum weight.
- Exploring other alternative manufacturing processes like additive manufacturing.

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