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Design Assessment and Fatigue Life Estimation for Aircraft EGT Sensor

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ABSTRACT

The problem concerns with the deep investigation of fatigue life estimation for exhaust gas temperature sensor. The high temperature of exhaust gases is sensed by two sensors provided in support tube which in turn connected to the junction box. Due to high temperature it will undergo deformation which can be analyzed and calculated by using the steady state thermal and harmonic analysis. The fatigue life estimation is being done by using modified Goodman method. If the temperature is above the prescribed range then we cannot get accurate readings and also it undergoes deformation to overcome these above problems we tested a sensor for fatigue life under dynamic loading and safe life is estimated. In this project the design of the EGT assembly will increases the efficiency of the turbofan engine and the turbine blades and mean while increases the fatigue life of the EGT assembly.

Keywords *– Fatigue, EGT, Exhaust Gases, Temperature, Sensor.*

1. INTRODUCTION

EGT (Exhaust gas temperature) is a critical variable of turbine engine operation. The EGT representing system gives a visual temperature indication in the cockpit of the turbine exhaust gases as they leave the turbine unit. EGT is an important engine working operating unit and is utilized to screen the mechanical integrity of the turbines, and to check engine operating conditions. A gas temperature thermocouple is mounted in an insulator and encased in a metal sheath the assembly forms structures which moves into the exhaust gas stream.

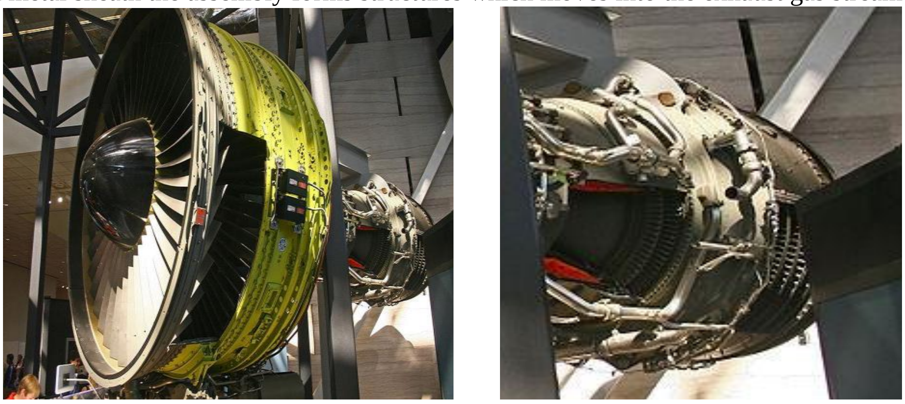

Fig 1.1: Overview of Turbine Fan Engine and Zoom in view of EGT assembly.

A gas temperature thermocouple is mounted in an insulator and encased in a metal sheath the assembly forms a structure which extends into the exhaust gas stream. The hot junction projects into a space inside the sheath. The sheath has move gaps toward the end of it which permit the exhaust gases to flow over the hot junction.

Two of the most critical elements influencing turbine engine life are EGT (exhaust gas temperature) and engine speed. Excess EGT of a couple of degrees wills lesser turbine blade life as much as 50%.

An EGT gauge measures, in degrees Celsius or Fahrenheit, the temperature of the Exhaust gases at the exhaust manifold system. This temperature estimation fluctuates with proportion of fuel to air entering the cylinders, and consequently can be utilized as a premise for controlling the fuel/air mixture. This is conceivable on the grounds that this instrument is very sensitive to temperature changes.

At the point when fuel and air are mixture in such a extent to have complete combustion, at the end of the day all the fuel and all the air are totally utilized and the subsequent temperature will be in the 15000c. This temperature is excessively hot for an internal combustion engine to support for any period of time without failure. This proposed work insights about the basic respectability evaluation for EGT assembly in light of limited component investigation.

The present research focuses on four major sections:

- Static strength analysis/ thermo mechanical analysis,
- Heat transfer analysis,
- High cycle fatigue,
- Goodman assessment

Thermal analysis is used to calculate the maximum temperature experienced by the components. Static strength analysis will be used to calculate the integrity under the normal and high loading conditions. The load essentially contributes to the high cycle fatigue has been detected as normal vibration loads. High cycle Fatigue is the degradation which happens in materials more than a high number of cycles. Proposed configuration or design will meet the necessity strength parameters and vibration requirements.

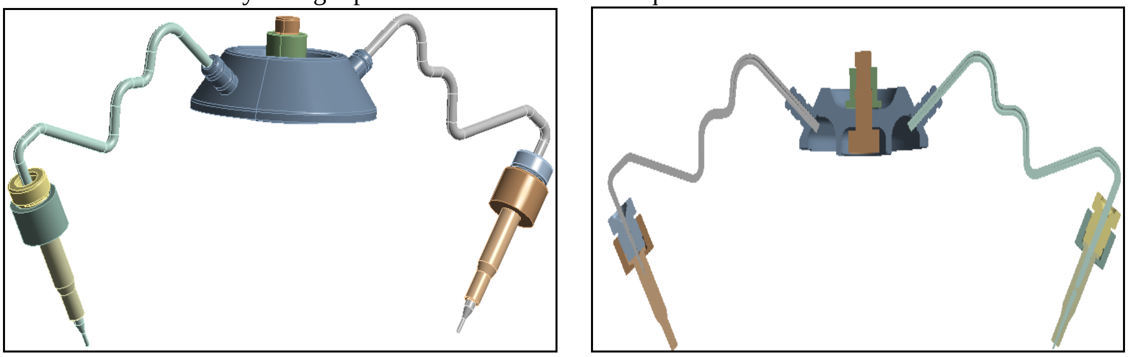

Fig 1.2: EGT Sensors (Full and Cross Sectional View).

Fig 1.2, demonstrates the 3-dimensional view of the EGT arrangement. It comprises of a junction box, ferrule, MI-cable sheath, gland nut, shealing sheath and support tube. Junction box is put in the middle of the two support tube and it performs the essential function of keeping the process fluid. It acts as a holding seal between rigid stationary surfaces. The junction box will stay situated when the friction, in respect to the surface, is sufficiently large enough to overcome the pressure exerted on it from the process fluid and hot Exhaust gases. Since junction box material is softer than the parts it is sealing, the junction box will, to some point, flow into the joint faces to close leakages.

At the point when the connections with junction box are utilized as a part of mechanical structures, for example, support tube, ferrule and Exhaust gas temperature sensor covers they are generally under thermal conditions. The cross sectional view of the EGT sensor is as indicated in the fig 1.2. High temperature Exhaust gases which make the aircraft engine to carry on suddenly which cause problems. After the fastener up procedure, both static stress and deformation on the interface between the junction box and the gland nut achieve their maximum values. At the point when inner pressure is applied to joints, load in the gland nut expands while stretch in the contact zone decreases.

1.1 Engine Operating Temperatures

High warm proficiency is reliant on temperature of high turbine section. Fig 1.3 shows the temperature ascends through the engine gas stream way. Today's engines can encounter turbine delta.

To place in point of view a 1500^{0}C parts in the turbine are working eight times more sweltering than a regular household boiler. The essential limit to turbine channel at high temperatures is the accessibility of materials can sustain higher temperatures. The general pattern is that raising the turbine bay temperature expands the particular thrust of the engines with increase in fuel utilization rate. The blend of a higher general weight proportion and turbine bay temperature moves forward warm proficiency. At last with a lower particular thrust prompts lower particular fuel utilization.

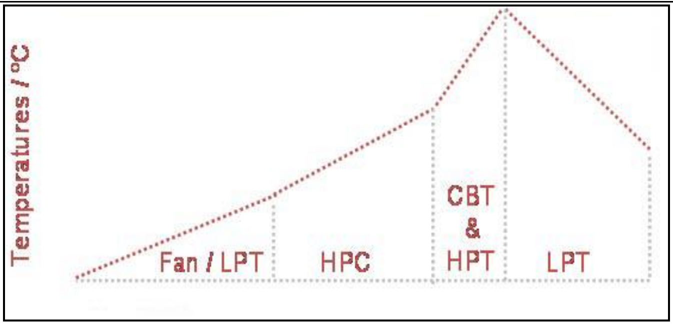

Fig 1.3: Temperature Rise through the Engine Gas Flow Path.

1.2 Engine Key Operating Parameters

The essential engine working parameters comprise of fan pace (N1-speed) and Exhaust Gas Temperature (EGT). Fan rate will be normally utilized for thrust sign though EGT is a typical situation checking parameter. Some engine models likewise make utilization of Engine Pressure Ratio (EPR) and N2/N3-speed for thrust checking and accompanying is a brief exchange of each execution parameters.

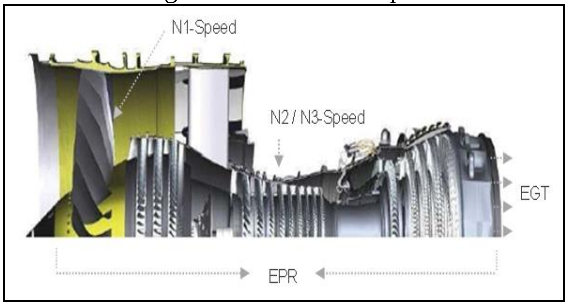

Fig 1.4: Primary Engine Operating Parameters.

Engine Pressure Ratio (EPR) - is characterized as aggregate weight proportion over the engine, registered by taking the proportion of an aggregate weight at the exhaust to aggregate weight at the front of the fan/compressor. This is utilized by some engine producers to gauge engine thrust.

N1-speed: N1-pace is the turn velocity of the fan and is commonly introduced as rate of configuration RPM. Quickly fluctuating N1 or EPR can be an indication of an engine slow down though as low EPR or N1-velocity can be an indication of a flameout. N1-velocity is likewise an essential parameter used to gauge thrust. N2-rate is the pivot of the high or halfway weight compressor and is additionally displayed as rate of its plan RPM.

Exhaust Gas Temperature (EGT) – will be in degrees Celsius, is of the temperature at the engine exhaust and measure of an engine's proficiency in creating its plan level thrust the higher the EGT the more wear and decay influence an engine. High EGT can be a sign of debased engine execution. An exceedance in EGT points of confinement can prompt quick harms of engine parts and/or an existence decrease of engine parts. On account of this it then turns out to be completely vital to keep the EGT as low as could reasonably be expected for whatever length of time that conceivable.

EGT Margin - Usually EGT achieves its top amid take-off or lift-off. The distinction between the greatest reasonable EGT (red-line) and the top EGT amid departure is known as the EGT Margin. EGT edge is communicated scientifically as EGT Margin = EGT Redline – EGT Gauge Reading.

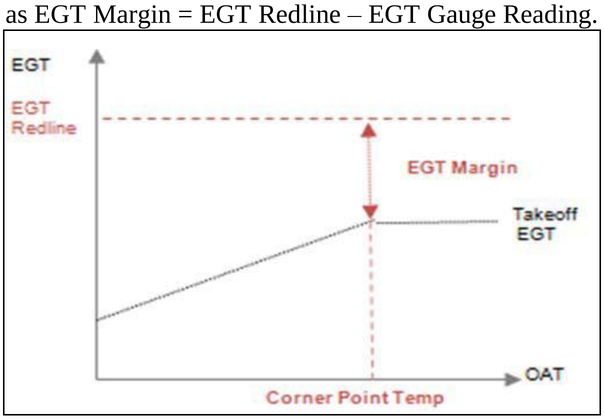

Fig 1.5: The Primary Engine Operating Parameters.

2. FINITE ELEMENT MODELING

2.1 FE Modeling

The first step in the FE analysis is the meshing of the geometry for which the FE Calculation needed. FE modeling is built with good quality of hexahedral elements using finite element software called Ansys Workbench. EGT Sensor geometry is built with 526647 no of nodes and 137540 no of elements and the Finite Element model is as shown in the below fig 2.1.

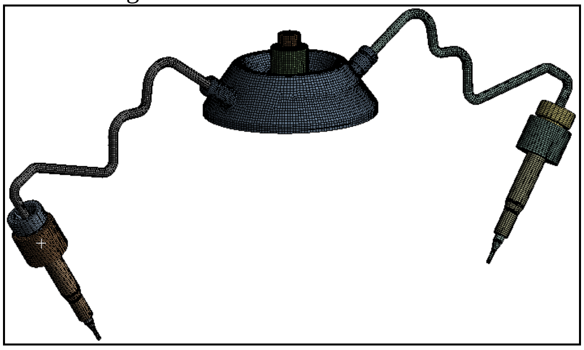

Fig 2.1: Meshed Model of the EGT Sensor.

2.2 Material Properties

As these sensor works at high temperature its material should be capable of taking high thermal loads. Hence, high grade steel (Inconel) is chosen. Material properties used in this calculation are shown in the table below.

Material	Inconel 650
Temperature	500^0C
Young's modulus, E	$2.9e^7$ psi
Poisson's ratio, ν	0.29
Density, ρ	0.304 lb/in^2, 0.0020 Mpa
Co-eff of thermal expansion, α	$7e^{-6}$ $mm/^0C/ mm$
Yield strength (σ_y)	36 ksi, 248.21 Mpa
Ultimate strength (σ_u)	78 ksi, 537.79 Mpa
Endurance strength (σ_e)	26 ksi, 179.26 Mpa
Proof stress	33 ksi, 227.52 Mpa

Table 2.1: The Material Properties.

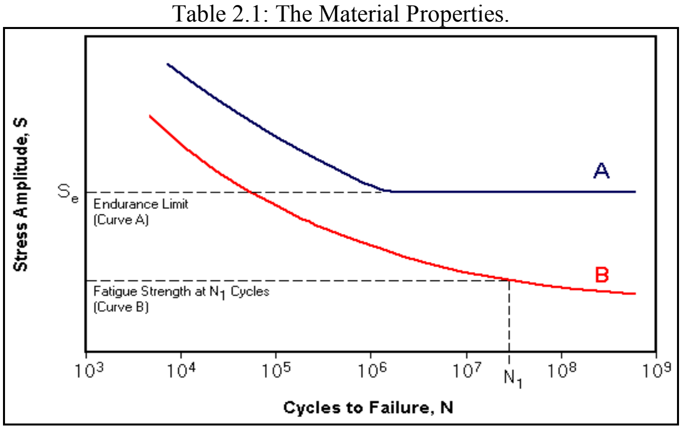

Fig 2.2: Typical S-N Curves of Inconel Material.

3. Boundary Conditions

This analysis comprises of both structural and thermal loads proper boundary condition need to be defined. Hence thermo mechanical analysis needs to be carried out.

3.1 Structural BC's

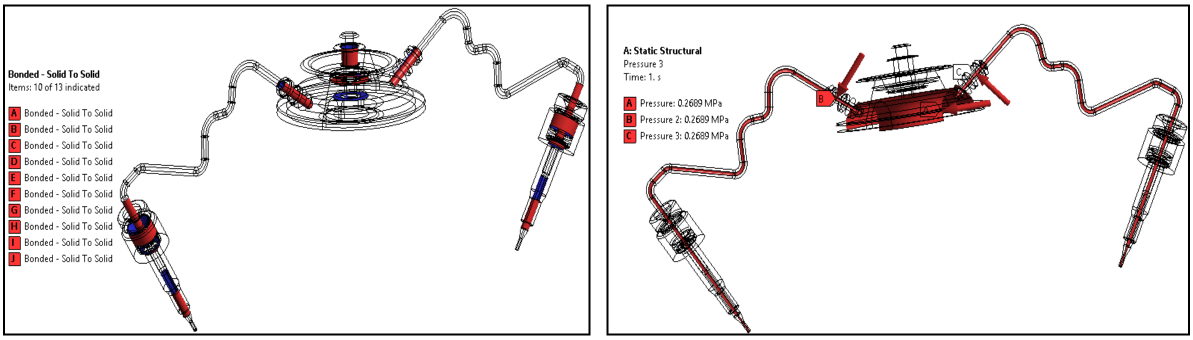

Fig 3.1: Contact and Pressure load acting on EGT sensor.

The pressure load acting on the EGT sensor as shown above and there are three pressure conditions acting the pressure A (0.2689Mpa) acts on the junction box due to the high temperature exhaust gas and pressure B (0.2689Mpa) and pressure C (0.2689Mpa) acting on the bonded contact region of the junction box and the gland nut.

3.2 Thermal BC's

The thermal analysis is used to calculate the temperature distribution and thermal parameters in a system. Convection calculation is carried out based on the different cross-section which is further divided into different zones as highlighted in the figure shown below (blue color).

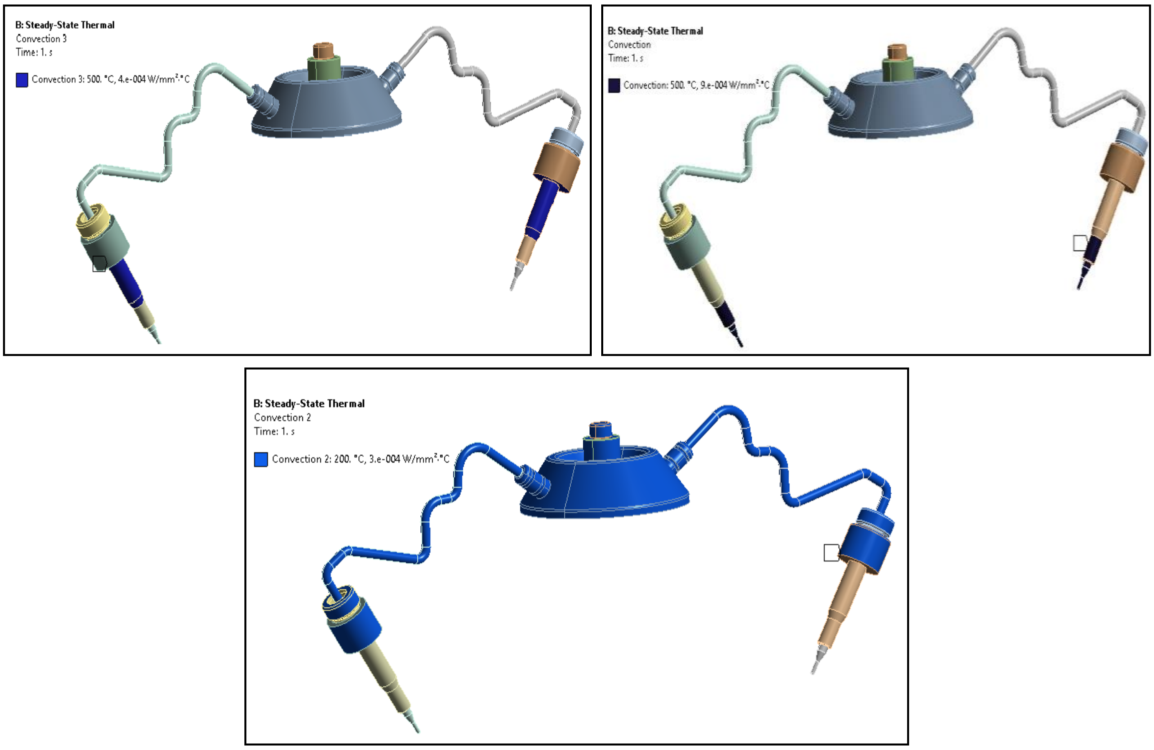

Fig 3.2: Shows the Convection at Support Tube, Sensor tip and EGT Pipe.

4. Results and Discussions

4.1 Static Thermo-Mechanical Analysis

The boundary condition for thermal and structural analysis is described briefly in the above section.

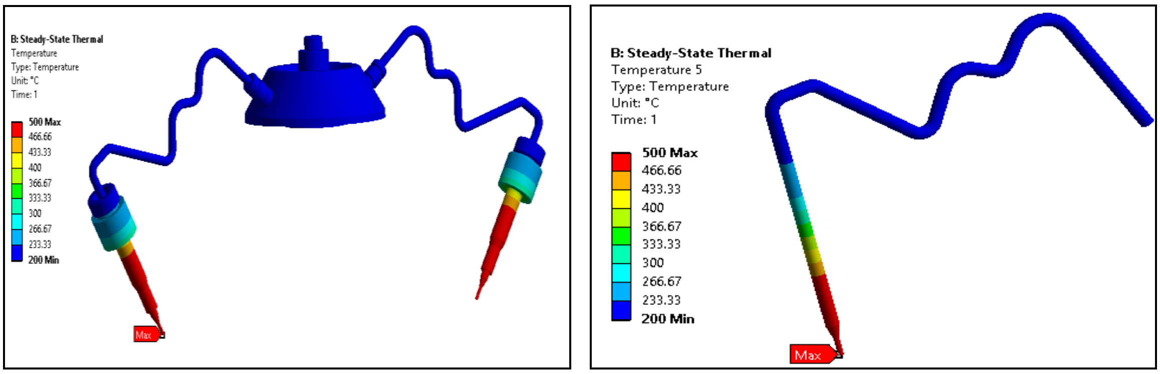

Fig 4.1: Maximum Temperature Plot.

As the exhaust gases passing through the EGT assembly the maximum temperature will be acting on at the sensor tip which will heat up the sensor tip and same can be noticed in the above fig 4.1.

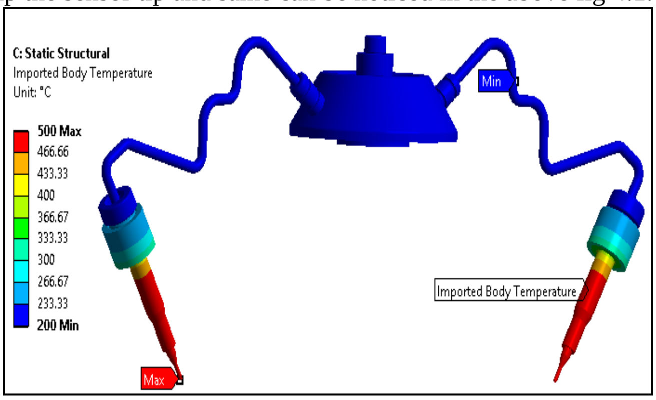

Fig 4.2: Maximum von-Mises Stress Plot.

4.2 Harmonic Analysis

Harmonic response analysis gives you the ability to predict the sustained dynamic behavior of your structures, thus enabling us to verify whether or not our designs will successfully overcome resonance, fatigue, and vibration. The results encompass the structure’s response at several frequencies and amplitude v/s frequency graphs to study the behavior of the component.

A pre modal analysis is conducted for the entire assembly and then the obtained frequency is used to the calculated the amplitude which interns help to check the resonance in the component.

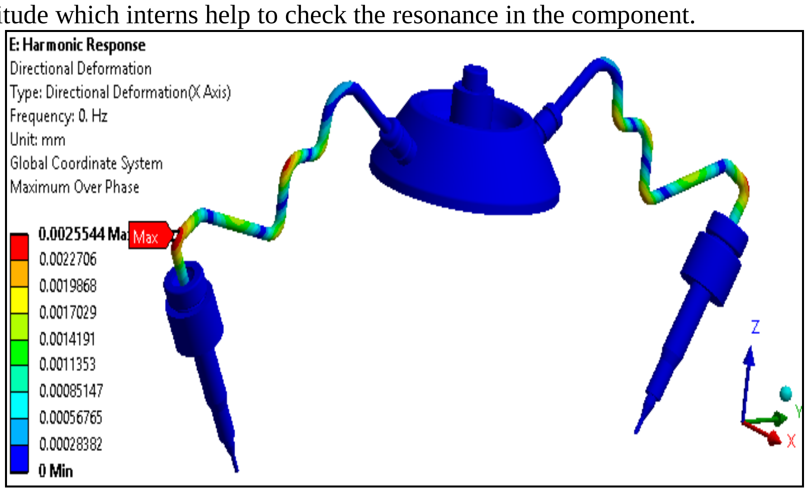

Fig 4.3: Maximum Deformation Plot.

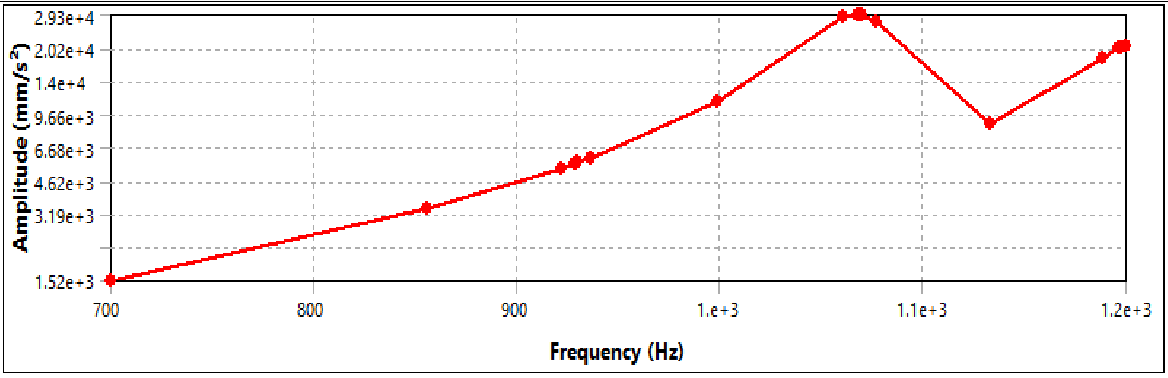

Fig 4.4: Amplitude VS Frequency Plot for Whole Assembly.

4.3 Fatigue Analysis

Fatigue analysis is conducted to the check the no of cycle to achieve for the whole assembly. Mean stress is calculated of for each individual component and alternating stress versus mean stress is plotted.
Goodman relation will be used to determine the corrected alternating stress:

Corrected Alternating Stress based on Goodman Relation:

$$\sigma = \frac{\sigma_a}{\left(1 - \left(\frac{\sigma_m}{\sigma_u}\right)\right)} \qquad \ldots\ldots.. 1$$

$$\sigma = \frac{0.2607}{\left(1 - \left(\frac{112}{537.79}\right)\right)} \qquad \ldots\ldots. 2$$

= 0.3297Mpa

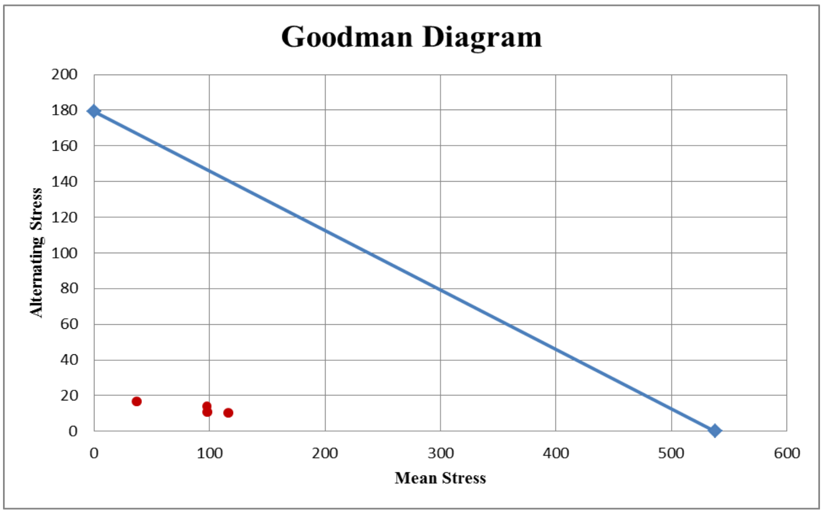

Fig 4.5: Comparison of Mean Stress Equations.

The above plot shows that alternating stress versus mean stress graph, form the graph we can see that the obtained stress are well within the safe limit of the material. Thus, the component is can achieve the required cycle.

5. CONCLUSION

From the above FE Analysis we can make the fallowing conclusions.

- There is an increase in the turbine blade efficiency of turbofan engine and also the turbofan engine efficiency.
- To avoid failure or defects of the turbofan engine the constant maintained of the exhaust gas temperature is obtained.
- This design can withstand the temperature up to 1500^0c and the instrument tested is very much sensitive it detects even the small changes in the temperature.

• Proper control of fuel/air mixture proportion entering the cylinder and also uniformity in the temperature in the engine can be achieved.

• The results obtained from the EGT assembly shows the good agreement with the fatigue analysis which in turn will increase the life of the EGT sensor.

• The above design shows the deformation of the EGT assembly which is observed within the limit of 1200Hz frequency within the safe limit.

• At last it is concluded that the fatigue life of the EGT assembly will be within the safe zone as shown in the Goodman diagram.

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