International Association of Scientific Innovation and Research (IASIR)
(An Association Unifying the Sciences, Engineering, and Applied Research)

ISSN (Print): 2279-0020
ISSN (Online): 2279-0039

International Journal of Engineering, Business and Enterprise Applications (IJEBEA)

www.iasir.net

Thermo Structural Analysis on a Marine Gas Turbine Flame Tube

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Abstract: *Gas turbine flame tube modeling has become essential to predict the flame tube temperature distribution and thermal stress as combustor components operate under high temperature due to combustion instabilities. Thermal analysis is performed on a marine gas turbine flame tube using FEM approach. A commercial software package relying on finite element method is used for simulation and mesh convergence. The main objective of this paper is to analyze the thermal stress on the structural elements of a gas turbine flame tube made up of oxidation resistant alloy steel (GH3039). The present model is divided into nine sections, operating temperatures with heat transfer coefficients varying along the axial direction of the flame tube.*
Key words: *Thermal structural analysis, Gas turbine, flame tube*.

I. INTRODUCTION

Gas turbine engines, an engineering development that has served mankind for over six decades. Both industrial sector and government research institutions have invested and still are investing millions to improve gas turbine performance. As technology advanced throughout the years, designers have been able to push the combustion process further and closer to the stoichiometric limit with the help of high temperature materials and advanced analytical and fabrication tools. However, this positive progress has also created more challenges to engineers and scientists, there are still many issues requiring greater improvement and better solutions. Immediately following the big north east blackout of 1965, air cooling and improved material allowed firing temperatures to increase above 845°C with efficiency approximately 25%. Because the fuel use act of 1978 seemed to require phasing out natural gas as a fuel, the gas turbine market again became sluggish. Nevertheless, material technology continued to develop quickly and the marked returned in the late 1980’s manufacturers were ready with more compressor refinements, high temperature material and even better cooling techniques. Due to the uncertainty in today’s electric energy supply market, both the utilities and non utility generators have put a premium on generation technologies that can be built with a short lead time, at reasonable cost and in affordable increments. Gas turbines in simple cycle, combined cycle and cogeneration modes fit these requirements well in many applications and thus they have come a long way in the past 100 years.

The objective of the present study is to determine the temperature distribution in the axial direction of the flame tube of combustor and to determine the stresses developed due to high temperatures in the flame tube. Thermal analysis is carried out with live trial data from an onboard marine gas turbine. Simulation results can help to identify the areas of concentrated thermal gradients for possible cooling studies to extend the expected life of the gas turbine combustor. Simulation studies enable us to forecast cooling strategies and significantly improve the design of the combustor. Dattaet et al., (1998) studied the influence of combustor pressure on combustion characteristics and found that an increase in combustor pressure for a fixed inlet temperature results in reduction in combustion efficiency. Min- Ki Kim et al., (2004) studied the effect of fuel-air mixture velocity on combustion instability in a model gas turbine combustor and predicted shape changing of the flame is mainly related to mixture fluctuation and the instability caused by flame-vortex interaction which can cause local flow vibration around the swirler. Gordon et al., (2005) performed a 3D numerical simulation on a small annular, reversal flow type combustor and predicted liner wall temperatures based on solutions from numerical simulations. Tinga et al., (2006) performed a life assessment on a fighter jet engine annular combustor liner, using a combined fluid/structural approach and developed models and tools that can be applied to perform comparative life assessment for different mission types. Yap-Sheng Goh (2006) studied thermo-fluid dynamic effects inside a combustor equipped with a swirler nozzle and predicted that the heat transfer peak location on a gas turbine combustor liner strongly depends on the peak location of turbulent intensity of the swirling flow.

Siaw Kiang Chou et al., (2008) developed a simple flame model to analyze the heat transport occurring in the cylindrical micro combustors and investigated the effects of various parameters. Kyung Min Kim et al., (2009) discussed the failure analysis in after shell section of gas turbine combustor liner under base-load operation and proposed the discrepancy in thermal expansion between hot and coolant side walls. Khaled Zbeeb et al., (2010) performed numerical simulations to test the combustion performance and emissions from the vortex trapped combustor when natural gas fuel (methane) is replaced with syngas, methane/hydrogen mixtures, and pure hydrogen fuels. Li Jibao et al., (2011) studied NOx emissions in a model commercial aircraft engine combustor and predicted using CFD under the condition of engine takeoff. The low emission stirred swirl (LESS) combustor has large potential to reduce NOx emission. S. Matarazzoet al., (2011) performed fluid analysis on gas turbine combustor and investigated the effects of changes in operational parameters on the temperature profile and heat flux distribution at the liner inner and outer interfaces.

II. OPERATING CONDITIONS OF THE FLAME TUBE

Combustors play a crucial role on performance characteristics, including thermal efficiency and the level of emissions. These are two well defined philosophies by which air is added to the chamber the first being small and frequent additions, the second as large and infrequent additions. The operating conditions in the flame tube are presented in Table.1

Table 1 OPERATING CONDITIONS IN GAS TURBINE COMBUSTOR

Combustor inlet temperature	140°C
Combustor outlet temperature	600°C
Air mass flow rate	86 kg/s for ten flame tubes
Fuel consumption	0.236 kg per HP per hour
Exhaust gas flow rate	98.5 kg/s
Exhaust gas temperature	360°C
Combustor inside max temp	865°C
Fuel	Low Sulphur High Speed Diesel

III. MODELLING OF THE COMBUSTOR

Structural and thermal analysis is performed using a finite element package. The geometry is modeled with CATIA V5 and the analysis is carried out using ANSYS 12.0. The structural, thermal modules of ANSYS 12 are used for the analysis of the flame tube. The flame tube is analyzed for temperature distribution, combined mechanical and thermal stresses with elongations. The combustor is mounted on the marine gas turbine engine between the compressor outlet and the turbine inlet. Fuel burning takes place inside the flame tube. It comprises of swirled spacer, three conical ferrules and a mixing chamber. The end of the mixing chamber is made into a segment shaped at tail end in cross section. Its forward side rests on the burner and retainer. All the burners are inter-connected with short tubes of elbow shaped. The air supply to the flame tube is 25% for complete burning, 55% for mixing in the mixing chamber to reduce temperature, 20% for cooling of walls and ferrules of HP turbine. The flame tube wall is kept cooled by the stream of air inside and outside through corrugated holes on the ferrules. The flame tube is made up of oxidation resistant alloy steel (GH3039). The properties and composition of oxidation resistant alloy steel (GH3039) is presented in Table. 2 and Table. 3 respectively.

Table 2 PROPERTIES OF OXIDATION RESISTANT ALLOY STEEL **GH 3039**

Density of the material	8300 kg/m^3
Thermal conductivity	13.8 W/m°C
Specific heat capacity	544 J/kg°C
Coefficient of linear expansion	11.5 x 10^{-6} /°C
Yield strength	735 Mpa

Table 3 COMPOSITION OF OXIDATION RESISTANT ALLOY STEEL **GH 3039**

Carbon	0.10% Max
Silicon	0.80% Max
Manganese	0.40% Max
Chromium	19-22%
Nickel	Base
Titanium	0.35-0.75%
Aluminum	0.35-0.75%
Molybdenum	1.8-2.3%
Niobium	0.9-1.3%
Sulphur	0.012% Max
Phosphorous	0.020% Max
Iron	3.0% Max

IV. GENERATION AND MESHING OF MODEL

The present model of the gas turbine flame tube is generated using CATIA V5 and the present model is divided into nine sections, heat transfer coefficients and temperatures vary along the axial direction the combustor. The analysis is carried out using ANSYS 12.0 software. The geometry is modeled using CATIA V5 and imported into HYPERMESH 11.0 for meshing. It is meshed using tetramesh with element size 5 as shown in Fig. 1. The quality of the mesh is checked in terms of skewness, minimum angle, minimum length, maximum angle, maximum length, aspect ratio. It is later imported from Hypermesh to ANSYS 12.0 for thermal analysis. In the element type table, two element types are used for analysis. Element for thermal analysis is solid quadrilateral four noded 55 and element in structural analysis used is plane 182.

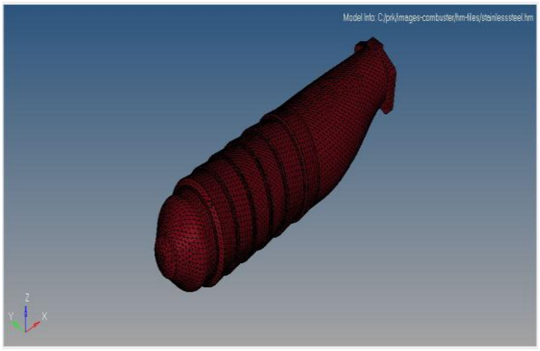

Fig. 1 MESHING OF THE MODEL USING TETRAHEDRAL MESH

V. RESULTS AND DISCUSSION

The convective heat transfer coefficient along the axial direction of the flame tube is shown in the Fig. 2 and Fig. 3. Maximum value of the convective heat transfer coefficient is found to be 590.2 W/m^{2}K, which occurred at a section of the combustor between 0.208m to 0.268m from the inlet of the flame tube. Minimum value of convective heat transfer coefficient is 504.63W/m^{2}K which occurred near the inlet of the flame tube.

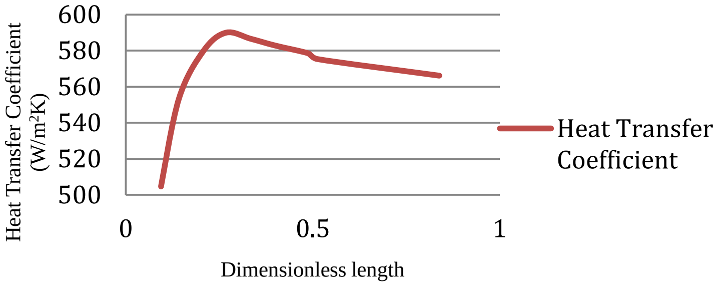

Fig. 2 HEAT TRANSFER COEFFICIENT ALONG DIMENSIONLESS LENGTH OF FLAME TUBE

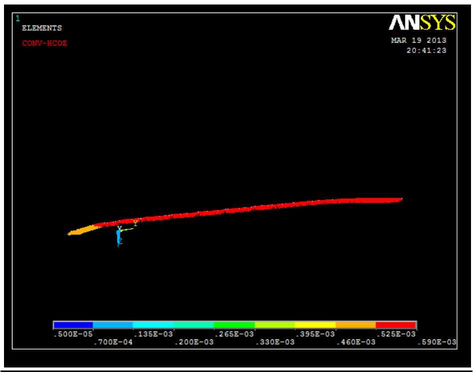

Fig. 3 CONVECTIVE HEAT TRANSFER COEFFICIENT INSIDE FLAME TUBE, W/mm^2 K

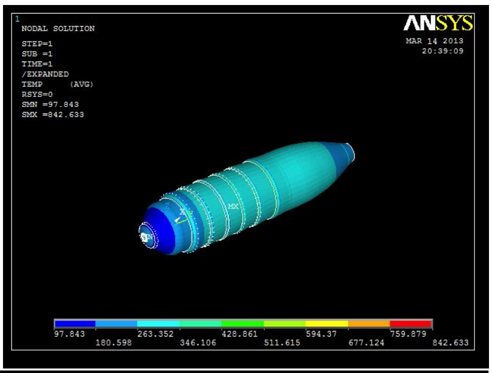

Fig. 4 TEMPERATURE DISTRIBUTION ON THE OUTER SURFACE OF THE FLAME TUBE IN °C

Fig. 4 reveals the temperature distribution on the outer surface of the flame tube. Temperature profile along the length is graphically represented in Fig. 5. The outer surface of the flame tube lies in the temperature range of 97°C to 428°C. Minimum temperature of 97°C occurs at the inlet of the flame tube where the working fluid enters at a temperature of 140°C and the maximum temperature of 428°C occurs near the igniter from where the combustion phenomenon begins. The temperature on the wall decreases along the length and it reaches a minimum value towards the tailend of the flame tube.

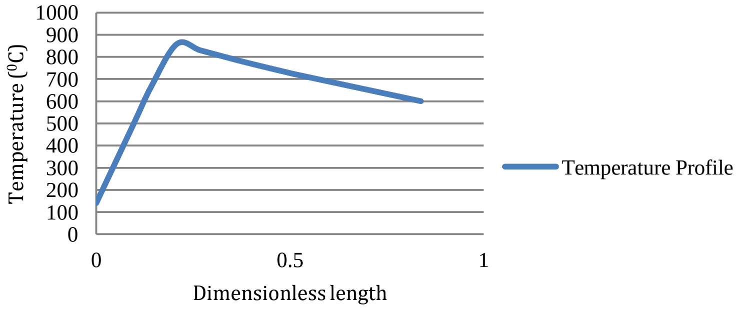

Fig. 5 **TEMPERATURE PROFILE ALONG DIMENSIONLESS LENGTH OF FLAME TUBE**

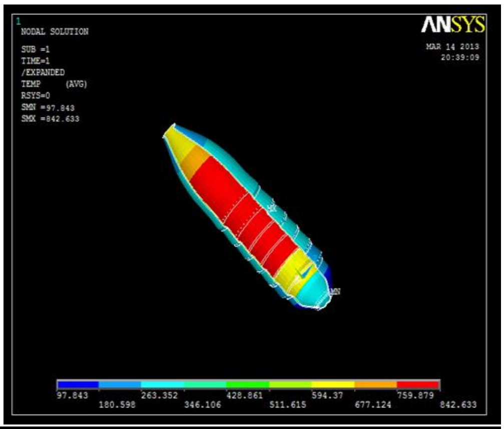

Fig. 6 **TEMPERATURE DISTRIBUTION INSIDE THE FLAME TUBE IN °C**

Fig. 6 shows the temperature distribution inside the flame tube. The temperature inside the flame tube reaches to a maximum of 842°C in the combustion zone where the combustion phenomenon begins. The temperature of the fluid at the entry of the flame tube is 140°C and leaves the flame tube at 600°C. The temperature initially is low, reach to a maximum after the combustion starts and then decreases slowly along the downstream of the flame tube. The dilution air mixes with the working fluid in the dilution zone bringing down to a temperature of approximately 600°C, which is acceptable by the first stage of turbine blade.

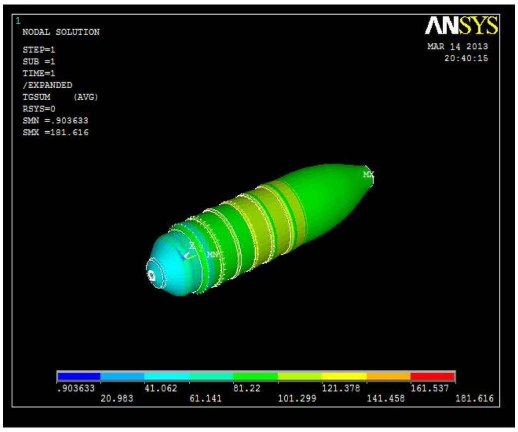

Fig. 7 **THERMAL GRADIENT VECTOR**

Fig. 7 shows the thermal gradient vector. The thermal gradient is minimum at the entry of the flame tube. As the combustion process begins it increases near the combustion zone and decreases towards the downstream of the flame tube. The maximum value of thermal gradient is 181.616°C /m and the minimum value of thermal gradient is 0.904°C /m.

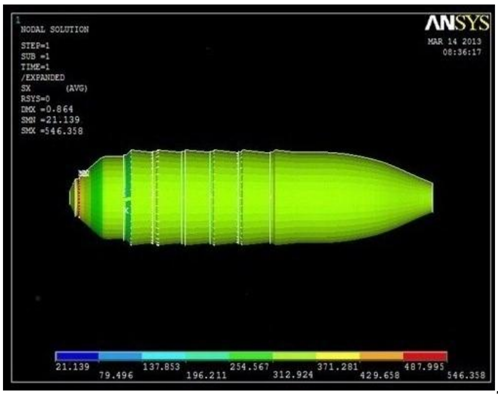

Fig. 8 **STRESS IN RADIAL DIRECTION IN N/mm^2**

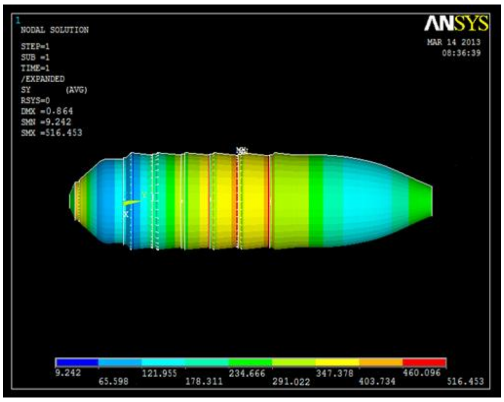

Fig. 9 **STRESS IN LONGITUDINAL DIRECTION IN N/mm^2**

Figs. 8 and 9 shows the stresses developed along the radial and longitudinal directions. The maximum stress in radial direction is found to be 546.36 Mpa which is less than the yield strength value of 735 Mpa. The minimum stress in radial direction is found to be 21.14 Mpa. Maximum stress in longitudinal direction is found to be 516.44 Mpa which is less than the yield strength. The minimum stress in the longitudinal direction is estimated as 9.24 Mpa.

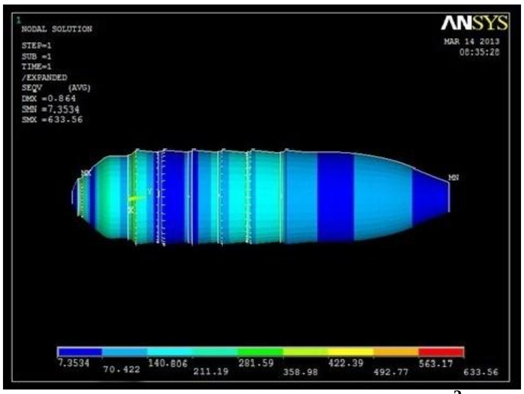

Fig. 10 **VON MISES STRESS IN N/mm^2**

Fig. 10 reveals the von Mises stress in the flame tube. The maximum stress is 633.56 Mpa which is developed near the regenerative burner of the flame tube. The minimum von Mises stress in the flame tube is 7.35 Mpa. The estimated maximum stress developed due to thermal loading in the selected material (Oxidation resistant alloy steel) is well below the yield strength.

VI. CONCLUSIONS

The thermal energy released during combustion inside the flame tube is transferred to the structure causing temperature gradients and heat flux oscillations in the flame tube.

The following are the conclusions from the above analysis:

- The thermal analysis performed on the flame tube reveals the areas of thermal concentrations inside and outside the flame tube. It is found that temperature concentration is high in the pre combustion and combustion zones inside the flame tube.

- The temperature distribution on outer surface of the flame tube is found to be around 420°C near the combustion zone and 180°C at the tail end of the flame tube.
- The maximum stress developed is found to be 633 Mpa near the regenerative burner in the flame tube and by virtue of primary, intermediate and dilution holes on the liner, stresses is found to decrease along the downstream of the flame tube.
- The maximum stress obtained from the analysis is found to be within the yield strength of the selected material.

REFERENCES

[1] Datta, A., Som, S.K., 1998, "Combustion and emission characteristics in a gas turbine combustor at different pressure and swirl conditions", Applied Thermal Engineering, Vol.19, pp. 949-967.

[2] Gordon, R., Levy, Y., 2005, "Optimization of wall cooling in gas turbine combustor through three-dimensional numerical simulation", Journal of Engineering for Gas Turbines and Power, Vol.127, pp. 704-723.

[3] Ko, T.H., 2006, "A numerical study on the effects of side-inlet angle on the mixing phenomena in a three-dimensional side-dump combustor", International Communications in Heat and Mass Transfer, Vol.33, pp. 853-862.

[4] Jun Li., Siaw Kiang Chou., Zhiwang Li.,Wenming Yang., 2008, "Development of 1D model for the analysis of heat transport in cylindrical micro combustors", Applied Thermal Engineering, Vol.29, pp.1854-1863.

[5] Zhang Man., FU Zhenbo., Lin Yuzhen., Li Jibao., 2011, "CFD study of NO_x emissions in a model commercial aircraft engine combustor", Chinese Journal of Aeronautics, Vol.25, pp. 854-863.

[6] Chaouki Ghenai., Khaled Zbeeb., Isam Janajreh., 2012, "Combustion of alternative fuels in vortex trapped combustor", Energy Conversion and Management, Vol.65, pp. 819-828.

[7] Kyung Min Kim., Yun Heung Jeon., Namgeon Yun., Dong Hyun Lee., Hyung Hee Cho., 2010, "Thermo-mechanical life prediction for material lifetime improvement of an internal cooling system in a combustion liner", Energy, Vol.36, pp. 942-949.

[8] Lei-Yong Jiang., Ian Campbell., 2007, "Reynolds analogy in combustor modeling", International Journal of Heat and Mass Transfer, Vol.51, pp. 1251-1263.

[9] Paolo Gobbato., Massimo Masi., Andrea Toffolo., Andrea Lazzaretto., 2010, "Numerical simulation of a hydrogen fuelled gas turbine combustor", International Journal of Hydrogen Energy, Vol.36, pp. 7993-8002.

[10] T. Tinga, J.F., Van Kampen, B., De Jager, J.B., Kok, W., 2007,"Gas turbine combustor life assessment using a fluid/structural approach", Journal of Engineering for Gas Turbine and Power, Vol.109, No.69, pp. 632-644.

[11] Matarazzo, S., Laget, H., 2011, "Modelling of heat transfer in a gas turbine combustor liner", Heat Transfer in Industrial Combustion, Vol.6, pp. 117-129.

[12] Kyung Min Kim., Namgeon Yun., Yun Heung Jeon., Dong Hyun Lee., Hyung Hee Cho., 2009, "Failure analysis in after shell section of gas turbine combustion liner under base-load operation", Engineering Failure Analysis, Vol.17, pp. 848-856.

[13] Danis, A. M., Burrus, D. L., and Mongia, H. C., 1997, ''Anchored CCD for gas turbine combustor design and data correlation", ASME J. Eng. Gas Turbines Power, Vol.119, pp. 535-545.

[15] Mongia, H. C., 2001, ''Gas turbine combustor liner wall temperature calculation methodology", AIAA Paper 2001-3267, 36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, 16–19 July, 2000, Huntsville, Alabama.