Elasto-Plastic Thermal Stress Analysis of Interference Fit in Turbocharger's Swing Valve Assembly by Estimating von misses stress Distribution

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Abstract- Newly developed turbocharger Swing valve assembly (arm and bush) has to be tested to study the product life cycle and to know the satisfactory working throughout entire duty cycle. The turbine housing consists of swing valve assembly used to bypass the exhaust gas directly to atmosphere whenever not required. This assembly consists of two types of fits. Interference fit between turbine housing and bush and clearance fit between bush and arm. But, it is expensive and requires more time to carry out experimental study and measurements can be made only at the limited number of time stations. So, Finite element method is considered as a standard approach which is economical avoiding frequent experimental studies to find the performance of turbochargers. This paper deals with structural analysis of turbocharger's swing valve assembly where von misses stress distributions are plotted for both minimum and maximum interference cases due to thermal loads acting b/w bush and turbine housing. Meshed turbocharger and swing valve assembly model is imported to ANSYS for solving and preprocessing and given run for structural analysis. Finally contact pressure v/s time graph is plotted.

Keywords – von misses stress, Finite element method

I. INTRODUCTION

A Turbocharger is an air compressor used for forced-induction of an engine. The purpose of a turbocharger is to increase the mass of air entering the engine to create more power. However, a turbocharger differs in that the compressor is powered by a turbine driven by the engine's own exhaust gases. The turbine housing consists of swing valve assembly used to bypass the exhaust gas directly to atmosphere whenever not required. This assembly consists of two types of fits. Interference fit between turbine housing and bush and Clearance fit between bush and arm which must work satisfactorily throughout the entire duty cycle for proper working of turbocharger. The swing valve assembly is exposed to high temperature exhaust gases and hence two types of valve fits experience thermo-mechanical loadings. Thus it is important to study the change in behavior of two types of fits throughout the entire duty cycle. It is difficult to analyze such complex thermo-mechanical loading using analytical methods. Finite element method is widely used for such studies.

Niccolo Baldanzini [1], presents general approach for designing interference-fit joints constituted of elastic-plastic components. The theory has been successfully validated by a result comparison with finite element models. Y. Zhang et.al.[2], presents interference-fits in ring gear-wheel connections showing the application of the "finite element method (FEM) for the three-dimensional stress analysis of interference fitted connections giving more complete and accurate results than the traditional method. K. Satish Kumar et.al.[3], showed rigorous elastic-plastic finite element analysis of joints subjected to cyclic loading. The results of the study are a useful input for the estimation of the fatigue life of joints. Albert Konter [4], presents the general overview of contact analysis using FEM and comparison of contact analysis in finite element (F E) software tool. S. Sen et.al.[5] presents general stress calculations in interference-fit designs estimated using conventional equations.. During heating and cooling the transient conduction heat transfer state was considered. Adnan O¨ zel et.al. [6], presents idea to calculate stresses and deformations in the shrink-fitted hub–shaft joint for various fit forms and been analysed using FEM. M. Ast, et.al.[9]

reviews the FEM contact analysis of a hydraulic pre stressed coupling and of a gear-shaft connection. Even the highly nonlinear transition from static to sliding friction has been analyzed.

The literature survey revealed that less number of papers are available on Elasto-plastic thermal stress analysis for turbochargers and particularly for swing valve assemblies. Only general studies are performed to study the interference fit using analytical formulation approach and few Finite element (FE) method using 2D contact elements. Still no systematic approaches have been carried out to ascertain the effects of thermo-mechanical distortion and displacement studies in the interface regions of fits. So there is a need to develop a Finite element method that gives the accurate results for interference fit studies subjected to thermo-mechanical loading.

The present study is focused on analyzing interference fit and estimating von misses distributions at various time stations across duty cycle of a swing valve assembly in open position of waste gate poppet valve using FEM.

II. METHODOLOGY

FEM model of arm bush and turbine is generated using HYPERMESH. Two types of elements namely TETRA elements for region away from study(turbine housing) and HEXA elements are created in interface region of turbine housing, bush and arm for displacement study and to create contact elements[1-2]. Meshed model is checked for any free edges, T- connection, and min. angle of element is greater than 15degree. Editing the element size stress concentration or sensitive area elements is refined to increase the density of elements and quality of elements is checked. FE model is prepared with 1131302 elements and 593851 nodes as shown below in fig.(1) and fig.(2) respectively.

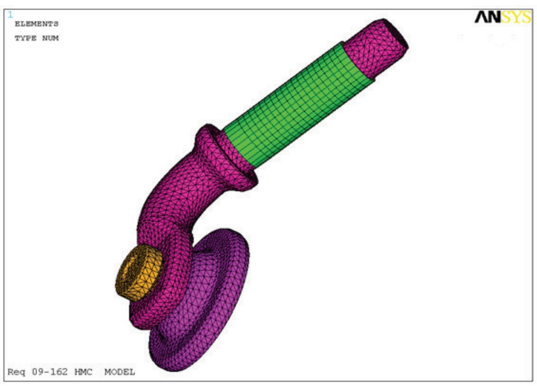

Fig.1 Arm and Swing Assembly

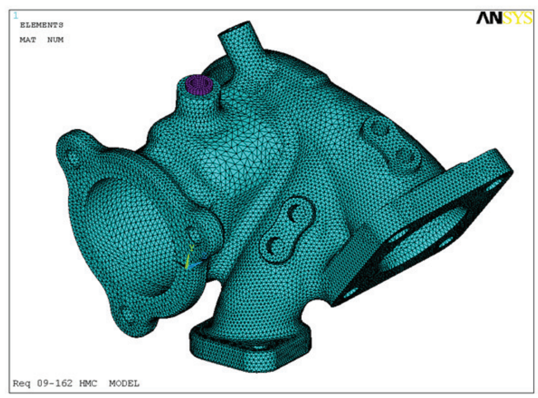

Fig.2 Turbine Housing and Bush Assembly

The position of bush (B) is shown in fig 3 (a). Six circles of nodes are prepared in Bushing, named as station C1 to station C6, & correspondingly six circles are mapped on turbine housing, named as station C1 to station C6 to find interference of mapped nodes shown below in fig 3(b).

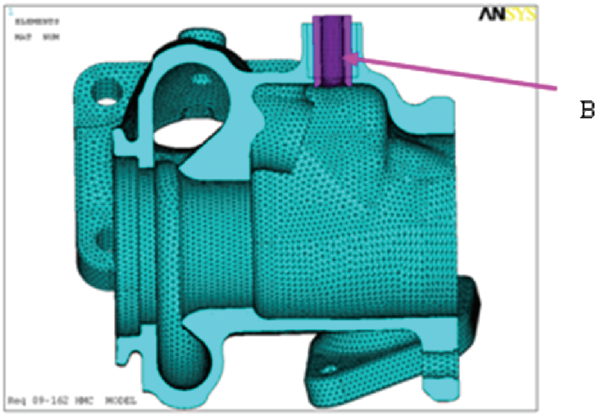

Fig.3 (a) Arm and swing assembly with clearance region

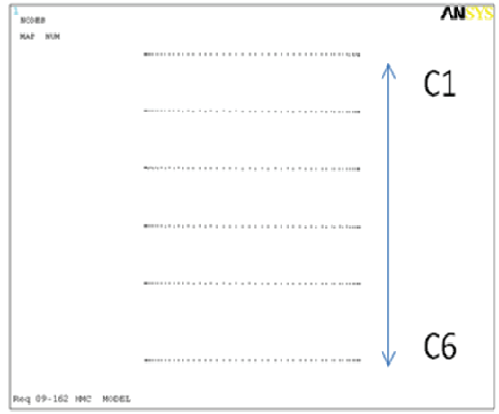

Fig.3 (b) nodal circles in interface region of interference fit

Arm and bush assembly is analyzed for both minimum (min.) and maximum (max.) clearance conditions (i.e. case 1 & 2) under thermal loads. Excel solver is developed to find the radius of nodal circles and angular position of each node using coordinate values of each nodes of a nodal circle with respect to defined coordinate system. Radial gap(radius) between adjacent nodes of Arm & bush elements is processed using excel post processing from deformed coordinates at various angular locations (Angular position of each node is calculated by finding which quadrate node is located then using Trigonometry function tan inverse y to x ratio is found) for all the stations of nodal circles defined. Radial distortion of axis is incorporated accordingly at each nodal circle.

2.1 Transient thermal analysis

Material properties are applied on FE model with element type SOLID 87 for tetra element and SOLID 90 for hexa element to obtain temperature distribution plots. Transient thermal analysis saved as .rth file (resulting temperature) in excels post processor as input for further analysis. Considering the material properties as shown below in table(1).

Table 1. Material properties of each component used in analysis.

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Component name	Material no
Turbine housing	IDM5365
Bushing	IDM6089
Arm, rivet & poppet valve	IDM6027

All material properties are non linear varying with temperature and time due to confidential, properties are not disclosed in detail. Turbine housing undergoes engine cyclic operations and considering one cyclic of operation include one heating phase and one cooling phase for worst condition graph below shown in fig(4) for worst possible temperature (758 to 80 deg) condition turbine housing is used.

The table (2) shows the thermal boundary condition like convection coefficient and bulk temperature for all components of turbine housing and inlet region during heating conditions. External surface component is thermally loaded due to turbocharger working conditions and engine environment both during heating conditions. Inlet and inlet region component allows exhaust gases to enter into the turbine which is having higher convective coefficient and bulk temperature.

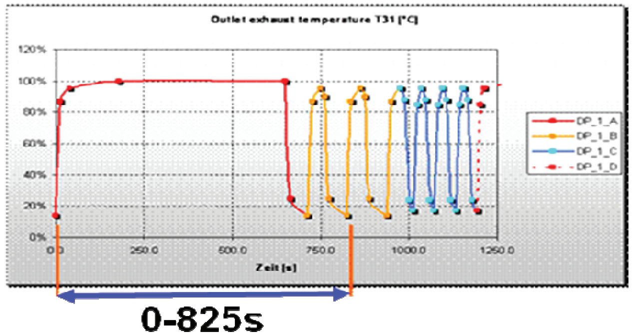

Fig.4.Duty cycle used in for analysis. (Source; Honeywell turbochargers)

	HTC (W/m2°C)	Bulk Temperature (°C)
DC_INLET	271	713
BFV_INLET	499	758
INLET & INLET REGION	683	754
GATE_ZONE	683	754
A_SURF	114	569
WHEEL_CONT	379	623
OUTLET_SURF	410	579
EXT_SURF	50	80

Table.2. Thermal boundary conditions on different components for BFV ON condition. (Source; Honeywell)

2.2 Elasto-Plastic Thermal Stress Analysis Performed For Whole Assembly

After transient thermal analysis meshed model is imported to ANSYS to change element type for structural analysis Solid 92 for tetra element and Solid 95 for hexa element. Applying mechanical boundary conditions whole assembly is analyzed for both min. and max.interference conditions (i.e. case 1 & 2). Mechanical boundary conditions applied as all normal displacements, one node in UX & two nodes in UY directions in plane displacements are arrested on turbine housing flange as shown below in fig(5). At all temperature and time points results of thermal analysis stored in (.rth) file is read and applied as body loads for elasto-plastic thermal stress analysis.

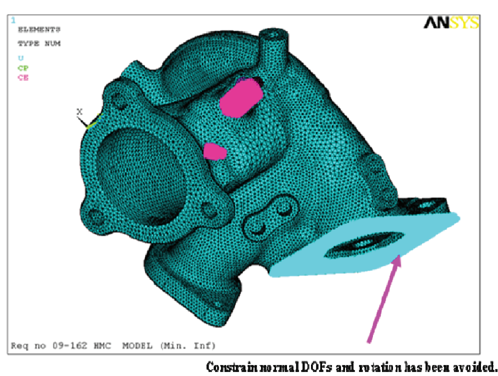

Fig.5. Structural boundary condition for whole assembly

Elemental nodal stresses, elemental displacements from time point from 0 to 825seconds(s) are found. Finally result file .rst is generated used for post processing.

III. RESULTS AND DISCUSSIONS

3.1Transient thermal analysis

Temperature plots are taken for steady state heating and cooling conditions. full and sections views are plotted, Temperature variation is 431 ˚C ~751˚C during heating condition shown in fig.6(a) and fig.6(b). Temperature variation is 127˚C ~408˚C during cooling condition shown in fig.7(a) and fig.7(b). Nodal temperatures are saved in .rth file for applying as body loads.

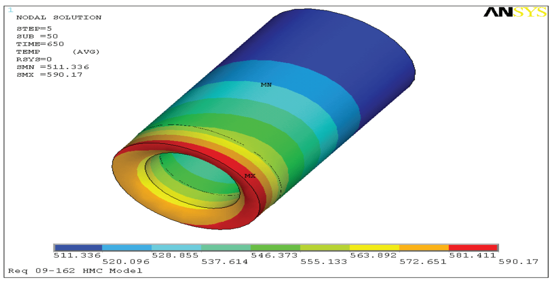

Fig.6 (a) Temperature Distribution at End of heating of bush (650s)

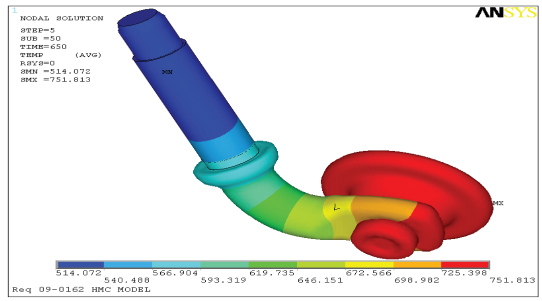

Fig.6(b) Temperature Distribution at End of heating of arm (650s)

Following results are derived from the plots.

1. At the end of heating phase arm and bush end surfaces are exposed to maximum temperature i.e. 751.813˚C and 590.17˚C respectively showing decreasing temperature trend towards top surface.
2. At the end of heating phase arm and bush top surface are exposed to minimum temperature i.e. 514.072˚C and 511.336˚C respectively.

In arm and bush, end surface is exposed to higher temperature and heat is transferring in conduction modes from inside of turbine housing to external atmosphere as shown in the temperature distribution plots.

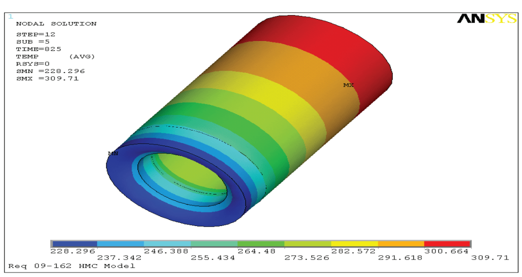

Fig.7 (a) Temperature Distribution at End of cooling of bush (825s)

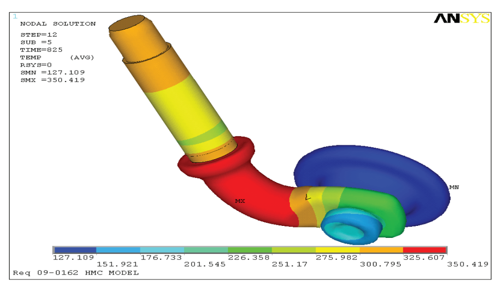

Fig.7 (b) Temperature Distribution at End of cooling of arm (825s)

Following results are derived from plots.

1. At the end of cooling phase arm and bush end surfaces are exposed to maximum temperature i.e.350.419˚C and 309.71˚C respectively showing decreasing temperature trend towards top surface.
2. At the end of cooling phase arm and bush top surface are exposed to minimum temperature i.e. 127.109˚C and 228.296˚C respectively.

3.2 Elasto-Plastic Thermal Stress Analysis Performed For Whole Assembly

Vonmissses stress plots represents the beginning of yielding for material due to higher tensile stress. The region representing red color is having higher values and blue color shows the lower yielding stress values shown in fig.8 (a)-fig.9 (b). In the interface region Vonmissses stresses are high and yields early compared to other region of turbine housing assembly because bush is forced inside the turbine housing bore to have interference fit. So initially it has some tensile stress in addition to that thermo mechanical distortion creating tensile stress which leads to yielding in early stages as shown in fig.10**.**

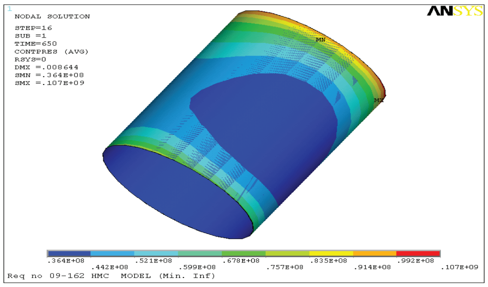

Fig.8 (a) Contact Pressure Distribution for Min. Interference Case at 650s

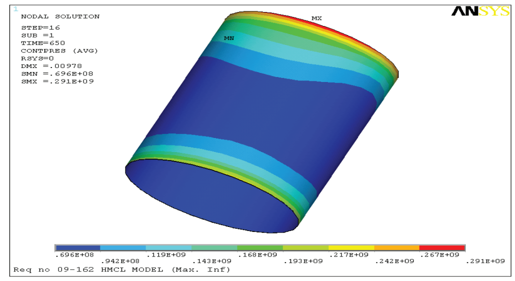

Fig.8(b) Contact Pressure Distribution For Max. Interference Case at 650s.

Following results are derived from the plots.

1. At the end of heating phase Vonmises stress b/w bush and turbine housing varies from 36Mpa-107Mpa with minimum interference.
2. At the end of heating phase Vonmises stress b/w bush and turbine housing varies from 69Mpa-291Mpa with maximum interference.

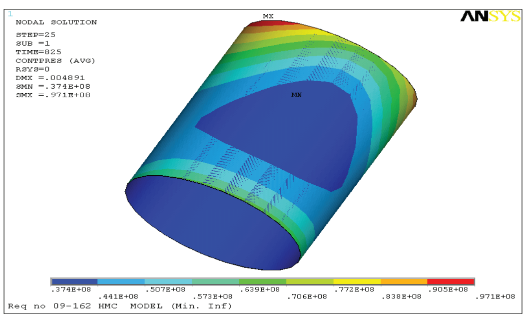

Fig.9 (a) Contact pressure distribution for Min. Interference case at 825s.

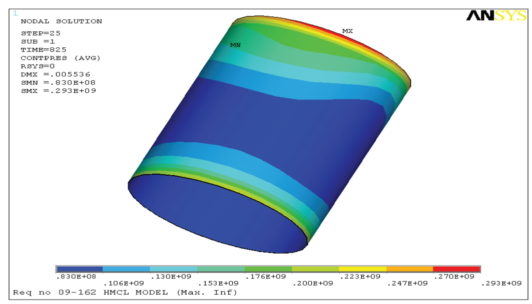

Fig.9 (b) Contact Pressure Distribution for Min. Interference Case at 825s.

Following results are derived from the plots.

1. At the end of heating phase Vonmises stress b/w bush and turbine housing varies from 37Mpa-97Mpa with minimum interference.
2. At the end of heating phase Vonmises stress b/w bush and turbine housing varies from 83Mpa-350Mpa with maximum interference.

Using above results from plots contact pressure v/s time graph is plotted as shown in fig.10 below.

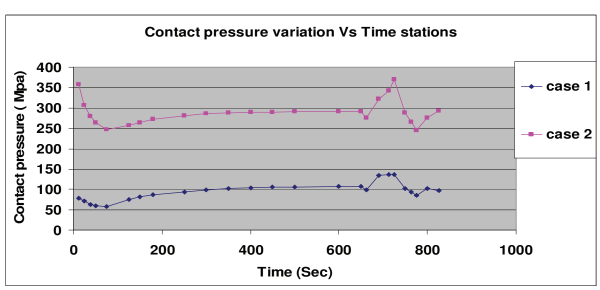

Fig. 10 Variation of Contact pressure with time

From fig.10 it is seen that contact pressure is decreasing in steady state heating up to 712.5 sec, increasing in transient heating between 712.5-750 sec, & remains constant during 750-825 sec. Contact problems present two significant difficulties. First is the regions of contact are not known until running the problem. Depending on the loads, material, boundary conditions, and other factors, surfaces can come into and go out of contact with each other in a largely unpredictable and abrupt manner as seen in graph. Second, most contact problems need to account for friction. There are several friction laws and models to choose from, and all are nonlinear. Frictional response can be chaotic, making solution convergence difficult.

IV. CONCLUSION

Clearance is reducing marginally in steady state heating till 650 sec & increasing in sharp heating from 712.5-750 sec. Clearance variation is marginal during sharp cooling between 650 – 712.5 sec & 750 -825 Sec.

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