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Develop Robust Finite Element Analysis For V-Band Clamp

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ABSTRACT

Turbochargers typically comprise a body in three parts; the turbine and compressor housings and the bearing housing. The reliability and characteristics of systems depend on the different properties of the joint. The preferred method of joining these three parts, is to use a band clamp with a flat bottomed V-shaped cross section mating with appropriate flanges on the body sections. This method of clamping allows for rapid assembly and infinitely variable relative rotational orientation of parts.

V-Band clamp is considered as the critical joint. Leakage being the major environmental issue due to V clamp loosening is the common failure and the mechanism of the failure is the load applied in the transverse and rotational directions causes self-loosening

FEA parameters have significant impact on the results hence appropriate modelling of the joint is essential for predicting the behaviour of the systems very accurately and efficiently. Hence this work is initiated to develop the FEA process to predict the clamp load generated at the V band flanges when the nut is tightened using FEA model.

Results shows that the accuracy of the FEA results depended on the element size, type of mesh, elements on sliding contact surface and coefficient of friction had influence on the analysis. This helped to set up FEA model in investigating the clamp load capacity of V-clamps. Also FEA results are very well correlated with the test results. Overall, this work helped to improve the correlation; improve understanding on the calibration of V band clamp load test rig and non-convergence issue during FEA analysis.

Keywords— V-band applications, V-band axial load calculation, failure modes, T-bolt, FEA model, nomenclature

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I. Introduction

V-Band clamps were invented during the Second World War by the Marmon Corporation. They are used to assemble satellite to their launching device[1].V-band having a toughened layer along its interior surfaces for gripping the flanges on the enclosure which it engages when it is installed on the enclosure to withstand high internal pressures without system failure. V-Band clamps are widely used for connecting components such as tubes, hose, duct, pipes rigid flanges and similar equipment. In automotive industry, connecting the exhaust manifold, charged air cooler, exhaust gas recirculation and the turbocharger are one of the application for which V-Band clamps were mass produced.

Applications of V band in engine

- Connecting the exhaust manifold and the turbo
- Exhaust gas purification (catalyst, particle filter)
- Exhaust gas recirculation
- Charged air
- Cooling circuits
- Use in Turbocharger
    - Turbine Housing – Bearing housing joint
    - Turbine Housing – Exhaust system
    - Compressor housing – Bearing Housing
    - Compressor housing – air transfer tube

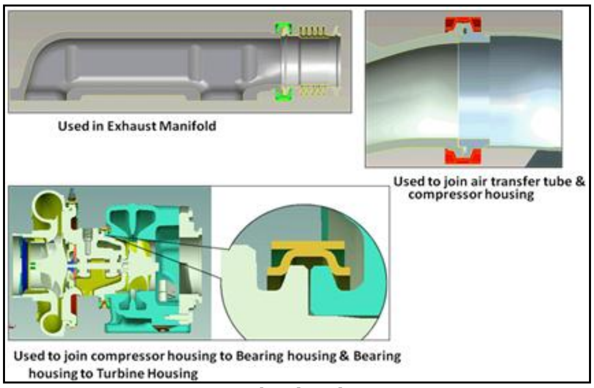

Figure 1: V-band applications

During the assembly process a V-band clamp is first loosely placed around the flanges, after that the T-bolt nut (Figure 2) is tightened. This leads to a radial force being generated in the band clamp, and due to the V-section of the band this results in the creation of an axial load. This axial load then pushes the flanges together[2]. V-band clamps are very critical for Turbocharger industry. Even though its wide application, once assembled to a pair of flanges little is known about the interaction between flange and band. Moreover the failure mode of V-band clamps when undergoing an axial load is not fully understood. Major failure modes of mechanical joints in which V-band clamps are used are loosening, rotation of joint, leakage & loss of clamp force/load

Due to this business need, this work has been initiated to generate a finite element model able to predict the axial load capacity and deformation of V-band Clamps

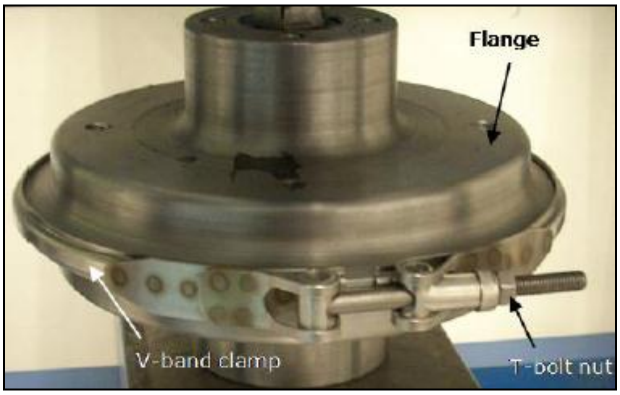

Figure 2: V-band clamp assembled position[2]

II. V BAND CLAMP THEORY

A. Working Principle

1. A torque applied to the V-Band clamp nut creates a radial force in the V-form. The V-Band clamp starts contracting and sliding over the flanges. Due to the wedge shape of the flanges, the V-form pushes the flanges together

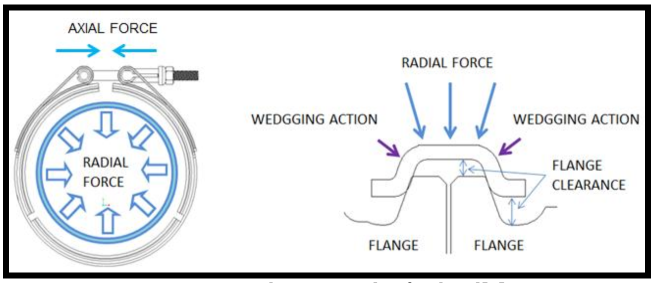

Figure 3: Working principle of V-band[3]

2. Tightening of the clamp nut results in the application of a radial force due to the increase in tension in the band.
3. The wedging action of the band on to the flanges then generates an axial load that can seal the joint and allow it to sustain applied rotational and bending moments.
4. The axial load imposed on the flanges of the component by the V-band clamp provides the clamping force required for the joint

B. V-Band manufacturing process

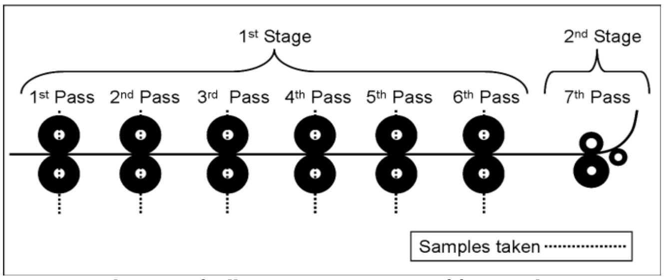

Figure 4. Schematic of rolling process - 1st stage of forming the V-section and 2nd stage of forming circular shape

V-band clamps are made of austenitic stainless steel and manufactured using a cold roll forming process. In the first stage an initial flat band-strip is deformed using six passes to form the V-section. The second stage consists of a cold roll-bending process in which the band gets its circular shape as shown in Figure 4.

Effect of cold rolling on material properties [4]:

Austenitic stainless steels contain about 16-25%wt. chromium, 0.1%wt. carbon and not less than 7.5%wt. nickel, which is indispensable to obtain the single-phase structure. These steels usually exhibit excellent corrosion resistance, toughness, ductility, low thermal and electrical conductivity and good weldability. However, the strength level, particularly the yield strength, is relatively low, about 200 MPa, in the annealed state. In order to increase their strength, austenitic stainless steels are often cold worked after solution annealing. Cold working is a convenient strengthening method since austenitic stainless steels normally have a high strain-hardening coefficient. After thermo-mechanical treatment a common steel such as X5CrNi18-10 (AISI 304) can have its yield strength increased to about 1400 MPa, with an elongation over 10%.

C. V-Band Clamp Load Theory[3]

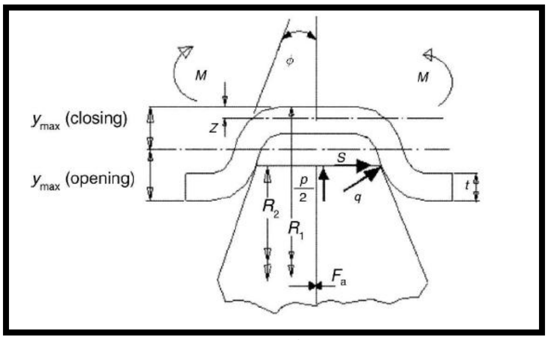

Figure 5: Loading of V section

Where
Fa – Axial Clamping Force (N)
Fβ – Force applied by T – bolt (N)
R2 – Radius of Flange (m)
μ – Coefficient of friction between V-band & flange

Taking the axial component, s, of the contact load, q, per unit length of the contact line, as shown in Figure4, gives

$$\boxed{s = q\cos\phi}$$

The total axial force may then be determined from

$$\boxed{F_a = 2\int_0^\beta s \, dl}$$

where dl is a small length of the contact line. This length is a circular arc of radius R2 and angle dα. Hence,

$$\boxed{F_a = 2R_2\int_0^\beta q\cos\phi \, d\alpha}$$

Combining above three equations then gives

$$F_a = 2R_2\int \frac{F_\alpha \cos\phi}{2R_2 \sin\phi} d\alpha$$
$$= \int_0^\beta \frac{F_\beta(\cos\phi)\exp[-\mu(\beta-\alpha)/\sin\phi]}{\sin\phi} d\alpha$$
$$= \frac{F_\beta\cos\phi}{\mu}\left[1-\exp\left(\frac{-\mu\beta}{\sin\phi}\right)\right]$$

Summary:
- Axial force is directly proportional to T-bolt force (Fβ)
- Axial force is independent of the radius, R2, of the flanges on the component.

Clamp load significance
- It is the v-band axial clamp load that maintains the contact between turbocharger component sealing faces.
- Maintains pretension in any seals that may be present.
- Resists rotation of the joint under external loading from turbocharger piping, engine vibration and turbocharger self-weight.

Maintains structural integrity of joint in failure condition

III. V BAND FINITE ELEMENT METHOD

A. Generate FE Model

Concept generation for FEA model

The models should be capable of predicting the ultimate axial load capacity and structural deformation of V-band clamps so different finite element analysis had been generated.
Several design and geometry concepts have been generated. Issues with concepts were convergence due to geometry, interferences between model, contact of interacting components and not replicating actual test rig condition. This is a iterative method of concept generation, run analysis and check results to have best concept.

Final concept

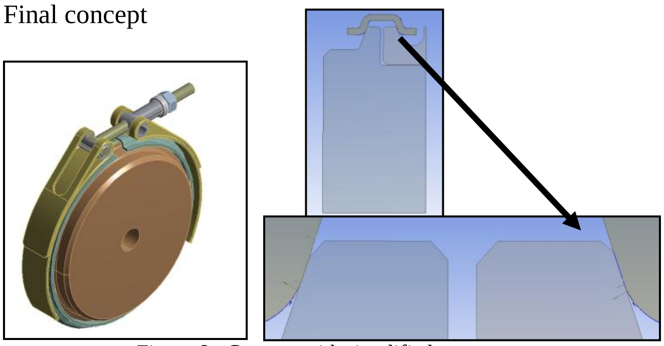

Figure 6 - Concept with simplified geometry

The features of this model are
- Clear geometry like interference due to which it was not converging
- Interference between the V-form & bearing, turbine housing has been removed by generating
- V-form by using DM tool, maintained node to node mapping between V-form to turbine & bearing housing
- Interference between the V-form & bearing, turbine housing has been removed (mating conditions)

The representative (best candidate) concept model from V bands are selected for analysis. The similar V-bands are used for testing so that we get the correlation between both the results.These models are made in Pro-E and once de-featuring is done it is transferred to Ansys Workbench

B. Boundary Conditions

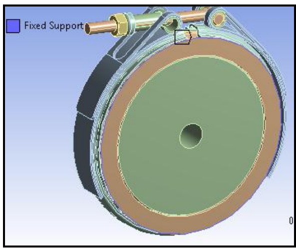

Figure 7

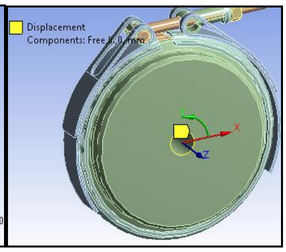

Figure 8

Edge is constrained in all directions (turbine housing side – Fig-7)& bearing housing side edge is constrained in rotational & axial direction (Fig-8)

C. V band material properties

Materials for v-band assemblies, including T-Bolt, Trunnion Cap, Trunnion, V-form, T-Bolt wrapper, V-Band Loops are taken from material standard and mostly Stainless steel 304[9],[10]

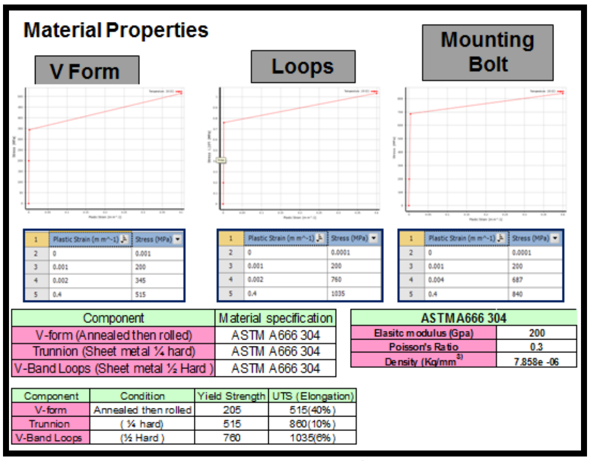

Figure 9- Material properties for analysis

D. Loading Conditions

During actual testing, torque applied is 5N-m so converted into bolt pretension using following formula

Preload =(Torque /(K*Dia of bolt))
K=0.18 is assumed
Preload – (5/(0.18*0.00635))= 4374N

Bolt pretention applied on T bolt 4374N

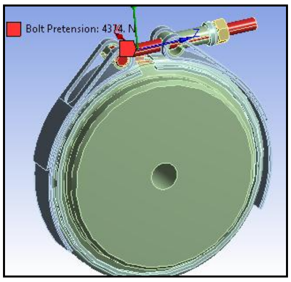

Figure 10- Loading condition

E. Meshing

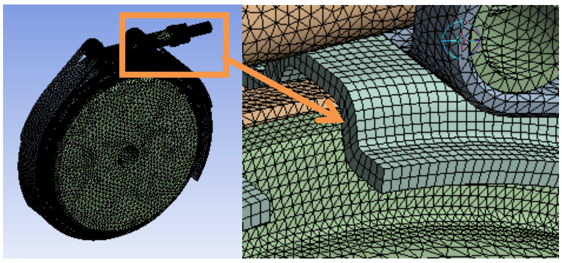

Figure 11- V-band is fine meshed

F. Analysis Approach

- The assembly containing (dummy components) turbine housing, bearing housing and V Clamp assembly is considered for stress analysis. Unwanted portion of the geometry has been chopped off to simulate the actual test condition.
- Frictional contact is used between turbine housing flange face to V-form, bearing housing flange face to V-form, turbine to bearing housing and Trunion to loop respectively, while rest of components are connected to through bonded contact.
- Geometry is constrained to avoid the rigid body motion
- The pretension of 4374 N corresponding to 5N-m assembly torque is applied to mounting bolt of V Clamp assembly.
- Finally stress analysis is carried out to determine axial clamp load generated due to pretension applied to mounting bolt.

G. FEA Results

Total Deformation of V clamp (mm)

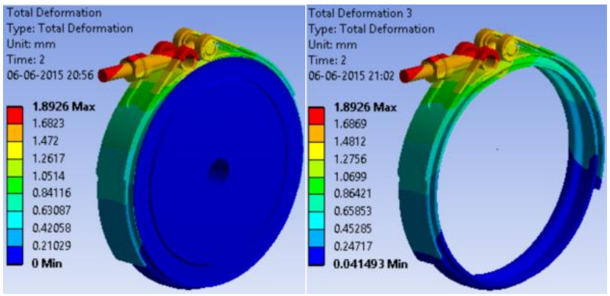

Figure 12- Deformation plots

Stress plots of V clamp (MPa)

1. Max Principal stress (S1)

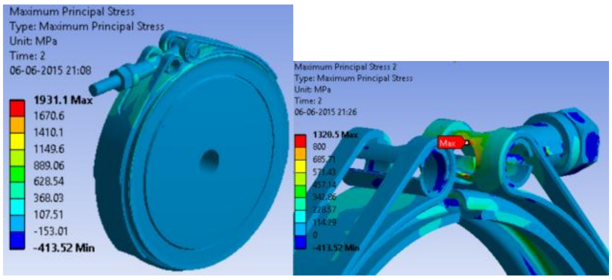

Figure 13- Maximum principal stress

2. Von Mises Stress (Seqv)

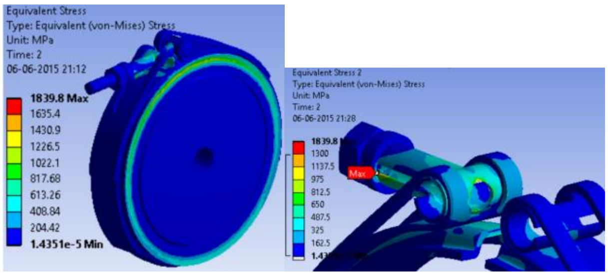

Figure 14- Von Mises Stresss

H. Plotting Results

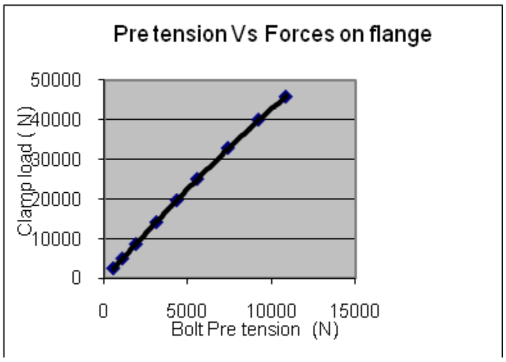

Figure 15. Bolt preload Vs Axial force on flange

IV. Experimental Test

I. Test setup & data interpretation

The main objective of the test is to investigate the axial clamping characteristics of a v-band clamp i.e. the axial load generated in the v-band joint when the v-band nut is tightened.

- A special fixture is designed to replicate flanges of the housings to be joined
- The fixture accommodates 3 load cells equi-spaced on a PCD. Load cells are designed to accept the load on the V-band

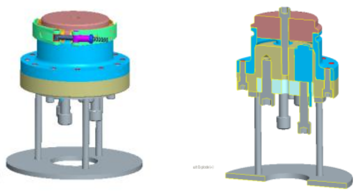

Figure 16- Test setup (3D view) & cross section

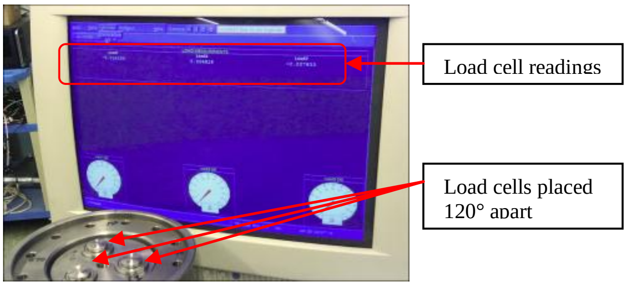

Figure 17 Test Hardware setup

- Initially nominal load is applied by tightening the V-band nut to a nominal low torque (say 2 Nm). The load in each load cell is recorded
- Nut torque is increased by rotating the nut through ½ turn and the load in each load cell is recorded
- The process is continued until agreed maximum nut torque or axial cell load is reached
- The load of each cell is recorded at the required nut torque and the total load is obtained by summing the three cell loads.

J. Test Results

Axial Clamp Load Vs Nut torque

Axial Clamp load, like load in the 'T' bolt, has a linear relationship to Nut Torque (directly proportional to T-bolt force)

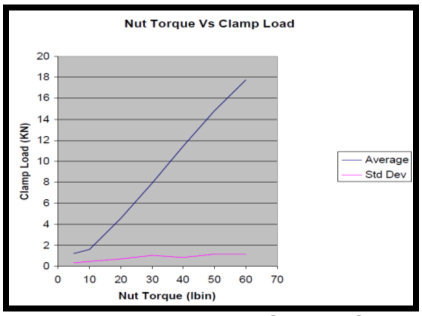

Figure 18. Nut Torque Vs Clamp Load

V. CONCULSION

The theory proposed by Shoghi concludes axial force is directly proportional to T-bolt force (Fβ). This was validated by sample calculations, similar axial force characteristics is drawn

The cold rolling process and its effect on material and strains was studied. It was observed that the plastic deformation is induced after cold roll operation

Finite Element Analysis shows that the accuracy of the results depended on the element size, amount of elements along the sliding contact surface and type of mesh.

It is observed that total axial load generated at turbine housing flange location due to 5 N-m assembly torque to V Clamp mounting bolt is 10740N. With 5NM torque axial load generated from test is: Mean – 15.4KN, Minimum - 10.8KN.

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