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# Component Level Failure Analysis of Mounting Strap Joint Fitted on Vehicle Engine Exhaust After-Treatment System

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***Abstract:** Exhaust Gas Processors (EGP) or Exhaust After Treatment Systems (EATS) are usually mounted on vehicle chassis or engine body with the help of mounting straps due to its ease of installation. It is prescribed for any industry to manufacture an optimized design of strap joint and duly test it before making an entry to the market. There is no standard method available to be followed by the industry for strap validation at an earlier stage. Most of the strap joint designed and tested based either on MAST test (done in the later stages) or on the experience. So, to test the strap joint at an earlier stage there is a need to design a component level strap joint validation method with a goal to assess the durability of strap joint vulnerable to fatigue failures due to vibration over-amplification in a bracketed after-treatment assembly while able of detecting any design flaws and eliminating or reducing numbers of potential test induced failures. The objective of this work is to define and document a systematic approach for component level strap joint validation method used to mount after treatment system components. Due to geometrical complexity and nature of material, geometrical nonlinearity and material nonlinearity were considered in the analysis. Also, for getting the most realistic results contact nonlinearity was also considered. And finally, out of various approaches investigated, an approach which was able to replicate failures in a more exact manner comparable to assembly level test was recommended as the component level strap validation method.*

***Keywords:** Aftertreatment system (ATS), Exhaust Gas Processors (EGP) or Exhaust After Treatment Systems (EATS), Multi axis shaker table (MAST), Strap joint.*

## I. INTRODUCTION

The exhaust systems in on and off highway applications consist of a passage that helps the exhaust gases generated by the engine to pass through exhaust gas processor. This system encompasses various components such as the Selective Catalytic Reduction (SCR), Diesel Oxidation Catalyst (DOC), and Diesel Particulate Filter (DPF) [2][12]. This exhaust gas processor is mounted over the chassis with the help of mounting straps (with the help of brackets) popularly called as clamps. The assembly of a T bolt, trunnion, and nut makes up a strap joint. Because they are simple to install, clamps are employed in seismic applications and additionally it avoids the welds which makes it more reliable [3]. The functioning of strap joint involves several steps, which commences with the application of torque which converts it to bolt pretension. This increased tension, in turn, generates frictional force that enables the clamping action [2]. During installation, when the band clamp is in the open condition, bending stress occurs, indicating the over-opening of the clamp. When the T bolt is furthest away, the bending stress is highest. But as the band clamp is tightened, the frictional force that results creates hoop stress, or circumferential stress, which is especially noticeable in the vicinity of the T bolt [4]. During operation the strap joint can face various failures which can be divided as assembly level failure such as yielding of strap joint, bottoming out and operating level failures such as slip and separation at joint, huge preload loss, fretting failure and fatigue failure [6][8][9][10][11]. So, the strap must be designed so as it may serve the purpose without facing failures. These straps need to be validated before using them in operation at an earlier stage rather going for a MAST test which is done at a later stage. So, there is a need of a test at a component level with a goal to assess the durability of strap joint vulnerable to fatigue failures due to vibration over-amplification in a bracketed after-treatment assembly during testing. This paper presents work in developing an approach for validation of mounting strap at the component level. There were several failures associated with this strap joint while in function but in this paper the work majorly focusses on saving the joint from slip and separation which in turn saves the joint from fretting as well[5][7]. Several approaches/configurations were formulated and simulated at the component level against the loading and boundary conditions experienced by the strap joint. The primary objective was to prevent slipping and separation of the joint under different loading conditions. During the FEA simulation, contact nonlinearity was considered to address intermittent loss of contact between the parts, resulting in abrupt changes in the stiffness matrix.

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Material nonlinearity was incorporated to account for the nonlinear properties of the material during the simulation. Geometrical nonlinearity was also considered to accommodate significant deflections in the strap, even with the application of a relatively small force.

## II. STRAP JOINT MODEL

The figure 1 depicts the model of strap joint with M8 bolt mounted over the cylinder. The cylinder considered in the analysis was taken as a replacement of exhaust gas processor to simplify the analysis.

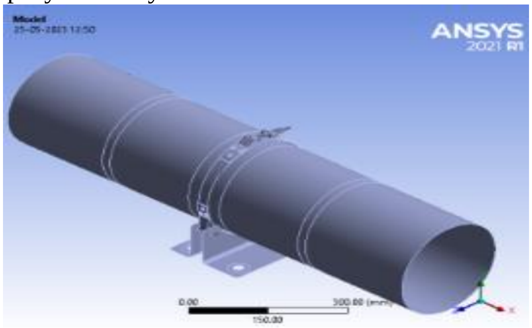


**Figure 1. Strap Joint Model**

**Table 1. Material Property of SS 439**

| **Material Property of SS 439 Annealed Atlas** | | |
|---|---|---|
| Material property | Value | Unit |
| Material density | 7850 | kg/m3 |
| Young's Modulus | 200 | GPa |
| Poisson's ratio | 0.3 | Unitless |
| Bulk modulus | 166.6 | GPa |
| Shear modulus | 76.92 | GPa |
| Tensile yield strength | 290 | MPa |
| Tensile ultimate strength | 460 | MPa |

Assumptions:

1. The actual exhaust gas processor was replaced by a thin cylindrical body.
2. The nut factor was taken as 0.18.
3. Strap material and cylinder material are taken as non-linear.

## III. COMPONENT LEVEL STRAP JOINT ANALYSIS APPROACH

In this approach the cylinder was fixed and excitation at bracket locations was given. Mesh size influences numerical accuracy as well as the computation time. Element size for majority of the parts is taken as 2mm to have an optimization between the time and accuracy. Majorly Quad elements were used for both straps and cylindrical body.

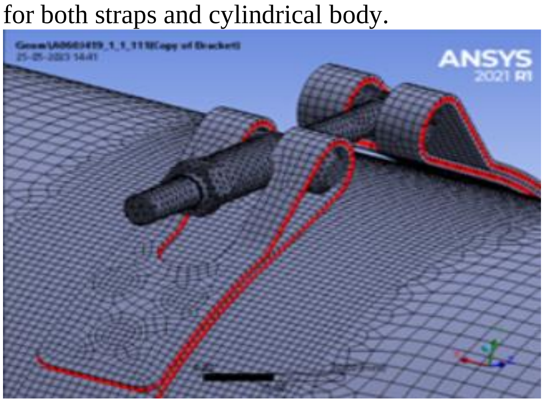


**Figure 2. Mesh Details**

Assumptions:

i. The coefficient of friction for the frictional contact was taken as 0.15.

ii. The temperature effects were neglected.

The parts contact state indicates whether they are in contact or not. All of the contacting surfaces of the strap with cylinder and bracket with cylinder were in frictional contact with one another.

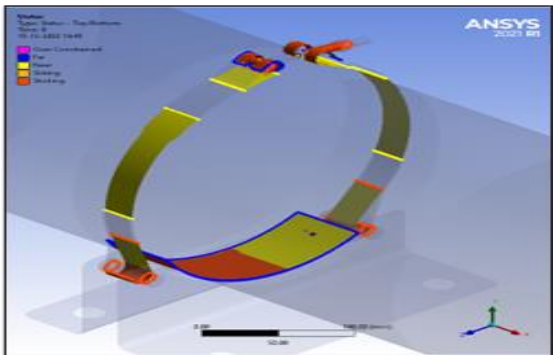


**Figure 3. Contact Status**

Loading conditions

i. Assembly Loading Condition:

To prevent the convergence error, preload was applied in smaller increments. The computed torque value for an M8 bolt is 19.93 N-m.

Torque=Nut factor*Diameter*Preload

Hence, bolt pretension of 9692 N-m (taking 30 percent as torque relaxation) was applied by dividing it into load steps and on further load steps was kept as locked. The figure 4 is only a graphical representation of pretension applied.

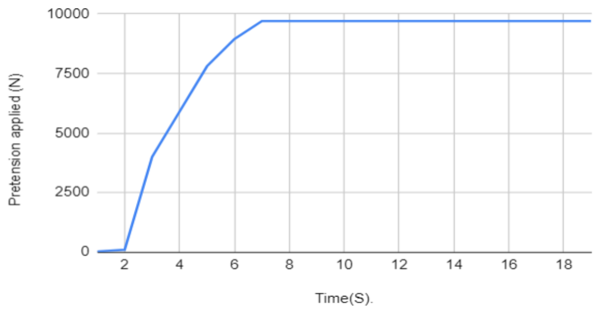


**Figure 4. Applied Pretension**

ii. Operating Loading Condition:

Excitation load was provided dividing into two different cases, first being in axial direction and second being in the vertical direction to check for slip and separation simultaneously. The figure 5 and 6 is only a graphical representation of loads applied.

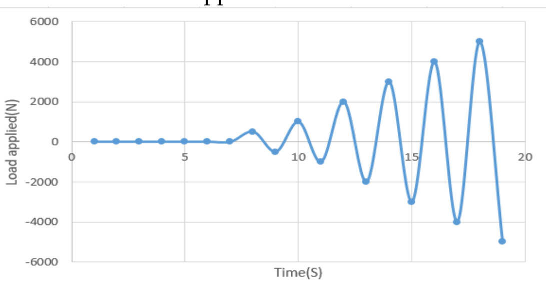


**Figure 5. Load in Axial Direction**

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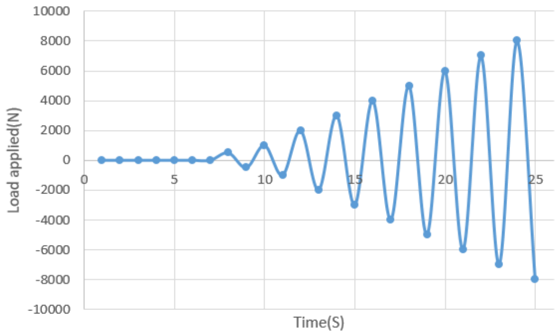


**Figure 6. Load in Vertical Direction**

## IV. ASSEMBLY LEVEL TEST SETUP

The test setup shown in figure 8 represents a standardized procedure employed by industries to assess failures caused in several components. The results obtained from this setup were utilized for comparing against the outcomes obtained from different approaches for component level test setups. This comparison aimed to replicate the failure modes in the component level in a similar manner as in the assembly level. A similar kind of assembly loading condition were applied in terms of pretension to this setup.

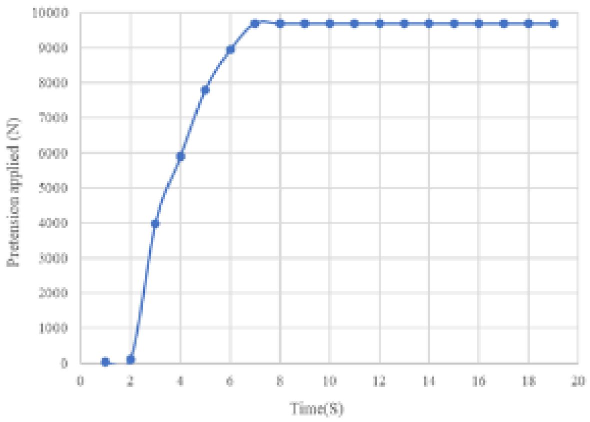


**Figure 7. Applied Pretension**

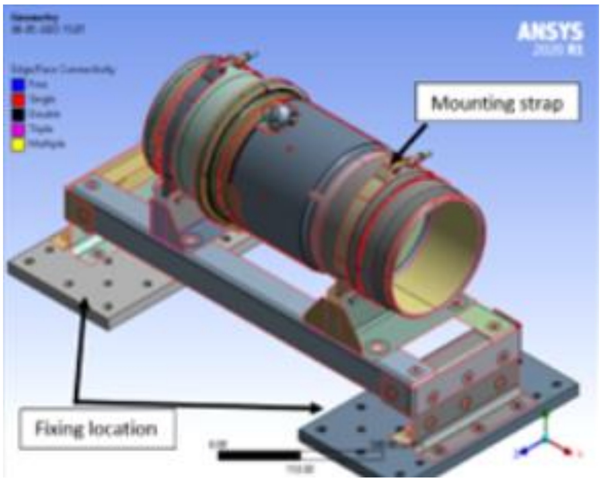


**Figure 8. Assembly Level Setup**

Excitation load was provided in terms of acceleration to maintain a practical perspective and dividing it into two different cases, first being in axial direction and second being in the vertical direction.

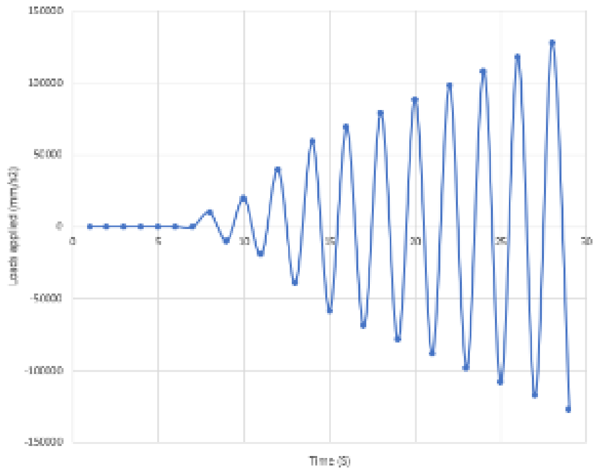


**Figure 9. Load in Axial Direction**

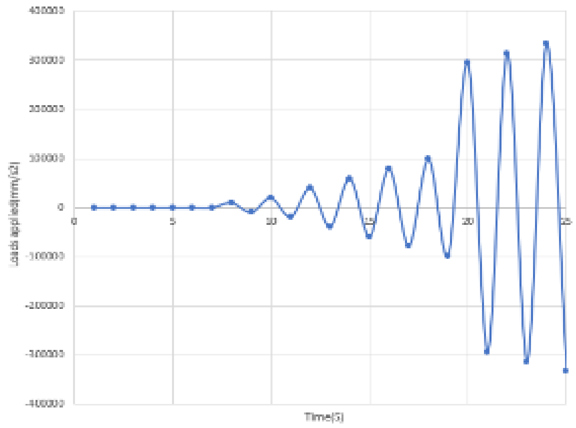


**Figure 10. Load in vertical direction**

## V. RESULTS AND DISCUSSIONS

### A. Slip Margin

It is a dimensionless number which signifies whether the surfaces in contact will be slipping or not. It's the proportion of slipping force to frictional force. The slippage will begin if the ratio falls below 1 at that point. The figure 11 clearly indicates a strong correlation in both the approaches between the slip margin trend and the corresponding calculation results obtained at the assembly level, with both showing an exact match.

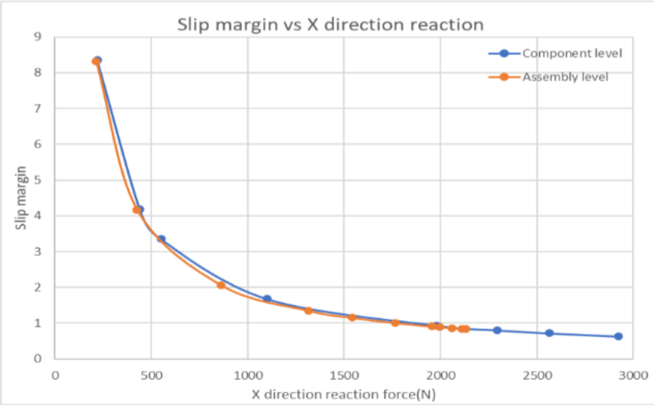


**Figure 11. Slip Margin Variation**



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### B. Sliding Distance

It is sum of the frictional slip and the elastic slip. It is majorly calculated in the axial direction. From previous literature[1] it was concluded that beyond the point of slippage the sliding distance increases at a steeper rate due to loss in contact. When the reaction forces at the contact location reaches approximately to 2000N the slippage of contact was observed through the calculation of slip margin and the same was verified by the graph of sliding distance representing a steeper rise in slope. And it was observed that the trend was caring the alignment of the component level test setup with the assembly level test setup.

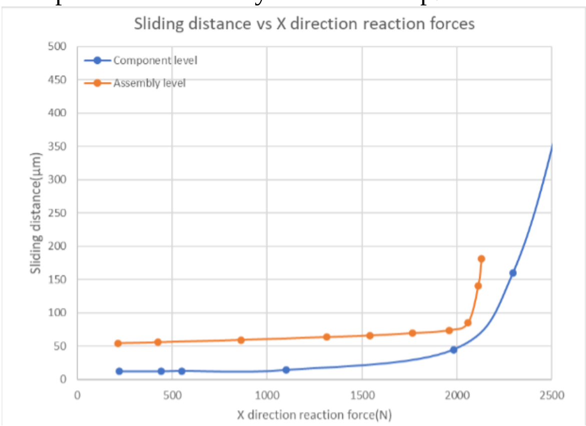


**Figure 12. Sliding Distance Variation**

### C. Stress Amplitude

The stress amplitude is the amount of stress that deviates from the mean. During the initial phase of the joint, the load path followed a sequence from the chassis to the bracket, then through the strap, and finally reaching the EGP. Once slip occurs at the joint, the load path is reversed, and the strap becomes directly subjected to the majority of load. This, in turn, leads to an increase in the stress amplitude experienced by the strap after the point of slippage.

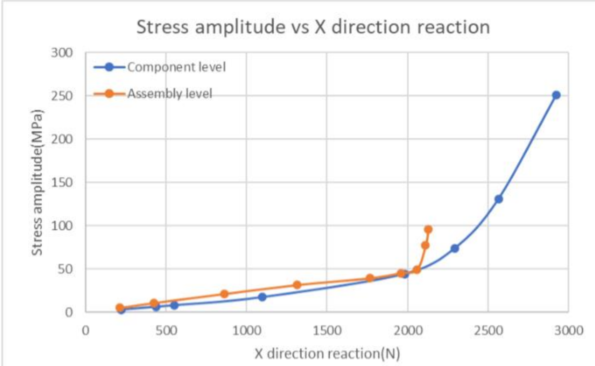


**Figure 13. Stress Amplitude Variation**

### D. Separation Margin

When the test setup was loaded in transverse direction the cylinder was inclined to fail through separation and to investigate this separation margin was calculated. The figure 14 clearly indicates a strong correlation between the separation margin trend and the corresponding calculation results obtained at the assembly level, with both showing an exact match.

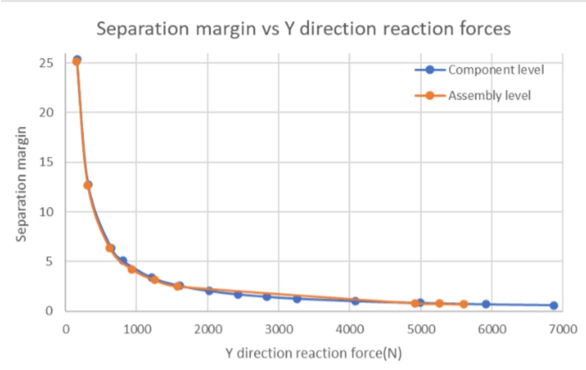


**Figure 14. Separation Margin Variation**

## VI. CONCLUSION

Concluding to this work it was seen that the approach (Fixed at cylinder location and excitation at bracket location) followed all the trends with the assembly level results. So, it was suggested as the component level strap validation method as being able to capture the failures. The recommended test setup will help in saving the cost of testing and prototype failures in later stages and reduce lead time.


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| Ethical Approval and Consent to Participate | No, the article does not require ethical approval and consent to participate with evidence. |
| Availability of Data and Material/ Data Access Statement | Not relevant |
| Anthors Contributions | All authors have equal participation in this article. |

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