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# MODAL AND THERMAL ANALYSIS OF EXHAUST MANIFOLD FOR TURBO DIESEL ENGINE USING FE METHOD

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## ABSTRACT:

Exhaust manifolds are generally simple cast iron or stainless steel units which collect engine exhaust from multiple cylinders and deliver it to the exhaust pipe.

In this project the modal analysis and thermal deformation of stainless steel exhaust manifolds for turbo diesel engine is investigated by finite element analysis (FEA). The software's used are PRO-E 4.0, HYPERMESH-10 and ANSYS-11.The FE model includes the temperature dependent material properties as well as the interactions between exhaust manifold, cylinder head and fasteners. The result of analysis revealed that natural frequencies and remarkable thermal deformation and stresses occurred along the longitudinal direction. The new design of fastener hole, which allows sliding behavior, is expected to reduce thermal stress in turbo diesel engine exhaust manifold.

**Keywords:** Exhaust Manifold, Modal and Thermal analysis, Finite Element Analysis.

## 1. INTRODUCTION

Exhaust manifolds are generally simple cast iron or stainless steel units which collect engine exhaust from multiple cylinders and deliver it to the exhaust pipe. For many engines, after market high performance exhaust headers — also known as extractors — are available [1-4]. These consist of individual exhaust head pipes for each cylinder, which then usually converge into one tube called a collector. Headers that do not have collectors are called zoomie headers, and are used exclusively on race cars [5-6].

The most common types of aftermarket headers are made of either ceramic, or stainless steel. Ceramic headers are lighter in weight than stainless steel; however, under extreme temperatures they can crack.

The goal of performance exhaust headers is mainly to decrease flow resistance (back pressure), and to increase the volumetric efficiency of an engine, resulting in a gain in power output [6-8].

## 2. DESCRIPTION

In this work static, modal and thermal analysis of the stainless steel exhaust manifold was carried out

Length of the axle housing = 275 mm
Maximum load capacity = 2 $N/mm^2$
Maximum thermal load = $690^o c$

**Material properties of stainless steel**

Young's modulus = $2.1 \times 10^5$ MPa
Poisson's Ratio = 0.28
Density = $7.8 \times 10^{-6}$ $Kg/mm^3$

## 3. MODELLING AND MESHING

The chosen problem is considered as 3-D solid model. With the dimensional parameters the structure is modeled in Pro-E wildfire3.0 modeling software as shown in Fig.1. The model is meshed for further analysis using a meshing package hyper mesh 10 with tetra mesh.
The model consists of 17904 elements. Fig. 2 shows the solid 92 element considered for meshing. FE model of the exhaust manifold is shown in Fig 3. Appropriate boundary conditions are incorporated in the analysis. The solid 92 is defined by ten nodes having three degrees of freedom (UX, UY and UZ) at each node translations in the nodal x, y and z directions. The element has Plasticity, Creep, Swelling, Elasticity, Stress stiffening, Large deflection, Large strain, Adaptive descent, Initial stress import capabilities.

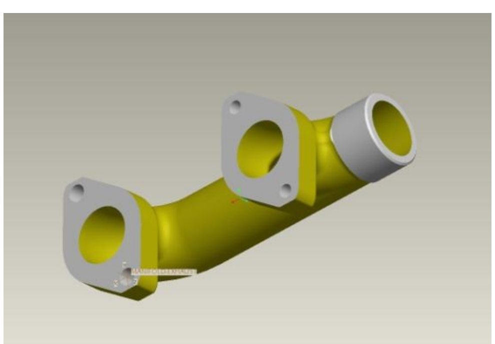

**Fig 1: Solid model of Exhaust Manifold**

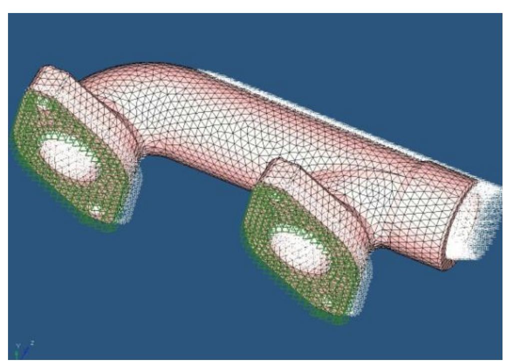

**Fig 2: Finite Element model of Exhaust Manifold**

**Table 1: Mesh is created in Hyper mesh with following quality parameters**

| | |
|---|---|
| Aspect Ratio | 8 |
| Tet collapse | 0.5 |
| Length | 5 |
| Min. angle of trias | 25 |
| Max. angle of trias | 135 |

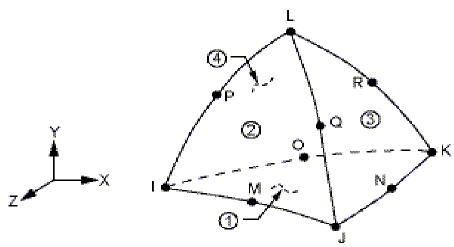


**Fig 3: Solid 92 Element**

## 4. EXHAUST MANIFOLD

### Static Analysis

Static analysis was carried out to know the strength of the exhaust manifold by applying the internal pressure.

### Modal Analysis

Modal analysis was carried out to calculate the natural frequencies and mode shapes of a structure.

### Thermal Analysis

Thermal analysis was carried out to know the thermal stresses of the exhaust manifold by applying uniform temperature.

## 5. RESULTS & DISCUSSION

### 5.1 Static Analysis:

Static Analysis of exhaust manifold made up with stainless steel is performed. Displacements in X, Y and Z directions are shown in Fig.4, Fig.5 and Fig.6 respectively.Fig.7 shows stress in X direction. Stress in Y direction is shown in Fig 8. Fig.9 shows stress in Z direction. The Vonmises stress of the exhaust manifold shown in Fig.10

**Table 2: Static Analysis of Exhaust Manifold**

| Name | Results as per Analysis | Allowable stress as per ASME (MPa) | Reference figure |
|---|---|---|---|
| Displacement in X-direction, mm | 0.00140 | 7 | 4 |
| Displacement in Y-direction, mm | 0.00325 | 7 | 5 |
| Displacement in Z-direction, mm | 0.00486 | 7 | 6 |
| Stress in X-direction, MPa | 10.226 | 590 | 7 |
| Stress in Y-direction, MPa | 15.938 | 590 | 8 |
| Stress in Z-direction, MPa | 14.678 | 590 | 9 |
| Vonmises stress, MPa | 15.876 | 590 | 10 |

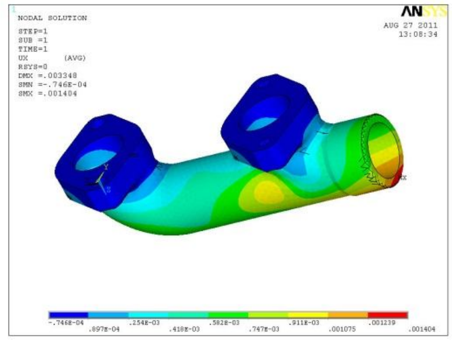


**Fig. 4: Displacement in X- direction**

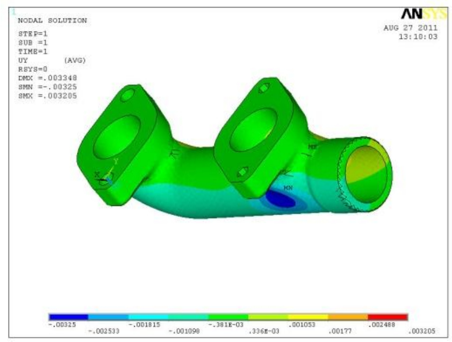


**Fig. 5: Displacement in Y- direction**

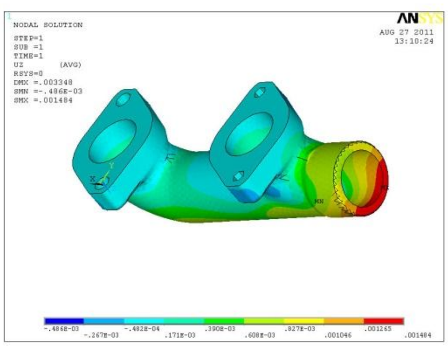


**Fig. 6: Displacement in Z- direction**

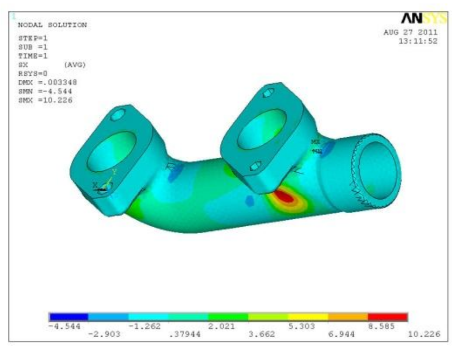


**Fig. 7: Stress in X direction**

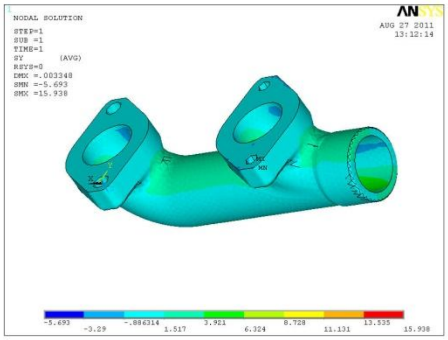

**Fig. 8: Stress in Y direction**

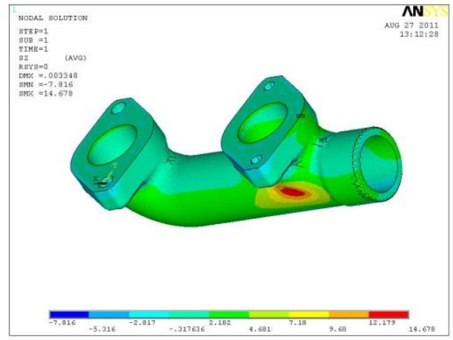

**Fig.9: Stress in Z direction**

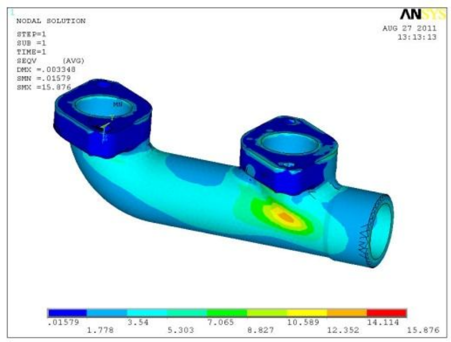

**Fig.10: Vonmises Stress**

### 5.2 Modal Analysis:

Model Analysis of exhaust manifold made up with stainless steel is performed. Fig.11 shows Mode Shape 1 of the exhaust manifold housing. Mode Shape 2 of manifold is shown in Fig.12.Mode Shape 3 of manifold is shown in Fig.13 and mode shape 4 & 5 is shown in Fig.14 & Fig.15.

**Table 3: Modal Analysis of cast Iron**

| Name: Modal Analysis | Frequency (Hz) |
|---|---|
| Mode shape 1 | 138.245 |
| Mode shape 2 | 238.365 |
| Mode shape 3 | 242.025 |
| Mode shape 4 | 320.842 |
| Mode shape 5 | 363.962 |

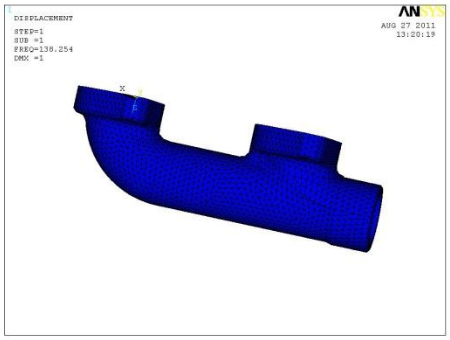


**Fig. 11: Mode shape 1**

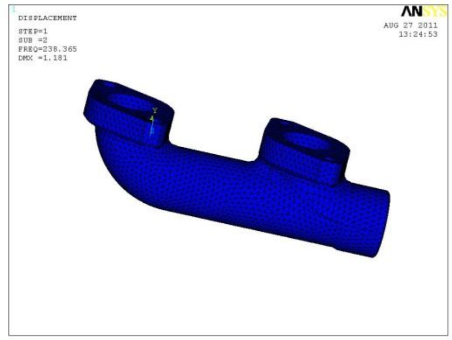


**Fig. 12: Mode shape 2**

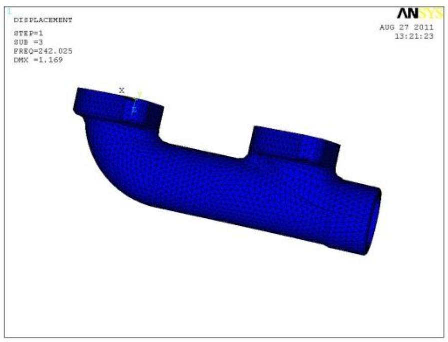


**Fig. 13: Mode shape 3**

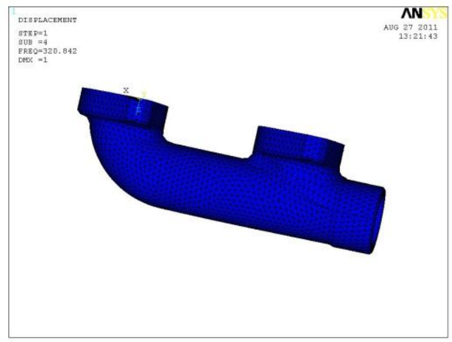


**Fig. 14: Mode shape 4**

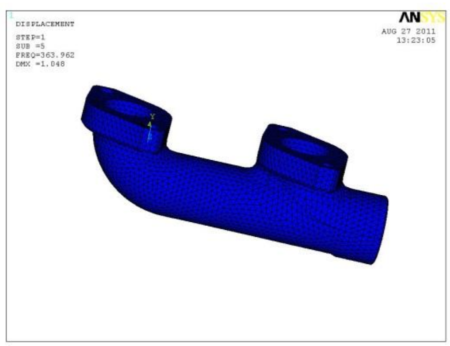


**Fig. 15: Mode shape 5**

## 5.3Thermal Analysis

Thermal analysis of exhaust manifold made up with stainless steel is performed. Displacements in X, Y and Z directions are shown in Fig.16, Fig.17 and Fig.18 respectively.Fig.19 shows stress in X direction. Stress in Y direction is shown in Fig. 20. Fig. 21 shows stress in Z direction. The Vonmises stress of the exhaust manifold shown in Fig. 22

**Table 4: Thermal Analysis of Exhaust Manifold**

| Name | Results as per Analysis | Allowable stress as per ASME (MPa) | Reference figure |
|---|---|---|---|
| Displacement in X-direction, mm | 0.02796 | 7 | 16 |
| Displacement in Y-direction, mm | 0.00689 | 7 | 17 |
| Displacement in Z-direction, mm | 0.0235 | 7 | 18 |
| Stress in X-direction, MPa | 128.01 | 590 | 19 |
| Stress in Y-direction, MPa | 158.366 | 590 | 20 |
| Stress in Z-direction, MPa | 222.316 | 590 | 21 |
| Vonmises stress, MPa | 314.786 | 590 | 22 |

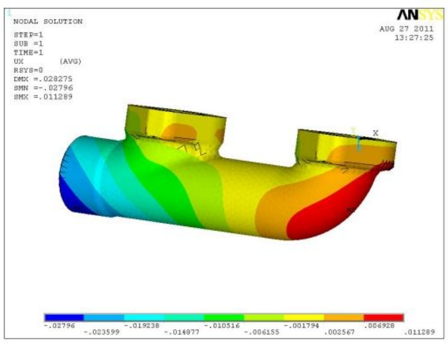

**Fig. 16: Displacement in X- direction**

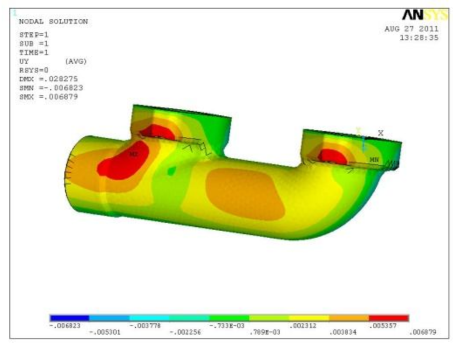

**Fig. 17: Displacement in Y- direction**

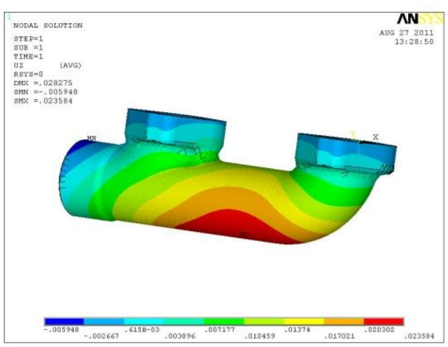

**Fig. 18: Displacement in Z- direction**

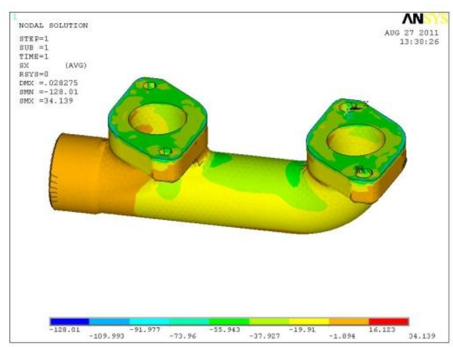

**Fig. 19: Stress in X direction**

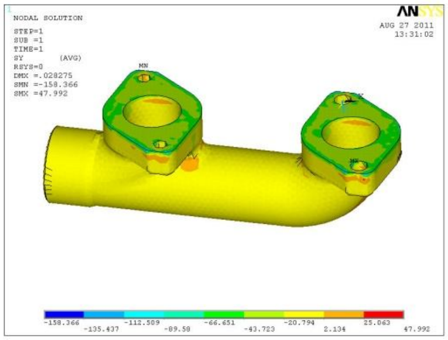


**Fig. 20: Stress in Y direction**

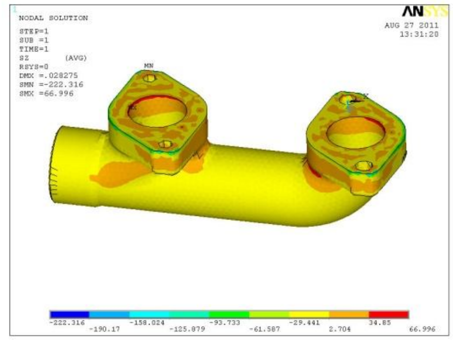


**Fig. 21: Stress in Z direction**

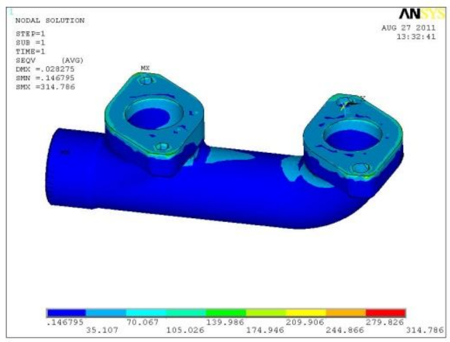


**Fig. 22: Vonmises stress**

## 6. CONCLUSION:

The following conclusions are drawn from the present work.

1. The maximum deflection induced 0.00486 mm under 2 MPa loads which is within the allowable limits i.e. < 7mm.
2. The maximum stress induced is 15.938 MPa which is less than allowable limits of 590 MPa.

3. The maximum deflection induced 0.02796 mm under uniform temperature of $690^0$C load which is within the allowable limits i.e. < 7mm.
4. The maximum stress induced is 314.786 MPa which is less than allowable limits of 590 MPa. Hence the factor of safety is 1.45.
5. The natural frequency obtained for Stainless steel is 138.245Hz.

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