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Evaluation of Structural Integrity of Passenger Car Exhaust System

Dr.Maruthi.B.H[1], Rudresh.M[2] Vikram.B.V.[3]
1HOD,2Asst.Prof,3M.Tech student.
Dept. of Mechanical Engineering, East West Institute of Technology, Bangalore

Abstract-This project aims to evaluate the structural integrity of passenger car exhaust system components by Computer Aided Engineering (CAE) Simulation.The results obtained assure the structural integrity of the exhaust system and also contribute to a better understanding of this system. Finite element modeling is carried out for Hyundai i10 passenger car exhaust system using Altair's pre-processing tool Hypermesh. Static analysis is performed by using Msc Nastran for exhaust components to determine the high stress region, and also the maximum displacement and reaction forces are observed at the bracket and hanger locations. The results are viewed through Altair's post-processing tool HyperView. Modal analysis is carried out to determine the structural behavior of the exhaust system. Displacements are found at accelerometer placing locations under dynamic loading by carrying Modal frequency response analysis.

Index Terms- Catalytic converter, Exhaust manifold,Muffler,Exhaustflange,Vibration isolater,coupling.

1. INTRODUCTION

Every increasing demand for durability, lighter and cost effective designs of automotive products have lead to more frequent usage of powerful Numerical techniques for solving structural problems. In the automotive industry, the detection of structural failures has traditionally relied on proving ground road load tests. It is generally recognized that developing designs through testing and retesting using several prototypes is not helping in accelerating the product development. Hence designing the exhaust system for structural analysis is extremely important. The automotive exhaust system Physical tests offer durability evaluation of all the exhaust system components. There are several different tests for validating the exhaust component designs under different loading conditions. For example, oscillating load test is used to test all welds under bending loads, the road load rig test is used to test the entire exhaust system and components under road and thermal loads, and engine dynamometer test is carried out under exhaust and thermal loads. Exhaust systems present a special case because of their geometry and the constraints placed on their design by the underbody of the car. Exhaust systems are submitted to many dynamic input loads, the most important one coming from the engine. The induced vibrations are spread along the exhaust system, and forces are transmitted to the car body through the attached points.

Overview of an exhaust system

Exhaust system plays an important role in the performance of the vehicle. It carries out all the burnt gasses from engine to atmosphere. As a traditional procedure, track tests are made to assure the proper structural design of vehicles and life determination. There is a worldwide trend to use more computer simulation structural behavior and decreases the time to market and coasts. A complicated real world environment seen by an exhaust system in the vehicle can be simplified and modeled using numerical simulation. By using engineering experience and time-tested assumptions, valuable information can be acquire d in relatively cost and time-effective way, thanks to the computation power boosted in recent years.

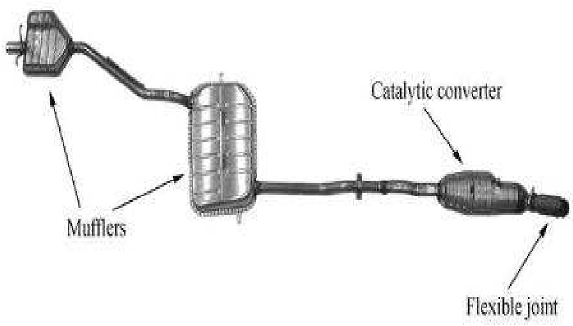


Fig 1.1: Typical exhaust system design.

2. Experimental Analysis

The modal tests were performed for the given exhaust system. In the test, initially exhaust system was suspended with free-free boundary conditions. During the second modal test, the exhaust system was installed on a dynamic test bench in a similar way as it would be in operational conditions. The acquisition of experimental data was carried out using shaker excitation. Tri-axial accelerometers were used to measure the response in every point.

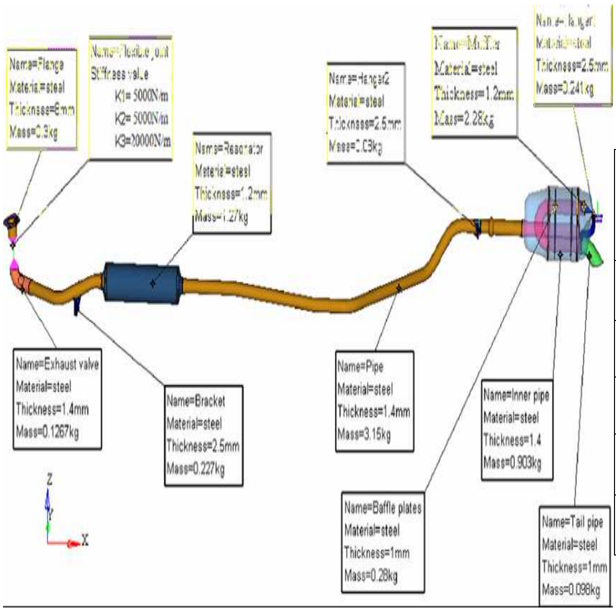
To sufficiently realize the free boundary conditions in Experimental modal analysis [EMA] the Exhaust system is suspended at the hanger attachments and at the connection flange.

From the initial FE analysis it is known that motion is in the z-direction perpendicular to the x-y plane of the system .The excitation developed from the engines are generated in the test bench. The shaker is connected to exhaust through stringer and force transducer. Triaxiality accelerometers are used to measure the gravity load or acceleration. Accelerometers are attached on each hanger location and different location of the Exhaust system.

Table 2.1 Experimental data

S No	Modesshapes	Experimental frequency(Hz)
1	1 s Mode	12.2
2	2nd Mode	13.8
3	3rd Mode	16.4
4	4th Mode	19.28
5	5th Mode	21.3
6	6th Mode	26.61
7	7th Mode	34
8	8th Mode	44.4
9	9th Mode	54.18
10	10th mode	71

3.Geometrical overview:



3.1Geometrical configuration and material property of the Exhaust system

3.1.1 2D drafted CAD model

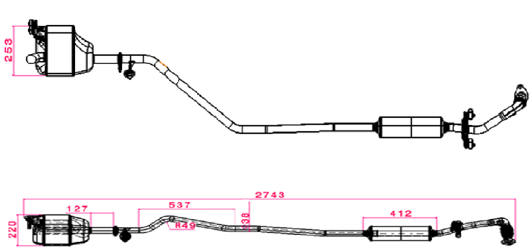


Fig 3.1: Schematic front and bottom view of 2D drafted model

3.1.2 3D catiaV-5 model

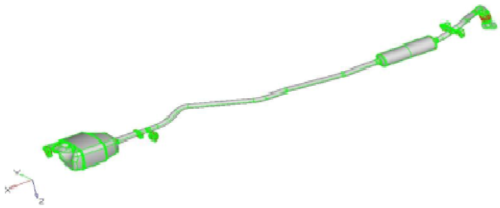


Fig 3.2: Representation of exhaust system in 3D view

3.2 Material property:

Stainless steel started to be used as material for decoration in automobile. However, in recent years, it is mostly used as material for the exhaust system. It is because those stainless steels with good performance of high temperature characteristics and high corrosion resistance meet the social needs for clean exhaust gases and reduced weight for better fuel economy. Material used for structural analysis of Exhaust system is Stainless Steel (SUS 304B).The isotropic material properties used in a FEA analysis are as follows.

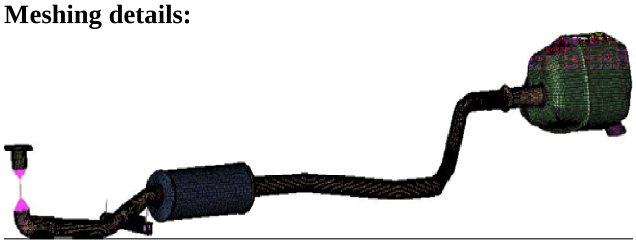
Table3.1: Mechanical properties of steel material used in Exhaust system

Sl.No	Mechanical property of Stainless Steel	Value
1	Young's Modulus(E)	$2.08x10^5$ N/mm^2
2	Poisson's Ratio(v)	0.31
3	Density(p)	$7.85x10^9 Ton/m^3$
4	Yield Stress(ay)	350 N/mm^2
5	Ultimate Strength(au)	450 N/mm^2

4. Finite Element Method

Import the IGS file to hypermesh and clean up the geometry.Types of elements created is listed below.

Meshing details:



SI no..	Type of element	No of element
1	Quad4	67490
2	Tria3	129
3	Penta5	1296
4	Hexa8	479
	Total	69394

5.Boundary conditions

1.Boundary Condition at the flange region

Bolt holes of Flange connecting to Exhaust manifold is constrained in all dof(Ux, Uy, Uz, Rx, Ry, Rz = 0) with rigid element RBE2.

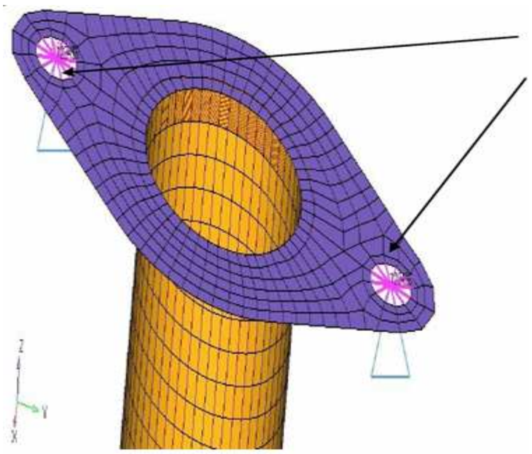
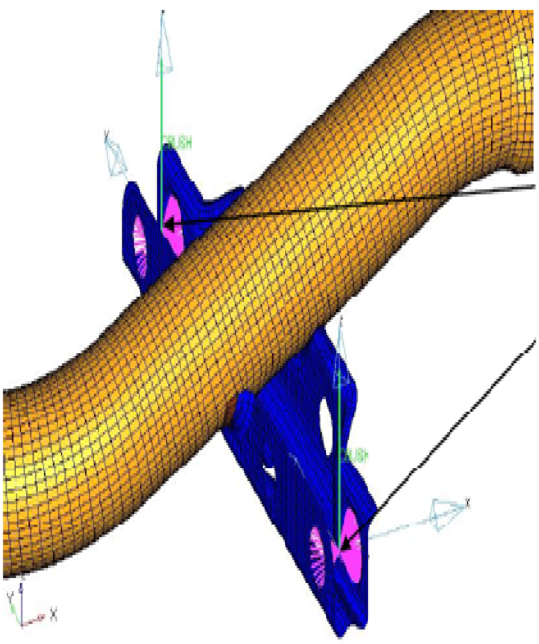


Fig 5.1: Boundary Condition at the flange region

Boundary Condition at the Bracket region.

A bolt hole of Bracket region is constrained in all 6 dof with rigid element RBE2.The PBUSH element is used to mount the exhaust

2. Boundary Condition at the center of the exhaust pipe on hanger region.



3.Boundary Condition at the rear muffler region.

The PBUSH element is fixed to the rigid RBE2

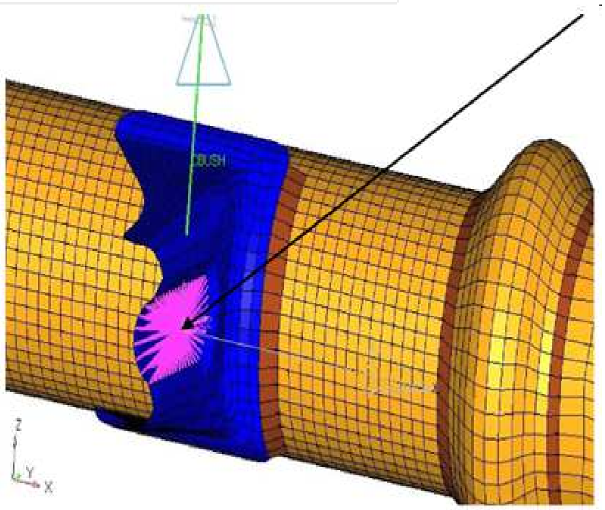
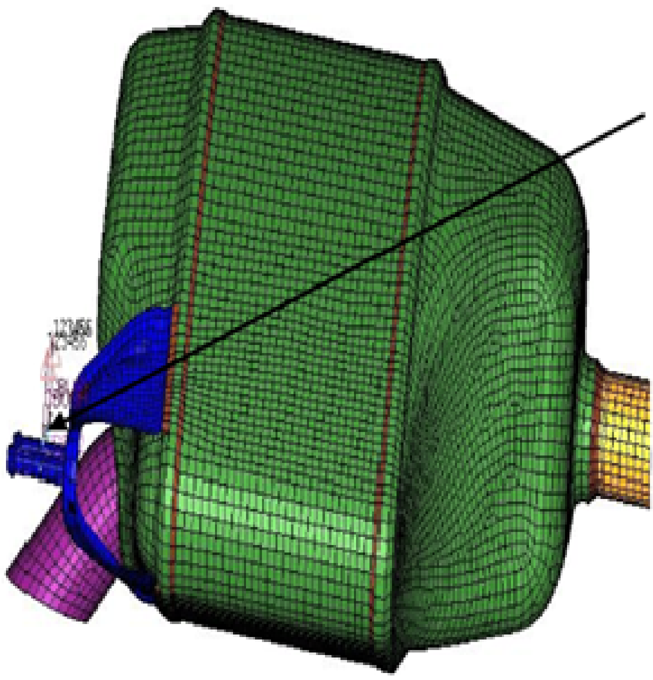


Fig 8.3: Boundary Condition at the center of the exhaust pipe on hanger region.

4. Boundary Condition at the rear muffler region.

The 2 PBUSH elements at the 2 bolted region of 40 mm length are constrained in all 6 DOF.

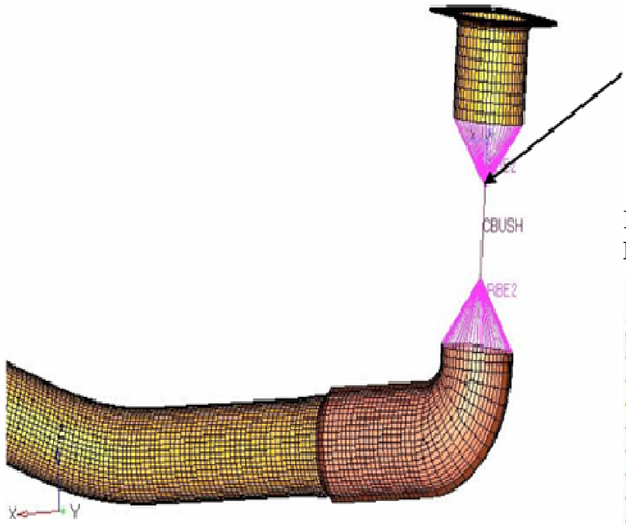


5. PBUSH element is used in region of Flexible Joint.

The stiffness of bush element is

K1=15N/mm

K2=15N/mm K3=30N/mm



6. RESULTAND DISCUSSION OF MODAL ANALYSIS

Mode shapes of exhaust system

Mode 1

Fig 6.1: 1st mode shape Natural frequency 13.35 Hz

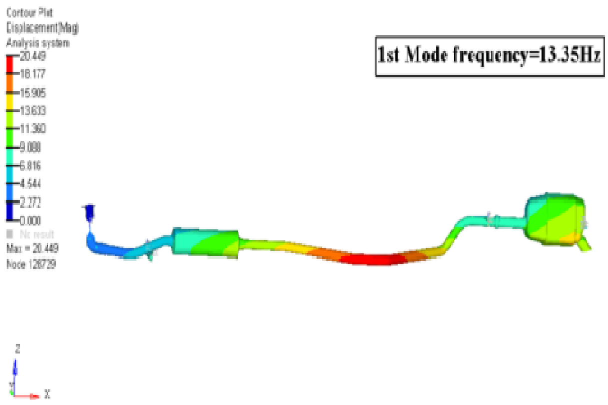


Fig 6.1: 1st mode shape Natural frequency 13.35Hz

Mode 2

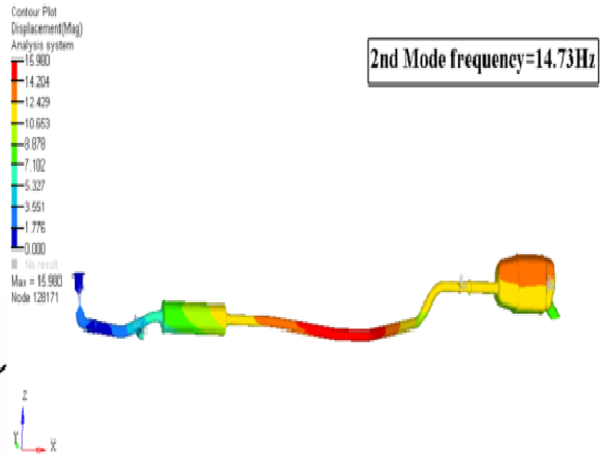


Fig 6.2: 2ndmode shape Natural frequency 14.73 Hz

Mode Mode 3

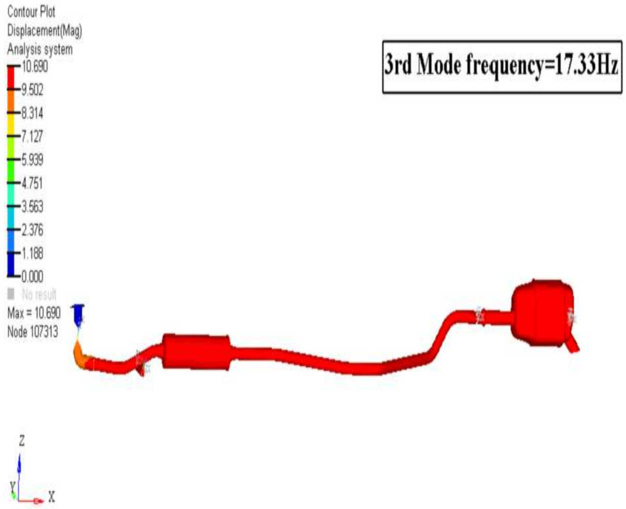


Fig 6.3: 3rd mode shape Natural frequency 17.33 Hz

Mode 4

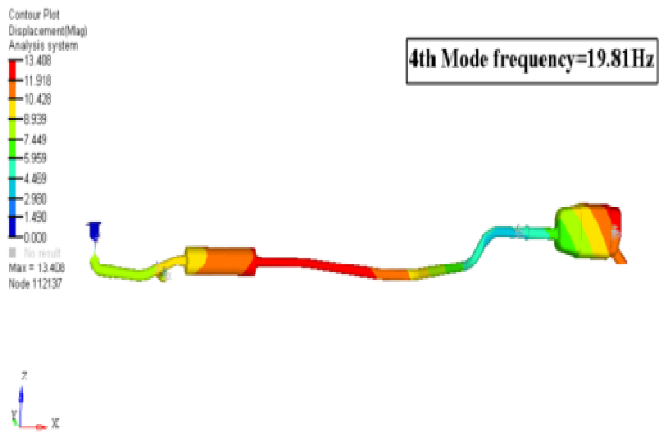


Fig 6.4: 4th mode shape Natural frequency 19.81 Hz

Mode 5

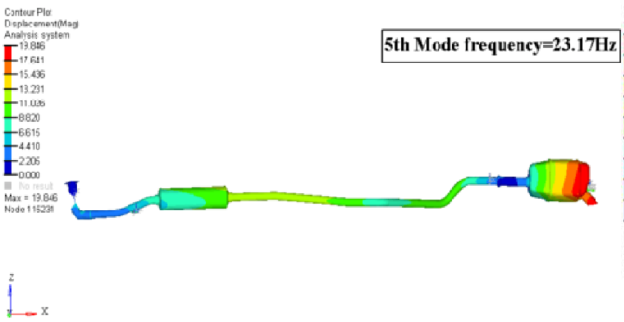


Fig 6.5: 5th mode shape Naturalfrequency23.17 Hz

Mode 6

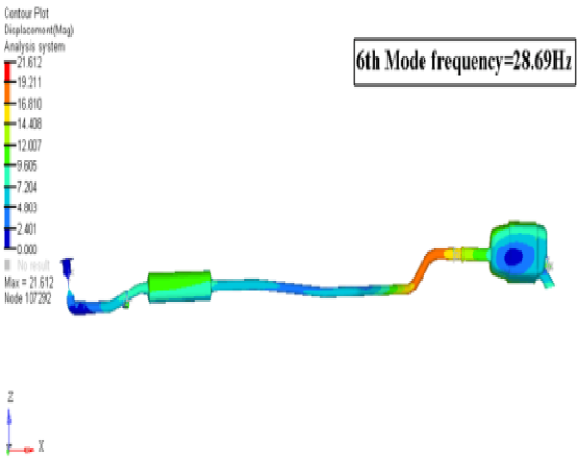


Fig6.6: 6th mode shape Naturalfrequency 28.69 Hz

Mode 7

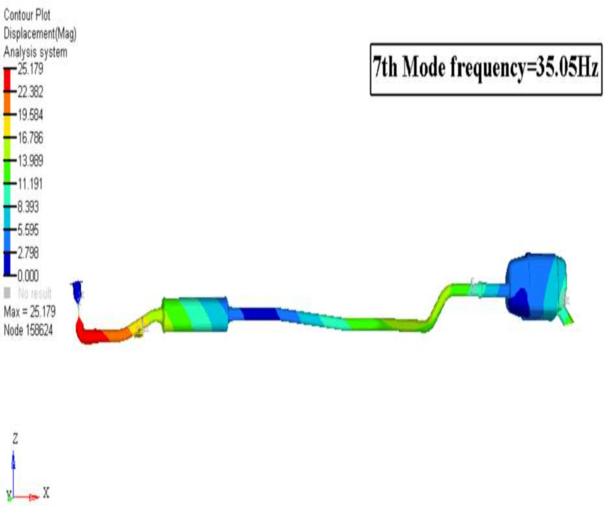


Fig6.7: 7th mode shape Natural frequency 35.05 Hz

Mode 8

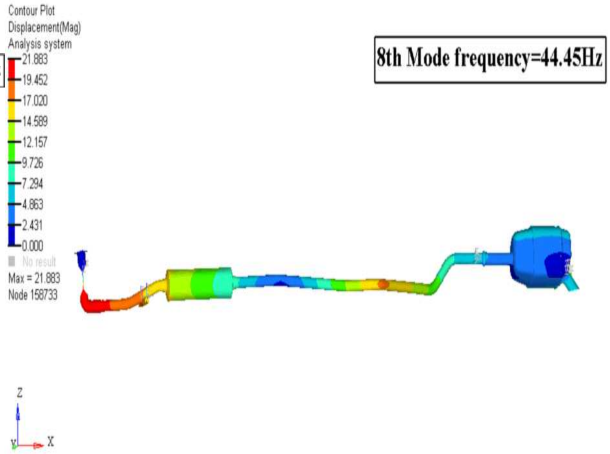


Fig 6.8: 8th mode shape Natural frequency44.45 Hz

Mode 9

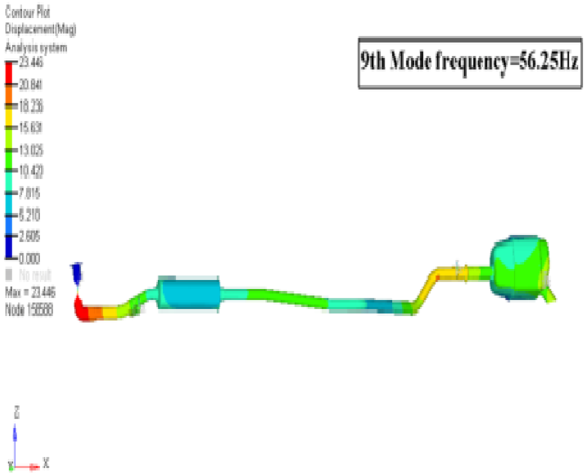


Fig 6.9: 9th mode shape Natural frequency 56.25 Hz

Mode 10

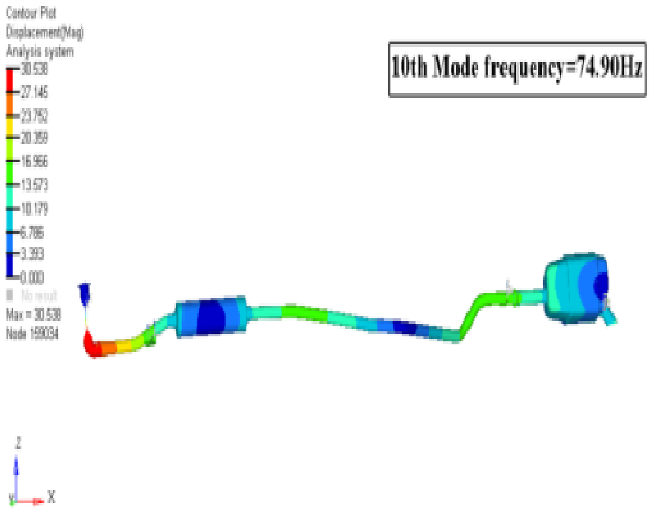


Fig 6.10: 10th mode shape Naturalfrequency 74.90 Hz

7. CONCLUSION

The present work illustrates meshed model of exhaust system satisfied all quality criteria‟s hence the results are accurate. Typical road conditions are considered for loading. Static 1g load is preferred for smooth road, whereas road load for rough road which included with pot holes, bumps etc., Loads and boundary conditions are accurately simulated to obtain the realistic loading conditions.

From the normal mode analysis we are obtaining the natural frequency and mode shapes. The obtained natural frequencies are correlated with the experimental results. By the percentage error in the comparison is well below the 10%, hence the results obtained is acceptable. Mounting of bracket and hanger locations are determined based on mode shapes obtained by normal mode analalysis.

From the structural design point of view the structure is considered safe as the stress levels are well below the ultimate stress. It was verified that numerical models validated with experimental data are a powerful tool during the development phases of vehicle, reducing project time and costs.

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