DESIGN AND VIBRATIONAL CHARACTERISTIC ANALYSIS OF EXHAUST MANIFOLD WITH EXPERIMENTAL VALIDATION USING FFT ANALYZER

Shubham Mittal [1], Dr.Kiran C.More[2],
[1] *P.G.Student,Mechanical Engg.Department, D.Y.Patil Institute of Engg.&Technology,Pune,MH,India*
[2] *Associate Professor,HOD,Mechanical Engg.Department, D.Y.Patil Institute of Engg.&Technology,Pune,MH,India*

ABSTRACT

The vibrations observed in internal combustion engines transfer to the Tail pipe via exhaust manifold. Such Vibrations cause failure of exhaust system. Two types of vibration can affect the exhaust manifold: the sonic pressure waves coming from the exhaust ports, and the vibration of the engine itself. Pressure wave vibrations are usually transparent, travelling through the exhaust system to either absorb into or cancel out in the muffler. These waves are harmonic, like the vibration of a speaker, but they are usually too minute to cause noise through component movement. Engine vibrations, on the other hand, can easily shake your complete exhaust system. Such cyclic loading of waves can cause component rattling or failure.
This vibration failure occurs due to resonant frequencies occurring in defined frequency range. The 'frequency match' could lead to a response detrimental to the life of the structure.FEA techniques are proposed in this work to avoid resonance. Physical experimentation is proposed using FFT Analyzer. This work deals with the damping of such later mentioned vibration problems with a concept of CAE (Computer Aided Engineering). In this project we are analyzing the exhaust system under various conditions for modal (natural vibrations). Static and modal analysis of exhaust manifold has been performed using ANSYS 19 software along with experimental validation of manifold using FFT and impact hammer test. Different types of methods for reducing vibration of manifold are studied. After studying these methods and procedures for reducing a vibration, we conclude that, exhaust manifold concept 02 is more efficient by changing the geometry or adding proper stiffener for reducing vertical vibration which further increases the frequency response of component.

Keyword : - *Internal combustion engines, exhaust system, Pressure wave vibrations, rattling, FFT Analyzer and CAE ,ANSYS 19 software ,impact hammer test etc….*

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1. INTRODUCTION

Vibrations in automobile are the major causes for failure of most of the automobile components. These vibrations have to be minimized to their extent so that, each component can perform to their maximum extent. Such vibration in an automobile system occurs during idle and running conditions. Most running condition vibrations are because of the ups and downs on the roads and because of the reason that the engine is running below its rated speed. Whereas the idle running vibrations are considered, the cause for the vibrations is observed as the frequency that is produced by the engine and its parts. The out coming frequency is transferred through the drive line axis and damped to the road, but not all the frequency is damped. Some are observed by the sub-assemblies of the chassis/frame through linkages. When considered in case of exhaust system, two types of vibration can affect the exhaust.

The sonic pressure waves coming from the exhaust ports, and the vibration of the engine itself because of torqueing. Pressure wave vibrations are usually transparent, travelling through the exhaust system to either absorb into or cancel out in the muffler. These waves are harmonic, like the vibration of a speaker, but they are usually too minute to cause noise through component movement. Engine vibrations, on the other hand, can easily shake the exhaust pipes enough to cause component rattling or impact which leads to the improper functioning of the exhaust components. These vibrations are to be controlled to ensure the proper working of interior parts of the system.

The most common types of aftermarket headers are made of mild steel or stainless-steel tubing for the primary tubes along with flat flanges and possibly a larger diameter collector made of a similar material as the primaries. They may be coated with a ceramic-type finish (sometimes both inside and outside), or painted with a heat-resistant finish, or bare. Chrome plated headers are available, but these tend to blue after use. Polished stainless steel will also color (usually a yellow tint), but less than chrome in most cases.

Another form of modification used is to insulate a standard or aftermarket manifold. This decreases the amount of heat given off into the engine bay, therefore reducing the intake manifold temperature. There are a few types of thermal insulation but three are particularly common: Ceramic paint is sprayed or brushed onto the manifold and then cured in an oven. These are usually thin, so have little insulator properties; however, they reduce engine bay heating by lessening the heat output via radiation.

A ceramic mixture is bonded to the manifold via thermal spraying to give a tough ceramic coating with very good thermal insulation. This is often used on performance production cars and track-only racers.

Exhaust wrap is wrapped completely around the manifold. Although this is cheap and simple, it can lead to premature degradation of the manifold. 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. The processes occurring can be explained by the gas laws, specifically the ideal gas law and the combined gas law.

The exhaust manifold is mounted on the cylinder head of the engine. It is connected to the
catalyst converter at the other end. The exhaust gases emitted from the cylinder come out at temperatures of nearly 8000 C and with pressures ranging from 100 to 500 kPa.The exhaust manifold is subjected to high temperatures and pressures which will lead to thermo mechanical failure. A back pressure is created due to not completely vacating the exhaust system before the gases from the other cylinder is released. These Pressure waves from gas restrict the engine's true performance possibilities. As the exhaust gases are very hot, the pipe must be heat-resistant. The pipe should be able to send away the toxic gases away from the user.

To achieve reliable models both theoretical and experimental modal analysis should be performed so that finite element and test model can be compared and successfully improved. Free-free boundary condition is recommended for this model. At an early stage of product development process, the boundary conditions that exhaust system will have under operation are not always known. By using free-free boundary condition it is still possible to develop FE models of exhaust system or part of it, which corresponds well with measurements. It is found out that approximately 70 %pressure drop can be reduced if length of exhaust pipe at starting reduced by 50 mm and restriction to the flow in chamber is removed. It can be seen that first 3 iterations show slight increase in the pressure drop across the exhaust system which will result in to increased work for the two-wheeler engine to overcome the resistance by exhaust system.In iteration 4 design pressure drop across the exhaust system drop down by 12.3 KPa and it is observed to be 5 KPa which reduces the required work by the engine to force exhaust gases out of the system drastically in particular, attention has been focused on a production multivalve spark-ignition engine during the intake phase. To this purpose, a numerical and an experimental investigation were carried out to evaluate the influence of novel intake valves opening strategies on the system permeability and on the in-cylinder flow field, highlighting their effectiveness and their advantages with respect to the standard (symmetric) valves opening configurations. As concerns the numerical analysis, a n immersed boundary approach for a cell-centered finite volume solver was adopted to simulate efficiently the flow field using Cartesian grids. For the 20 experimental investigation, the fluid dynamic efficiency of the intake system was analyzed at a steady flow rig in terms of flow coefficients.

The present study is focused on the comparison between the estimated lives obtained through the von Mises, the ASME code, the Sonsino-Grubisic, the Kandil-Brown-Miller, and the Fatemi-Socie multiaxial damage assessment criteria. These predictions have been also compared with the experimental life available in literature of an actual commercial exhaust manifold, very similar to the simulacrum analyzed in this work in terms of geometrical features and loading conditions. A numerical code developed by the authors, named FAST-Life and implementing the analytical expressions constituting the proposed criteria, has been used to perform life predictions. The aim of the code is to process the stress-strain data computed by simulations according to the different damage models used, giving as output the number of cycles corresponding to each area analyzed, after the required constitutive material parameters have been specified.

Exhaust manifold selection is a tricky thing where we need to have narrow pipes as possible with least back pressure. If wider pipes are selected, no doubt that there will be low backpressure, but will be losing power because there will be no good exhaust flow. So, recommendation is that, if engine power band lies somewhere around 2000-3000rpm, narrow pipes are good, whereas if it lies somewhere around 6000rpm, wider pipes lead to better performance.
In another study, two different manifold designs which were commonly used in automotive industry were numerically analyzed in terms of flowing material and manifold types. In the numerical analyses, pressure, velocity, and temperature changes were explored and compared through the manifold at different points. Following conclusions can be drawn from this study, Lower pressure and velocity were obtained at gasoline fluid compared to the other two fuels due to characteristics of gasoline fuel. For type A of manifold, While the velocity increases towards the exhaust outlet, the pressure decreases to atmospheric pressure, Pressure and velocity values of type A exhaust were higher than those of type B, For all fuels, high pressure values of type A were obtained, and this improves the performance and efficiency of the engine. The following conclusions can be drawn from the study: The four failures investigated resulted from one or more of the following: local stress raisers, operations outside design temperatures and/or reduced creep strength because of poor fabrication. Creep life calculations with an end life utilization lower than 1.0 (as per EN code), or design calculations based on a maximum allowable primary stress (as per ASME code), is not a guarantee for low risk of creep failure during the boiler service life. All four investigated cases failed prematurely (for different reasons) even though the design life could be considered "safe". This leads to the conclusion that life calculations based on hoop stress and design temperature alone is not necessarily conservative. Using Weld Strength Reduction Factors (in combination with hoop stress) when designing a safe component creep life is not a guarantee for low risk of creep failure during the boiler service life.

1.1.Research Gap

All the reviewed papers showed need of the Muffler in the automotive Sector, its working, performance characteristics, Types depends on the applications. Many more papers consist of design iterations for the better performance. Some papers are having FEA iterations for finding out the best model from number of models. Experimental work on FFT is also discussed in some paper. Some analytical methods are also referred. Some methods become old and critical for the calculation still that methods are used due to the better result orientation.
After studying all research papers, it is observed that the diesel engine mufflers and two-wheeler mufflers are studied for vibration analysis. Also, the emission tests for different vibrating conditions are carried out but study on vibration analysis is less for industrial mufflers. So, Vibration analysis is considered for the study of industrial mufflers.

2. PROBLEM STATEMENT

The exhaust system is the crucial part of the engine, due to flaws in exhaust piping the life of the muffler itself get affected and it also causes back pressure on the side of exhaust valve which crates improper scavenging. Also due to road vibrations and engine vibration the exhaust manifold gets hampered, so these vibrations must be analyzed for damping these vibrations.

3. OBJECTIVES

- Modeling of exhaust manifold in CATIA V5R20 software.
- Analyzing for mode shapes and frequency response of actual exhaust manifold in ANSYS workbench software.
- Experimental analysis of exhaust manifold using FFT technique.
- Validation of experimental testing and FEA results.
- To check the behavior of the exhaust manifold for engine vibrations.

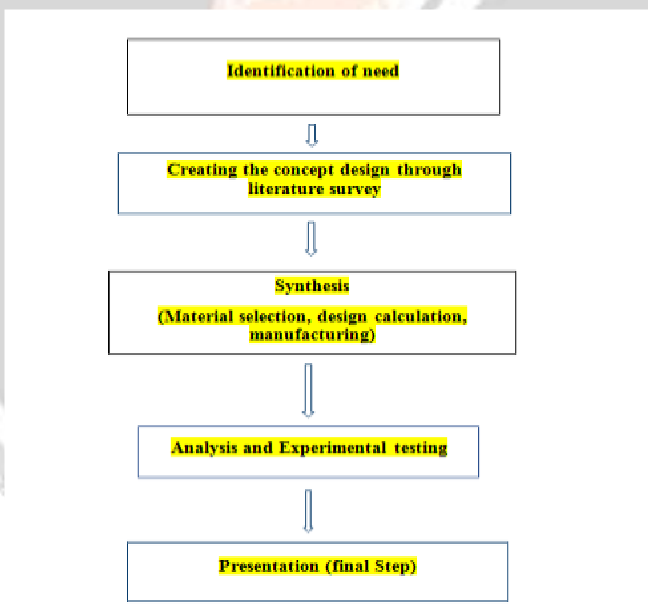
4. SCOPE

In this study we are going to perform FFT analysis on the exhaust manifold by Impact hammer test, to study the behavior of the exhaust manifold on externally applied force. This study also includes FEA modal analysis of the custom exhaust manifold to study the behavior of the exhaust manifold on random vibration and find the natural frequency of the custom manifold.

5. METHODOLOGY

- In this semester we started the work of this project with literature survey. Gathered many research papers which are relevant to this topic. After going through these papers, we learnt about the vibrations causing the failure of Exhaust manifold.
- After gathered research paper we describe literature gap on and identify need of project. Then started work on concept design with the help of literature survey market survey.
- After finalizing concept 3D model of project, we started work on material selection design calculation and discuss about component selection. After deciding the components, the 3D Model and drafting will be done with the help of CATIA software.
- FEA modal simulations of exhaust manifold will be done with the help of ANSYS.

Flow-Chart for Methodology:



6. 3D Model Design Concept

6.1 CAD Methodology

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term CADD (for *Computer Aided Design and Drafting*) is also used. Its use in designing electronic systems is known as electronic design automation (EDA). In mechanical design it is known as mechanical design automation (MDA) or computer-aided drafting (CAD), which includes the process of creating a technical drawing with the use of computer software.

CAD software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) space. CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

The design of geometric models for object shapes, in particular, is occasionally called *computer-aided geometric design* (*CAGD*)

USES:

Computer-aided design is one of the many tools used by engineers and designers and is used in many ways depending on the profession of the user and the type of software in question.CAD is one part of the whole Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) processes, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as:

- Computer-aided engineering (CAE) and Finite element analysis (FEA)
- Computer-aided manufacturing (CAM) including instructions to Computer Numerical Control (CNC) machines
- Photorealistic rendering and Motion Simulation.
- Document management and revision control using Product Data Management (PDM).

CAD is also used for the accurate creation of photo simulations that are often required in the preparation of Environmental Impact Reports, in which computer-aided designs of intended buildings are superimposed into photographs of existing environments to represent what that locale will be like, where the proposed facilities are allowed to be built. Potential blockage of view corridors and shadow studies are also frequently analyzed using CAD.It has been proven to be useful to engineers as well. Using four properties which are history, features, parameterization, and high-level constraints. The construction history can be used to look back into the model's personal features and work on the single area rather than the whole model. Parameters and constraints can be used to determine the size, shape, and other properties of the different modeling elements. The features in the CAD system can be used for the variety of tools for measurement such as tensile strength, yield strength, electrical or electromagnetic properties. Also its stress, strain, timing or how the element gets affected in certain temperatures, etc.

TYPES:

There are several different types of CAD, each requiring the operator to think differently about how to use them and design their virtual components in a different manner for each.

There are many producers of the lower-end 2D systems, including a number of free and open-source programs. These provide an approach to the drawing process without all the fuss over scale and placement on the drawing sheet that accompanied hand drafting since these can be adjusted as required during the creation of the final draft.

3D wireframe is basically an extension of 2D drafting (not often used today). Each line has to be manually inserted into the drawing. The final product has no mass properties associated with it and cannot have features directly added to it, such as holes. The operator approaches these in a similar fashion to the 2D systems, although many 3D systems allow using the wireframe model to make the final engineering drawing views.

3D "dumb" solids are created in a way analogous to manipulations of real-world objects (not often used today). Basic three-dimensional geometric forms (prisms, cylinders, spheres, and so on) have solid volumes added or subtracted from them as if assembling or cutting real-world objects. Two-dimensional projected views can easily be generated from the models. Basic 3D solids don't usually include tools to easily allow motion of components, set limits to their motion, or identify interference between components.

There are two types of *3D Solid Modeling*

1. Parametric modeling allows the operator to use what is referred to as "design intent". The objects and features created are modifiable. Any future modifications can be made by changing how the original part was created. If a feature was intended to be located from the center of the part, the operator should locate it from the center of the model. The feature could be located using any geometric object already available in the part, but this random placement would defeat the design intent. If the operator designs the part as it functions the parametric modeler is able to make changes to the part while maintaining geometric and functional relationships.
2. Direct or Explicit modeling provide the ability to edit geometry without a history tree. With direct modeling, once a sketch is used to create geometry the sketch is incorporated into the new geometry and the designer just modifies the geometry without needing the original sketch. As with parametric modeling, direct modeling has the ability to include relationships between selected geometry (e.g., tangency, concentricity).

Top end systems offer the capabilities to incorporate more organic, aesthetics and ergonomic features into designs. Freeform surface modeling is often combined with solids to allow the designer to create products that fit the human form and visual requirements as well as they interface with the machine.

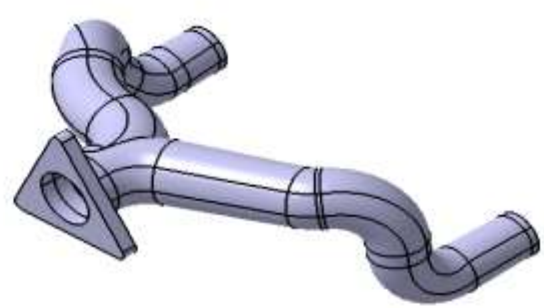


Fig. Concept 01

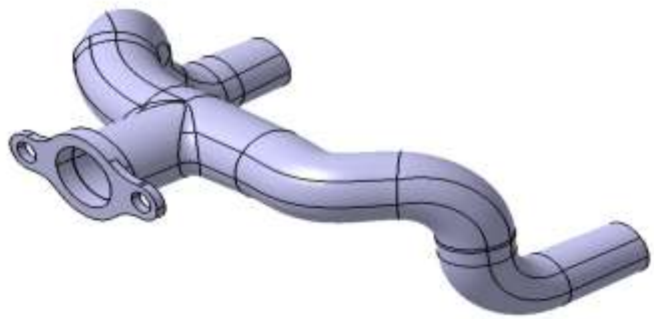


Fig. Concept 02

Detailing of CAD Model

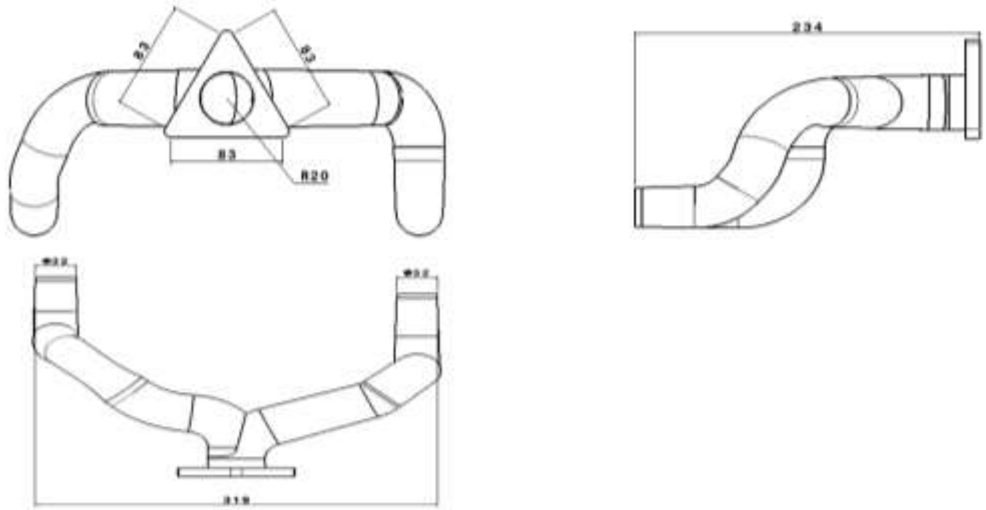


Fig. Concept 01 Drafting

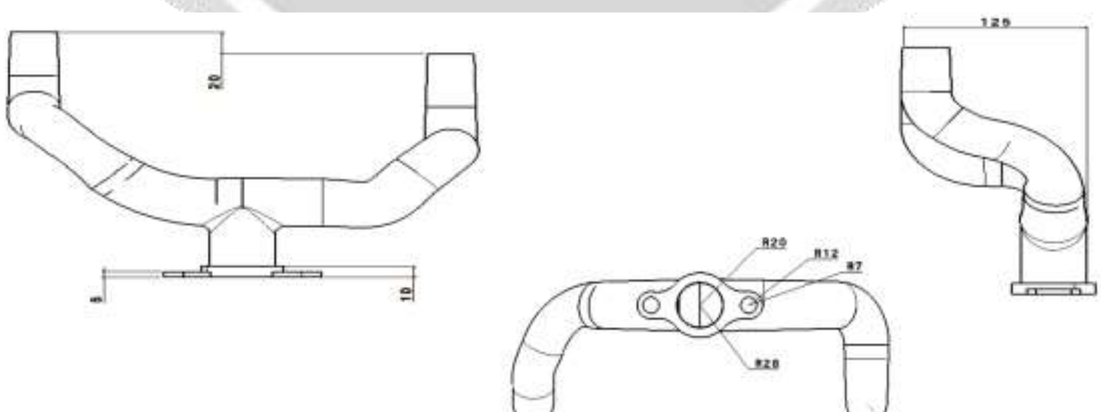


Fig. Concept 2 Drafting

6.2.Finite Element Analysis - FEA

6.2.1.Finite Element Method

The finite element method (FEM) is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The FEM is a particular numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

Studying or analyzing a phenomenon with FEM is often referred to as **finite element analysis** (**FEA**).

6.2.2.Basic concepts

The subdivision of a whole domain into simpler parts has several advantages:[2]

- Accurate representation of complex geometry
- Inclusion of dissimilar material properties
- Easy representation of the total solution
- Capture of local effects.
- Easy representation of the total solution
- Capture of local effects

A typical work out of the method involves (1) dividing the domain of the problem into a collection of sub domains, with each sub domain represented by a set of element equations to the original problem, followed by (2) systematically recombining all sets of element equations into a global system of equations for the final calculation. The global system of equations has known solution techniques and can be calculated from the initial values of the original problem to obtain a numerical answer.

In the first step above, the element equations are simple equations that locally approximate the original complex equations to be studied, where the original equations are often partial differential equations (PDE). To explain the approximation in this process, FEM is commonly introduced as a special case of Galerkin method. The process, in mathematical language, is to construct an integral of the inner product of the residual and the weight functions and set the integral to zero. In simple terms, it is a procedure that minimizes the error of approximation by fitting trial functions into the PDE. The residual is the error caused by the trial functions, and the weight functions are polynomial approximation functions that project the residual. The process eliminates all the spatial derivatives from the PDE, thus approximating the PDE locally with

- a set of algebraic equations for steady state problems,
- a set of ordinary differential equations for transient problems.

These equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equation sets that arise in the steady state problems are solved using numerical linear algebra methods, while ordinary differential equation sets that arise in the transient problems are solved by numerical integration using standard techniques such as Euler's method or the Runge-Kutta method.

In next step above, a global system of equations is generated from the element equations through a transformation of coordinates from the sub domains' local nodes to the domain's global nodes. This spatial transformation includes appropriate orientation adjustments as applied in relation to the reference coordinate system. The process is often carried out by FEM software using coordinate data generated from the sub domains.

FEM is best understood from its practical application, known as **finite element analysis (FEA)**. FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm. In applying FEA, the complex problem is usually a physical system with the underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed in either PDE or integral equations, while the divided small elements of the complex problem represent different areas in the physical system.

FEA is a good choice for analyzing problems over complicated domains (like cars and oil pipelines), when the domain changes (as during a solid-state reaction with a moving boundary), when the desired precision varies over the entire domain, or when the solution lacks smoothness. FEA simulations provide a valuable resource as they remove multiple instances of creation and testing of hard prototypes for various high-fidelity situations. For instance, in a frontal crash simulation it is possible to increase prediction accuracy in "important" areas like the front of the car and reduce it in its rear (thus reducing cost of the simulation). Another example would be in numerical weather prediction, where it is more important to have accurate predictions over developing highly nonlinear phenomena (such as tropical cyclones in the atmosphere, or eddies in the ocean) rather than relatively calm areas.

6.2.3.Meshing

ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Multi physics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you must wait for mesh generation. Creating the most appropriate mesh is the foundation of engineering simulations. ANSYS Meshing is aware of the type of solutions that will be used in the project and has the appropriate criteria to create the best suited mesh. ANSYS Meshing is automatically integrated with each solver within the ANSYS Workbench environment. For a quick analysis or for the new and infrequent user, a usable mesh can be created with one click of the mouse. ANSYS Meshing chooses the most appropriate options based on the analysis type and the geometry of the model. Especially convenient is the ability of ANSYS Meshing to automatically take advantage of the available cores in the computer to use parallel processing and thus significantly reduce the time to create a mesh. Parallel meshing is available without any additional cost or license requirements.

6.2.4.Modal analysis

Modal analysis is a process of extracting modal parameters (natural frequencies, damping loss factors and modal constants) from measured vibration data. Since the measured data can be in the form of either frequency response functions or of impulse responses, there are frequency domain modal analysis and time domain modal analysis. The fundamental of modal analysis using measured frequency response function data is about curving fitting the data using a predefined mathematical model of the measured structure. This model assumes the number of DoFs of the structure, its damping type and possibly the number of vibration modes within the measured frequency range. These assumptions should dictate the mathematical expression of each FRF curve from measurement. As a result, the subsequent work will be a curve fitting process trying to derive all modal parameters in a mathematical formula of an FRF using measurement data. The accuracy of modal analysis is not a simple question of how a measured FRF curve is best fitted in a pure mathematical sense. Obviously, the more accurate the measured FRF data are, the better chance we must get more accurate curve fitting. In mathematics, the accuracy or successfulness of a curve-fitting endeavor can usually be appraised by defining an error function and aiming to minimize it. This approach is only valid if the correct mathematical formula is used in the curve fitting. If, however, an incorrect mathematical model is used, the curve-fitting outcome is doomed to be a bad one if not a failure, even if the error function is minimized numerically. Every object has an internal frequency (or resonant frequency) at which the object can naturally vibrate. It is also the frequency where the object will allow a transfer of energy from one form to another with minimal loss. As the frequency increases towards the “resonant frequency,” the amplitude of response asymptotically increases to infinity. In other words, the results of the modal analysis are these frequencies at which the amplitude increases to infinity.

Every system can be described in terms of a stiffness matrix that connects the displacements and forces. These frequencies are known as natural frequencies of the system and are provided by the eigenvectors of the stiffness matrix. These frequencies are also known as the resonant frequencies.

Modal analysis is an indispensable tool in understanding the structural dynamics of objects - how structures and objects vibrate and how resistant they are to applied forces. The modal analysis allows machines and structures to be tested, optimized, and validated.

Modal analysis is widely accepted in a broad range of applications in the automotive, civil engineering, aerospace, power generation, and musical instruments industries, among countless others. Natural resonance frequencies of the objects and damping parameters can be calculated, and mode shapes can be visualized on an animated geometry of the measured objects. The collection of modal parameters - natural frequencies, damping, and mode shapes - are referred to as a Modal Model. To determine accurate modal models thorough modal analysis must be performed based on accurate modal test measurements.

Modal Test and Analysis typically involves:

- One or more exciters, such as modal shakers or an impact hammer
- Force transducers that acquire the input excitation signals
- Accelerometers that acquire the output response signals
- A DAQ device (Data Acquisition) device to display and record the test
- A computer with a Modal Test and Analysis software application

6.2.5.Test Preparation

Before starting a modal test some test preparation is required, including:

- Mounting of the Test Structure
- Type of excitation force(s)
- Location(s) of excitation (driving points)
- Hardware and sensors to measure the force(s) and responses
- Geometry Model

6.2.6.Mounting of the Test Structure

When performing modal testing the DUT (Device Under Test) must be able to vibrate dynamically in ways that will reveal all and correct natural frequencies and mode shapes of the structure.To pursue free vibration patterns, or similar vibration patterns as expected when the structure is operating in real life, materials like rubber bands, elastic wires, foam pads, and other materials providing a soft elastic system are often used to hang or place the structure on at the locations the structure is designed to be fixed.

If e.g. the test structure is fixated at some positions under test, that is going to vibrate freely when the test structure is operating in real life, then the measured dynamic properties will not fully relate to the real-life usage of the structure - since adding stiffness to the structure will shift the frequencies upwards, and it might also cause some mode shapes to be undetected.

6.3.Modal analysis for Concept 01 of exhaust manifold

6.3.1.3D geometry of concept 01

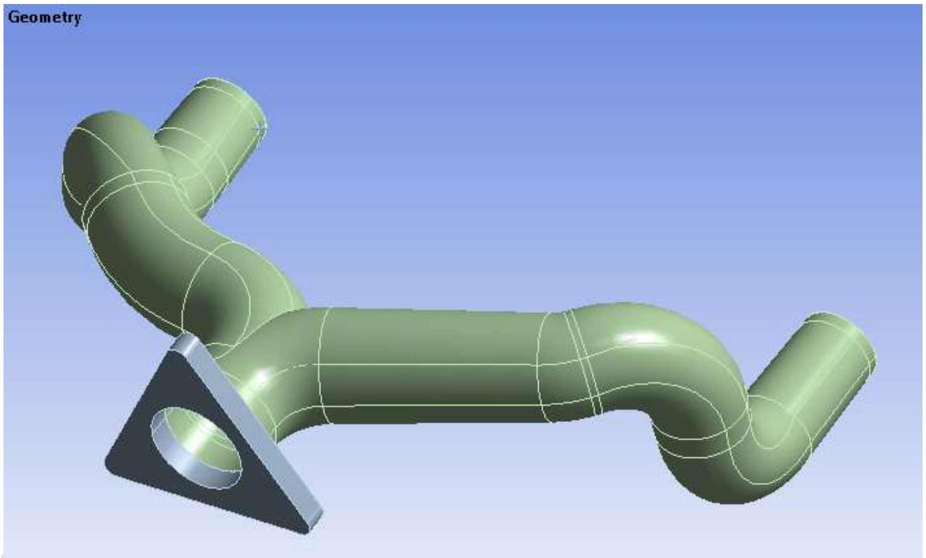


Fig. 3D CAD for Concept 01

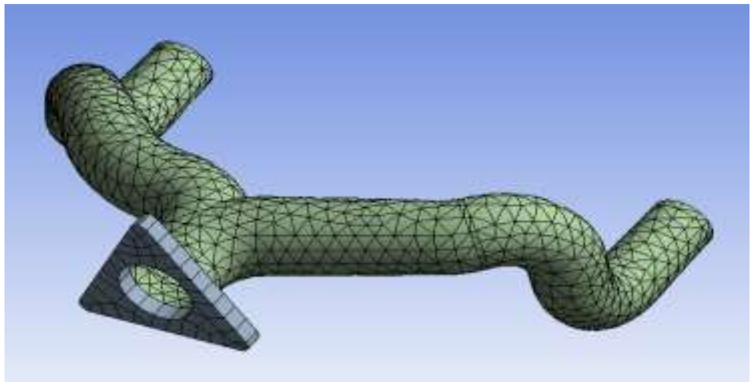
Material Properties

Properties of Outline Row 3: Stainless Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7750	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	1.93E+11	Pa
9	Poisson's Ratio	0.31	
10	Bulk Modulus	1.693E+11	Pa
11	Shear Modulus	7.3664E+10	Pa

Fig. Material Properties for Concept 01

Mesh Model for Concept 01



Statistics	
Nodes	13790
Elements	6866

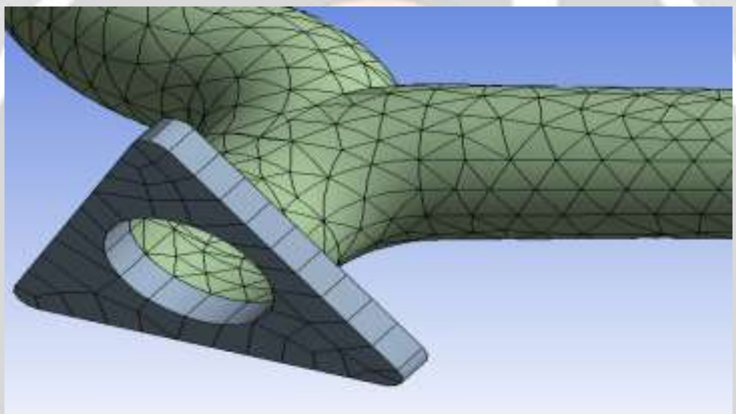


Fig.Mesh model for Concept 01

Boundary condition modal analysis

As the exhaust manifold is mounted at the outlet of engine cylinder and the remaining part act as a cantilever. So, we are fixing the region of manifold where it is bolted with the Engine.

Fig. Boundary Condition for Concept 01

Mode shape results of concept 01 of exhaust manifold

These are the frequency modes for ensuring the fundamental frequencies of manifold.

Mode shape 01

Natural frequency of model 01 for random direction is 1218.7 Hz.

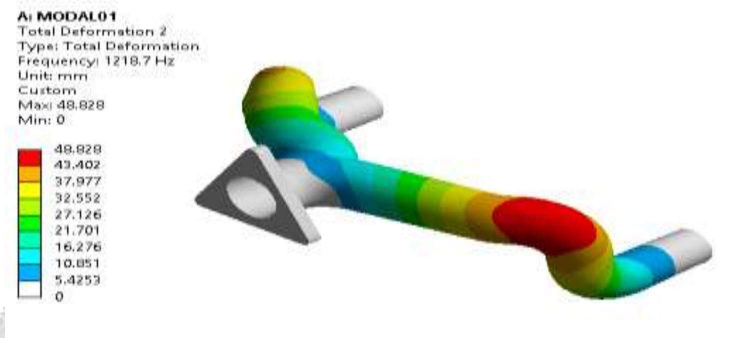


Fig. Mode shape 01 for Concept 01

Mode shape 02

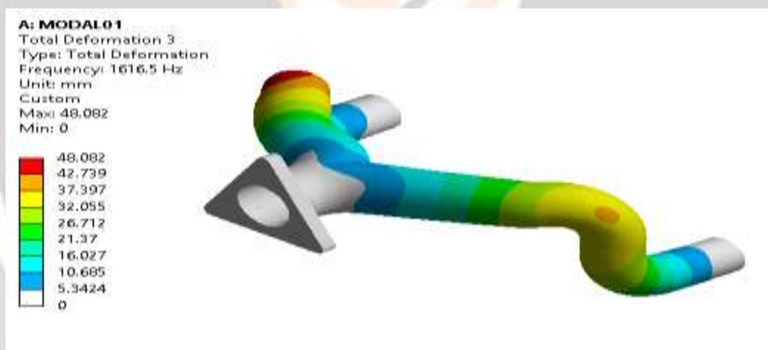


Fig. Mode shape 02 for Concept 01

Mode shape 03

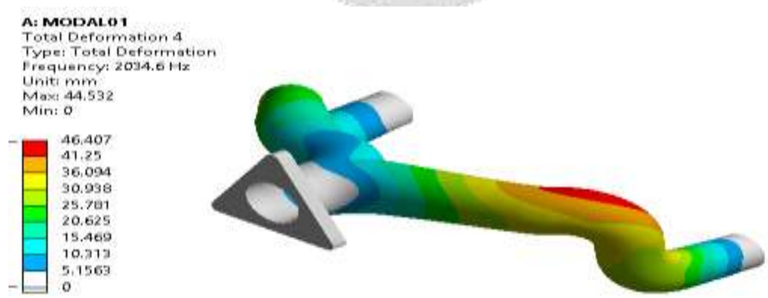


Fig. Mode shape 03 for Concept 01

Mode shape 04

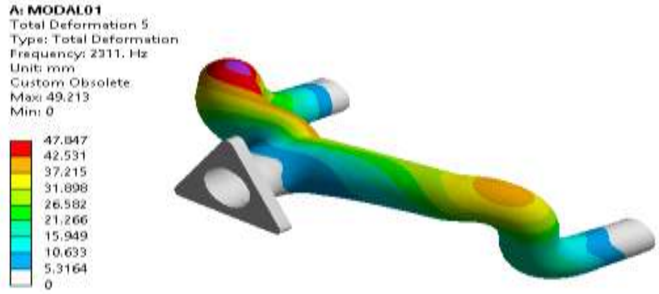


Fig. Mode shape 04 for Concept 01

Mode shape 05

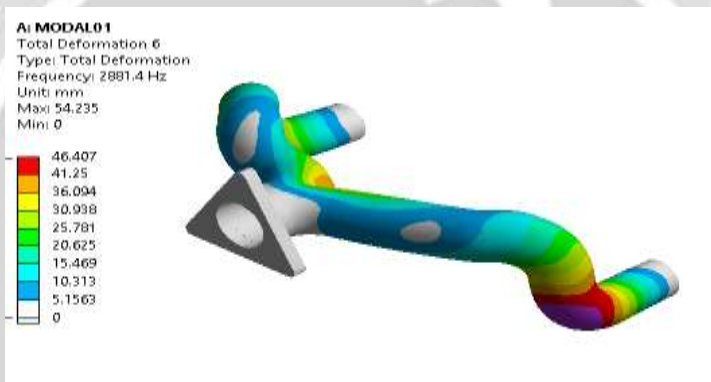


Fig. Mode shape 05 for Concept 01

Modal analysis for concept 02 of exhaust manifold

3D Geometry of Concept 02

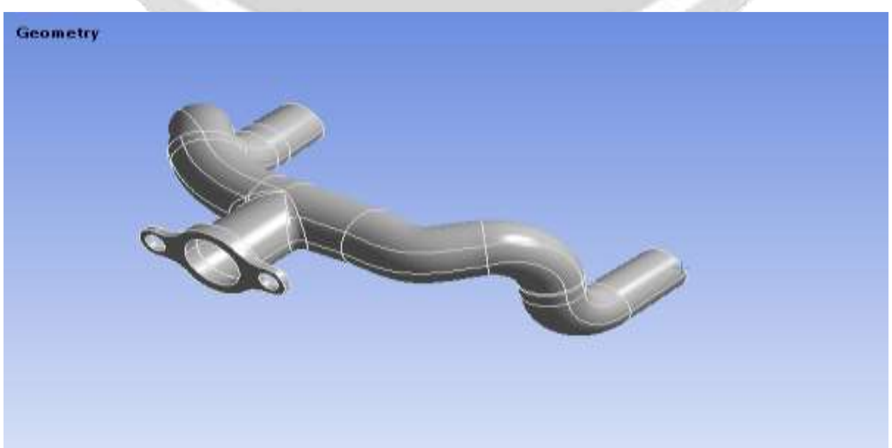


Fig. 3D CAD for Concept 02

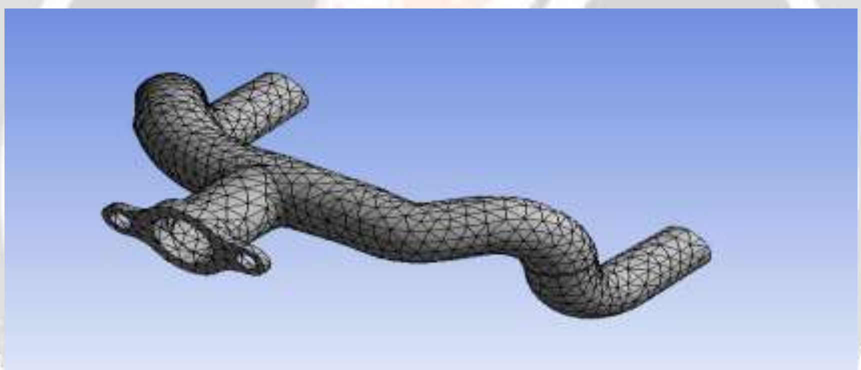
Material Properties

Properties of Outline Row 3: Stainless Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7750	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	1.93E+11	Pa
9	Poisson's Ratio	0.31	
10	Bulk Modulus	1.693E+11	Pa
11	Shear Modulus	7.3664E+10	Pa

Fig. Material Properties for Concept 02

Mesh Model for Concept 02



Statistics	
Nodes	12068
Elements	6009

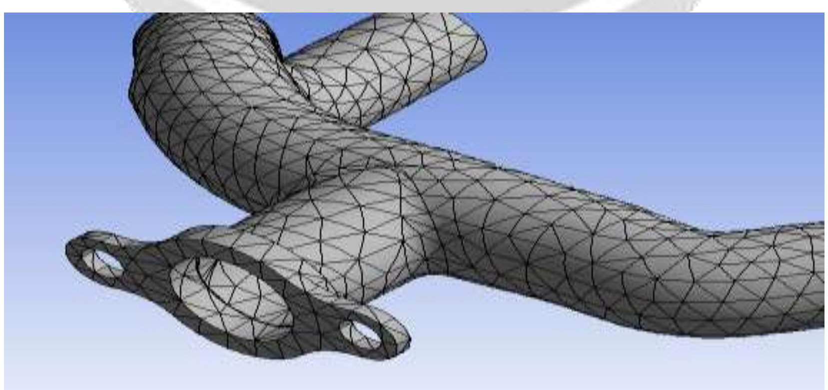


Fig. Mesh model for Concept 02

Boundary condition modal analysis

As the exhaust manifold is mounted at the outlet of engine cylinder and the remaining part act as a cantilever. So, we are fixing the region of manifold where it is bolted with the Engine.

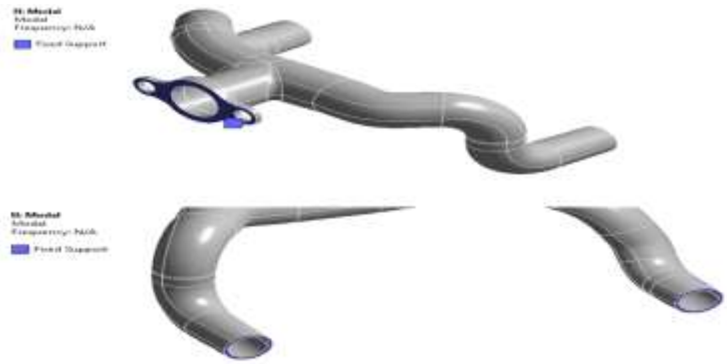


Fig. Boundary Condition for Concept 02

Mode shape results of concept 01 of exhaust manifold

Mode shape 01

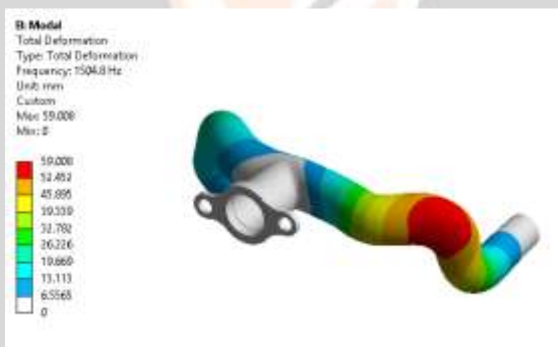


Fig. Mode shape 01 for Concept 02

Mode shape 02

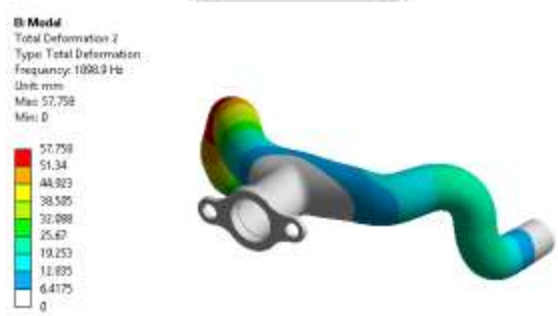


Fig. Mode shape 02 for Concept 02

Mode shape 03

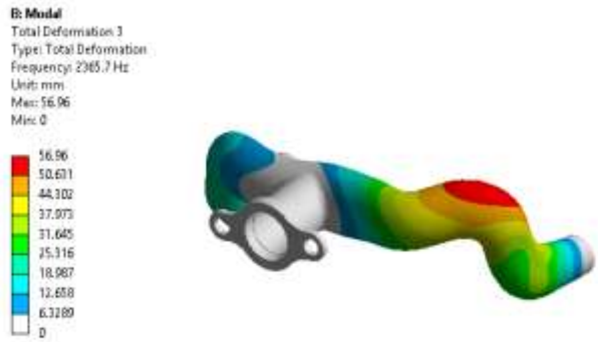


Fig. Mode shape 03 for Concept 02

Mode shape 04

Fig. Mode shape 04 for Concept 02

Mode shape 05

Fig. Mode shape 05 for Concept 02

Table Comparison of Mode Shapes

Mode shapes	Concept 01	Concept 02
Mode shape 01	1218.7 Hz	1504.8 Hz
Mode shape 02	1616.5 Hz	1898.9 Hz
Mode shape 03	2034.6 Hz	2365.7 Hz
Mode shape 04	2311 Hz	2799.3 Hz
Mode shape 05	2881.4 Hz	3092.3 Hz

7.Experimental Testing

7.1.Fast Fourier Transform

FFTs were first discussed by Cooley and Tukey (1965), although Gauss had described the critical factorization step as early as 1805 (Bergland 1969, Strang 1993). A discrete Fourier transform can be computed using an FFT by means of the Danielson-Lanczos lemma if the number of points N is a power of two. If the number of points N is not a power of two, a transform can be performed on sets of points corresponding to the prime factors of N which is slightly degraded in speed. An efficient real Fourier transform algorithm, or a fast Hartley transform (Bracewell 1999) gives a further increase in speed by approximately a factor of two. Base-4 and base-8 fast Fourier transforms use optimized code and can be 20-30% faster than base-2 fast Fourier transforms. prime factorization is slow when the factors are large, but discrete Fourier transforms can be made fast for $N=2$, 3, 4, 5, 7, 8, 11, 13, and 16 using the Winograd transform algorithm.

The experimental validation is done by using FFT (Fast Fourier Transform) analyzer. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. The advantage of this technique is its speed. Because FFT spectrum analyzers measure all frequency components at the same time, the technique offers the possibility of being hundreds of times faster than traditional analog spectrum analyzers. Fourier analysis of a periodic function refers to the extraction of the series of sines and cosines which when superimposed will reproduce the function. This analysis can be expressed as a Fourier series. The fast Fourier transform is a mathematical method for transforming a function of time into a function of frequency. Sometimes it is described as transforming from the time domain to the frequency domain. It is very useful for analysis of time-dependent phenomena

7.2.Impact Hammer Test

Impact excitation is one of the most common methods used for experimental modal testing. Hammer impacts produce a broad banded excitation signal ideal for modal testing with a minimal amount of equipment and set up. Furthermore, it is versatile, mobile and produces reliable results. Although it has limitations with respect to precise positioning and force level control, overall, its advantages greatly outweigh its disadvantages making it extremely attractive and effective for many modal testing situations.

The use of impulse testing with FFT signal processing methods presents data acquisition conditions which must be considered to ensure that accurate spectral functions are estimated. Problems stem from the availability of only a finite duration sample of the input and output signals. When a structure is lightly damped the response to the hammer impact may be sufficiently long that it is impractical to capture the entire signal. The truncation effect manifests itself in terms of a spectral bias error having the potential to adversely affect the estimated spectra. The signal truncation problem is further compounded in practice by the computational and hardware constraints of the FFT processing equipment. Typically, the equipment has a limited number of data capture lengths or frequency ranges which are available for an operator to select.This artificial reduction is obtained by multiplying the slowly decaying vibration signal by an exponential function. However, the application of the exponential window must be considered carefully since it may also adversely affect the estimated spectra.A phenomenon commonly encountered during impact testing is the so called "double hit". The "double hit" applies two impulses to the structure, one initially and one time delayed. Both the temporal and spectral characteristics of the "double hit" input and output are significantly different than a "single hit". The input force spectrum for the "double hit" no longer has the wide band constant type characteristics of a single hit. The purpose of this paper is to examine the use of impact vibration testing in relation to the constraints imposed by typical FFT' signal processing techniques. The results from these related studies are combined to provide insight into data acquisition guidelines for structural impact testing.

7.3.FFT Analyzer

An FFT spectrum analyzer works in an entirely different way. The input signal is digitized at a high sampling rate,like a digitizing oscilloscope. Nyquist's theorem says that as long as the sampling rate is greater than twice thehighest frequency component of the signal, then the sampled data will accurately represent the input signal. In theSR760, sampling occurs at 256 kHz. To make sure that Nyquist's theorem is satisfied, the input signal passes through ananalog filter which attenuates all frequency components above128 kHz by 90 dB. This is the anti-aliasing filter. Theresulting digital time record is then mathematically transformed into a frequency spectrum using an algorithm known asthe Fast Fourier Transform or FFT. The FFT is simply a clever set of operations which implements Fourier's basictheorem. The resulting spectrum shows the frequency components of the input signal. Now here's the interesting part.The original digital time record comes from discrete samples taken at the sampling rate. The corresponding FFT yields aspectrum with discrete frequency samples. In fact, the spectrum has half as many frequency points as there are timepoints. (Remember Nyquist's theorem). Suppose that you take 1024 samples at 256 kHz. It takes 4 ms to take this timerecord.

Procedure for Vibration analysis by FFT

- Firstly, decide the areas where to take readings.
- Clean that area with the help of clean cloth.
- One end of accelerometer connects to the FFT port.
- FFT analyzer then connected to Laptop having „RT Photon pro‟ software installed in it.
- After these settings, give power supply to whole system.
- Another end of accelerometer mounts on the bearing housing in radial direction.
- This set up gives the analysis in the form of time and frequency domain curves.
- Wait for 1 minute to achieve accurate graphs.
- Then do the same procedure for induced draft fan and forced draft fans.
- For the above components take two readings each in radial and axial directions.
- After achieving all readings compare these readings with ISO 10816 and with Severity and acquisition charts.
- With the help of all standard results diagnose that what causes take place into each equipment and conclude their remedies for each equipment’s.

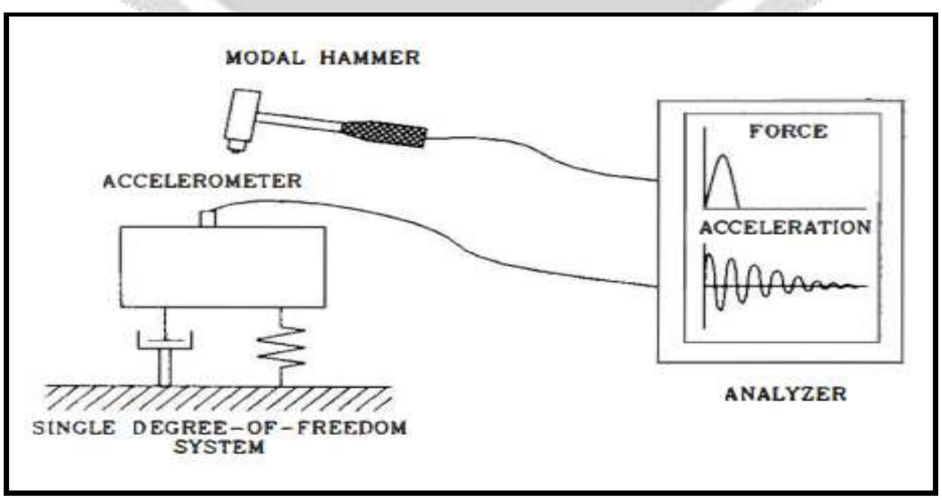


Fig. FFT Construction

7.4.Measuring the Resonance frequency of a structure

When an external force at a frequency close to the resonance frequency is applied to a structure, strong vibration will occur. This can lead to breakdown of machinery, product quality degradation, and other problems. In order to guard against such risks, measuring the resonance frequency is very important.

To measure the resonant frequency, the structure is struck with a hammer or similar and the resulting vibrations are subject to frequency analysis.

7.5.Experimental set-up for Exhaust manifold vibration analysis using FFT

Manufactured exhaust system component is selected for theexperiment. For free analysis the component is hanged byusing string. Accelerometer is mounted on flange end bygeneral observation. Ensured the FFT connections for theready signal. Impact hammer is used for manually excite thestructure so that it produces signals. These signals excite thesystem with varying amplitudes & phases, averages are thencollected. The following figure shows the experimentalsetup. The setup is designed to get naturalfrequency at free -free vibrations. The current setup hasnegligible structural vibrations.

The validation of the manifold is done by physical prototype development. While the manifold is made availablein the physical form, the trials and testing would address the phase of validation. The correlation between theexperimental and theoretical results will be analyzed and recommendations can be made for future scope ofwork.

Considering the use of software's like FFT/ Lab view or equivalent towards the measurement of vibration. Thevalues obtained by from the test bench would be evaluated for arriving at an appropriate design with adevelopment of a full-scale working prototype which would be typically produced by modifying the existingcomponent in the physical form (manifold). The same would be used for validation further. The FFT analysis orVibration Test is carried out. Basedon the measurement obtainedduring test, the results will be adopted for modification of existing silencer.The experimental validation is done by using FFT (Fast Fourier Transform) analyzer. The FFT spectrumanalyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays thespectrum of these measured frequency components. The advantage of this technique is its speed. Because FFTspectrum analyzers measure all frequency components at the same time, the technique offers the possibility ofbeing hundreds of times faster than traditional analog spectrum analyzers.

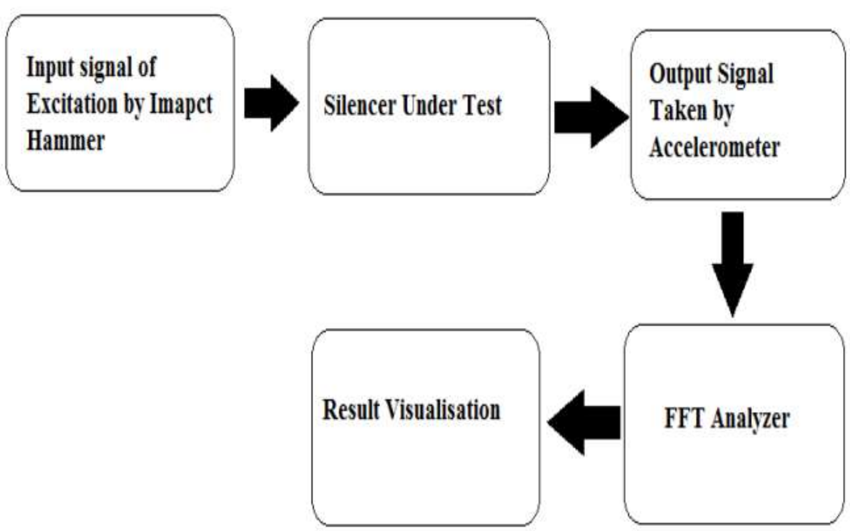


Fig. Block Diagram of Experimental Set-up

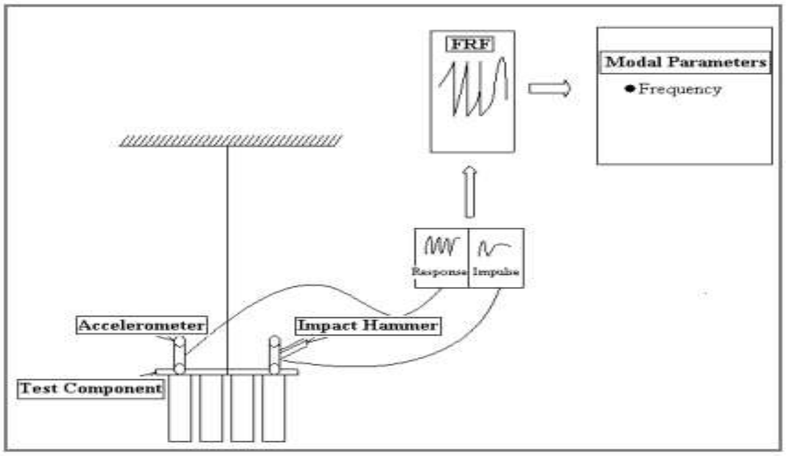


Fig. Schematic diagram of experimental set-up

Fig. Physical Model

Fig. Experimental Set-up

FFT results for Modal Frequencies

To achieve reliable models both theoretical and experimental modal analysis should be performed so that finite element and test model can be compared and successfully improved. Free-free boundary condition is recommended for this model. At an early stage of product development process, the boundary conditions that exhaust system will have under operation are not always known. By using free-free boundary condition it is still possible to develop FE models of exhaust system or part of it, which corresponds well with measurements.

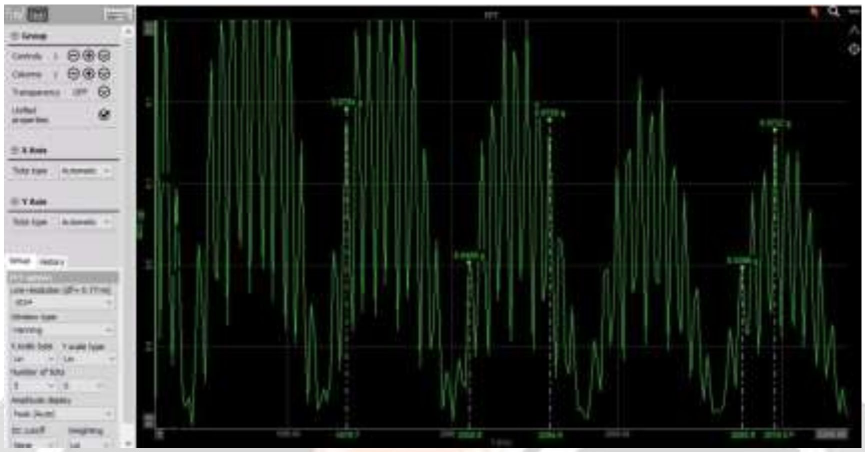


Fig. FFT Result Plots

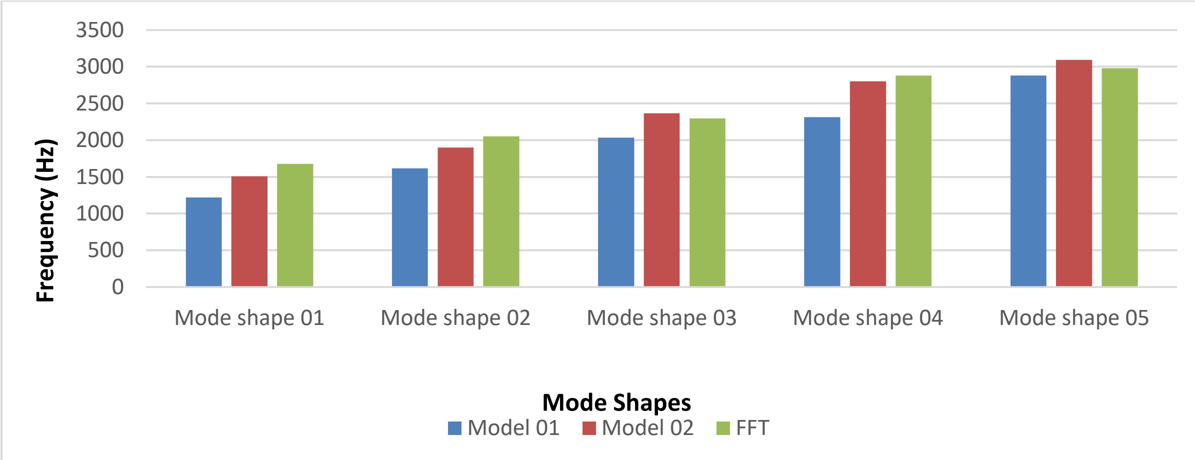
8.Conclusion

Modal analysis of both the concepts shows improved results for concept 02 against concept 01. Optimized shape of runner in concept 02 for strengthening of manifold has resulted in higher resistance against load. Moreover, it has shown higher frequency response for the same modal analysis, resulting better stiffness of the exhaust manifold.

As the frequencies are improved in the second model for mode shapes, we have concluded that the concept 02 has more frequency range than the previous model.The result includes the systematic study of straight exhaust system with the known engine conditions, loads and boundary conditions. It will give the general guidelines such as modal analysis is to be performed in the initial stage of the project by considering the boundary condition only at the manifold flange where it is connected to engine and checked for nodal and anti-nodal points from mode shape animation. The nodal points are to be considered as preliminary hanger locations for the exhaust system. Also, same modal analysis is used to check for resonance by comparing modal frequency with engine frequency from rated speed. It has been observed from Modal analysis that modal frequency has been compared with engine excitation frequency and resonance won't occur.

Table Comparison of FEA & FFT Results

Mode shapes	Model 01	Model 02	FFT RESULTS
Mode shape 01	1218.7 Hz	1504.8 Hz	1679 Hz
Mode shape 02	1616.5 Hz	1898.9 Hz	2050.8 Hz
Mode shape 03	2034.6 Hz	2365.7 Hz	2294.9 Hz
Mode shape 04	2311 Hz	2799.3 Hz	2880.9 Hz
Mode shape 05	2881.4 Hz	3092.3 Hz	2978.9 Hz



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