

Design and Validation of Holding Fixture for Auto-Rickshaw Silencer Based on FEM and FFT Analyzer

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Abstract:

Designing a vibration fixture for the testing of automobile components poses a significant challenge for engineers. With numerous tests conducted in recent years to determine operating frequencies and assess stress and failure in automobile parts due to vibration, the importance of vibration testing in industries cannot be overstated. This project focuses on the development, implementation, and testing of a holding fixture for the vibration testing of an autorickshaw silencer using FEA analysis. The modal analysis of the muffler fixture is conducted using ANSYS software, revealing a natural frequency of 654.4 Hz. Experimental modal analysis is performed using an impact hammer to provide excitation, and data is analyzed and validated using an FFT spectrum analyzer. The experiment is meticulously planned and executed using design of experiment techniques to ensure statistical significance in the results obtained.

Keywords:

Natural frequency, Silencer, Mode shapes, Experimental modal analysis, Finite element method, FFT analyzer.

Acronyms And Nomenclature:

D	Bore Diameter (mm)
L_1	Chamber Length (mm)
L_5	Stroke Length (mm)
L_2	Tail Length (mm)
N	Speed (RPM)
n	Number of Cylinders
P	Power (BHP)
V	Engine Volume (Liter)
V_5	Swept Volume (Liter)
V_m	Muffler Volume (mm ³)
$\%V$	Volumetric Efficiency
d_e	Exhaust Pipe Diameter (mm)
S_2	Muffler Body Diameter (mm)
S_3	Inlet Pipe Diameter (mm)
d_b	Bypass Pipe Diameter (mm)
N_c	Number of Perforated Holes in Inlet Pipe
N_b	Number of Perforated Holes in Bypass Pipe
N_e	Number of Perforated Holes in Extended Pipe
UNL	Unsilenced Noise Level (dBA)
ENC	Exhaust Noise Calculation (dBA)
RNC	Receiver Noise Criteria (dBA)
IL	Insertion Loss (dBA)

1. Introduction

A fixture serves as a vital device in the manufacturing sector, providing support and stability during operations [18][19]. Its primary function is to accurately position and hold the workpiece, ensuring consistency and interchangeability in the produced parts. By employing fixtures, production processes become more efficient, facilitating seamless transitions between tasks and minimizing the need for highly skilled labour. This results in enhanced productivity and uniformity throughout the manufacturing process [17].

1. Purpose: The fundamental role of a fixture is to provide a stable foundation for securing a workpiece, ensuring support during operations and enhancing accuracy, precision, reliability, and interchangeability in the resulting components [18]. Additionally, fixtures streamline setup procedures, minimize working time, and facilitate smooth transitions between tasks. They often simplify processes, enabling unskilled workers to effectively execute them and transferring the expertise of toolmakers to less experienced personnel [19]. Moreover, fixtures contribute to operator safety by reducing the need for intense focus and effort to stabilize a workpiece [18].

2. Design: When designing fixtures, economic considerations are paramount. These devices are typically intended to lower costs; thus, their design should prioritize achieving cost reductions that exceed the implementation expenses. Economically, it's often more advantageous for a fixture to yield a modest cost reduction for a frequently utilized process, rather than a substantial reduction for a process with occasional use. Each component of a fixture is designed for one of two purposes: location or support.

When designing a vibration fixture, it's crucial to account for the unique geometry and mass of the product under test. Additionally, the number of test items to be mounted should be determined to optimize the fixture's configuration. Efforts should be made to maintain a low centre of gravity for the combined fixture and test item [15]. Moreover, it's essential to consider the combined bandwidth of dynamic tests to prevent fixture resonances. Analysis should be conducted to mitigate any resonance occurrences.

Given that dynamic testing often involves multiple axes, incorporating mounting holes in various locations can offer advantages [13]. When choosing materials for fixtures, factors such as stiffness, weight, and cost must be considered. Aluminum, magnesium, and steel are commonly used materials, each with its own set of advantages and disadvantages in terms of these factors [20].

2. Problem Statement

Vibration plays a significant role in the failure of automobile parts, making vibration testing crucial for identifying failure modes and frequencies of key components. Therefore, the industry often requires holding fixtures to secure these components onto shaker tables for testing. Hence, it is essential to conduct studies on various design parameters and analyze holding fixture designs for optimal performance.

3. Material Selection

Choosing the right material for a design is a critical stage in the process as it can enhance service performance and is a pivotal decision that directly impacts the effectiveness of the design. Materials, along with the manufacturing processes that shape them into functional parts, form the foundation of engineering design. The selection of materials is intricately linked with design, particularly the

configuration of the part. Therefore, it is essential to consider both material selection and design simultaneously [20].

Selecting the right material for fixture design involves a comprehensive assessment of various factors to achieve optimal performance and cost-effectiveness:

1. **Mechanical Properties:** Evaluate stiffness, strength, hardness, and toughness needed for the fixture's intended use. The material should withstand operational loads and stresses without deformation or failure.

2. **Corrosion Resistance:** Consider environmental factors like moisture, chemicals, and temperature changes. Choose a material with sufficient corrosion resistance for long-term durability.

3. **Weight:** Balance material weight against handling ease and transportation costs. For materials with an appropriate strength-to-weight ratio while keeping overall weight manageable.

4. **Cost:** Evaluate material costs along with potential savings in manufacturing, maintenance, and replacement expenses over the fixture's lifespan.

5. **Machinability:** Assess how easily the material can be machined and fabricated to meet design requirements. Choose materials that allow for efficient shaping into complex configurations.

6. **Temperature Stability:** Determine the temperature range the fixture will encounter and select materials with suitable thermal stability to maintain performance integrity.

7. **Material Compatibility:** Ensure the chosen material won't cause contamination or adverse reactions with other components during manufacturing or assembly.

8. **Industry Standards:** Adhere to relevant industry regulations and standards to ensure compliance and safety, especially in sectors like aerospace, automotive, or medical industries.

By carefully considering these factors and prioritizing the specific application's requirements, you can make an informed choice for your fixture design [21].

Fixtures are crafted from a diverse range of materials. In instances where durability is paramount, metals are often hardened to withstand wear and tear. Conversely, to safeguard workpieces

from potential damage, fixtures are occasionally fashioned from materials like nylon or fiber.

Phosphor Bronze Most suitable in corrosion-resistant parts.

Below are some of the materials used [22]:

Material	Description
Mild Steel	Contains carbon (<0.3%). Most suitable for most jigs applications as it is the most economical and most widely used material in jigs and fixtures.
Carbon Steel	Contains carbon (0.85%~1.18%). Most suitable for workpieces like woodworking tools and hand tools. It can be hardened to serve as locators and bushings.
High Speed Steel	Contains tungsten (18% ~22%) for toughness and cutting strength, chromium (4.3%) for hardening and wear resistance, vanadium (1%) for retention of hardness at high temperature.
High Tensile Steel	Contains carbon (0.45% ~ 0.65%) and alloys Ni2Cr1M028 (40%). Most suitable for fasteners as well as high-stress machines
Die Steel	Contains carbon (1.5%~2.3) for hardness, high chromium (12%) but alloyed with molybdenum (1%) and vanadium (0.3%~1%) for hardness retention used at high temperatures.
Oil Hardening Non-Shrinking Tool Steels	Contain carbon (0.9%~1.1%), tungsten (0.5%~2%) and carbon (0.45%~1%). Most suitable for engraving tools and intricate pressing jigs.
Cast Irons	Contain carbon (2%~2.5%). Most suitable for milling fixtures, machine slides and guide ways, as they can withstand extreme vibrations.
Aluminium Alloy	Lightweight nature, corrosion resistance, and excellent strength-to-weight ratio.
Nylons & Fibres	Most suitable for use in soft linings for lever presses/clamps to prevent dents to workpieces under high-pressure forces.

Table 1: Common Material used for Fixtures

Aluminum, magnesium, and steel are materials most often employed for fixtures. Each has its own trade offs for stiffness, weight, and cost [7].

- Steel has excellent stiffness characteristics and is , but because of its weight, is not always the best choice. The overall weight of the fixture and item under test can often exceed the capabilities of smaller vibration test equipment. Weight is also a concern for ease of set up and break down during testing. Steel is often not the best choice for testing where higher frequencies are being used because of the potential of resonances [11].
- Aluminum is a good material for most fixtures. It is relatively inexpensive and is light as compared to steel. It is easily worked and can be constructed to provide the required rigidity.
- Magnesium provides the best material for tensile strength to weight ratio. It also has better dampening at high frequencies. It is however, more costly and is not as easy to machine. It is therefore usually reserved for high test performance requirements [7].

Properties	Mild steel	Aluminum Alloy	Magnesium Alloy
Density (kg/m ³)	7850	2700	1740
Tensile Stress (MPa)	350	280	105
Ultimate Stress (MPa)	400	310	205
Modulus of Elasticity (GPa)	200	68.9	44
Poissons Ratio	0.25	0.31	0.35
Shear Modulus (GPa)	80	26	16
Cost (Rs) [Square Tube/ Kg]	85-110	200-280	1600-1700
Machining Cost	Less Expensive	Expensive	Very Expensive
Weight to Weight Ratio	Heavy to High	Medium Higher	Light Highest

Damping Capacity	Low	Medium	High
Corrosion Resistance	Bad	Good	Fair

Table 2: Comparison of Mild Steel, Aluminum Alloy & Magnesium Alloy

4. Calculation

A. The following points are considered as guidelines to designing of muffler [3].

1. An angle between the diverging walls of about 6° – 10° gives best diffuser performance.
2. For a given area change per unit length of duct, diffuser of circular cross section gives the best effectiveness, with square cross sections next.
3. For most commonly used area ratios an abrupt area increase result in less total pressure loss than a diffuser with wall angle greater than 40° – 50°.
4. The material used to guide the exhaust flow and sound waves to escape, is usually perforated steel with an open area of approximately 20% [23].
5. Lightness could be possible if the thickness is decreased or the volume is reduced. However, this causes high back pressure [1].

B. Muffler Volume Calculation [2]

Engine Data:-

Bore (D)=86mm

Stroke Length(L_s) = 75mm

No of Cylinders (n) = 1

Engine Power (P) =5.82 Kw or 7.8 BHP at 3600 rpm

- Engine Swept Volume (V_s) = 0.25×π×D²×L

(1)

$$=0.25 \times 3.14 \times 86^2 \times 75$$

=0.43543 Liter

- Engine Volume to be considered for calculation

$$(V) = 0.5 \times V_s \times n \quad (2)$$

$$=0.5 \times 0.43543 \times 1$$

=0.217715 litre

- Silencer Volume: Volume of silencer must be at least 12 to 25 times the volume

$$= \text{Factor} \times V \quad (3)$$

$$= 25 \times 0.217715$$

= 5.442875 litre

C. Four Stroke Engine Airflow Calculations [1]

- Intake Airflow = $\frac{\text{Engine Size (CID)} \times \text{Speed}}{3456} \times$

%V (4)

$$= \frac{26.6064 \times 3600}{3456} \times 0.9$$

=249.435 CFM or 423.793 m³/hr

Here,

- Engine Size = 26.6064 CID = 436 CC
- Volumetric Efficiency of naturally aspirated engine = 90%

Now,

- Exhaust Flow = $\frac{\text{Engine Temp.} + 460}{540} \times$

Intake Airflow

(5)

$$= \frac{1000 + 460}{540} \times 249.435$$

= 674.39 CFM or 114.8 m³/hr

Here,

- Engine Temperature is taken 1000°F

Now,

- Exhaust Gas Velocity = $\frac{\text{Exhaust Flow (CFM)}}{\text{Silencer Pipe Area (ft}^2\text{)}}$

(6)

$$= \frac{674.398}{0.01318}$$

= 51145.84 ft/min or 15589.25 m/min

D. Selection of Muffler Grade [3]

- **Unsilenced Noise Level (UNL)**

The Overall noise level from most unsilenced engine exhaust system varies from about 100 dBA to 120 dBA.

$$\text{We have assumed average} = \frac{100 + 120}{2} \quad (7)$$

= 110 dBA

- **Exhaust Noise Calculation (ENC)**

We assume that Receiver Noise Criteria (RNC) = **85 dBA**

Hence,

$$\text{ENC} = \text{RNC} - 5 \quad (8)$$

$$= 85 - 5$$

= 80 dBA

- **Insertion Loss (IL) = UNL – ENC – 5** (9)

$$= 110 - 80 - 5$$

= 25 dBA

Now, according to Insertion Loss it is a 'Residential Grade' type muffler,

So, according to ASHARE technical Committee 2.6 for 'Residential Grade' type muffler,

Insertion Loss	20 to 30 dB
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Body / Pipe	2 to 4
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Chamber Length / Pipe	6 to 10
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Table 3: Residential Grade Type Muffler

E. Chamber Length Selection

- Chamber Length according to ASHARE Technical Committee 2.6

$$6 \times d_e \leq \text{Length (L}_1\text{)} \leq 10 \times d_e \quad (10)$$

$$6 \times 35 \leq \text{Length } (L_1) \leq 10 \times 35$$

$$210 \leq \text{Length } (L_1) \leq 350$$

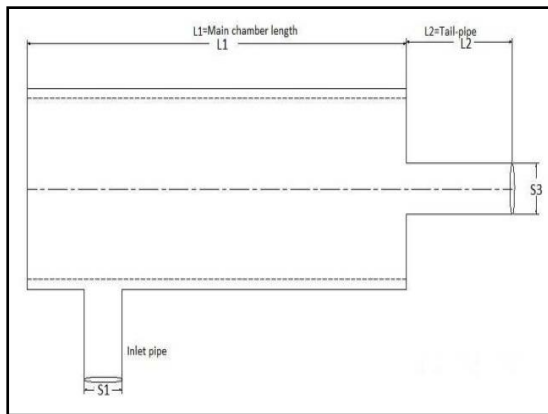


Fig. 1: Chamber Length Selection

- Selection of Chamber Length considering exhaust gas temperature

As we already assumed that maximum exhaust gas temperature = 1000°F

$$= 1459.67^\circ\text{R}$$

$$0.5 \left(\frac{49.03 \times \sqrt{^\circ\text{R}}}{2\pi f} \right) \leq L_1 \leq 2.6 \left(\frac{49.03 \times \sqrt{^\circ\text{R}}}{2\pi f} \right) \quad (11)$$

$$0.5 \left(\frac{49.03 \times \sqrt{1459.67}}{2\pi \times 550} \right) \leq L_1 \leq 2.6 \left(\frac{49.03 \times \sqrt{1459.67}}{2\pi \times 550} \right)$$

$$0.2710 \text{ ft} \leq L_1 \leq 1.4093 \text{ ft}$$

$$82.6 \text{ mm} \leq L_1 \leq 429.55 \text{ mm}$$

Here,

- Attenuation Frequency (f) = 550 Hz

Hence, according to these two limits and available space in vehicle; $L_1 = 350 \text{ mm}$

F. Selection of Body Diameter

- Body Diameter from Muffler Volume Calculation

$$\text{Muffler Volume } (V_m) = \frac{\pi \times L_1 \times S_2^2}{4} \quad (12)$$

$$5442875 \text{ (mm}^3\text{)} = \frac{\pi \times 350 \times S_2^2}{4}$$

$$S_2 = 140.71 \approx 150 \text{ mm}$$

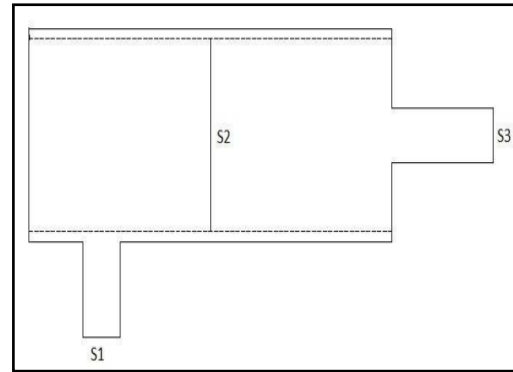


Fig. 2: Selection of Body Diameter

G. Tail Pipe Length

Exhaust tail pipe will have resonance that can amplify engine tones. To avoid amplification of tones use short tail pipe length.

$$\text{Optimum Tail Length } (L_2) = \left(\frac{\text{Speed of Sound}}{4f} - \frac{S_3}{2} \right) \times 5 \quad (13)$$

$$= \left(\frac{1082.68}{4 \times 550} - \frac{30}{2} \right) \times 5$$

$$L_2 = 72.5 \text{ mm}$$

Here,

- Speed of sound = 330 m/s = 1082.68 FPS

H. Calculation of Bypass Tube

Area of exhaust pipe = Area of bypass pipe

$$\frac{\pi}{4} \times 35^2 = 2 \times \frac{\pi}{4} \times d_b^2 \quad (14)$$

$$d_b = 24.74 \text{ mm} \sim 25 \text{ mm}$$

I. Calculation of Perforated Holes

- Diameter of perforated hole = $1.29 \times \sqrt{n}$ to $2 \times 1.29 \times \sqrt{n}$ (15)

$$= 1.29 \times \sqrt{1} \text{ to } 2 \times 1.29 \times \sqrt{1} = 1.29 \sim 2 \text{ mm to } 4 \text{ mm}$$

- Number of perforated holes on expansion cone

Area of c/s of exhaust pipe = Area of perforated holes

$$\pi \times (35/2)^2 = N_c \times \pi \times (4/2)^2 \quad (16)$$

$$N_c = 76.5 \sim 77 \text{ mm, of dia. } 4 \text{ mm}$$

- Number of perforated holes on extended pipe

Area of c/s of baffle pipe = Area of perforated holes

$$2 \times \pi \times (32/2)^2 = 2 \times N_e \times \pi \times (4/2)^2 \quad (17)$$

$$N_e = 64 \text{ mm, of dia. } 4 \text{ mm}$$

- Number of perforated holes on bypass pipe

Area of c/s of baffle pipe = Area of perforated holes

$$2 \times \pi \times (25/2)^2 = 2 \times N_b \times \pi \times (3/2)^2 \quad (18)$$

$$N_b = 69.44 \sim 70 \text{ mm, of dia. 3mm}$$

Note:

1. Above mentioned calculations can be used for any vehicle to find the parameters of exhaust.
2. The calculations shown in this paper is the case study of Three Wheeler Auto Rickshaw.
3. According to ASHARE committee 2.6 the noise frequency range achieved from chamber length calculation is 700 Hz to 1200 Hz.
4. The frequency attained here is random vibration, which depends on many factors.
5. Fixture is being designed only on the basis of Natural Frequency attained by the exhaust system.
6. These random vibration values can be used to determine the maximum limit of the frequency needed to be achieved for the fixture.

5. Digital Prototype (CAD Model)

Fixtures play a crucial role in securing engineering components during various processes. However, ensuring their safe design is paramount to safeguard both workers and the components in use. Fixtures are work holding members and so lot of literature is available on the fixture design, usage and testing. Few of the salient fixture design literature are as follows (see Fig. 3). A failure in fixture design can cause a cascading disruption to the manufacturing process and system delivery. Therefore, it is imperative to meticulously design fixtures with adequate thickness and rigidity. Given the involvement of vibration in the current work, verifying the structural integrity of the fixture is of utmost importance [11].

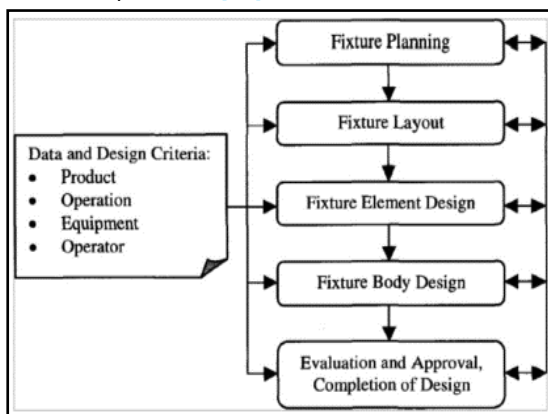


Fig. 3: Design Aspects of Fixture Alignment

The CAD 3D model, or digital prototype, is crafted utilizing Creo Parametric 5.0.0.0 software. The

fixture design process involved utilizing a silencer readily available in the market for three-wheeler auto-rickshaws.

To create the CAD model in Creo Parametric, precise measurements of the silencer's dimensions were obtained using a coordinate measuring machine (CMM). Outer body dimensions, comprising the main pipe and tail pipe, were captured using the CMM, while internal body dimensions, including short pipe, long pipe, baffle plates, and perforated tubes, were measured using a Vernier caliper [6].

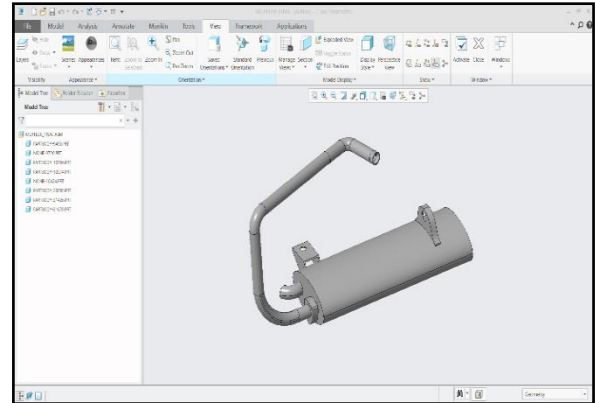


Fig. 4: Geometry of Existing Silencer

After preparing the CAD model of the silencer, the mounting points are identified. These mounting points serve as the basis for creating the CAD model of the fixture (refer to Fig. 5). By utilizing the dimensions of the silencer, the final dimensions of the fixtures are determined.

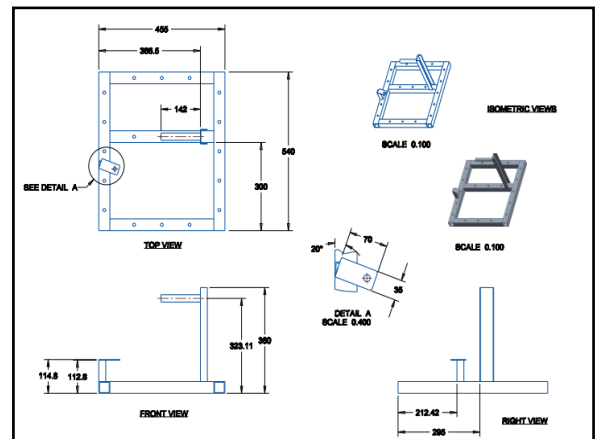


Fig. 5: Drafting of CAD Modelled Fixture

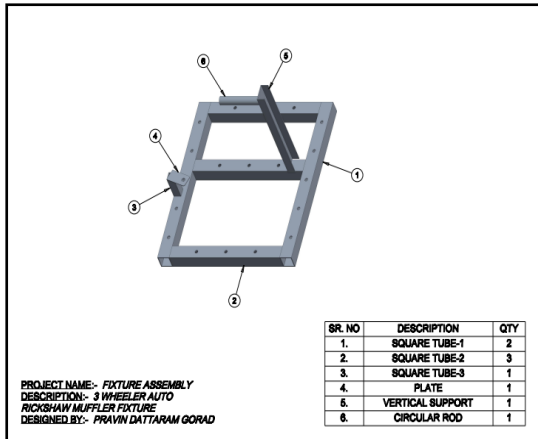


Fig. 6: CAD Model of Fixture

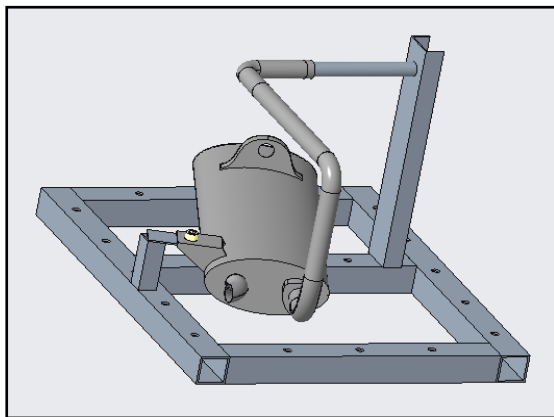


Fig. 7: Assembly of Fixture and Silencer

To ascertain the weight of the fixture, two distinct materials are allocated to the model. This weight data serves as a crucial parameter in determining the ultimate material choice. The materials assigned to the CAD model are:

1. Aluminium Alloy (6061) having density 2700 kg/m^3 , tensile stress 280 MPa, ultimate stress 310 MPa and poisons ratio 0.31.
2. Mild Steel having density 7820 kg/m^3 , tensile stress 350 MPa, ultimate stress 400 MPa and poisons ratio 0.25.

Upon assigning the material to the CAD model, the fixture's weight was determined as presented in Table 4.

Material	Weight
Aluminium Alloy 6061	2.8 Kg
Mild Steel	7.8 Kg

Table 4: Weight of Fixture

6. Modal Analysis

Modal analysis will exclusively be conducted on the CAD model of the fixture using Ansys 2022 R2, an FEA software. ANSYS analysis serves as a crucial tool

in engineering, enabling simulation, analysis, and optimization of complex systems across various applications. It aids in predicting the dynamic response of structures or components to external forces or vibrations by identifying natural frequencies, mode shapes, and damping characteristics. This insight allows engineers to evaluate how the structure will perform under different loading conditions, leading to enhanced product performance, reduced development costs, and faster time-to-market.

The fixture model was utilized for modal analysis, with Fig. 9 detailing some of the properties exclusively employed in the simulation. Fig. 8 depicts the geometry file drawn and modeled using the Ansys package, while Fig. 10 illustrates the meshing of the fixture model, utilizing Tetrahedral elements. In the meshing process, a simple tetrahedral mesh element was selected in Ansys. Both geometry and meshing are critical steps in numerical simulations, thus meticulous attention was dedicated to fixture modeling.

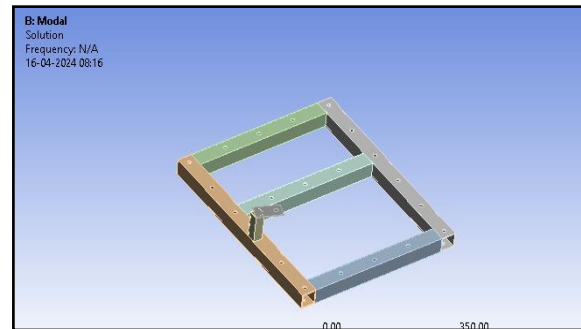


Fig. 8: Fixture Geometry

Subsequently, understanding the physics of the system became imperative. Initial and boundary conditions were carefully considered for solving this complex system, as showcased in Fig. 11.

Common Material Properties	
Density	$2.77 \times 10^{-6} \text{ kg/mm}^3$
Young's Modulus	71000 MPa
Thermal Conductivity	$\text{table}(T) = 0.14862 \text{ W/mm} \cdot ^\circ\text{C}$
Specific Heat	$8.75 \times 10^5 \text{ mJ/kg} \cdot ^\circ\text{C}$
Tensile Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa
Nonlinear Behavior	False

Fig. 9: Material Properties

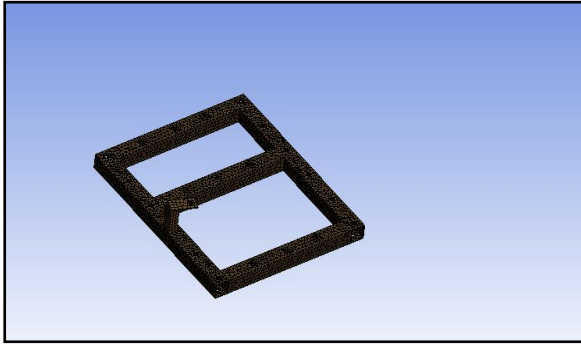


Fig. 10: Meshing of Gemoetry

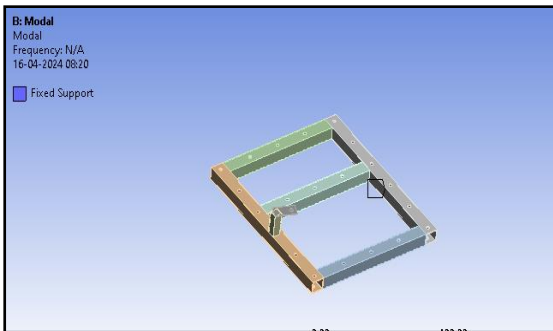


Fig. 11: Boundry Condition for Fixture

Following meshing, simulations were conducted to derive model analysis for the first five natural frequencies, as detailed in Table 5.

Mode	1	2	3	4	5
Frequen	654.	981.	1422.	1962.	2373.
cy (Hz)	4	2	5	1	7

Table 5: Natural Frequency at First 5 Modes

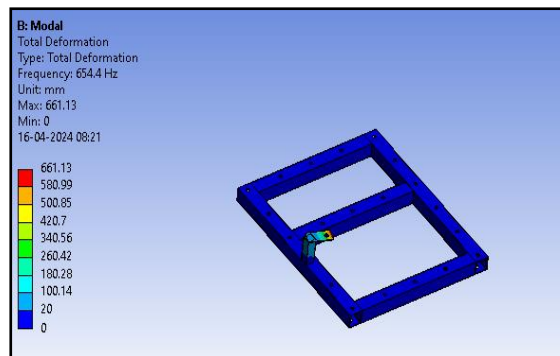


Fig. 12: Mode Frequency for 654.4 Hz

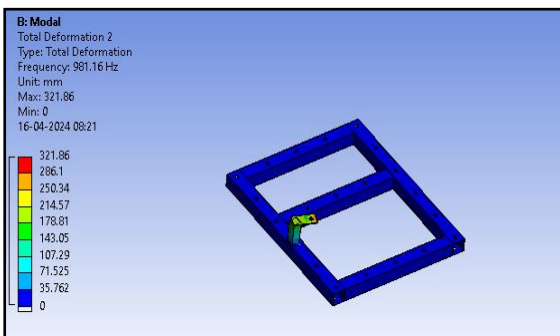


Fig. 13: Mode Frequency for 981.6 Hz

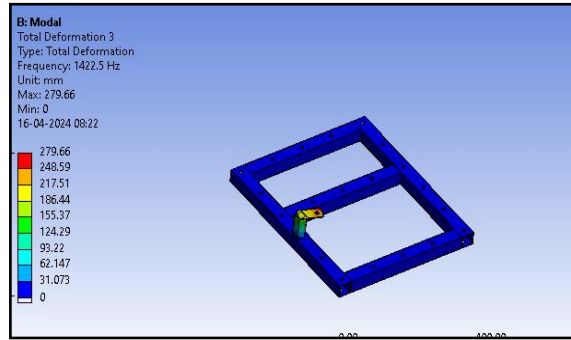


Fig. 14: Mode Frequency for 1422.5 Hz

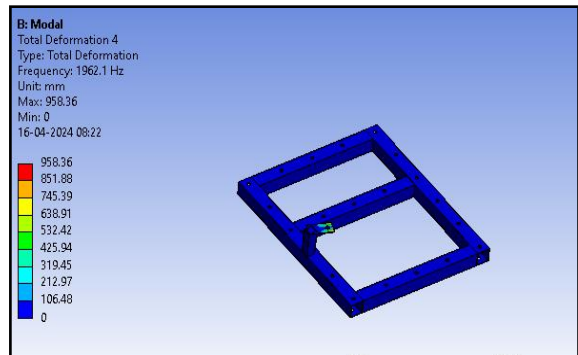


Fig. 15: Mode Frequency for 1962.1 Hz

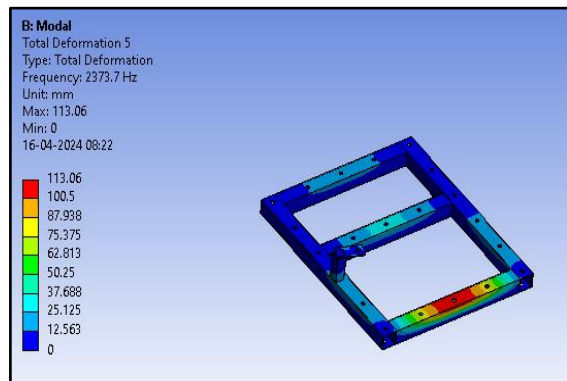


Fig. 16: Mode Frequency for 2373.7 Hz

7. Finalization of Design

After completing all the necessary parameters for finalizing the design, as detailed in steps 3 through 6 of the design methodology:

1. **Material Selection:** Aluminium alloy was chosen for the fixture due to its lightweight nature, resistance to corrosion, higher strength-to-weight ratio, and adequate damping capacity necessary for vibration testing. The main factor behind selecting aluminium alloy was its cost-effectiveness combined with superior parameters.
2. **Cost Consideration:** While mild steel is cheaper, its higher weight makes it less favorable. Approximately 8 kg of mild steel would be required

for this design compared to only 3 kg of aluminium alloy, with costs of Rs. 880 and Rs. 840 respectively.

3. Tube Shape: Square tubes were preferred over round tubes due to their superior stiffness, better boundary conditions, ease of modeling, and compatibility with mounting and attachment requirements for vibration analysis.

4. Tube Dimensions: Square tubes with dimensions of 40×40×2 mm were selected for this design.

5. Safety Factor: The geometry was finalized while considering the safety factor, ensuring that the natural frequency of the silencer, typically within the range of 200-400 Hz, was met. In this design, a frequency of 654.4 Hz was achieved at the 1st mode, exceeding the requirement by 1.7 to 3.4 times

8. Prototype Manufacturing

Following the finalization of all parameters required for prototype manufacturing as outlined in step 7 of the design methodology, aluminium alloy was selected as the material due to its suitability based on those parameters. Square tubes of the chosen material were procured from a local vendor.

Upon acquisition, the tubes were measured and marked using a measuring tape before being cut to the required length using a high-speed metal cutting machine. Subsequently, holes were drilled in the tubes using a vertical drilling machine, and any burrs were removed using a hand grinder.

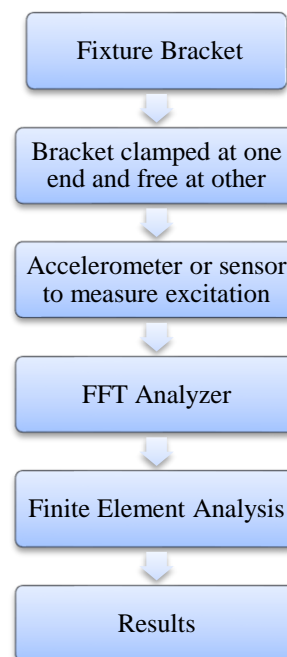
Finally, the cut tubes were connected through the brazing process (Brazing is a metal-joining process in which two or more metal items are joined by melting and flowing a filler metal into the joint, with the filler metal having a lower melting point than the adjoining metal.)



Fig. 17: Manufactured Prototype

9. Experimental Validation

Experimental validation is conducted using an FFT (Fast Fourier Transform) analyzer, which samples the input signal, computes the magnitude of its sine and cosine components, and presents the spectrum of the measured frequency components. This technique is advantageous due to its speed; FFT spectrum analyzers can measure all frequency components simultaneously, making them potentially hundreds of times faster than traditional analog spectrum analyzers.



Flow Chart 1: Experimental Analysis

To conduct experimental modal analysis of the fixture, an impact hammer is employed to provide excitation. The temperature of the fixture is monitored to ensure it remains within the operational temperature range of the accelerometer. A magnetic-based accelerometer is affixed to a specific end of the fixture. Using an FFT spectrum analyzer, data is analyzed and experimentally validated. The impact is applied to the end of the fixture via an impact hammer connected to the FFT analyzer through cables. Additionally, the response of the fixture is captured with the accelerometer positioned at the end. The analyzer receives analog voltage signals from the accelerometer, which are then used to identify natural frequencies and mode shapes through graphical analysis using software installed on a computer.

The results obtained by the FFT analyzer for the first five natural frequencies are determined and tabulated as follows.

Mode	1	2	3	4	5
Frequen	673.	957.	1396.	1923.	2353.
cy (Hz)	8	0	5	8	5

Table 6: Modal Frequency by FFT Analyzer

Frequency response function of the fixture is shown in Fig. 18 for different modes.

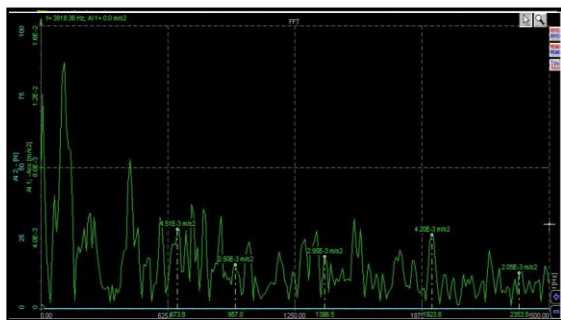


Fig. 18: Frequency response function of the exhaust system for different modes.

10. Result

Table 7 presents a comparison of the natural frequencies of the vibration silencer obtained through FEA package and FFT analyzer. The comparison indicates that the natural frequencies obtained through both methods are nearly identical, as illustrated in Fig. 19.

Mode	FEM (Frequency in Hz)	FFT (Frequency in Hz)
1	654.4	673.8

2	981.2	957.0
3	1422.5	1396.5
4	1962.1	1923.8
5	2373.7	2353.5

Table 7: Modal Frequency of Vibration

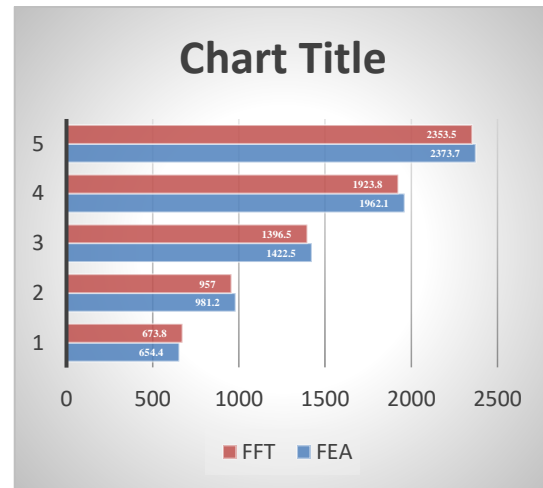


Fig. 19: Comparison of FEA and FFT Result.

11. Conclusion

The natural frequencies of the fixture were determined using both the ANSYS package and FFT analyzer, yielding similar results. This consistency is valuable in fixture design as it helps prevent resonance. Specifically, the natural frequency of the fixture, determined using Ansys 2022 R2, exceeded the typical range of 200-400 Hz for silencers, registering at 678.8 Hz (as per the FFT result), which is 1.7 to 3.4 times higher than the desired frequency. This indicates the fixture design's suitability for securely holding three-wheeler silencers. Employing FEM simulation offers a more effective approach than traditional trial and error methods for identifying errors in modal analysis, facilitating the development of a systematic strategy for modal investigation.

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