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Maximizing Versatility and Minimizing Costs: Turbocharger Design Optimization using an Adjustable Actuator Bracket

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Abstract. It is evident that the environmental pollution has become one of the major issues all over the globe, which is the cause of some of the major problems including Health problems for all human, animals and for the plants and vegetation also. So, there rises a need to overcome this problem and find the solutions for a better future. In this study, research was done around automobiles and found out some of the best techniques, currently being used to reduce emissions from the exhaust, and among them, Turbocharging was identified as a potential solution, which can help reduce automotive emissions from the IC engine, while improving the power output, performance and maintaining the good fuel efficiency at the same time. So, this was selected as area for further research and study. Using DFMA method, various experiments and analysis were performed during the process and a versatile design of turbocharger was identified, which can, not only bring down the overall cost of turbocharger, but can also help in reducing the time required to manufacture same turbochargers with multiple inlet and outlet connections and orientations by avoiding unwanted time required for redesigning, validation, and analysis of new component, which is required in the current designs. It was observed that when compared with two different currently used designs for actuator mounting, the concept got 5% to 52% cost savings than other, already available designs. Also, the analysis results were found to be good for the concept and if required, only the optimization in thickness can be done to use it in different application where the vibrations in the engine can vary from the assumptions and the minimum natural frequency required is varied. The analysis was performed assuming different operating conditions and using different actuator type and mounting position on the compressor housing.

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I. INTRODUCTION

Environmental pollution nowadays has become a major issue, which is affecting the health and lifestyle of people throughout the world. There are so many sources of pollution, but specifically the emissions from internal combustion engines (ICEs), is one of the main causes of pollution. Carbon monoxide, nitrogen oxides, and particulate matter are just a few of the pollutants that IC Engines release into the air and harm both human health and air quality. In IC Engines, there are various measures nowadays being taken to bring down the number of pollutants being produced during their operations. Turbocharger is also one from them and considered to be one of the most important components, which is effective in reducing the number of pollutants while improving the performance and efficiency of the engine in an automobile.

A turbocharger is a device, used in IC Engines, to serve various purposes. Its primary function is to provide more dense air into the combustion chamber so as the process of combustion occurs more efficiently and properly. It also provides advantage of increasing the fuel efficiency due to the engine downsizing and proper combustion of fuel during the process. Apart from all these advantages, it also helps in more efficient functioning of the After treatment Systems mounted onto the Tailpipe after the Turbocharger. The basic principle of the turbocharger is that it uses the energy from the exhaust gases of an IC Engine to compress and deliver the denser air into the combustion chamber then that of a naturally aspirated engine. A Turbocharger consists of a turbine and a compressor. A shaft rigidly connects the compressor with turbine. Shaft in between the bearing housing, is supported by journal Bearings and various other internal components. When the gases from the engine's exhaust are directed towards the turbine wheel inside the turbine side, the compressor wheel on the other side rotates with same speed as that of turbine wheel and compress the outside air to deliver it into the Engine's combustion chamber. Apart of them, there are some additional parts also, like Wastegate, actuator, and various internal small parts like thrust bearing, thrust collar, oil seals, heat shield, etc., which are responsible for the proper functioning of the turbocharger. A lot of research has already

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been done in this domain. Kaiser, K. F., Sarle, C. R., & Schwitzer, B. R. O. (1979), discussed about the importance of supercharging/turbocharging in an automobile. The objective of their work was majorly focused on comparison of naturally aspirated engine and a turbocharged/supercharged engine. The two major problems faced by the manufacturers are Cost and the versatile design of the turbocharger and these problems now have become a corporate goal rather than the engineering goal. To achieve the mounting versatility, they proposed for a solution which uses a base design to be a universal design for more than one application. By this they mean that one basic design can be used in various application which will be helpful in achieving mounting versatility and ultimately as a result, lower cost of a turbocharger. The study concluded stating three innovative concepts, versatile mounting, the rotary valve concept, and the non-rotating pin bearing system. Kokotovic, V. v., & Zhang, X. (2020) presented the trend of engine downsizing, emissions controls and fast driver input response using a turbocharger. The research majorly focused on wastegate actuation mechanism for the improved performance of the turbocharger. Pneumatic actuator has been compared with electrically controlled actuator and a SBAC system has been chosen to be applied in electric wastegate actuator for an improved performance. The need of using an electric control system for the actuation is that in a mechanically driven actuator, the lag in the mechanical links in the system results in bad air fuel ratio being put into the engine's combustion chamber. Wang, D., & Qian, X. (2010) presented some modifications in the current design of turbocharger and improved some of the parameters which in return have reduced the cost and increased the efficiency of the turbocharger. The changes include, changing impeller bearing into a magnetor which can be controlled by a displacement sensor placed on the accelerator pedal. Also, a delay circuit has been used to overcome the lag in the response of the accelerator pedal, specifically when the pedal is pressed slowly.

The research studies above make it truly clear that numerous studies have already been conducted and a large number are still in progress in turbocharger performance improvement. However, a lack of research was noticed, in the field of turbocharger's design optimisation and cost reduction. According to the literature review, the use and demand of turbochargers have been growing because of their numerous benefits, including engine downsizing, improved efficiency, higher torque output, comparably increased power generation in a smaller engine, etc. Additionally, it aids in lowering the emissions produced by the IC Engine. As far as the investigation of the turbocharger's research current state was done, there was found a scope of improvement in the design of the turbocharger, specifically which can simplify the manufacturing process as well as reduces the overall production costs for the turbocharger. It was observed that there is a need of looking deep into the manufacturing process of the turbocharger and find the specific area where there can be good scopes of improvement. It was identified as the Casting process for Compressor Housing for a compressor mounted actuator with integrated mounted Bracket. In this study, research has been conducted on wastegated turbocharger only, as it is currently the most widely used in the automotive industry.

➢ *Problem Formulation.*

Most of the turbocharger's components are manufactured by casting process. Once the casting mould is made ready for any specific geometry, it becomes exceedingly difficult, costly, and time-consuming task to redesign and recreate the mould and start production of another part with different geometry. The search narrowed down further to investigate the area where small changes in the geometry leads to the change in the casting moulds for the component and that can be eliminated. So, when a wastegated turbocharger is manufactured with the integrated bracket for the actuator can mounting, the position of bracket on the housing is fixed according to the requirement of the orientation of inlet and outlet connections of the engine with the turbocharger. It is well known that most of the time, turbochargers with same performance and specifications are used in various engines, but with different positions of its inlet and outlet connections with intake manifold and exhaust manifold. For a fixed geometry turbocharger, this is not a problem as the connections angle can easily be changed by rotating without any issue. But in wastegated turbochargers, which is now a days the most widely used turbocharger in automobile applications, a problem of mounting the wastegate actuator on the turbocharger arises. To be more specific, assume that the manufacturing is going to start, and all the moulds and processes are already finalized and due to any specific reason, there is a last-minute change in the orientations of the inlet and outlet connections, due to which the position of bracket on the compressor housing needs to be changed, which requires changing the Casting Mould geometry. Another scenario can occur when manufacturing the same turbocharger with different application where only the orientations of inlet outlet connections are varying and rest all other specifications are same. In both the cases, it is required, that different casting moulds for the different orientation must be used where the only change is the position of the Bracket. One alternate option is to mount actuator on turbine housing itself, but it becomes an expensive approach as there are various constraints that needs to be kept in mind while mounting it on the Turbine side like costly material, more material and hardware used on turbine. So, if, by any way the integrated bracket on the compressor housing can be eliminated and a bracket, which can be used at multiple orientation can be produced, not only a good amount of cost reduction but also some more undesired factors like unwanted delay in production due to design, validation and analysis of new geometry again, can be eliminated. The main objective for this research was conceptualizing a versatile design of turbocharger which is cost effective as well. For this, wastegated turbochargers can be considered as the best option, as they are the most widely type of turbochargers being used nowadays in automobile applications. The objective is to eliminate, using multiple Casting moulds for compressor housing, for multiple orientations of inlet and outlet connections. The purpose is to modify current design of the turbocharger while meeting the basic requirements like achieving minimum natural frequency greater than engine's excitation frequency while functioning. Manufacturing

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feasibility checks were also to be performed to check whether the new design is easily manufacturable. After this, comparison for the various related costs of concept design with the already present alternatives in the market needs to be done.

II. METHODOLOGY

➢ *Designing*

Designing process, not only includes the 3D Modelling of the part in the designing software (CREO), but it includes all the processes from the beginning of the design to the end where still some issues are identified in the model during the analysis phase and then some features of the part need to be redesigned to resolve the issue. It includes Brainstorming, DOE approaches, Trial and errors, feasibility checks, etc. The preliminary analysis was done using Creo analysis tool only, to meet the required thickness of the bracket design during the design phase only. For this, various options were explored, which can be helpful in resolving the identified issue. During this process, the following major options were found to be capable of serving the desired purpose.

Circular Clamp. In this, a circular clamp, as in Figure 1, can be mounted on a circular spot on the compressor housing. To lock the angular position of the clamp, it was proposed to use a flat section on the clamp as well as on compressor housing wherever it will be required according to the orientation provided. Compressor housing's circular surface can be machined accordingly as per the Orientation requirement to lock the position.

Additional material on *outer* surface. In this option extra material on the outer side of the compressor housing is added, which can be used to mount the actuator bracket. For this, when the required orientation is fixed, a flat surface can be machined along with the Tapings for the Bolts to mount bracket on the housing. An L-Type bracket was the best option to use in this type of design with two holes for the bolts to mount on the Compressor Housing and another two holes to let actuator's studs pass through them.

Bracket with Bosses. In this, some bosses were to be added on the Compressor housing on which the bracket can be fixed using nut and bolts. The idea was to keep the number of bosses as low as possible and achieve orientations as more as possible. Bracket can be manufactured in such a simplified way that it can be used from both its alternative side and can reach most of the possible orientations in a specific turbocharger. Further, three more options under this concept were discovered, as follows: -

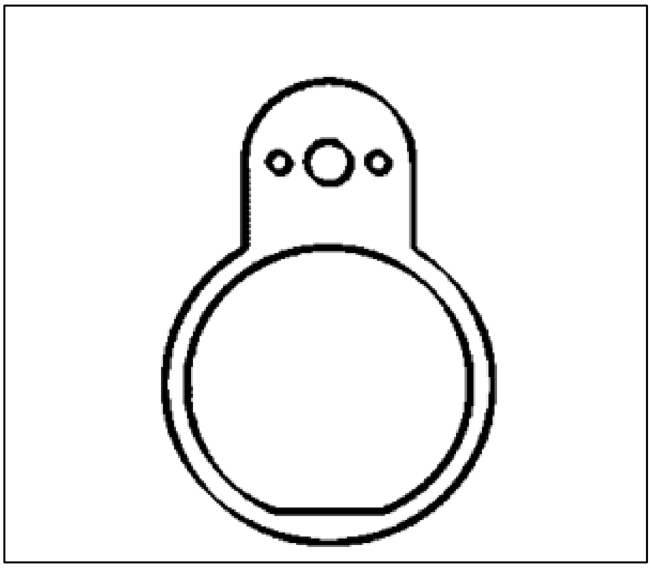

Fig1 Circular Clamp

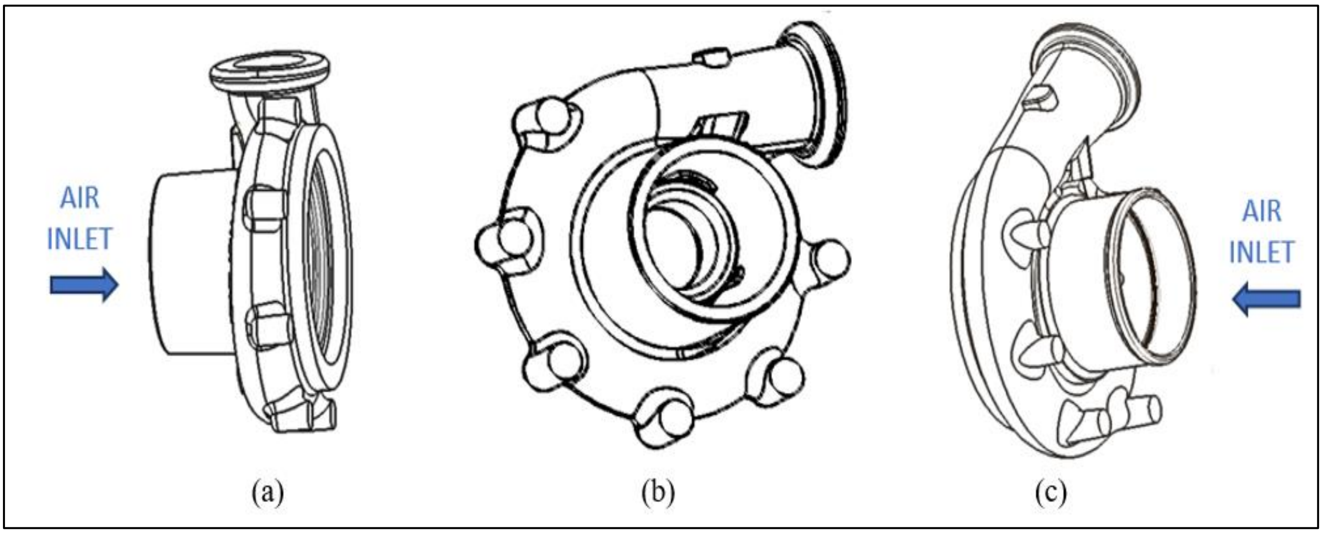

Fig 2 (a) Bearing Housing Side, (b) Outer Side, (c) Air Inlet Side

The compressor housing with bosses on the front face Fig. 2(c) is the most suitable choice for moving ahead for several reasons, including:

In finalized concept, the radius of PCD for all the bosses from the center line of the turbocharger can be kept as same which can be helpful in simplifying the design of the Bracket as there will be no need of providing adjustment for the variation in PCD of the various bosses. In the design with the bosses on outer side of the compressor housing Fig. 2(b), it was not possible to achieve the same PCD for all the bosses and maintaining same distance between each boss. Another advantage was with the manufacturing feasibility as if bosses were on the back side of the housing as in Fig. 2(a), it becomes very difficult to use Assembly tools in that region as there is limited space and also, during the assembly process of the turbocharger, turbine side is kept on the bottom side, which makes it very challenging to assemble properly, Therefore the front facing bosses were more feasible in that manner also.

For the Design Process, all the Design and Analysis Practices were Performed on a Small Sized Turbocharger 3D Model, which Further have two Variants: -

- *Compressor Mounted Integrated Actuator Bracket.*
- *Turbine Mounted Bolted Joint Actuator Bracket*.

Below are Some Major Points, which Must be Kept in Mind during the Entire Process: -

- The PCD for the Actuator shaft throughout any orientation, remains same with respect to the turbocharger center line.
- When positioning bosses and performing any machining operation on the compressor housing, minimum wall thickness needs to be maintained throughout the housing.
- There are some positions of the actuator, which are not possible in any assembly.

As the concept design was finalized, some further design optimization in the selected design were done. In concept design, at any given orientation, any two bosses out of 6 bosses are required (in casting) for bracket mounting and any one from the remaining 4 boss as per convenience, can be used for Boost Tapping, if required. By using the same boss for boost tapping, one specific boss for the same can be eliminated. The casting part will include 6 bosses, but finished part will have only three: two for bracket and one for boost tapping. It will eliminate the use of multiple casting moulds requirements for multiple orientations of customer connections and rather only one universal Compressor housing can be used for different inlet and outlet connections. When the specific orientation is finalized, it can be easily identified that which, out of the 6 bosses are going to be used for bracket mounting and which one for the Boost tapping purpose. Then the non-required bosses can be either removed using the loose core in the casting itself or by machining. That will depend on the process feasibility. Although the PCD from the turbocharger centreline will remain same for all the bosses. During the machining process, the top surfaces of the bosses will be machined at equal heights from the datum plane and then the Drilling and tapping will be done for bolts. For boost tapping, top surface will be machined as per the requirement and the hole will be made for boost tapping Hose connection elbow. In machining of holes also, the PCD will be maintained same for each bolt.

For the bracket part, there will be two slots provided in the lower portion of the bracket so that it can be mounted on the Compressor housing at any position according to the required orientation regardless of fact that the position of the bosses is fixed. The PCD for the Slots provided will remain same as the PCD for the Bosses on the compressor housing. By this, bracket can be rotated up to its slots limits without any issue. Also, as discussed earlier, the hole for the actuator shaft will be at the same PCD at any given position, therefore there will not be any change in its position radially, at any orientation.

By this design, various orientations were achieved by moving the bracket over the bosses up to its slot's limits, but there were still some constraints in the model which were decreasing its efficiency and the bracket was not able to cover most of the positions that were expected. Although, when compared to the conventional design, it was doing much better job. But it was decided to further do some optimizations in its design, by which, the reach of the bracket can be enhanced as much as possible. For this, the trial-and-error method was used. The different bracket models were made for trial and error, by changing the number of slots, dimensions of slots, positions of the slots etc. And some more designs, which looks like below, were identified and considered further.

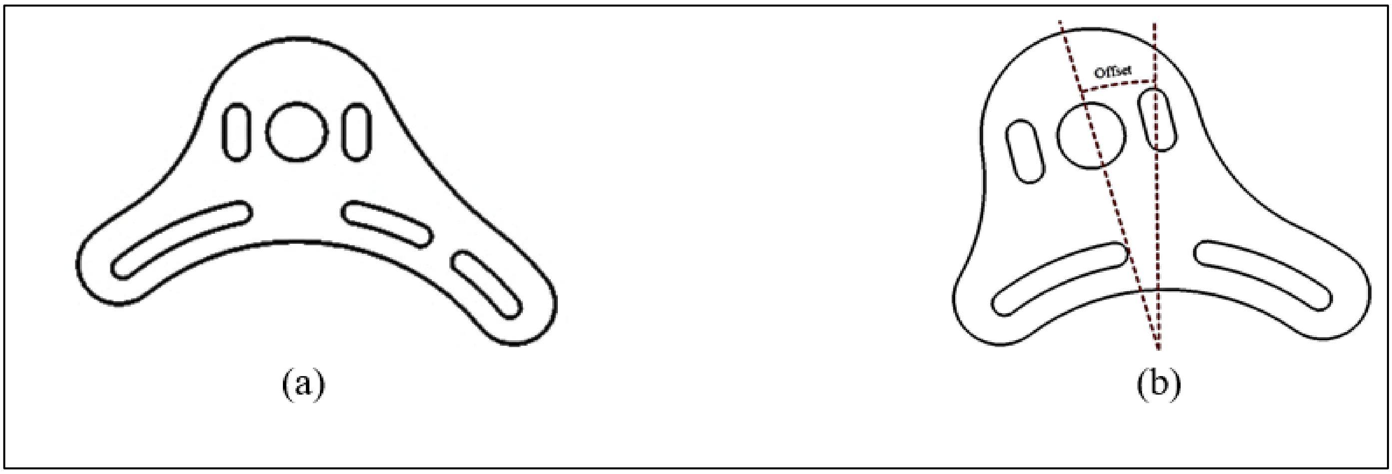

Fig 3 (a) Without Offset with Three Slots, (b) Offset with Two Slots

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As in Fig. 3(b) the one with two slots and one side offset, with respect to the center of the slots was best suited to meet the requirements because it has the beneficial advantage of being able to cover different actuator positions from its alternate face sides when flipped. Some additional changes to the chosen model were done before conducting analysis for the degrees that it covered with various offset angles. The observations after analysing the model in Assembly mode are listed in Table 1

Table 1 Orientations Covered by Different Offsets Provided, using 4mm Thick Bracket

Offset Angle	**Orientations Covered**	**Offset Angle**	**Orientations Covered**
0°	138°	10°	192°
3°	170°	12°	202°
5°	174°	14°	256°
8°	171°	17°	226°

The length of the slots in bracket is limited, and it cannot be assembled at all the positions where the slots end. But, if it is flipped to its alternate side, the assembly can be made possible at those positions also, and the required orientation can easily be achieved with the same compressor housing and the same Bracket. This is the most important feature for the concept.

➢ *Assembly Process*

In the assembly process, only Compressor housing, Bracket, and Actuator-Can body were considered. As it is already mentioned, the position of the actuator-can remains same in any given orientation with respect to the turbine housing, so there is no need of considering other components in the further process. Assembly is made while keeping the Central axis of Bracket PCD and that for the Compressor housing to be Coinciding with each other.

Also, as it is a wastegated turbocharger, a hose pipe is also assembled with one side, connected to the actuator and another to the compressor housing which uses the air pressure inside the compressor as an input to actuate the Diaphragm inside the Actuator and Open/Close the wastegate valve accordingly.

➢ *Analysis*

For analysis, the major criteria that must be satisfied is to achieve bracket's first natural frequency to be more than the excitation frequency generated by the engine, as it plays very crucial role in the lifetime of the Bracket in operating conditions. Analysis was performed, both in CREO and ANSYS. Firstly, a preliminary analysis for all the bracket designs was performed in the CREO right after it was designed to check parameters like thickness and any other major design change. To find out the target frequency, initially the frequency generated by the engine is calculated as below: A 4-cylinder engine with rated RPM of approximately 2500rpm was considered. The calculations for the same are below.

$$F = \frac{(engine\ speed \times No.of\ Cylinders)}{60}$$

$$Where\ F = Frequency\ (Hz)$$

Keeping in mind the unidentified variations in values, the value is calculated taking (engine speed+10%) rpm, to be on the safer side while doing analysis.

$$F = \frac{\{(engine\ speed + 10\%) \times No.of\ Cylinders\}}{60}$$

$$F = \frac{\{(2500 + 10\%) \times 4\}}{60}$$

$$\boldsymbol{F = 183.33Hz}$$

This is the minimum target frequency, or excitation frequency of the engine which the bracket must achieve to sustain failure. Firstly, the analysis was conducted in CREO using Bracket and the Actuator Can only to check whether the bracket meets the requirement or not. For this, only the thickness, actuator type and the position of mounting was changed in different arrangements of assembly to conduct the analysis.

The results from the CREO analysis as in Table 4**,** signifies that the 4mm bracket is enough to meet the expectations, i.e., having first natural frequency more than the excitation frequency of the engine, so further analysis in ANSYS 2021 R1 was done using 4mm bracket with some small optimizations in its design. A simple Dummy shaker table model with two bosses as replacement for the Compressor housing was modelled to simplify the structure for Analysis. After this, different combinations by changing actuator size and mounting positions of bracket on the Dummy Shaker Table were made. The 3D model was made in Creo and then saved as .STP file. STP file then imported into the ANSYS, and same process was followed for other combinations also.

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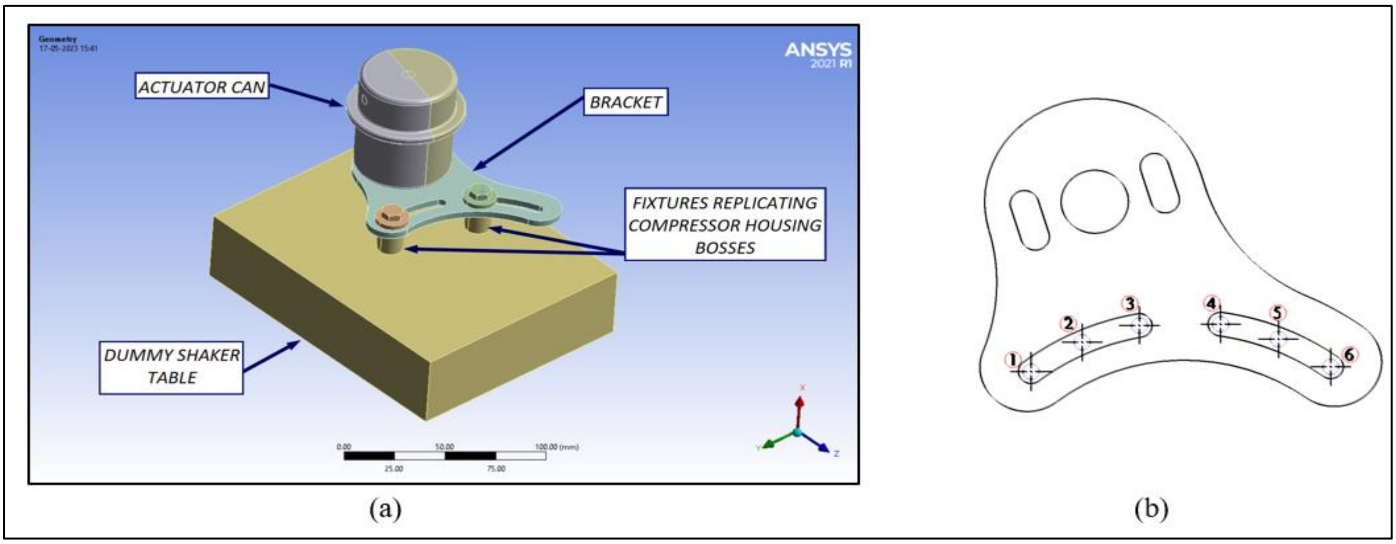

Fig 4 (a) Geometry Setup Detail from ANSYS Mechanical, (b) Mounting Positions on Bracket

First, the Structural analysis was performed so to add fixed support and preloads in the bolted joints. Then its solution was given as initial condition for Modal analysis Setup. After the Modal analysis generated the results, the solution of modal analysis was given as input for the Harmonic Setup, by which, the stresses generated during operation at those specific frequencies were checked. Harmonic Responses consists of three different setups which are given acceleration in X, Y, and Z directions respectively with frequency ranging from 20-200Hz.

Now the next Steps, which Needs to be Followed in ANSYS before Starting to Solve the Solutions are Listed as below: -

➢ *Geometry is Imported into Design Modeller.*

- All the surfaces, which are going to have contacts, with the connected geometry, or needs to have different mesh sizing are imprinted using the Imprint Face option.
- In ANSYS Mechanical, Materials are assigned to the bracket, Shaker table, Actuator can, Nut & Bolts as Structural Steel.
- Coordinate systems to the Bolts and Studs on Actuator can are added, to apply bolt pretension in later stage.
- For the contacts, all the surface in contact with each other, are given frictional Contact. For Bolts and nuts, the area with the thread engagement are given bonded joint.

Meshing is done by applying body sizing of shaker table, nut and bolts, actuator can and bracket as 5mm, 1mm, 1.5mm, and 1.5mm respectively and all the Imprinted faces are applied Face Sizing of 0.5mm

- Fixed support to the shaker table's bottom surface is applied.
- For bolt pretension, M6 bolts were considered. So, bolt pretension was calculated and applied accordingly as below.

$$P = \frac{T}{KD}$$

Where, P = Pretension
K= 0.2 (Torque coefficient)

D= 6mm or 0.006m (Thread Nominal Diameter)

T= 8.5Nm (Torque)

$$P = \frac{8.5}{0.2 \, X \, 0.006}$$

$$\boldsymbol{P = 7083.33N}$$

The Bolt pretension of 7083.33N was applied to each bolt and studs in the assembly. After applying the preload, in the analysis setup for Harmonic Response, 20G acceleration is applied in each direction (X, Y, and Z), with Frequency range (20Hz-200Hz).

➢ *Cost Analysis*

In the concept design, there is a major benefit of cost saving when manufactured in bulk quantity as well as in less quantity. A comparison was done between the three types of actuators mounting types i.e., turbine mounted bolted bracket, compressor mounted integrated bracket, and concept i.e., compressor mounted bolted bracket. Different assumptions were made, and the comparison was performed excluding other parts then the modified parts. Only the bracket, compressor housing and turbine housing were considered in this comparison as there is not any other major change in the model which will affect the cost. The cost comparison was done for 100k, 50k and 10k volumes of turbocharger having five different orientations/Inlet-Outlet connections.

➢ *Prices for the Raw Material: -*

Grey Cast Iron for Turbine Housing= Rs 60/kg

Aluminium for Compressor Housing = Rs 260/kg

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Steel for Bracket = Rs 85/kg

- For Turbine Housing, around 12% weight reduction was observed by removing the additional material which was there to mount Bracket.
- For Compressor housing, there is a slight increase in the weight of casting of around 1% to that of the current design.
- For Bracket, the reduction in weight is around 26% in concept design.

Table 2 Raw Material Cost and Weight

	Change (%)	**Current design Raw Material**		**Concept design raw material**	
	+/-	Weight(kg)	Cost	Weight(kg)	Cost
Turbine Housing	-12%	5.0	₹ 300	4.40	₹ 264
Compressor Housing	+1%	2.0	₹ 520	2.02	₹ 525.2
Bracket	-26%	0.20	₹ 17.0	0.15	₹ 12.58

$$\text{Total Cost for Compressor housing} = \text{Mould cost} + \text{Raw Material cost}$$

For compressor housing casting mould cost, five orientations for Inlet Outlet connections were considered.

➢ *Moulding Cost for Compressor housing*

$$\text{Cost for One piece} = \frac{\text{Total cost}}{\text{Total Volumes}}$$

$$\text{Mould cost in current design} = ₹1{,}50{,}00{,}000$$

$$\text{Mould cost for concept design} = ₹30{,}00{,}000$$

$$\text{Weight of casting for current design} = 2 \text{ kg}$$

$$\text{Weight of casting for New concept design} = 2.02\text{kg}$$

Table 3 Compressor Housing Total Cost

	Volumes	**Raw Material Cost**	**Moulding Cost/Piece**	**Total Cost Per Piece**
Current Design (Uses five moulds)	100k	₹ 520.00	₹ 150.00	₹ 670.00
	50k		₹ 300.00	₹ 820.00
	10k		₹ 1,500.00	₹ 2,020.00
Concept Design (Uses One mould)	100k	₹ 525.20	₹ 30.00	₹ 555.20
	50k		₹ 60.00	₹ 585.20
	10k		₹ 300.00	₹ 825.20

For machining cost of bracket, it is calculated based on hourly basis for the machine and the cycle time, that one bracket requires for complete manufacturing. In current design, it requires around three different processes, which needs to be performed on the bracket for complete manufacturing, but the concept design of bracket can be manufactured in only one step process as all the geometrical features can be made on the sheet metal using one die and punch only. So, it clearly shows the cycle time for the concept in one-third to that of the current design. Therefore, the machining cost for the concept design will be one third to that of the old design.

$$\textit{Assuming machining cost for Old Bracket} = Rs\ 10/piece$$

$$\textit{For our concept, machining cost after reduction} = Rs\ 3.33/piece$$

$$\textit{Total Cost for one bracket} = \textit{Raw material} + \textit{Machining cost}$$

$$\textit{For Current Design} = \boldsymbol{Rs\ 27.^{00}/piece}$$

$$\textit{For Concept Design} = \boldsymbol{Rs\ 15.91\ /\ piece}$$

III. RESULTS AND DISCUSSIONS

Table 4 Modal Analysis Results in CREO

Sr. No	**Thickness**	**Mounting Position**	**Frequency (Hz)**
1	3mm	1-4	145.99 - 175.56
2	3mm	2-5	181.89 - 216.24
3	3mm	3-6	147.93 - 176.88
4	4mm	1-4	197.69 - 230.58
5	4mm	2-5	256.68 - 305.84
6	4mm	3-6	199.59 - 235.98
7	5mm	1-4	242.78 - 292.51
8	5mm	2-5	334.11 - 402.92
9	5mm	3-6	246.55 - 294.85

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- *The Mounting Position are Determined Assuming the Bolts, Bolted as in Fig. 4(b).*
- *The Modal Analysis was Performed Taking three Distinct types of Actuators Varying in their Masses.*

In Ansys, the analysis was performed on 4mm thick bracket only which was already identified as the optimum thickness for the application during Preliminary analysis in Creo. Analysis was performed on three distinct positions using three different types of actuators varying in their masses and the results obtained were as following: -

Table 5 Modal Analysis Results from ANSYS

Sr No	**Mounting Position**	**Frequency (Hz)**
1	1-4	248.4-359.7
2	2-5	310.1-366.3
3	3-6	304.0-312.2

After getting the above results, the same configuration of the bracket and compressor were used for further analysis of cost to get an idea of how much potential is there for the savings, taking various scenarios regarding number of volumes being manufactured.

Table 6 Cost Comparison with Current Designs

	Volumes	**Turbine mounted Actuator (₹)**	**Comp b Mounted Integrated (₹)**	**Concept Design (₹)**
Turbine Housing Costs	-	300	264	264
Bracket total costs	-	27	-	15.91
Comp. Hsg. raw Material Costs	-	520	520	525.2
Compressor Housing Moulding Cost	100k	30	150	30
	50k	60	300	60
	10k	300	1500	300
Total cost	100k	₹ 877	₹ 934	₹ 835.11
	50k	₹ 907	₹ 1084	₹ 865.11
	10k	₹ 1147	₹ 2284	₹ 1105.11

- Concept, when compared with turbine mounted actuator bracket configuration, savings are 5%, 5%, and 4% for 100k, 50k, and 10k volumes, respectively.
- When compared with Compressor mounted integrated actuator bracket configuration, savings can be as huge as 11%, 20%, and 52% for 100k, 50k, and 10k, volumes, respectively.

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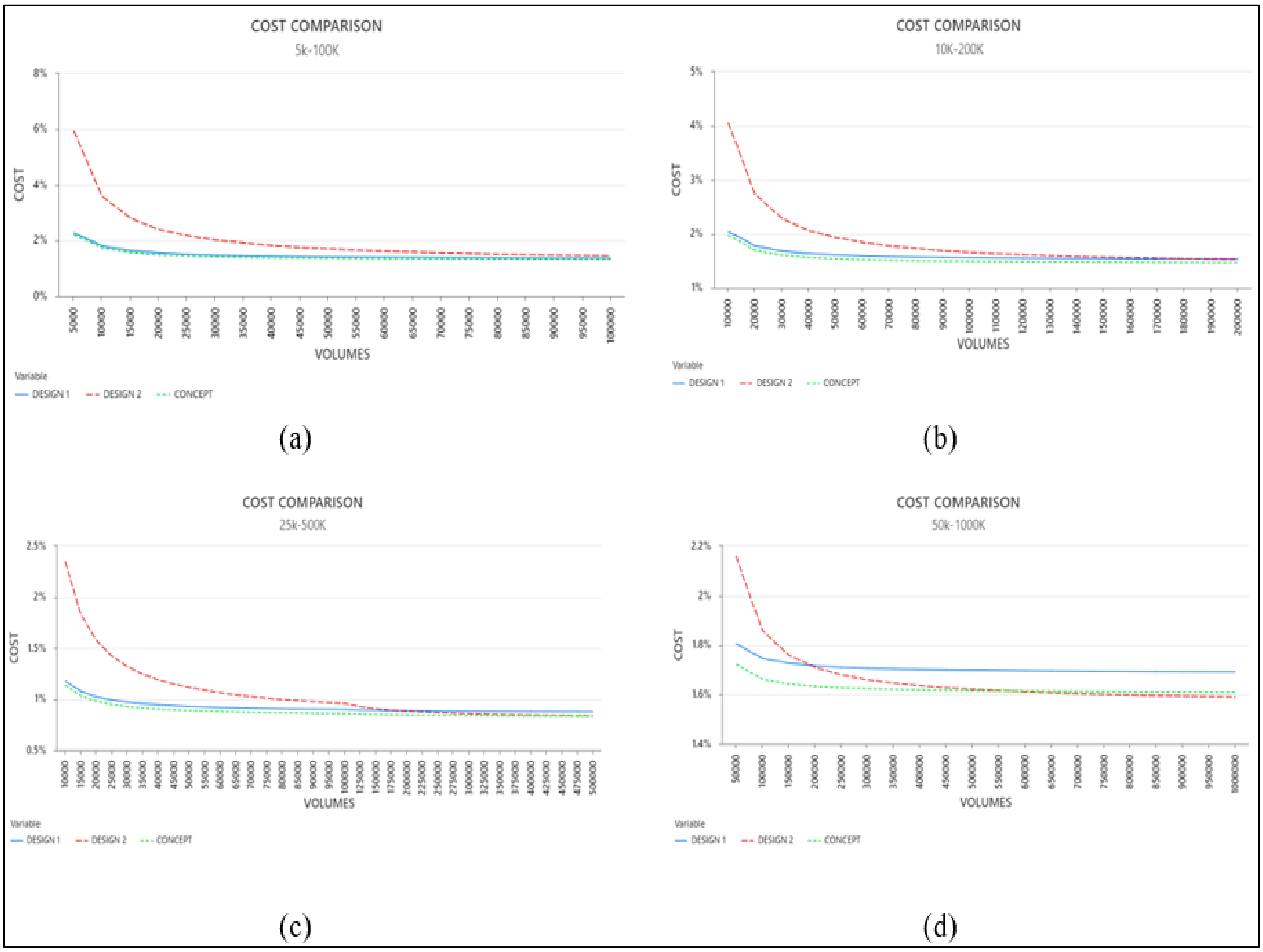

Fig 5 Graphical Representation for Cost Comparison Between Available and Concept Design for Volumes Ranging, (a) 5k to 100k, (b) 10k to 200k, (c) 25k to 500k, (d) 50k to 1000k

The above graph represents the variation in the cost of turbocharger with respect to the different ranges of volumes being manufactured.

Although the actual cost of a turbocharger includes numerous other expenses such as for raw materials, processing, validating, labour, energy, etc. However, only the costs that will be directly impacted by the concept design process are included in the study above. For this, all other costs can be assumed as to be same.

IV. CONCLUSION

The turbocharging has been identified as one of the most prominent solutions for the Emission reductions from an Automobile IC Engine. The optimization of turbocharger design has been explored in this research work with a primary focus on attaining cost reductions.

➢ *This Study's Primary Outcomes Include the Following:*

- Through a combination of theoretical analysis, computer simulations, and experimental investigations, an optimal design of the actuator bracket was developed and has achieved its desired feature of serving multiple orientations of inlet-outlet connections while using only one Compressor housing mould.
- The First natural frequency is more than 25% above the minimum required limit, if worst case is considered, which makes it compatible for majority of the Automobiles application in its segment.
- It can contribute to reduce the overall cost of the turbocharger in case of multiple orientations of turbochargers due to varying inlet and outlet connections.
- Total savings in the concept varies from 4% to 52% when compared with different configurations and depending on number of total volumes ranging from 10k to 100k.
- For a particular range of volumes being manufactured, it shows a significant reduction in the cost.

This study has highlighted the gap in the current studies being done on the Turbochargers, through a thorough literature review. Accordingly, the design process was performed, and the overall results were found as per the required criteria.

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