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# DESIGN AND VALIDATION OF TURBOCHARGER COMPRESSOR HOUSING WITH INTEGRATED ACTUATOR BRACKET THROUGH ROBUST ENGINEERING APPROACH

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**Abstract:** Robustness means developing products that are insensitive to noise factors such as a. variations in customer usage, b. manufacturing variations, c. variations in ambient conditions, d. degradation over time and e. interactions from neighboring systems. Robust Engineering is a process to "design in product capability and its verification" versus "build-test-fix-build-test-fix…" mentality. The purpose is to design, develop and verify products that will deliver the intended functions with quality. The OEMs are behind developing cost-effective products without comprising on quality and performing intended functions. A typical waste gated turbocharger has an actuating mechanism mounted on the turbine housing of the turbocharger. This type of fixing would be preferred if the compressor housing is required to be flexible for its orientation with respect to the turbine housing. To accommodate the mechanism design on the turbine housing, the design of the housing would be made such that it has got enough mounting space to have the waste gate mechanism seated on it. This would make the housing and hence the turbocharger heavier. The actuator bracket being close to turbine will be subjected to high temperatures and shock loads from the housing and its surroundings. A lot of cost is spent on fabricating the bracket and a lot on its validation. As an alternate option, the actuating mechanism could be mounted on the compressor housing which is away from heat sources. Sheet metal brackets came into usage at compressor side. A minimum of 3mm thick sheet would serve the purpose of keeping the actuator intact with the housing. As a new approach, in order to reduce the cost to fabricate and validate the sheet metal bracket to be mounted on compressor housing, the bracket feature is introduced as an as cast feature in the housing. This design being modular saves huge amount of cost. The paper is all about the design and development of the integrated bracket compressor housing using Robust Engineering Methodology to demonstrate product quality, performance and at the same time meet the customer's stringent cost targets.

**Keywords:** Turbocharger Compressor, Robustness

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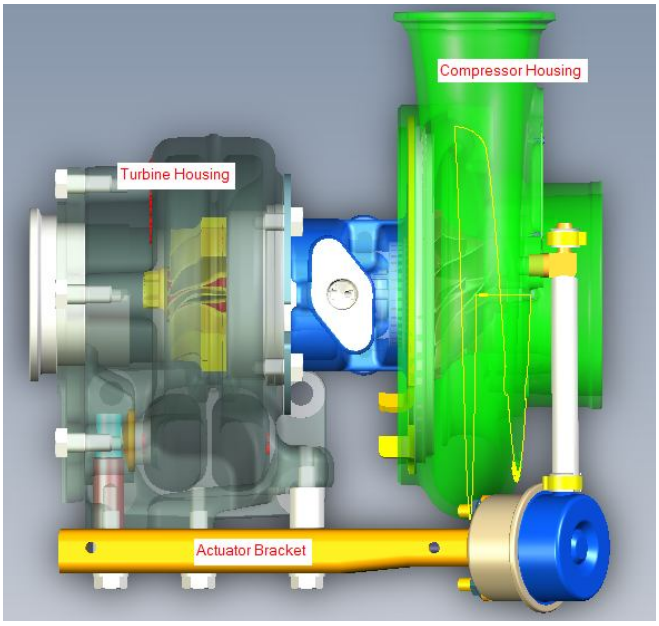
## INTRODUCTION

Turbochargers with actuator mounted on Turbine housing looks like what is shown in Pic.1. The actuator



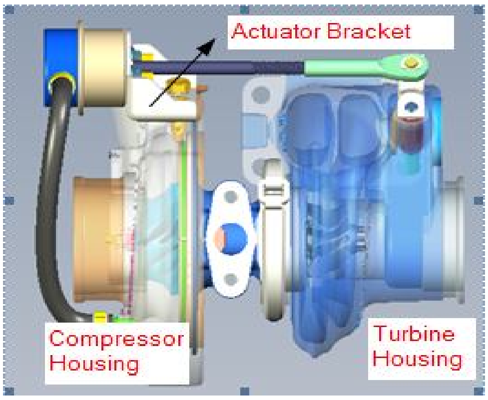

Pic1: Actuator Mounted on Turbine

does not have a contact with compressor housing and thus making it free to rotate during turbocharger assembly or installation on engine. An addition of 400gm of mass on an average is expected on the turbine side while attempting to accommodate actuator mounting, which increases the final cost of the turbine housing and hence the overall turbocharger system.

Most automotive engines require waste gate turbochargers. The waste gating is achieved by the actuator controlled by a valve and the whole mechanism can be either mounted on turbine or compressor through an actuator bracket. The waste gate operates due to pressure difference created between the end housings – one by the exhaust gas and one by the compressed air. A typical actuator bracket not only holds the waste gate actuator intact but also withstands vibration and other effects from the surrounding. Thus, actuator bracket has to be deisgned to withstand the weight of the housing, structural loads exerting on it and vibration. A typical bracket failure on field is as shown in Pic.2

Pic 2: Typical Bracket failure

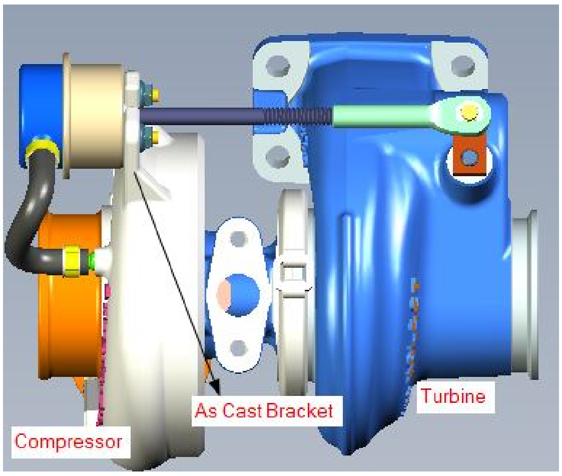
Bracket failures are very severe to turbocharger performance. As an alternative to turbine mounted actuators, compressor mounted actuators are considered cost effective. See Pic.3 – A typical compressor mounted actuator is shown below.




Pic 3: Compressor Mounted Actuator

The actuator mechanism as shown above has its mounting on compressor housing using a sheet metal bracket. The bracket may be bolted with the housing, brazed or welded depending on the requirement and assembly of turbocharger in situ. The bracket design is very simple compared to the turbine mounted bracket. There is no or negligible amount of mass addition to accommodate a bracket in the compressor housing. It is not going to be possible to rotate the compressor housing to suit to the turbine orientation as the compressor end would be fixed. Compressor mounted actuators are commonly used in applications where the turbo charger orientation is fixed.

A typical 3-4mm thick bracket, would be designed and developed. During the design stage, frequency and modal analysis is done on the bracket to understand the stresses developed at the bracket region and what would be the ultimate strength of the bracket material. To validate the simulation, a vibration endurance test is conducted. Compressor mounted actuators with sheet metal bracket typically involves a new tool development for bracket, simulation of the bracket and validation of the bracket. The new generation of compressor mounted actuators has a cost advantage over the sheet metal bracket. See Pic 4.




Pic 4: As Cast Mounting for Actuator

## CONCEPT SELECTION

When the different types of mounting interfaces compared with each other using a Six Sigma tool "Pugh Concept Selection Matrix", the "As cast mounting" interface came out to be best concept that can be offered to the customer. Below is the snap shot of the result from Pugh Matrix.

| *Bracket Mounting on Compressor/Turbine* | | | | |
|---|---|---|---|---|
| | Concept | | | |
| Criteria/Concept | Datum | | | |
| | As Cast with Compressor | Sheet Metal on Compressor | Turbine Mount | Brazed on Compressor |
| Weight of the housing incl. bracket mount | S | - | - | - |
| Ease of mounting bracket on housing | S | S | - | S |
| Number of parts required to mount | S | - | - | S |
| Cost of the mounting interface | S | - | - | - |
| Interference with Neighboring systems | S | S | S | S |
| Aesthetics | S | S | S | S |
| Weight of the Bracket | S | + | - | + |
| Unintended Function | S | S | + | S |
| Safety | S | - | - | - |
| Total Σ + | 0 | 1 | 1 | 1 |
| Total Σ – | 0 | 4 | 6 | 3 |
| Total Σ S | 13 | 4 | 2 | 5 |
| Total | 0 | -3 | -5 | -2 |
| Rank | 1 | 3 | 4 | 2 |

Table 1: Pugh Concept Selection

**DESIGN FAILURE MODES & EFFECTS ANALYSIS**

Towards making a successful product, understanding of failure modes of the part is the most important and critical aspect of product design. A DFMEA was done inorder to understand and better design the As cast bracket feature in the compressor housing.

Pic 5: As Cast Bracket for DFMEA

Typical failure mode on the function of the bracket are:

- Bracket bending during operation
- Bracket hole deformation
- Bracket crack due to excessive load

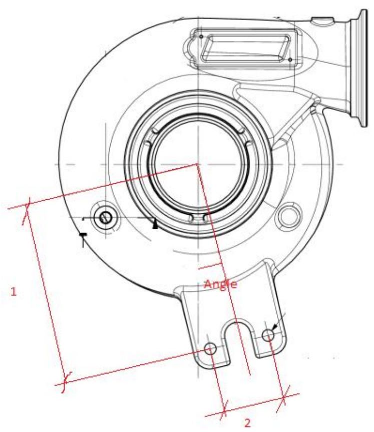
Failure of bracket means failure of turbocharger to deliver the required performance and hence it has the highest severity.

| *Failure Mode* | *Potential Root Cause or Failure Mechanism* | *Design Controls – Prevention* | *Design Controls – Detection* |
|---|---|---|---|
| No interface for mounting actuator assy. | No integrated feature | Concept design, 3D model | Assembly trials (3D) |
| Mounting interface is longer than actually | Thick bracket | Concept design, 3D model; CFT review | Assembly trials (3D) |
| Mounting interface deforms | Mounting design not capable | Reliability data of similar design; | Vibration testing |
| Not enough interface to hold actuator assembly | Mismatch of holes in bracket and stud | Concept design, 3D model | Assembly trials (3D) |
| | Area available at the bracket surface less than the area of the actuator Can | Concept design, 3D model | Assembly trials (3D) |
| | Bracket height too much (cantilever effect) | Concept design; Reliability data of similar design | Random Vibration Analysis |
| | Mounting design not capable (bracket angle) | Concept design; Reliability data of similar design | Assembly trials (3D) |
| | Bracket thickness not optimized | Concept design; Reliability data of similar design | Random Vibration Analysis |
| | Casting defect at bracket region | Concepet Design; Proper standard in place | Inspection |
| No holes drilled or Only one of the holes drilled | Drawing not correct | DQR, Design Review | Hardware inspection |
| Holes too big or too small | Huge variation in hole sizes | DQR, Design Review | Hardware inspection |
| Hole deforms | Material creep | | |

Table 2: DFMEA on As Cast Bracket

Through DFMEA, a root cause for each failure mode was arrived at, decision on preventing the failure to occur the second time is taken and what validation can be done to detect the failure mode is also arrived at. As recommended by the FMEA committee, a Modal Analysis and Random Vibration analysis was carried out on the design.

**Design of Bracket**



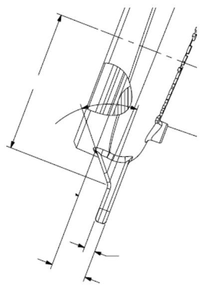



Figure 1: Front View of Bracket Figure 2: Side View: Ribs

Bracket design specification:

- Center distance from Axis
- Bracket width
- Ribs for stiffness
- Center distance for mounting holes
- Clearance for actuator rod

Based on the castability of the product, existing company standards, engineering judgement and experiences of the supplier, the as cast bracket design have been arrived at.

**Modal Analysis**

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. For evaluating the brackets, care must be taken that the least natural frequency of bracket should be more than the natural frequency of the engine to avoid resonance. This target frequency can be calculated using the formula below, **Target Freq. = (Rated Engine Speed + 10%) X No. of Cylinders / 60**

Using the above formula, the target frequency for a 6 cylinder engine with rated speed as 2500rpm would be 183Hz.

Modal Analysis was run in Ansys Work bench 14.5 and the following material properties were input.

**Actuator Can- Structural steel**

E = 200 GPA

Density = 7850 Kg/m^3

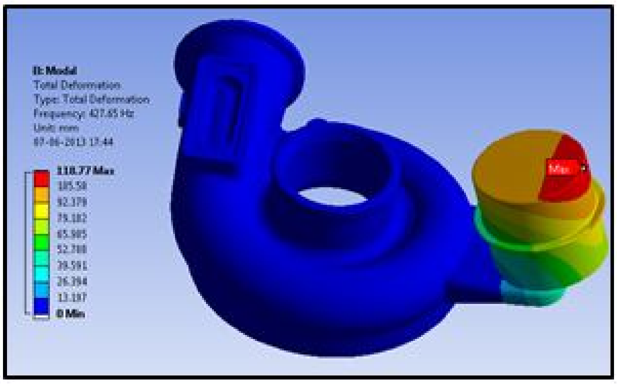
Poison Ratio = 0.30

**Compressor-Aluminum**

E = 71GPA

Density = 2770Kg/m^3

Poison Ratio = 0.30




Pic 6: Mode Shape

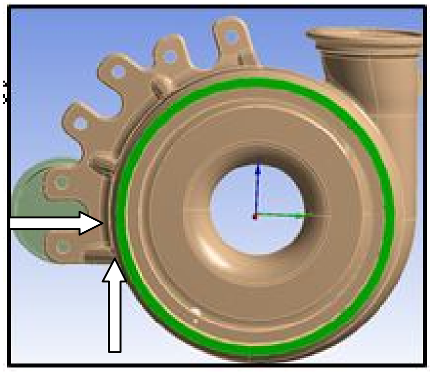
Result – Modal Frequency 427Hz which is higher than the target frequency.

**Random Vibration Analysis**

In Mechanical engineering, random vibration is the most indeterministic. The modal analysis gives the information on the mode shapes and natural frequencies where as there is no emphasise on whether the bracket design is good enough to withstand load and what are the stress concentration areas, etc. Random Vibration analysis would give a clear picture of the stress plot in the bracket region. Based on the RVA, the design could be changed / enhanced. Some common examples include an automobile riding on a rough road, wave height on the water or the load induced on an airplane wing during flight.

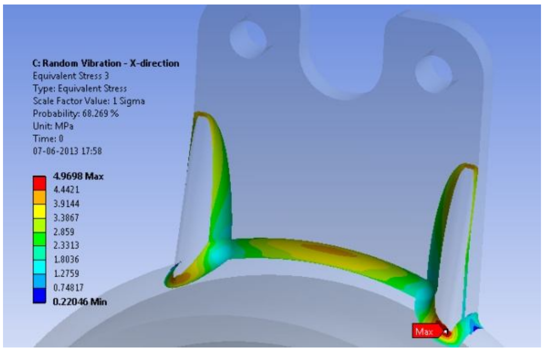
Power Spectral Density is commonly used to specify a random event. A spectrum analysis is one in which the results of a modal analysis are used with a known spectrum to calculate displacements and stresses in the model. A PSD spectrum is a statistical measure of the response of a structure to random dynamic loading conditions. It is a graph of the PSD value versus frequency, where the PSD may be a displacement PSD, velocity PSD, acceleration PSD, or force PSD. Mathematically, the area under a PSD-versus-frequency curve is equal to the variance (square of the standard deviation of the response).

Load conditions are applied in three directions X, Y and Z. Stress and deformation plot is looked into in each direction.

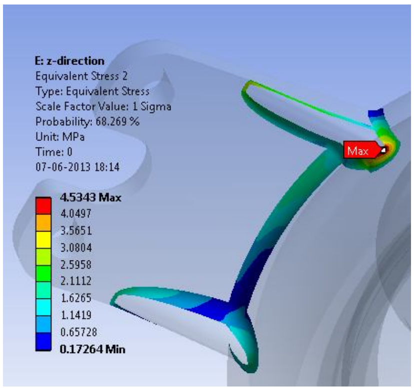


Pic 7: Load Application

The stress plot at the bracket region is shown in Pic 8.




Pic 8: Stress Plot – X Direction

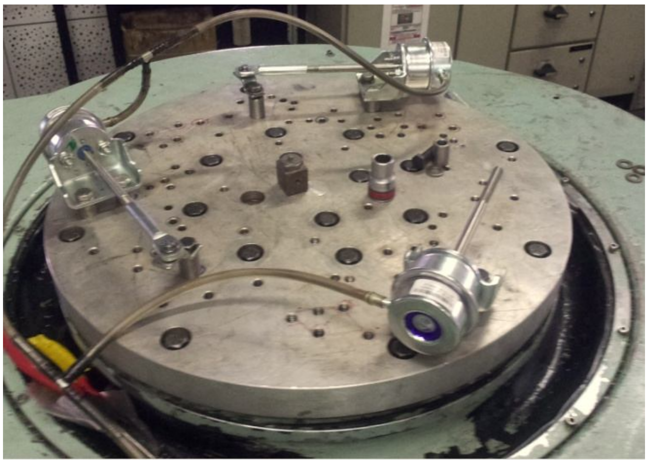



Pic 9: Stress Plot – Y Direction

Similarly the Z Direction plot is also taken. Since the Random Vibration Analysis did not show any sign of risk in bracket failure or breakage, the failure mode which was considered earlier can be prevented.

## EXPERIMENTAL TESTING

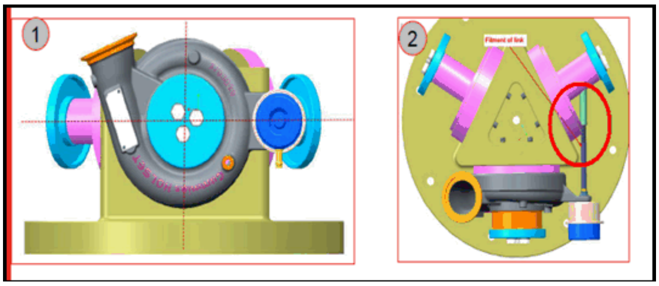
The next step in robust engineering methodology is verification. Simulation results from RVA need to be validated through Electro dynamic Shaker Rig Testing. A shaker is a device that excites the object or structure according to its amplified input signal. Several input signals are available for modal testing, but the sine sweep and random frequency vibration profiles are by far the most commonly used signals.



Pic 10: Typical Shaker Rig Test Set up for Sheet Metal Actuator Bracket

Small objects or structures can be attached directly to the shaker table. With some types of shakers, an armature is often attached to the body to be tested by way of piano wire (pulling force) or stinger (Pushing force). When the signal is transmitted through the piano wire or the stinger, the object responds the same way as impact testing, by attenuating some and amplifying certain frequencies. These frequencies are measured as modal frequencies. Usually a load cell is placed between the shaker and the structure to obtain the excitation force.

A new test fixture was developed to install the as cast bracket on to the shaker table.




Pic 11: Fixture for As cast Bracket

**Test Cycles:**

The test is conducted in 3 directions X, Y and Z like the RVA. In each direction, the shaker is run for 50 hours at 20G acceleration and at the frequency level of 75 – 250Hz.

**Test Acceptance Criteria:**

If the product sustains 50 hours without any failure, then the test is regarded successful.

**Test Result:**

The Compressor housing with as cast bracket passed 50 hours in all the directions without any failure.

After the test has been completed the DFMEA is again visited and the risk associated with the failure mode in terms of RPN would be reduced based on the success of the test.

## CONCLUSIONS

Robust engineering helps one to define a problem in a basic fashion initially and applying logic to it, an approach can be outline to which technical details can be added. Instead of going in reactive engineering robust engineering teaches how to apply proactive engineering. The design of compressor housing with integrated actuator bracket is a classic example of how robust engineering can be applied.

Integrated actuator bracket compressor housing design is cost effective compared to its sheet metal design. As a first time, the vibration endurance testing is conducted to validate the simulation. The design has proved its robustness. Henceforth, the integrated bracket design would not require to be vibration tested, there-by creating a cost saving opportunity.

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