Analysis Led Design of Actuator Bracket with the Effect of Pretension, Actuation Force and Coefficient of friction

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***Abstract*—The pneumatic actuator is the type of actuator used in wastegate turbocharger. For functional requirement of actuator mechanism, it is mounted on turbine housing or compressor cover using actuator bracket. The actuator bracket is subjected to conditions such as Engine vibration and High temperature, therefore it is required to design the actuator bracket which will sustain these conditions. The intent of this project is to identify critical factors contributing to the dynamic behavior of turbine mounted actuator bracket. To ensure the actuator is enduring in all operating conditions, the effect of various parameters (Preload, Actuator Force, Coefficient of friction) on actuator bracket design need to be studied in order to improve the existing analysis process and to get more accurate results by depicting analysis model very close to actual actuator system.**

Keywords*— Preload, Actuator Force, Coefficient of friction, Actuator bracket, Watsegate turbocharger.

I. Introduction

In the turbocharger industry, on most commonly turbocharged engines there is mechanical system called a wastegate, which is a valve that allows some of the exhaust gas to pass directly from exhaust manifold to exhaust pipe to control maximum boost in turbocharger. Smaller turbine housing with wastegate valve can be used for better performance and improved emissions at high altitudes. Wastegate is usually controlled by actuator mechanism that is connected to manifold pressure. The wastegate valve is held closed with the spring inside actuator canister at predetermined boost pressure.

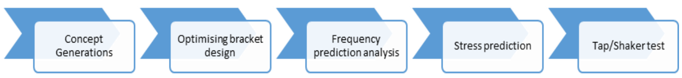
Turbocharger works at very high speed say 80000 to 100000 rpm and above. As a result turbochargers are subject to many sources of vibration and operates at very high temperature. Vibration plays an important role on durability, warranty costs and end user's perception of vehicle quality. Design of each sub-component of a system requires a consideration of its oscillatory behaviour and the structural parameters that drive any problematic response. For turbocharger, there is risk of resonance points within engine operating range due to overhang mass.

The pneumatic actuator is the most common type of wastegate actuator and although apparently simple in construction, it must be designed carefully to avoid failures in the field. Any damage in the wastegate actuator mounting bracket, mounting bolts, actuator canister, actuator rod and wastegate lever could result in the failure of the wastegate actuator to operate. For functional requirement and various constraints like space, application requirements etc. actuator mechanism (Actuator can, Push rod assembly) is mounted on turbine housing or compressor cover using bracket. This bracket plays an important role in the functioning of wastegate mechanism.

This actuator bracket is designed to avoid resonance condition within engine operating range considering various parameters affecting on its frequency to ensure its structural integrity.

II. Methodology

In analysis led design, the brackets are designed with help of advanced software. A brief methodology for actuator bracket design is:



A. Optimizing bracket design:

The brackets themselves are designed using the CAD program Pro-Engineer/CREO. The design is then transferred to ANSYS CAE software for the prediction of natural frequencies and the stress in the bracket due to engine vibrations.

The actuator is designed so that it can:

- Provide the required force to keep the wastegate valve closed under exhaust gas pressure.
- Provide long enough travel to open the wastegate valve far enough so that exhaust gas pass easily.
- Be of such an area that the boost pressure can be used to control the valve lift.
- Be durable in a harsh vibrating environment.
- Ensure the functioning of seals and diaphragms in actuator at high temperatures.

B. Frequency prediction analysis:

The wastegate actuator bracket first natural frequency mode of vibration needs to have a frequency higher than the engine excitation frequency. The analysis-led design allows us to design a bracket having first mode natural frequency more that engine firing frequency.

C. Stress prediction:

Random vibration analysis is used for stress prediction, in which the instantaneous magnitudes of the response can be specified only by probability distribution functions. Based on the test data and stress levels of previous designed/ analysed brackets, it is now possible to achieve one standard deviation (one sigma) stress level for new brackets subjected to the physical test.

D. Tap / Shaker test

Finally, Tap/ Shaker test is used to confirm the CAE analysis and that the actuator bracket assembly will withstand the expected vibration levels of engine.

The steps taken to complete the project:

1. Study of existing method/ standard used for the analysis of actuator bracket.
2. Evaluating current gap areas and finalizing the parameters to overcome gap areas.
3. Comparative analysis of each parameter for various types of bracket.
    - Static analysis
    - Pre-Stress modal analysis
    - Experimental analysis (Rap and Tap testing)
    - Correlation of numerical result with experimental result.
    - Design recommendation for improving dynamic behaviour of actuator bracket.

The analysis-led design gives us the provision to design an actuator bracket such a way that it does not resonate with a frequency inside the running range of the engine and carries the wastegate actuation loads.

III. Analysis Approach

The assembly containing dummy shaker table, actuator bracket, spacer, washers, mounting bolts and long actuator can is used to perform the modal analysis.

- The static analysis is performed to calculate assembly stresses due to preload and actuation force.
- The static analysis will be used as the initial condition for the modal analysis (pre-stressed modal) which allows the model to be performed with any stress stiffening that may affect the mode shape.

A. Model details

Seven types of wastegate mounting bracket with pneumatic actuation in Cummins Turbo Technology (CTT) group for all diesel engine applications and gas applications are analysed.

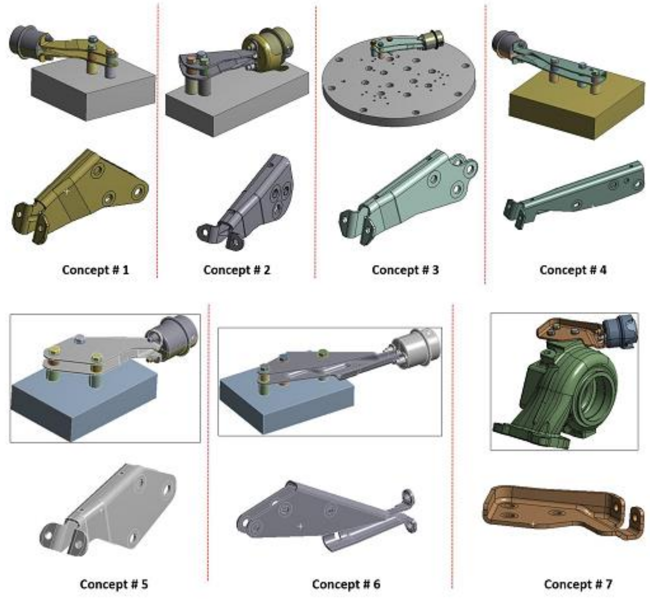


Fig 1: CREO models of actuator bracket (Concept # 1 to Concept # 7)

The wastegate bracket supports the actuator in the desired position (usually dictated by installation considerations), isolates it from the hot turbine housing, positions it in such a way as it is not adversely affected by radiant heat from exhaust manifold, does not resonate with a frequency inside the running range of the engine and carries the wastegate actuation loads.

B. Flange geometry details

Depending on application area and space constraints, the geometrical parameters do vary. Contact area between bracket and canister depends on the flange design (flange pad height and area).

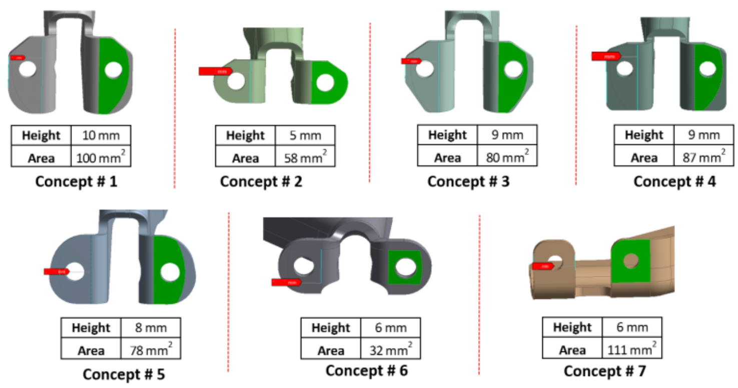


Fig 2: Normalized flange details for seven types of bracket

Contact area plays an important role in first natural frequency of actuator bracket assembly. Following table 1 gives an idea of flange design in terms of flange area and pad height.

Bracket Details	Contact Area (mm^2)	Height of Pad (mm)
Concept # 1	100	10
Concept # 2	58	5
Concept # 3	80	9
Concept # 4	87	9
Concept # 5	78	8
Concept # 6	32	6
Concept # 7	111	6

Table 1: Normalized flange geometrical details for seven types of bracket

C. Fillet and Neck region details

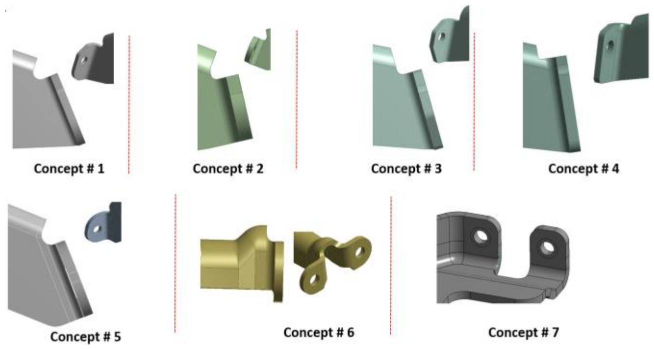


Fig 3: Fillet and Neck region details for seven Types of Bracket

Since the bracket is made up of sheet metal pressing method, its thickness and fillet radii at sharp corners are maintained within specified standards.

D. Geometry details

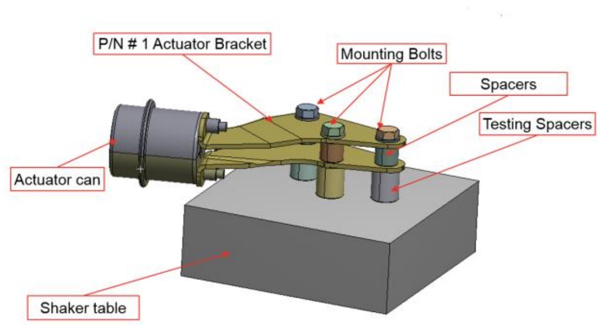


Fig 4: Geometry details of concept # 1 bracket

Above figure 4 is showing the nomenclature for Concept # 1 bracket. For all other the bracket types it remains same.

E. Material properties

All actuator brackets used for turbocharger application are made of steel alloy. In this project for FEA analysis structural steel is used. Properties of structural steel used are listed below,

Density: 7850 kg/m3, Young's Modulus: 210 GPa

F. Pretension Effect on the contacts

Model used for the FEA analysis contains various contacts. In reality these contact will be frictional in nature. Hence to simulate similar effect a pretension force with frictional contact settings are applied in ANSYS to depict the real model of actuator bracket assembly.

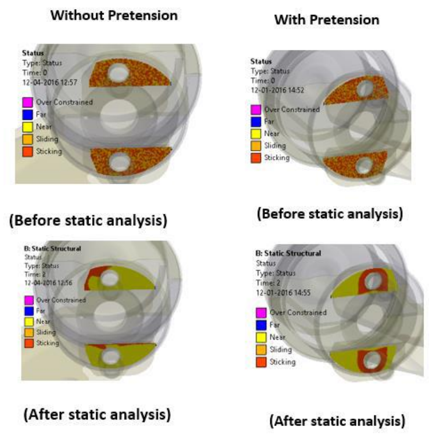


Fig 5: Effect of pretension on contact status

Model used for the FEA analysis contains various contacts. In ANSYS contact given in actuator bracket assembly are listed below,

1. Bracket to Spacer
2. Testing spacer to Bracket
3. Testing spacer to Block
4. Bolt to Block
5. Bolt to Washer
6. Washer to Bracket
7. Can bolt to Bracket
8. Actuator can to Bracket

G. Actuation Force Effect on the contacts

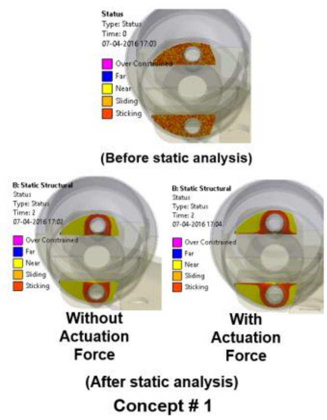


Fig 6: Contact status with and without actuation force

All contacts status are similar that of pretension case except the contact between actuator can bolt and bracket. As shown in figure 6, contact between can bolt and bracket extends slightly due to application of actuation force.

H. Calculation

a) Pretension Force:

$$\tau = p_m k d$$

Where:

p_m: Nominal preload (N)
k: Nut factor or torque coefficient
τ: Applied torque (N-m)
d: Bolt nominal diameter (m)

b) Actuation Force:

= (Gauge pressure*Diaphragm effective area) = P * A_d

I. Nomenclature used for esult post processing of bracket

From several analysis, it has been observed that actuator bracket fails in neck region hence stress induced due to pretension in the neck region of actuator bracket is analysed. The nomenclature used for processing is as shown in figure 7.

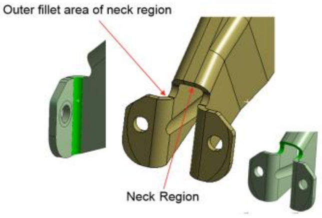


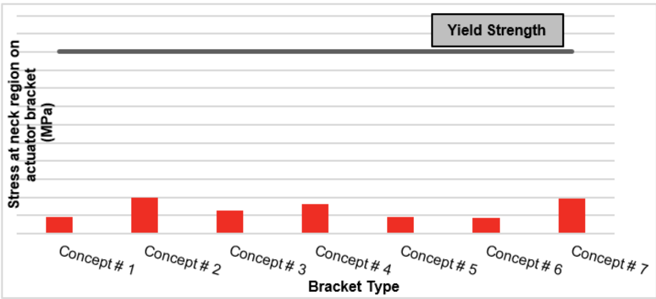
Fig 7: Nomenclature used for post processing of bracket

IV. Result Summary

All seven brackets are analysed with same ansys setup and setting such as contact settings, mesh controls, boundary conditions and loading conditions.

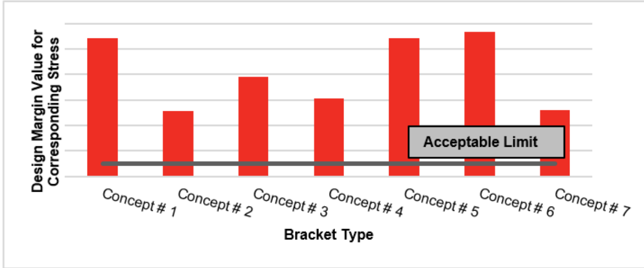
A. Pretension Effect

a) Stress induced in bracket critical region (neck region):



Graph 1: Stress at critical region of bracket (Pretension Effect)

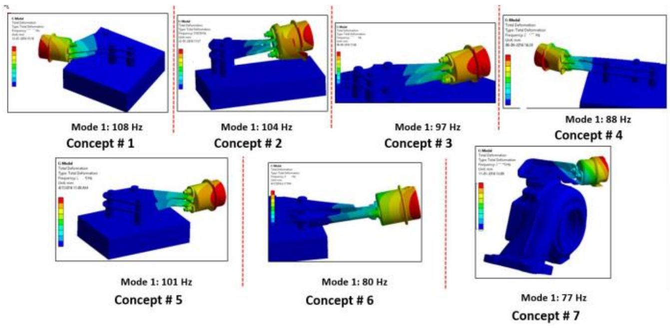
1. Stress induced due to pretension in the neck region of above all actuator bracket is dominated by compressive stress.
2. For all types of bracket stress induced in critical region of bracket is well below yield strength.
3. For all bracket stress induced in critical region of actuator bracket is within acceptable limit based on the design margin value which can be calculated by using formula mentioned below.



Graph 2: Design margin value for stresses at critical region of bracket (Pretension Effect)

$$\textit{Design Margin}: \frac{\textit{Yield Strength}}{\textit{Stress at critical region}}$$

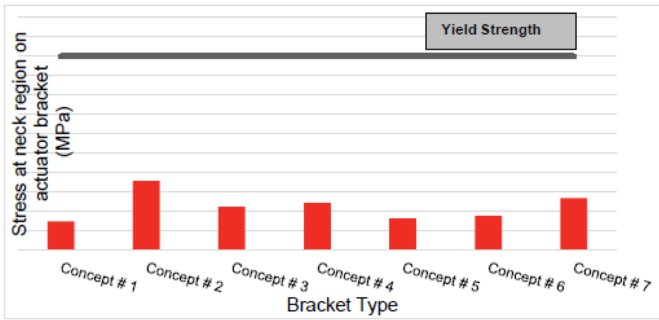
b) First mode deformation plot with Pretension Effect*:*



** Above frequency values are normalized with suitable mathematical expression

B. Actuation Force Effect

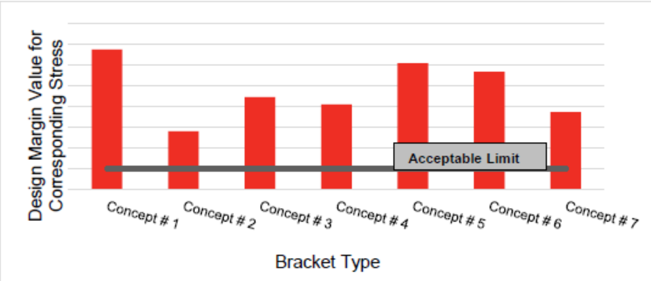
a) Stress induced in bracket critical region (neck region):



Graph 3: Stress at critical region of bracket (Actuation Force Effect)

1. Von-Mises stress value at the neck region of actuator bracket increases with the application of actuation force.
2. Even though stress induced in critical region of bracket increased with the application of actuation force, it is still well below yield strength value.

3. The stresses induced in neck region is compressive in nature because actuation force compresses the bracket flange.
4. Even though the stress value at critical region of bracket increases with actuation force application, stresses observed within acceptable limit based on the design margin.



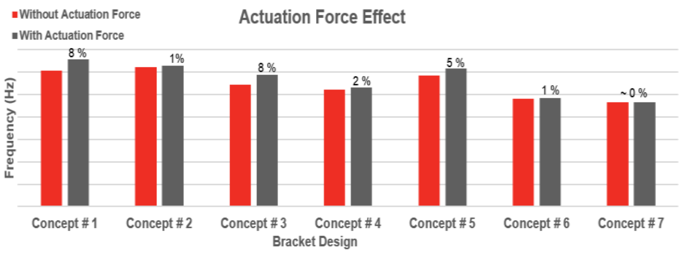
Graph 4: Design margin value for stresses at critical region of bracket (Actuation Force Effect)

b) Modal analysis result summary with the Effect of Actuation Force:

Bracket Details	First Mode Natural Frequency in Hz		Stress at Neck region of actuator bracket (MPa)	Contact Area (mm^2)	Height of Pad (mm)	Percetage difference due to actuation force (%)
	Without Actuation Force	With Actuation Force				
Concept # 1	100	108	50	100	10	8.6
Concept # 2	103	104	120	58	5	1.1
Concept # 3	90	97	76	80	9	8.4
Concept # 4	86	88	82	87	9	1.9
Concept # 5	97	101	55	78	8	4.8
Concept # 6	79	80	59	32	6	1.0
Concept # 7	77	77	91	111	6	0.0

Table 2. Normalized result summary (Actuation Force Effect)

Above table 2. Shows that effect of actuation force is dependent on the contact area between bracket face and actuator can. If the contact area between bracket face and actuator can is large, then more area is coming in contact with bracket and can (It increases joint stiffness.) and percentage increment in frequency is high.

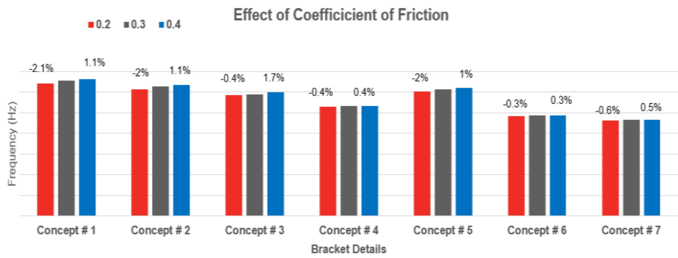


Graph 5. Actuation force effect on natural frequency of bracket

Graph 5 shows the effect of actuation force on the first mode natural frequency of actuator bracket assembly in terms of percentage change indicated for each concept.

C. Effect of Coefficient of Friction

a) Modal analysis result summary with 0.2, 0.3, and 0.4 coefficient of friction:



Graph 6. Effect of coefficient of friction value on natural frequency of bracket

Bracket Details	First Mode Natural Frequency in Hz				
	Coefficient of friction				
	0.3	**0.2**	**Percentage Change**	**0.4**	**Percentage Change**
Concept # 1	**108**	106	-2.1	110	1.1
Concept # 2	**104**	102	-2.0	105	1.1
Concept # 3	**97**	97	-0.4	99	1.7
Concept # 4	**88**	87	-0.4	88	0.4
Concept # 5	**101**	99	-2.0	102	1.0
Concept # 6	**80**	80	-0.3	80	0.3
Concept # 7	**77**	76	-0.6	77	0.5

Table 3. Normalized result summary (Effect of Coefficient of Friction)

V. CONCLUSION

Application of the finite element method to analyse the dynamic characteristics of turbine mounted actuator bracket was studied for seven brackets. The geometrical design (Closed and open type design), boundary constraints, lug design (Height and Width), neck area, fillet radius at neck region of bracket have impact on the natural frequency, mode shapes and stresses induced in the critical region of the actuator bracket.

Pretension at joints help to simulate actual contact area between components. Contact status shows perfectly sticking nature after static analysis which is close to actual condition. Stress induced due to pretension in the neck region of above all actuator bracket is less than yield strength of the material and it is dominated by compressive stress.

Under combined loading of pretension and actuator force, stress induced in the neck region of actuator bracket is less than yield strength of the material. Effect of Actuation Force is dependent on the contact area between bracket face and actuator can i.e. lug design (Height and Width). More the contact area more the stiffness of actuator bracket assembly, results in the increased natural frequency.

With increase in coefficient of friction at the contact regions of actuator bracket assembly contacts, the stiffness of bracket assembly increases which result in the increase of natural frequency.

VI. ACKNOWLEDGMENT

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