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# Implementation of Turbocharger in Petrol Engines and its Thermal Analysis

**Swapnil Bhurat[1], Amit Yadav[2], Atreya pathak[3]**
[1, 3] Department of Mechanical Engineering, Chameli Devi Group of Institutions'
[2]Department of Mechanical Engineering, S.G.S.I.T.S Indore, India
Assistant Professor[1], M. E. Student[2], Lecturer [3]

## Abstract

***In this paper we have discussed about turbocharging of four stroke petrol engine, difference between turbocharging of diesel and gasoline engine and possibilities to reduce losses in Exhaust system are highlighted. However, it omits to discuss two stroke engines due to their different gas exchange processes. Designing of different components involved in turbocharging is done and thermal analysis of turbocharger's connector pipe has been done along with different kind of stress analysis.***

## Keywords

***Turbocharging, supercharging, Thermal analysis, Von Mises stress, stress intensity, stress distribution.***

## 1. Introduction

Turbocharged spark ignition engines have been around since the 1970s, but their popularity outside the motorsport sector has been small until the recent advances in engine control. The lack of popularity could partly be due to the drivability issues associated with early turbocharged engine. The engine's response to a sudden increase in driver's demand was delayed due to turbocharger lag. The lag was then usually followed by a rapid increase of power which resulted in loss of traction and possible loss of control over the car. The developments made in the electronic control and management of internal combustion engine made it possible to overcome most of these drivability limitations. Passenger vehicle with turbocharged SI engines are now becoming more common. Number of companies like Audi, Volvo now offer different passenger vehicle model with turbocharged SI engine whereas Mercedes offers supercharged and turbocharged engines.

The operating principle of the turbocharger is to use the energy recovered from the exhaust gases to force the more air into the combustion chamber. This increases the amount of oxygen in the combustion chamber and hence more fuel can be burned, more power can be produced. Therefore turbocharged engine can produced can produced more power than a similar size naturally aspirated engine. It is claimed that the displacement of turbocharged engine can be reduced by upto 40% relative to NA engine, without compromising power output. Thus the turbocharged engine could be smaller, lighter and more fuel efficient as well as produce less emissions.

The engine available for analysis was (2.2 litre Vauxhall) naturally aspirated but it needed to increase its power and also a thermal efficiency by using a exhaust heat and pressure which would normally be wasted, contributes some of work required to compress the air, installation of turbocharger is needed. For the installation of turbocharger in naturally aspirated engine numbers of parts are required like exhaust manifold, turbocharger, pipe which connects exhaust manifold and turbocharger, pre-compressor intake pipe, post-compressor intake pipe etc. This project is concentrating on designing some of these parts. Firstly it's concentrating on evaluating the concepts of exhaust manifold and then design and analyze the connector pipe with proper selection of material

**Literature Survey:**

As the project is related to improve the efficiency of the four stroke petrol engine by improving the power output and optimizing the energy use from exhaust gases of naturally aspirated engine and which can be possible only by turbocharging of the four stroke SI engine. Turbocharging is nothing but to increase the air density by increasing its pressure before it enters the cylinder.

Turbocharging is kind of supercharging but beneficial than supercharging due to turbo charger uses use nearly wasted energy from exhaust gases to run rotary compressor and it compresses the inlet air going to inlet manifold at the same time supercharger used for same reason but it runs on the power from the crankshaft.

Turbocharger consists of radial compressor and radial turbine on the same shaft on the same shaft. Exhaust gases from the exhaust manifold comes out and goes to the turbine radially and revolve turbine and at the same time air from outside compressed by rotary compressor.

Turbocharger is required for the petrol engine because petrol engine is cost effective for same power output. For more power output turbocharger needs to be utilized maximum power from exhaust gases. The theoretical energy that could be extracted from the gases called 'blow down energy'. Energy available from the flue gases is nothing but the blow down energy and work done by piston. The addition of these two is nothing but the maximum possible energy available for turbocharging.

Various kinds of turbocharging is available now a days, constant pressure and pulse turbocharging. In constant pressure turbocharging exhaust parts from all cylinders are connected to a single exhaust manifold which volume is sufficiently large to damp down the unsteady flow from each cylinder outlet. In ideal case turbine will run on available energy of exhaust gases and only the energy loss during transfer of the exhaust gases from cylinder exhaust to turbine inlet is heat loss that to can avoid by using insulated manifold. Because of so many advantages of constant pressure turbocharging as explained, it can be used in engine.

Pulse turbocharging is also a process of turbocharging in which each pipe goes to the pulse generator of throughout same diameter. Pulse turbocharging is used with vast majority in Europe because the energy available for conversion to useful work in the turbine is greater. The ideal pulse turbocharging must have the following characteristics:

- The peak blow down pulse must occur just before the bottom dead centre of the cylinder, followed by a rapid pressure drop to below boost pressure.
- The boost pressure must be above the exhaust manifold pressure to aid the scavenging process during the valve overlap.

Pulse converter is used in pulse turbocharging to avoid the average turbine efficiency and expansion ration from falling due to wide spacing of exhaust gases pulses. Each nozzle of pulse converter must be larger than last which results in high manufacturing cost. Again the whole installation is bulky and complex. Due to those disadvantages pulse turbocharging is not affordable system for naturally aspirated engine.

## 2. Research Approach and Design

A standard NA engine was converted to turbocharged engine. A 2.2 litre Vauxhall Vectra B engine was chosen for the project. The maximum power output target was set as 145 kW and a torque as 276 N-m. the speed range was set as 3500rev/min up to 6000rev/min.

**Table 2.1: Test Engine specification**

| Specification | Standard | Target | Pre defined |
|---|---|---|---|
| Engine Size [cc] | | | 2198 |
| Valves /Cylinder | | | 02 |
| Compression Ratio | | | 10 |
| Bore *stroke [mm] | | | 86*94.6 |
| Maximum Power [kW] | 108 | 145 | |
| Engine Speed @Max Power [rev/ min] | | | 5000 |
| Maximum Torque [N-m] | 203 | 276 | |
| Engine Speed @Max 6000 Torque [rev/ min] | 4000 | 3500 | |
| Turbocharger | No | Yes | |
| Intercooler | | | No |
| Injection Sequence | | | 1-3-4-2 |

### 2.1 Design Specification:

**Table2.2: Design Specification**

| | |
|---|---|
| Temperature | 600-700 Deg. C |
| Pressure | 1.3 to 1.5 Bar |
| Weight | 1.00kg |
| Thickness of pipe | 6 mm |

To connect the exhaust manifold and turbocharger MS8 bolt are used.

### 2.2 Exhaust manifold:

**Concept 1**: concept 1 shown in figure 2.1 is the manifold which is easiest to manufacture, simple to model, easy to assemble and it fits in confined space. Disadvantage of this concept is that pulse interference is unavoidable because of its small volume. The flow path from the cylinder 4 to the turbine entry makes very sharp turn and a collector is absent at the transition from the three into one junction. The pipes used to make up concept 1 are mild steel, have an inside diameter 34.9 mm and 1.6 mm thickness. This was a standard size for exhausts. The flange that fitted against the engine was laser cut from mild steel with 11 mm thickness and the flange that was fitted against the turbine was also made from mild steel, but was hand cut.

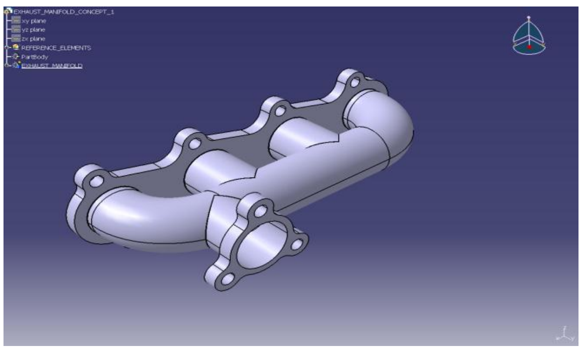

**Figure 2.1: Exhaust Manifold: concept1, CATIA model**

The strength calculation were based on an internal peak pressure of 2.5 bar absolute, the turbocharger weighs 5kg and the exhaust manifold temperature was assumed to be 700 degree Celsius.

**Table 2.3: Material Properties of Mild Steel at High Temperature**

| Temperature (degree Celsius) | Yield Strength (MPa) | Young's Modulus (GPa) |
|---|---|---|
| 600 | 80 | 36 |
| 700 | 37 | 16.5 |
| 800 | 18 | 8 |
| 900 | 7 | 3 |

(British Iron and Steel Association Metallurgy)

**Concept 2:** Figure 2.2 may appear simpler, but is actually much more complex. Simple pulse converters are used at each 2-1 junction, thus totaling 3 pulse converters. The advantage of such manifold is that short runners are used, thus manifold volume smaller than that of concept 1 and consequently more of pulse energy could be harnessed.

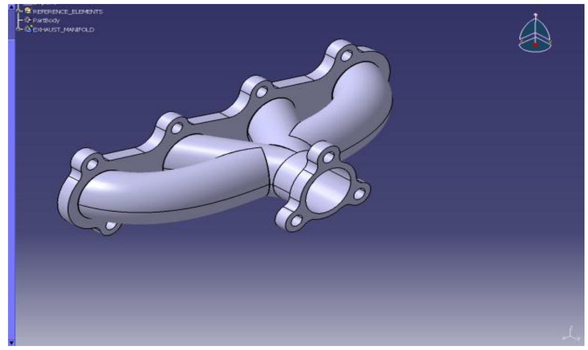

**Figure2.2: Exhaust Manifold: concept2, CATIA model**

The disadvantages of concept 2 are that it is more complex, thus more difficult to manufacture, and assembly would be more complicated due to the placement of bolts at the turbine entry.

## 3. Connector Pipe

The connector pipe is nothing but the metal tube with the folded structure which permits the displacement of turbocharger inlet and the outlet of exhausts manifold relative to each other in axial as well as in transverse direction.

### 3.1 Design Specification:

**Table 3.1: Design Specification for Connector Pipe**

| | |
|---|---|
| Temperature | 600-700 Deg. Celsius |
| Pressure | 1.3 to 1.5 Bar |
| Weight | 1.00kg |
| Thickness of pipe | 6 mm |

**Material Investigation & Manufacturing Process**

As shown in 3.1 long pipe will be gas cut in circle form, where short pipe will be welded, so that the welding strength should be more than the parent material. Weld the flanges at the exhaust manifold outlet end which is of required size, shape, thickness and with fastening holes. Same procedure would be follow at the turbocharger inlet.

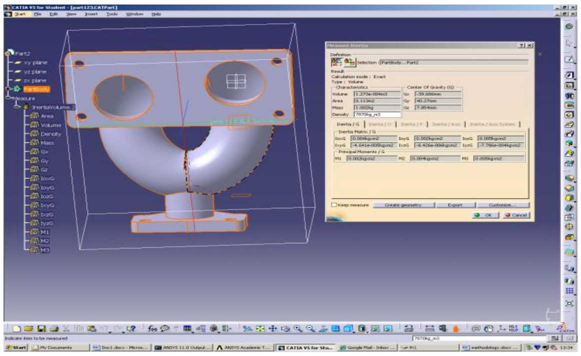

**Figure 3.1: Connector Pipe CATIA model**

In the above manufacturing process the suitable material would be chosen on the basis of their characteristic which matches with requirement. Two materials (Mild Steel & Cast Iron) were compared for selection of material.

# 4. Thermal Analysis: (Ansys)

## 4.1 Problem specification:

**Table 4.1: Problem Specification**

| | |
|---|---|
| ANSYS product | Connector Pipe |
| Discipline | Thermal |
| Element used | Plane55, solid45 |
| Analysis Type | Steady- state thermal analysis |

Since this was a thermal analysis of a connector pipe, the main objectives was to track the temperature distribution on different areas of the pipe. The pipe was made of Mild Steel with thickness of 6 mm. It attached with two flanges, exhaust manifold flange and turbocharger flange respectively.

## 4.2 Problem Description

Since this was a thermal analysis of a connector pipe, the main objectives was to track the temperature distribution on different areas of the pipe. The pipe was made of Mild Steel with thickness of 6 mm. It attached with two flanges, exhaust manifold flange and turbocharger flange respectively.

## 4.3 Input parameters

Input parameters required for analysis of connector pipe were:

**Table 4.2: Input Parameters**

| | |
|---|---|
| Material properties of Steel | |
| Conductivity (KXX) | 76.2 W/m-k |
| Density (DENS) | 7.87 g/cc |
| Specific heat (C) | 0.44 J/g-$^{o}$C |
| Modulus of Elasticity | 200 GPa |
| Poisson's Ratio | 0.291 |
| Emissivity | 0.35 |

(Source:http://www.matweb.com/search/DataSheet.aspx?MatGUID=654ca9c358264b5392d43315d8535b7d&ckck=1)

Real constants are provided for getting additional geometry information for element types whose geometry is not fully defined by its node locations. Typical real constants include shell thicknesses for shell elements. All properties required as input for a particular element type are entered as one set of real constants. There are two sets of real constants are used because two element types were used in the analysis.

# 5. Solutions

## 5.1 Temperature Analysis

Since it was a steady-state thermal analysis, it determines the temperature distribution and other thermal quantities under steady-state loading condition. A steady-state loading condition is a situation where heat storage effect varying over a period of time is ignored.

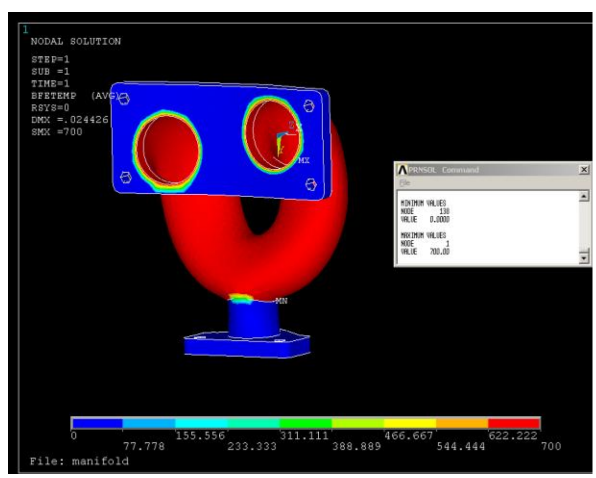


**Figure 5.1: Temperature Distribution**

**Table 5.1: Temperature Range**

| | |
|---|---|
| Minimum Temperature | $0^oC$ |
| Maximum Temperature | $700^oC$ |

As the temperature of the connector pipe is varied between 622.22 to $700^oC$, it can easily sustain to that temperature because pipe materials (M.S.) melting temperature is $1538^oC$. Deformation occurred after passing the high temperature exhaust gases at above atmospheric pressure is 0.024426 mm. But because of elasticity property of mild steel it regains its original shape after deformation. Element type used for the pipe was PLANE55 which is quadrilateral in shape.

### 5.2 Von Mises Stress

Von Mises criterion suggests that the yielding of material begins when it reaches to its critical value. It can be applicable for ductile material. It is convenient to find the yielding of Mild Steel. Yielding strength of mild steel can be defined as the stress at which material begins to deform.

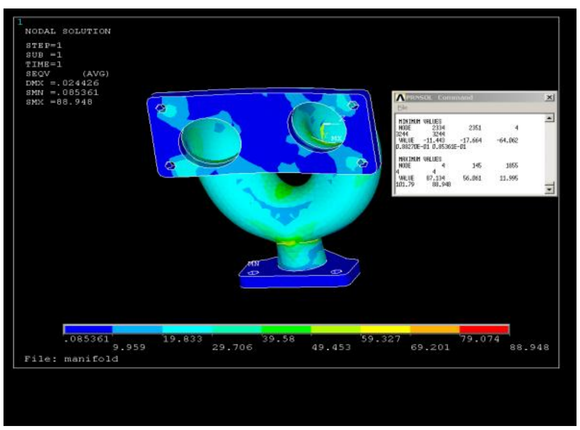


**Figure 5.2: Von Mises Stress Distribution**

So here in this model since deformation is very less i.e. 0.0244 and that also occurred after long period of time. So yield strength of Mild steel is good at such a high temperature. From figure it is clear that maximum stress is occurred at joints where two pipes intersected with each other and i.e. 0.114 $N/mm^2$ which is very less than normal stress.

### 5.3 Stress Intensity

The stress intensity factor is used for the accurate prediction of state of stress near to the tip of the crack. As here maximum stress intensity factor is 0.021873 which is very less. So there are very less chances of getting crack to the pipe.

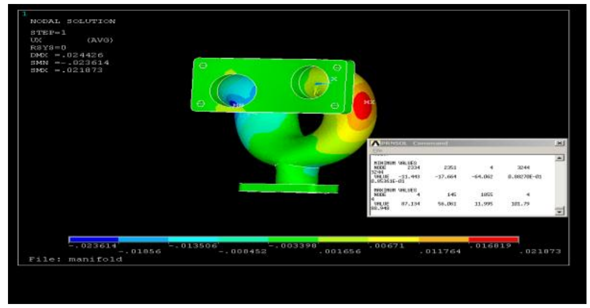


**Figure 5.3: Stress Distribution**

## 6. Recommendation

**Evaluate the exhaust manifold**

Exhaust manifold is the device that carries the flue gases to the atmosphere which comes from I.C. engine cylinder after exhaust stroke for naturally aspirated vehicle.

Properties that should lie along with the exhaust manifold are as following:

- The exhaust manifold design should be such that easy scavenging of the flue gases should occur from I.C. engine cylinder so that the pressure at the exhaust manifold should be lower than the cylinder pressure after the exhaust stroke where flue gases contains blow-down energy.
- It should be simple in construction and easy to manufacture.
- Material used for exhaust manifold should sustain & absorb large vibrations from engine because exhaust manifold is directly connected with the engine with the help of bolting.
- No traffic jam of flue gases should occur at the exhaust manifold pipe and the material used should sustain for the pressure & temp. of the flue gases( Maximum 2.0 bar & 700 degree C, respectively).

With this above discussion it is recommended that **exhaust manifold concept1** would be suitable for engine.

**Implication of adding turbocharger to naturally aspirated engine**

In naturally aspirated engines exhaust flue gases directly leaves at atmosphere which are hot. While leaving the engines exhaust they contain lot of energy with them which will nearly be wasted which decreases the efficiency i.e. power output of the naturally aspirated engine. So the turbocharger is used which uses the blow-down energy from the flue gases.

## 7. Conclusion

Design and analysis of connector pipe between exhaust manifold and turbocharger in Vauxhall 2.2 litre engine and evaluate the different concepts of exhaust manifold which will be suited of the engine were the objectives and scope of this research project. These objectives were successfully accomplished by the comparison of naturally aspirated and turbocharged engine. Further the results obtained from temperature analysis and stress analysis reflects the favourable condition for the designed turbocharger connector pipe to be used in turbocharging of four stroke petrol engine.

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**Swapnil Bhurat**, born at Dhule on 11/11/1983. B. E. from University of Pune, Pune, 2007. M. S. from University of Hertfordshire, U.K 2009 Currently working as Assistant Professor in Department of Mechanical Engineering Chameli Devi Group of Institutions' Indore.

**Amit Yadav**, born at Faizabaad on 05/10/1985. B. Tech. from VIT University Vellore, 2009, currently pursuing M. E. from S.G.S.I.T.S. Indore.

**Atreya Pathak**, born at Dayaalbaag (Agra) on 08/07/1984,
B Sc. - Math & IT (Dr. B.R. Ambedkar University - Agra) (2004),
BE from IIST [RGPV University], 2009. Currently working as Lecturer in Department of Mechanical Engineering Chameli Devi Group of Institutions' Indore.