Increase in Power and Torque of Engine with Dual Compressor Turbocharger

Rohit Soni[#1], Roopesh Tiwari[*2], Suman Sharma[#3]

[#]PG student, Sage University Indore, [*]Professor Sage University Indore, [#]HOD Sage University Indore
Mechanical Engineering Department, Sage University, Indore

***Abstract*— *Turbochargers are mainly used to increase the engine power and torque. In this research work, modification has made on impeller of compressor and on turbine impeller. Here dual impeller compressor is used in which the faces of impellers are opposite. The face of first impeller is in the opposite direction of turbine while the face of other impeller is towards the turbine. These dual impellers are used for dual stage compression. Dual compressor turbo compresses air twice, compared to conventional single compressor turbo and generates high pressure inside the engine compared to single compressor turbo. This high pressure is used to create more power and torque by engine. Hence with this modification in compressor with dual stage compression, engine generates more power and torque at particular rpm. This turbocharger model has designed on CATIA software while flow analysis has done on ANSYS CFD.*

Keywords — *Impeller, Compressor, Turbine, CATIA, ANSYS CFD.*

I. Introduction

Turbocharger is an exhaust gas driven device which uses exhaust gas to spin its turbine. Exhaust gas from engine which is a composition of different emission gas comes with a higher velocity hits the turbine blades and force to spin at higher rpm more than 1,00,000 rpm. Turbocharger consists of three main elements –turbine, compressor and bearing housing. Turbine rotates by exhaust gas which comes from the exhaust manifold of engine at very high velocity and forces turbine impeller to spin. Compressor is another important component of turbocharger which sucks fresh atmospheric air and compresses it to a specific pressure which depends on the design of compressor. Another basic component of turbocharger is bearing housing which supports turbine and compressor shafts. It is basically a housing of bearing and gives support only. This bearing housing is full with lubrication oil. Lubrication oil provides smooth flow to turbine to spin at more than 1,00,000 rpm.

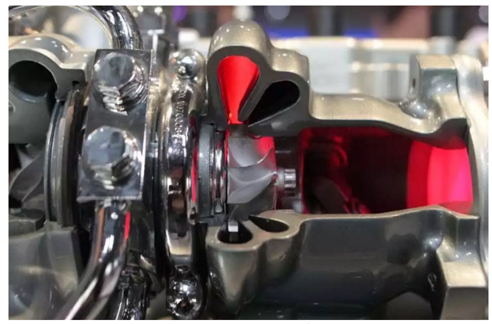

Fig 1: Cut sectional model of Turbocharger

II. Objectives

The main objective of this research work is to increase the pressure developed inside the compressor of turbocharger which is used to increase power and torque of the engine. It is possible with some modification in turbo compressor impeller. In this new concept of compressor, another impeller which has same specification as first one is attached with it but the faces of both impellers are opposite to each other. These dual impellers are used for dual stage compression of fresh air. In primary stage of compression, fresh air goes inside the compressor with atmospheric pressure, where impeller compress this air and send outwards and then with the periphery of the compressor case it goes to another side of compressor impeller, then second impeller again compress it which is a second stage of compression. This fresh air goes to engine where engine generates power and torque.
Objectives –

1. Increase in pressure of fresh air with dual impeller compressor turbocharger compared to single impeller compressor turbocharger.
2. Increase in power and torque of engine with the use of dual impeller compressor turbocharger compared to single impeller compressor turbocharger.

III. Design of Turbocharger

For design of turbocharger, CATIA software has been used -

A. Dual impeller compressor

In this model of compressor dual impellers are used where the faces of both impellers are opposite to each other. Face of first impeller is towards entry of fresh air while face of other is opposite to it and towards turbine side. Here the design has been done with same specification as turbocharger model Garett Turbo GT4088R. Specification of the Dual impeller compressor is as below-

Inducer diameter	= 63.5mm
Exducer diameter	= 88mm
No.of blades (in both impeller)	= 22
Blade angle at periphery	= 30^0[5]
Flow angle at rotor exit	= 60^0[5]
Manifold diameter	= 38.16mm
Housing Area/Radius	= 0.72

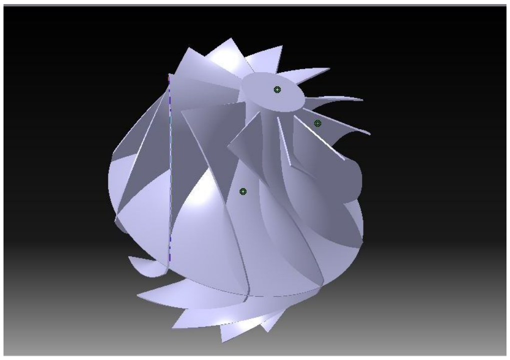

Fig 2: Dual impeller compressor

B. Single impeller compressor

This is a conventional type compressor model in which a single impeller is used where the face of the impeller is opposite to turbine. Here also the specification of the compressor is same as turbocharger model Garett Turbo GT4088R. Specification of Single impeller compressor as below-

Inducer diameter	= 63.5mm
Exducer diameter	= 88mm
No.of blades	= 11
Blade angle at periphery	= 30^0[5]
Flow angle at rotor exit	= 60^0[5]
Manifold diameter	= 38.16mm
Housing Area/Radius	= 0.72

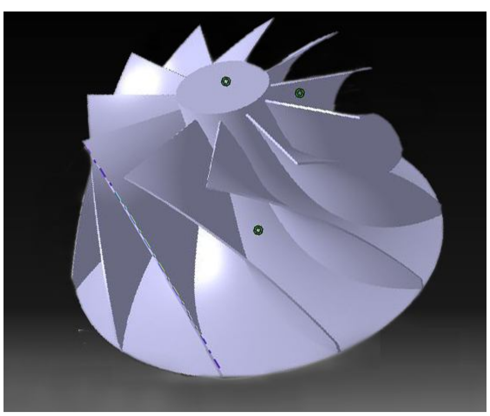

Fig 3: Single impeller compressor

C. Axial flow turbine

Axial flow turbine is based on reaction force, which is exerted by fluid. High velocity exhaust gases force full turbine periphery to spin at high rpm. The direction of gas is parallel to turbine shaft at entry and exit too. Here specification of turbine is same as eppler airfoil 376. Specification of Axial flow turbine as below-

Inducer diameter	= 68mm
Exducer diameter	= 77mm
No.of blades	= 11
Blade angle at periphery	= 8.25^0
Flow angle at rotor exit	= 0^0[6]
Manifold diameter	= 38.16mm
Housing Area/Radius	= 0.85, 0.95, 1.06, 1.19

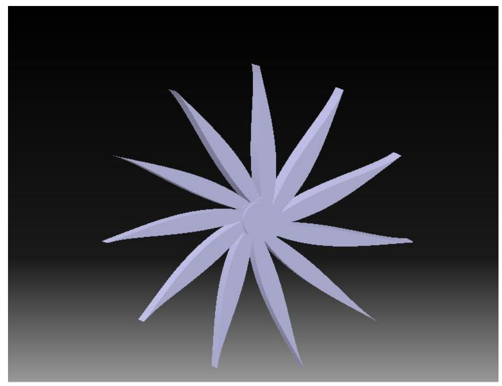

Fig 4: Axial flow turbine

D. Radial flow turbine

Radial flow turbine is based on impulse force where exhaust gas hits the turbine blades and force it to rotate at high rpm. Here the direction of exhaust gas at entry is radial while axial at exit.

Specification of Axial flow turbine as below-

Inducer diameter	= 68mm
Exducer diameter	= 77mm
No.of blades	= 11
Blade angle at periphery	= 0^0[5]
Flow angle at rotor exit	= 90^0
Manifold diameter	= 38.16mm
Housing Area/Radius	= 0.85, 0.95, 1.06, 1.19

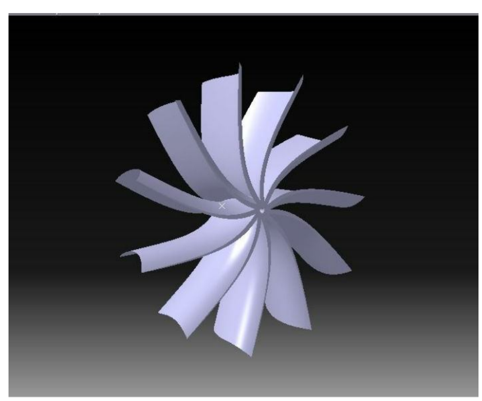

Fig 5: Radial flow turbine

IV. ANALYSIS OF TURBOCHARGER

For flow analysis on turbocharger, ANSYS CFD is used. There are some input parameters which are used for analysis-

1) RPM of turbine & compressor shaft(Approx) = 1,00,000 rpm
2) Fresh air velocity at inlet in compressor = the value of the velocity of the fresh air which is going inside the compressor through manifold can be calculated as below formula-

The mass flow rate is given as,

$$m = \rho . V . A$$

$$\Rightarrow \quad V = m/\rho . A$$

$$\Rightarrow \quad V = 0.447/(1.22 \times \frac{\pi (0.03816)^2}{2}$$

$$\Rightarrow \quad V = 159.808 \text{ m/sec} \approx 160 \text{m/sec}$$

Where,

ρ = density of fresh air, in kg/m^3
= 1.225 kg/m^3

m = air mass flow, in kg/sec
= 0.447 kg/m^3

D = manifold dia., in m =0.03816 m

V = Velocity of fresh air, in m/sec

A. Dual impeller compressor axial flow turbocharger

In dual impeller compressor fresh air enters in compressor axially where first impeller compresses it and with periphery of casing it goes to second impeller side where again second impeller compress it. Then compressed fresh air goes outside radially.

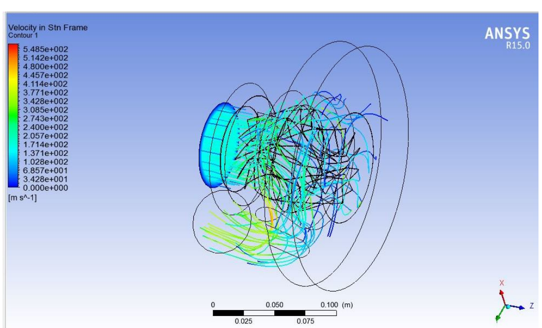

Fig 6: Analysis of Dual impeller compressor

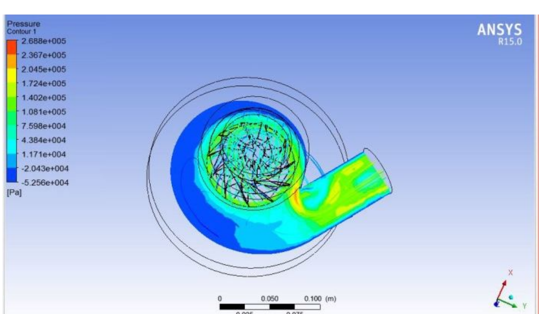

Fig 7: Analysis of Dual impeller compressor

Average pressure at entry of fresh air= 131055 Pa

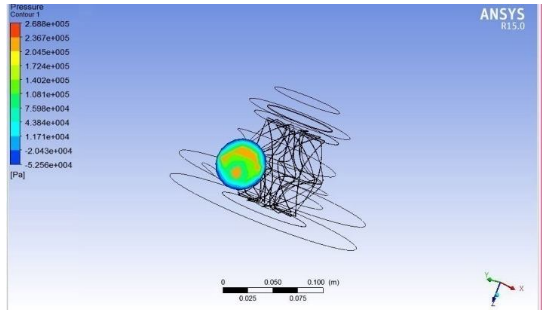

Fig 8: Analysis of Dual impeller compressor

Average pressure at exit= 211318 Pa

B. Single Impeller compressor radial flow turbocharger

This is a conventional type of compressor where a single impeller is used. In this compressor air enters axially where impeller compresses it and leaves it in radial direction.

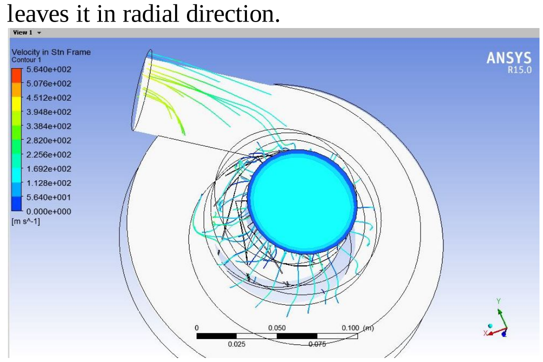

Fig 9: Analysis of Single impeller compressor

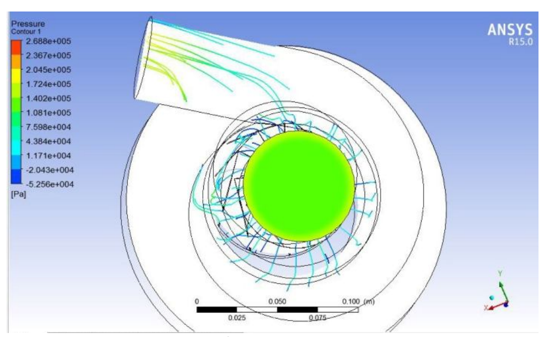

Fig 10: Analysis of Single impeller compressor

Average pressure at entry of fresh air= 131055 Pa

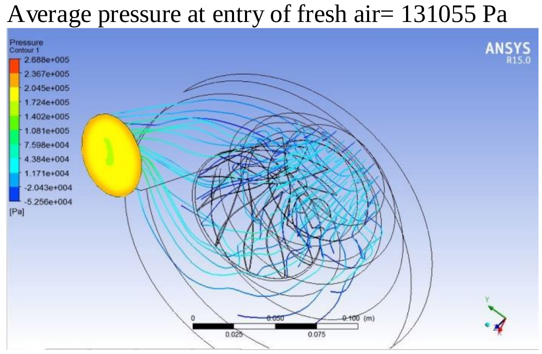

Fig 11: Analysis of Single impeller compressor

Average pressure at exit =198288.42 Pa

V. ENGINE DESIGN AND CALCULATIONS

Mean effective pressure is a measure of pressure developed inside the engine cylinder in one revolution. Higher the mean effective pressure inside the engine, higher the power and the torque.

Maximum pressure inside the engine cylinder can be calculated by below formula-

p_{max} = 9 x pressure developed by turbo[1]

A. *Pressure calculation-*

I. For dual compressor turbocharged engine

Through the analysis of dual compressor turbocharger the pressure developed inside the turbocharger is 211318 Pascal. Hence maximum pressure is-

$$p_{max} = 9 \times 211318 = 1901862 \text{ Pa}$$

II. For single compressor turbocharged engine

Through the analysis of single compressor turbocharged the pressure developed inside the engine is 211318 Pascal. Hence mean effective pressure is-

$$\Rightarrow p_{max} = 9 \times 198288.42 = 1784595.75 \text{ Pa}$$

B. *Engine calculation-*

Engine design parameters are-

I. Engine Volume V= 1.8 Liters = 1800CC=1800000cmm

II. Engine RPM range N = 1250-2500RPM

III. No. of cylinders K = 4

Engine design-

$$V = \pi/4\, D^2 \times L \times K[1]$$
$$\Rightarrow 1800000 = \pi/4\, D^2 \times 1.5D \times 4$$
$$\Rightarrow D = 72.55\text{mm} \approx 73\text{mm} \quad \&$$
$$\Rightarrow L = 1.5 \times 73 = 109.5\text{mm} \approx 110\text{mm}$$

C. *Power Calculation*

Engine Power can be calculated by below formula-

$$\text{Power} = \frac{p_{max} . L. A. n. K}{60000}, \text{ in kW [2]}$$

Where, p_{max} = pressure developed inside engine, ,in Pascal

$A = \pi /4\, D^2$, in m^2

L = length of stroke = 1.5D, in m

n = N/2, for four cylinder, in RPM

K = no. of cylinders in engine.

I. For Dual compressor turbocharged engine-

(i) When Engine revolution/min is N = 1250RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 1250 \times 4}{60000 \times 4 \times 2} = \mathbf{36.50\ kW}$$

(ii) When Engine revolution/min is N = 1500RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 1500 \times 4}{60000 \times 4 \times 2} = \mathbf{43.78\ kW}$$

(iii) When Engine revolution/min is N = 1750RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 1750 \times 4}{60000 \times 4 \times 2} = \mathbf{51.07\ kW}$$

(iv) When Engine revolution/min is N = 2000RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 2000 \times 4}{60000 \times 4 \times 2} = \mathbf{58.37\ kW}$$

(v) When Engine revolution/min is N = 2250RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 2250 \times 4}{60000 \times 4 \times 2} = \mathbf{65.67\ kW}$$

(vi) When Engine revolution/min is N = 2500RPM

$$\Rightarrow \text{Power} = \frac{1901862 \times 0.11 \times \pi \times (0.073)^2 \times 2500 \times 4}{60000 \times 4 \times 2} = \mathbf{72.97\ kW}$$

II. For Single compressor turbocharged engine-

(i) When Engine revolution/min is N = 1250RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 1250 \times 4}{60000 \times 4 \times 2} = \mathbf{34.23\ kW}$$

(ii) When Engine revolution/min is N = 1500RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 1500 \times 4}{60000 \times 4 \times 2} = \mathbf{41.08\ kW}$$

(iii) When Engine revolution/min is N = 1750RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 1750 \times 4}{60000 \times 4 \times 2} = \mathbf{47.93\ kW}$$

(iv) When Engine revolution/min is N = 2000RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 2000 \times 4}{60000 \times 4 \times 2} = \mathbf{54.77\ kW}$$

(v) When Engine revolution/min is N = 2250RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 2250 \times 4}{60000 \times 4 \times 2} = \mathbf{61.62\ kW}$$

(vi) When Engine revolution/min is N = 2500RPM

$$\Rightarrow \text{Power} = \frac{1784595.75 \times 0.11 \times \pi \times (0.073)^2 \times 2500 \times 4}{60000 \times 4 \times 2} = \mathbf{68.48\ kW}$$

D. *Torque Calculation*

Engine Torque can be calculated by below formula-

$$\Rightarrow P = T \times \omega, \text{ in Watts}$$
$$\Rightarrow T = P / \omega$$

Where, P = Power developed inside engine, in Watts

T = Engine Torque, in m

$\omega = 2\pi N/60$
N = Revolution/min

I. For dual compressor turbocharged engine-
Peak power of engine–72.97kW@2500RPM

(i) When Engine revolution/min is
N = 1250RPM
⇒ T = 72960/2πx1250
= **557.43 N-m**

(ii) When Engine revolution/min is
N =1500RPM
⇒ T = 72960/2πx1500
= **464.52 N-m**

(iii) When Engine revolution/min is
N = 1750RPM
⇒ T = 72960/2πx1750
= **398.16 N-m**

(iv) When Engine revolution/min is
N = 2000RPM
⇒ T = 72960/2πx2000
= **348.4 N-m**

(v) When Engine revolution/min is
N = 2250RPM
⇒ T = 72960/2πx2250
= **309.68 N-m**

(vi) When Engine revolution/min is
N = 2500RPM
⇒ T = 72960/2πx1250
= **278.71 N-m**

II. For single compressor turbocharged engine-
Peak power of engine – 68.48kW@2500RPM

(i) When Engine revolution/min is
N = 1250RPM
⇒ T = 68470/2πx1250
= **523.06 N-m**

(ii) When Engine revolution/min is
N =1500RPM
⇒ T = 68470/2πx1500
= **435.88 N-m**

(iii) When Engine revolution/min is
N = 1750RPM
⇒ T = 68470/2πx1750
= **373.61 N-m**

(iv) When Engine revolution/min is
N = 2000RPM
⇒ T = 68470/2πx2000
= **326.91 N-m**

(v) When Engine revolution/min is
N = 2250RPM
⇒ T = 68470/2πx2250
= **290.59 N-m**

(vi) When Engine revolution/min is
N = 2500RPM
⇒ T = 68470/2πx1250
= **261.53 N-m**

VI. RESULTS AND COMPARISON

After analysis of double impeller compressor axial flow turbocharger and single impeller compressor radial flow turbocharger results can be illustrated as-

TABLE I
PRESSURE DEVELOPED BY TURBO

Turbo Model	Pressure at entry, in Pascal	Pressure developed by turbo, in Pascal	Maximum Pressure in engine in Pascal
Dual compressor axial flow	131055	211318	1901862
Single compressor radial flow	131055	198288.42	1784595.75

These values also can be illustrated on graph –

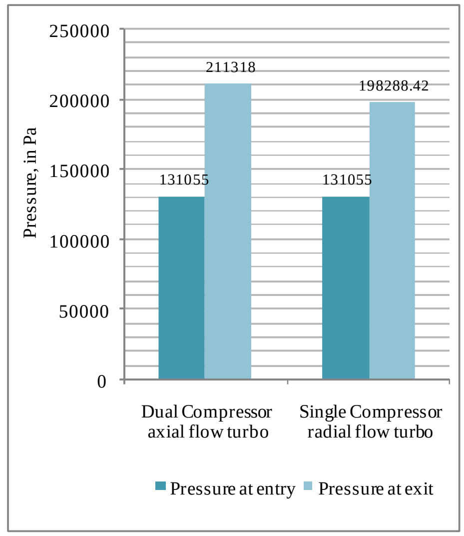

Fig 12: Graph for pressure in turbocharger

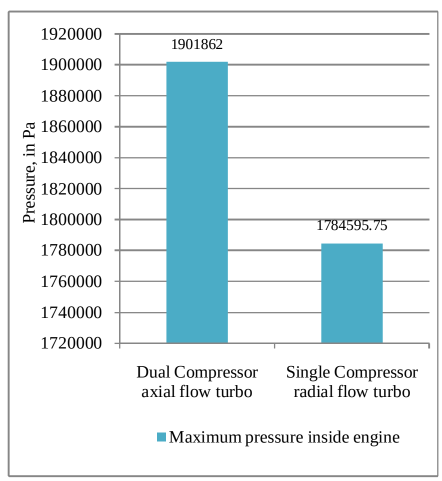

Fig 13: Graph for maximum pressure inside engine

TABLE II
POWER RESULTS

RPM Range	Dual compressor turbo engine ,in kW	Single compressor turbo engine ,in kW
1250	36.50	34.23
1500	43.78	41.08
1750	51.08	47.93
2000	58.37	54.77
2250	65.67	61.62
2500	72.97	68.48

These values also can be illustrated on graph –

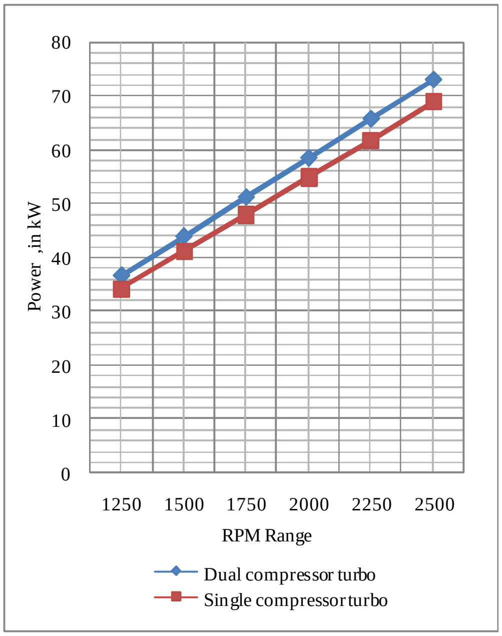

Fig 14: Graph for Power at different rpm

TABLE III
TORQUE RESULTS

RPM Range	Dual compressor turbo engine ,in N-m	Single compressor turbo engine ,in N-m
1250	557.43	523.06
1500	464.52	435.88
1750	398.16	373.61
2000	348.40	326.91
2250	309.68	290.59
2500	278.11	261.53

These values also can be illustrated on graph-

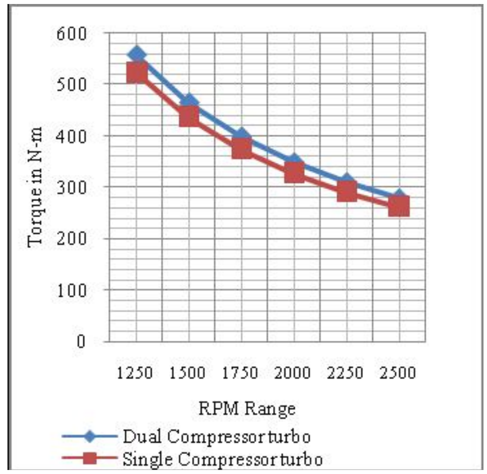

Fig 15: Graph for Torque at different rpm

VII. CONCLUSION

I. This paper shows the benefits of dual impeller compressor axial flow turbocharger over single impeller compressor radial flow turbocharger.

II. With some modifications in existing turbocharger in compressor side, the pressure developed by the turbocharger can be increased without any additional work.

III. With this increased pressure of fresh air engine power increased, as more compressed air gives more power and torque at same rpm.

IV. At particular rpm dual compressor turbocharged engine generates more peak power. Hence it also increases torque at particular rpm compare to single impeller compressor turbocharged engine.

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