KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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DEVELOPMENT AND ANALYSIS OF THE CONCEPT OF TWO STAGE VARIABLE GEOMETRY TURBOCHARGER

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Evaldas Narvydas

Kaunas 2017

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MECHANICAL ENGINERRING (M5016M21)

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Mechanical Engineering, 621H30001

(Title of study programme, code)

"Development and analysis of the concept of two stage variable geometry turbocharger"

Final project

DECLARATION OF ACADEMIC INTEGRITY

02 January 2017

Kaunas

I confirm that the final project of mine, **Gowtham Premkumar**, on the subject, **Development and analysis of the concept of two stage variable geometry turbocharger** is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources; all direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING - 621H30001

Approved by the Dean's Order No. V25-11-20 of December 8th, 2016 y

Assigned to the student **GOWTHAM PREMKUMAR**

(Name, Surname

1. Title of the Project

Development and analysis of the concept of two stage variable geometry turbocharger

2. Aim of the project

To develop a two-stage turbo with improved efficiency compared to existing turbo setup.

3. Tasks of the project

- Study of existing setup of turbocharging concepts.
- Design and analyze a standard turbocharger to compare with existing turbocharger efficiency.
- To produce a constant efficiency and torque through the entire cycle.
- Propose a model of turbocharging concept.

4. Specific Requirements

Engine displacement 3000 cm^3; Volumetric Efficiency 85%.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 January 2nd.

Task Assignment received	Gowtham Premkumar (*Name, Surname of the Student*)	(*Signature,date)*
Supervisor	Assoc. prof. dr. Evaldas Narvydas (*Position, Name, Surname*)	(*Signature,date)*

Gowtham Premkumar, “Development and Analysis of the concept of two stage variable turbocharger”. Master’s Final Project / Supervisor Assoc. Prof. Dr. Evaldas Narvydas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area: Technology science, Mechanical Engineering 09T

Keywords: turbocharger design, turbocharger analysis, turbocharger efficiency

Kaunas, 2017. 41p

SUMMARY

In this research study, a different set of turbocharger is used compared to existing standard setup. The combination of variable geometry turbocharger and a standard large turbo to produce more output efficiency and maintain standard level of supply of air depending upon the engine requirement. This research is based on existing twin turbo as parallel and sequential for a naturally aspirated engine.

For preparation, the turbo is setup in sequential order based on existing concepts to resolve turbo lag during start for faster response. The variable geometry turbocharger at lower rpm acts a smaller turbo in which condition vanes closed produce more rpm for the turbine causing compressor to run at high speed resulting in supply of high density and high pressured air to the manifold of the engine. The standard turbo at lower rate is set to supply high volume of air to variable geometry charger causing a high boost at lower rpm. At higher rpm, the variable geometry turbocharger vanes are caused to open due to high supply of air which result in converting the setup automatically as parallel to supply the pressurized air to the adjacent side of the engine. The turbocharger is designed and analyzed to prove the efficiency output is improved compared to existing setup. A set of valve are used on either side of turbo to convert as parallel and sequential for lower and higher.

Gowtham Premkumar „Dviejų turbinų komponuotės su kintamos geometrijos turbokompresoriumi koncepcijos kūrimas ir tyrimas“. Magistro baigiamasis projektas / vadovas doc. dr. Evaldas Narvydas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis: Technologijos mokslai, Mechanikos inžinerija 09T

Reikšminiai žodžiai: *turbokompresoriaus projektavimas, turbokompresoriaus analizė, turbokompresoriaus efektyvumas.*

Kaunas, 2017. 41 p.

SANTRAUKA

Darbe tiriamo turbokompresoriaus komponuotė skiriasi nuo standartinių turbokompresorių. Kintamos geometrijos turbokompresorius yra komponuojamas su dviejų turbinų sistema, kuri padidinant turbokompresoriaus efektyvumą. Joje oro padavimo turbinoms rodikliai yra reguliuojami, priklausomai nuo poreikio. Šis tyrimas remiasi *egzistuojančiomis lygiagrečiomis ir nuosekliomis dviejų turbinų turbokompresorių komponuotėmis varikliams su natūralia oro padavimo sistema veikiant atmosferiniam slėgiui.*

Nuoseklaus jungimo turbinų komponuotė leidžia turbokompresoriui greičiau sureaguoti variklio darbo pradžioje. Kintamos geometrijos turbokompresorius, esant mažesnėms variklio apsukoms, dalinai uždaro oro padavimo į turbiną menteles tuo padidindamas oro srauto greitį ir leisdamas kompresoriui veikti bei papildomai tiekti orą į variklio sistemą. Esant didelėms variklio apsukoms, kintamos geometrijos turbokompresoriaus oro padavimo turbinai mentelės atsidaro labiau, o turbinų jungimas iš nuoseklaus yra perjungiamas į lygiagretų. Turbinų jungimas iš nuoseklaus į lygiagetų ir atvirkščiai yra keičiamas tam skirtais vožtuvais. Atlikta turbokompresoriaus parametrų analizė parodė, tokios komponuotės efektyvumą ir pranašumą lyginant su egzistuojančiomis komponuotėmis.

Contents

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In general, all aspirated engines cannot inhale the entire displacement of air fuel mixture for each stroke. Volumetric efficiency for engines varies from one to another hence forced induction is used to satisfy the volumetric efficiency of the engine.

Turbocharger is a form of forced induction technique based on superchargers. It is driven by means of exhaust gas from engine outlet to turbine in the charger. Turbocharging is one of the wide spread and initial technology in improvement of engine efficiency by increasing the mass flow to cylinder in order produce a maximum fuel burn. In general engines have enough brake specific fuel consumption (BSFC- measure of the fuel efficiency of any prime mover that produce fuel burn and power output) and this normal produced efficiency can be pushed further by increase the flow of air to the engine by adding a turbocharging setup. The main risk will be a limited supply of air at low speed and reversing of air mixture due to excess amount of air at high speed. A possible way to solve these issues is by using a variable turbocharger and changing the layout of turbocharging setup to supply the required amount of air.

The main purpose is to improve the engine volumetric efficiency by increasing the density of air supplied and to reduce the exhaust gas emission. A lot of improvements in turbocharging technology is happening by changing various aspects such as: change of trim values, air flow ratio, downsizing and so on.

The main objective of this project is to compare the existing turbo setup and produce more efficiency by changing turbo arrangement in the engine. To produce a required mixture of fuel and to produce a constant efficiency a variable turbocharger is used. The use of variable turbocharger in the setup is to reduce turbo lag and to prevent knocking the engine. The change in efficiency is noted by means of brake specific fuel consumption curve between existing and new setup.

1. LITERATURE REVIEW

1.1 WORKING PRINCIPLE

Turbocharger works based on the principle of forced induction. They are mostly used in spark ignition and diesel combustion engines. The forced induction technique driven by means of exhaust air is turbocharger and when its mechanically driven is supercharger. In normally aspirated engines air is pressurized into piston chamber by means of atmospheric pressure. In every fourth stroke, a vacuum is created causing air to flow into the chamber. Turbocharger contains a turbine and compressor where turbine is driven by means of exhaust air making the compressor to run intake a large volume of air and converting into high pressurized and density of air. The turbocharging setup is classified as much as variety of engine setup depending on the amount of power required. There are six different setups of turbocharging:

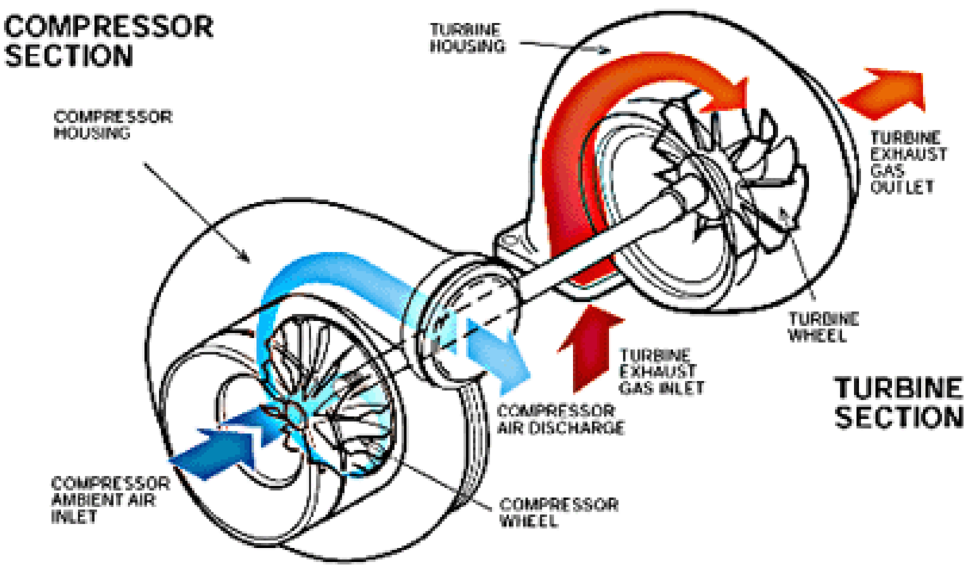

Figure 1 turbocharger general schematic[10]

1.2 SINGLE TURBO

Single turbo has a limited variability and chosen depending on the required torque. The single turbo is commonly known as fixed geometry turbo which contains components of unchanging dimensions. Fixed geometry turbo is either larger or smaller in size. Larger turbo is commonly known to produce more pressure and density at higher speed which prevents knocking but at lower speeds the pressure and density is insufficient, resulting in turbo lag. Smaller turbo produces enough pressure and density at lower speeds which produces a quicker response resulting in lower turbo lag whereas at higher speeds the a/r ratio is too low to produce enough pressure and density to satisfy engine volumetric efficiency. An intercooler is normally used in larger turbo which produce a high amount of pressure causing a rise in temperature of supplied air whereas in smaller turbo the air supply is comparatively low the temperature rise is satisfied by means of atmospheric air circulation. The main purpose of intercooler is to increase the density of intake air. The ambient air supplied depends upon the environmental conditions so the use of intercooler is maintain the air supply stable at all condition. The more cooler the air the amount of fuel burn is increased. Single turbo is a cost effect way to produce engine power and efficiency. Single turbo is easy to install and produce high efficiency in naturally aspirated engines.[1]

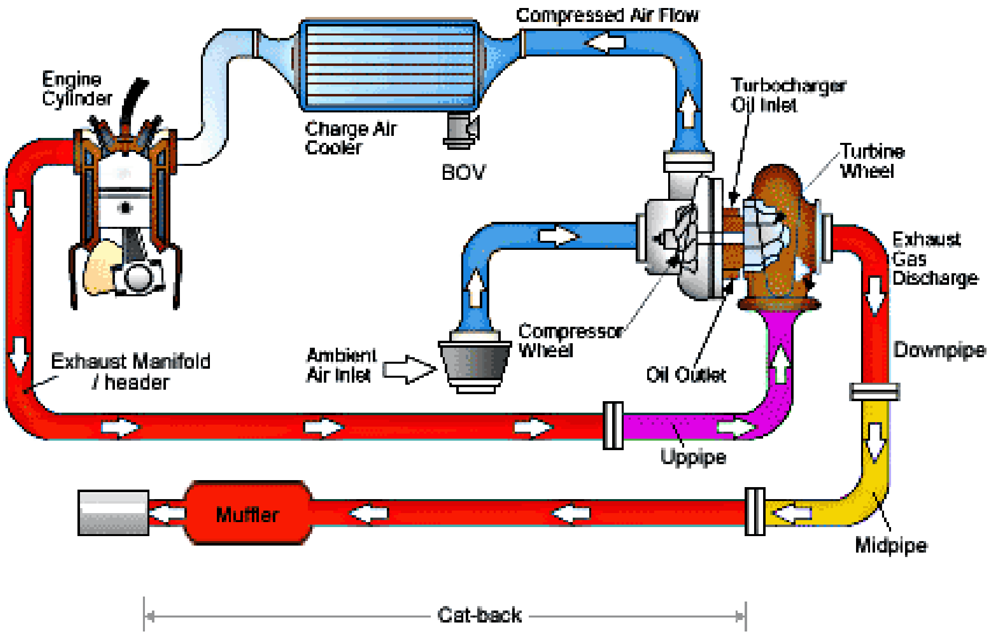

Figure 2 setup of single stage turbocharger[10]

1.3 TWIN TURBO

Twin turbo is similar like single turbocharger with a plenty of installment options. Twin turbo setup is commonly known as compound configuration setup. With two similar turbos either large or small are connected as parallel or sequential setup, as large for higher rpm and small for lower rpm. It also can be used a single for each cylinder bank. Twin turbo can be used to reduce turbo lag and knocking in the engine. The parallel or sequential turbo setup is more commonly used for V-shaped engines. In sequential, the setup is more complicated and the use of intercooler is necessary due to combined supply to air which produces a large temperature output from the turbocharger. The parallel setup is combined with a set of two fixed geometry single turbo supplying pressurized air to inlet manifold.[1]

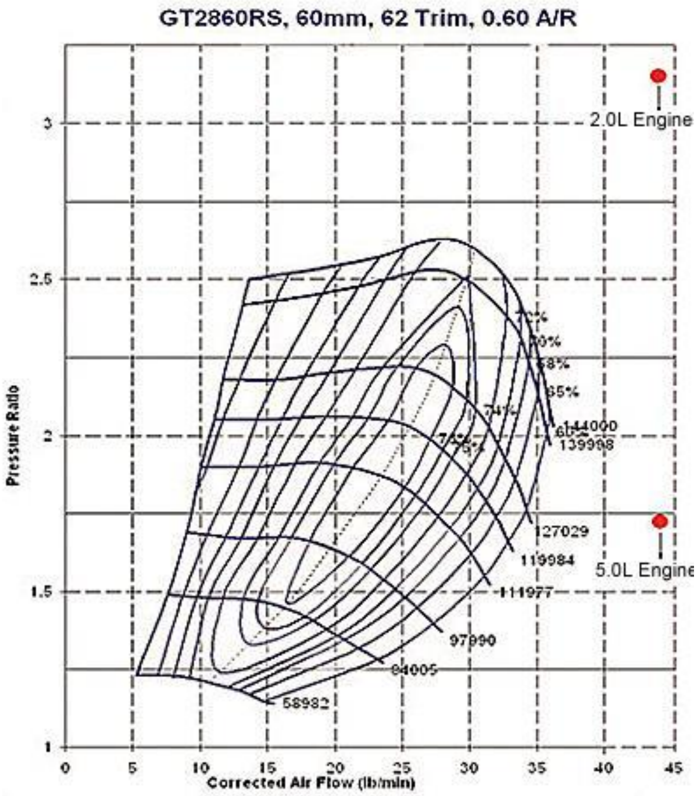

Figure 3compressor map for smaller turbine[8]

The main difference between a parallel and sequential setup is mainly use of two similar turbo in parallel and variable turbo as smaller and larger geometry in sequtial as mentioned in Figure 3. The parallel setup runs constantly at all rpm supplying compressed gas to all six cylinders similar to an aspirated engine. the intercooler used to combine air contains a bypass valve and waste gate which cuts the supply of air depending upon the volumetric efficiency.

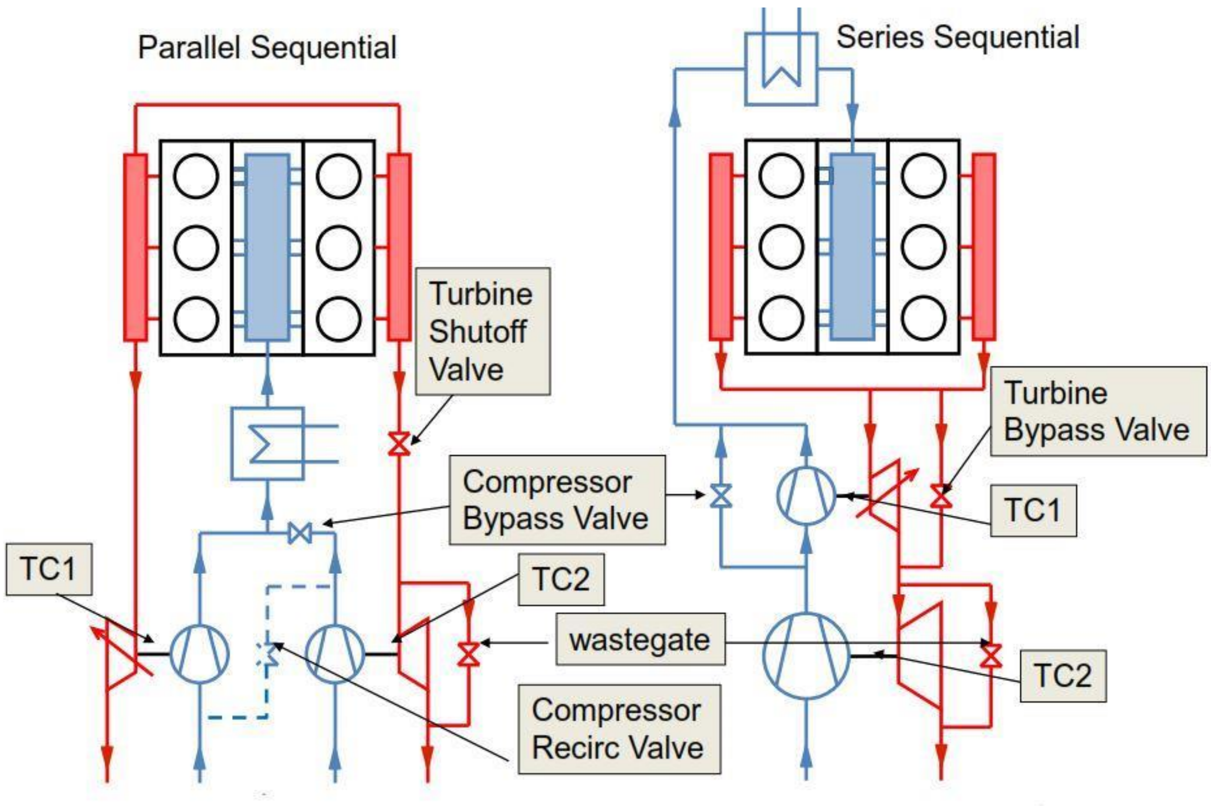

Figure 4 parallel and sequential turbocharging setup[1]

The sequential setup works based upon the rpm change, at lower rpm the exhaust gas is fully supplied to smaller turbo where bypass valve shuts the larger turbo to supply full efficient air to smaller turbo. In smaller turbo the a/r value causing turbine to rotate at high speed. The faster the response from turbo the amount of turbo lag is reduced. At average rpm the bypass valve is partially open and compressor valve is fully close, the supply of air from larger turbo is of high volume. The high volume of air is then supplied to the smaller causing a larger density of air supply to the engine. At higher rpm the smaller turbo is fully turned off by opening of turbine and compressor bypass valve fully, due to that larger turbo can handle more supply of air compressed air. The development and use of sequential turbo is mainly the reduction of turbo lag. The sequential setup helps reaching reaching the boost pressure easier.[2][3]

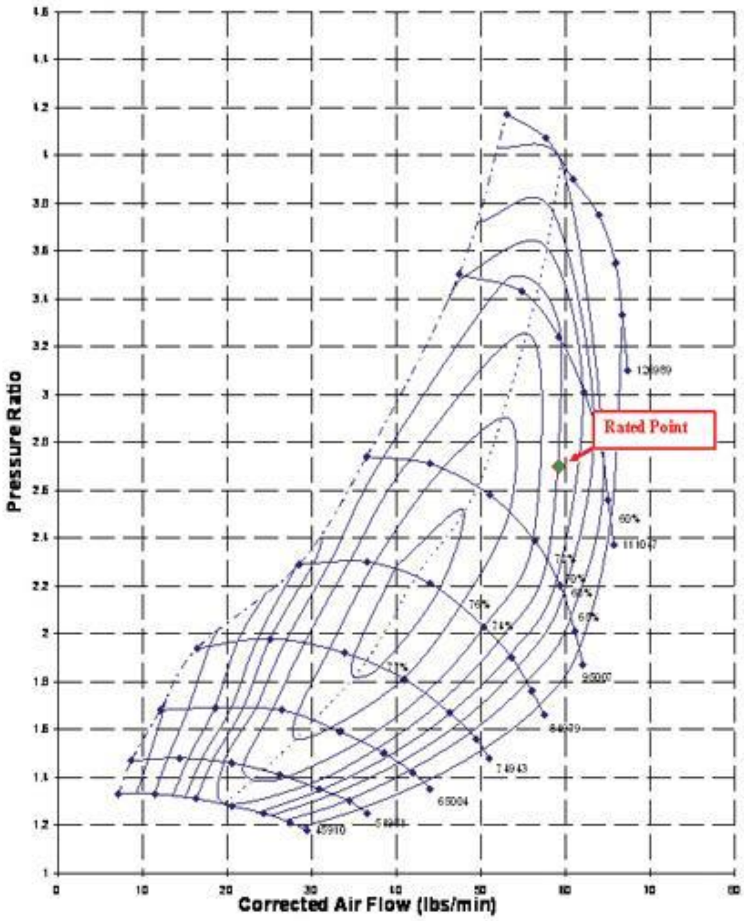

Figure 5 Compressor map for larger turbine[8]

1.4 TWIN SCROLL

Twin-scroll turbo was mainly introduced to separate the exhaust gas from the Wankel engine's two rotors to keep away from interference. anyway, dual-scroll turbo is also useful on four-cylinder and six-cylinder engines. twin-scroll has a faster response and better efficiency. At the same time, as conventional single-turbo arrangement has all exhaust manifolds connected collectively at the exhaust turbine, dual-scroll rapid splits into two separate paths. for example, in a typical 4-cylinder engine, cylinder 1 and four combines to at least one course, whilst cylinder 2 and 3 combines to another path. the two exhaust flows hit the turbine blades independently, as they're separated with the aid of a wall fundamental with the turbine housing. This prevents the two exhaust streams to intrude with each other.

when exhaust valves open, the new exhaust gas rushes out from the combustion chamber and generates a excessive-stress pulse and a terrible strain (decrease than atmospheric stress), as we have defined inside the Tuned Exhaust section. while the intake valve opens for the duration of the "overlap" duration, the stress gets reduced again. sooner or later, the exhaust valve closed and the pressure in exhaust manifold gets stabilizing.

The twin scroll turbo can create more efficiency with scavenging effect, where the inlet valve and outlet valve opens at same time causing the exhaust air to flow out resulting in suction of more clean and cooler air causing a high volumetric efficiency. The integrated compressor recirculation valve is controlled by means of speed sensor resulting in opening and closing of that valve by means of rpm and to full fill the volumetric efficiency of the engine. The use of parallel and series turbocharging leads to fuel economy and engine downsizing. The sequential turbocharging will result in high boost pressure with a wider range of flow.[6]

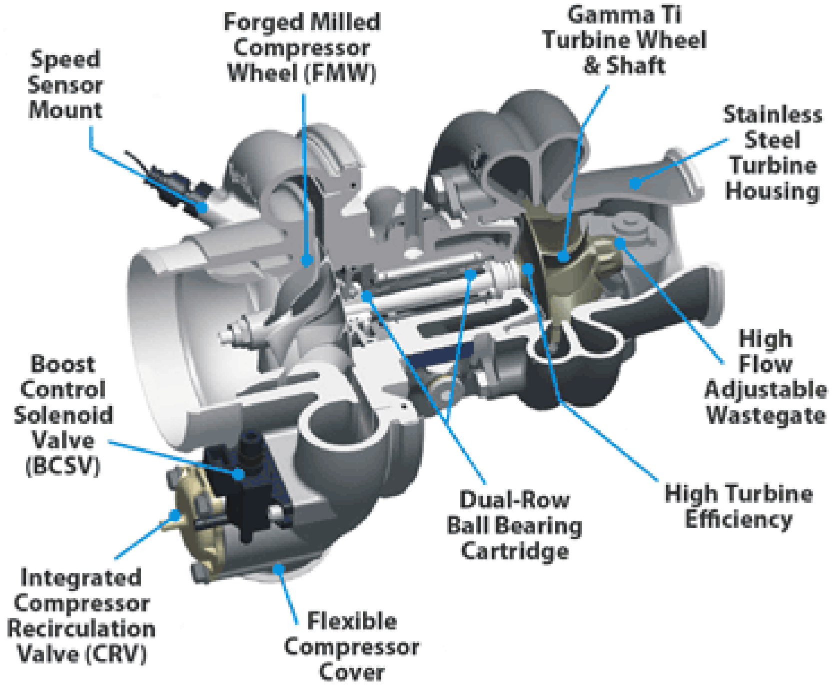

Figure 6 twin scroll turbo schematic[7]

1.5 VARIABLE GEOMETRY TURBO

Variable turbocharger is mostly used in diesel engine due to lower exhaust output at initial condition. It is primarily used to reduce turbo lag and to reduce the emission by means of exhaust gas recirculation technique. In normal turbochargers at lower rpm turbo lag is more common due to low operating speed due to lack of efficiency. Variable geometry turbo can produce more reponse at lower speed by altering the flow of exhaust gas in the turbine.

An actuator is used in variable geometry turbocharger to control the flow of exhaust inside the turbine by altering the vane angle. At lower rpm the vanes are partially closed reducing th flow area causing a high velocity flow towards the turbine making the turbine to spin faster. The faster response of tubine at lower speed reduces turbo lag in the engine.

At higher rpm flow from exhaust will be higher causing the vane to open fully making the exhaust air to directly impact at high velocity. In case of too high pressure the waste gate equipped in the turbocharger is opened to flow the excess amount of air to flow out. The main purpose of a variable geometry turbocharger is to determine the change of a/r(A-area; R-distance from center of turbine to the centroid are) ratio depending upon the rpm. The increase of area decreases the speed of turbine, decrease of area increases the speed of turbine. The change in are causes the volume of air flow to the turbine. The efficiency of a variable geometry turbocharger is comparetively high due to variable change in air flow ratio and due to air recircultion technique.

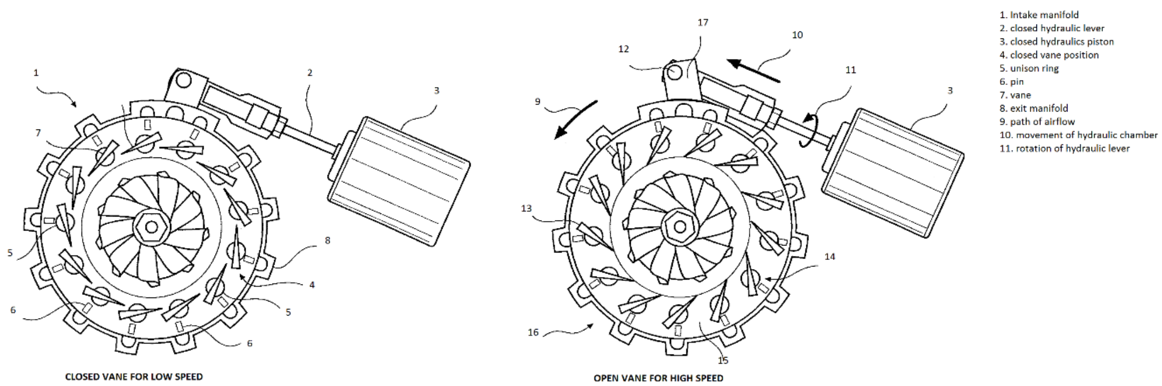

Figure 7 variable turbocharger[3]

1.6 VARIABLE TWIN SCROLL

In similar to variable geometry turbo, variable volume turbine is used for gasoline engines. Variable volume turbine is similar to variable geometry turbine in which instead of vanes two sets of chamber of chamber is used to control the flow of turbine. The variable volume turbine looks like a twin scroll turbine which contains two equal scroll whereas variable also contains two scrolls but are of different size. At lower rpm the flow is carried out by smaller scroll and at higher rpm the flow is controlled by means of larger scroll. An actuated lever is used to control the flow of air through different scroll. The scrolls define th volume of air supplied to the turbine thus rotational speed of turbine.[3]

When air supplied from smaller scroll causes the turbine to rotate faster at lower rpm and similarly for higher rpm a larger scroll is used. The manufacturing technique is costlier due to different set of scrolls in the turbine. The first set of variable geometry turbine is manufactured by means of 3d printing proces. The use of variable geometry turbo can result in high efficiency and improve the process of downsizing.

Variable twin scroll is a standard setup of turbocharging technique which uses variable geometry turbos to produce more efficiency and a wider range of flow path. The setup can mostly useful for higher V8. The higher amount of displacement need to be carried out at various rpm. In general breathing at lower rpm is low which in general is fully satisfied a standard smaller turbo, but at higher rpm a single larger turbo can't produce enough volumetric efficiency to fill the entire displacement of the engine. Hence a combined set of variable turbocharger is necessary to satisfy volumetric efficiency at all conditions. [11]

1.7 ELECTRIC TURBOCHARGERS

Electric turbochargers are mostly combined with any of the other turbo and an electrical motor. They are most common in high speed racing to reduce turbo lag and produce more efficiency at low speeds. It is generally by connecting an electric motor to exhaust turbine in recovery of waste energy at high rpm and used at lower speed. It gives a wide range of rpm and torque characteristic. The electric motor or the initial turbine is coupled to the engine drive shaft to acquire power for compressor at lower rpm which cause a decrease of power output.

The response of an electrical turbocharger is too low compared to any other turbo setup but producing a direct power loss in engine doesn't transfer full power output to flywheel. The response of an electrical turbocharger depends upon the type of electric motor used or on the condition of compressor and driven belt. Electrical turbo cannot produce enough output when running at higher rpm.

There is more turbocharging concept involved depending upon the engine setup and amount of torque and boost pressure required for an engine. The stages of turbocharging are more compared to sequential or parallel but it varies upon the type of turbocharger used. They are more like

1. normal turbo combined with a supercharger.
2. Standard turbo with a e booster in sequential or parallel
3. Full length e turbo for full and constant torque.

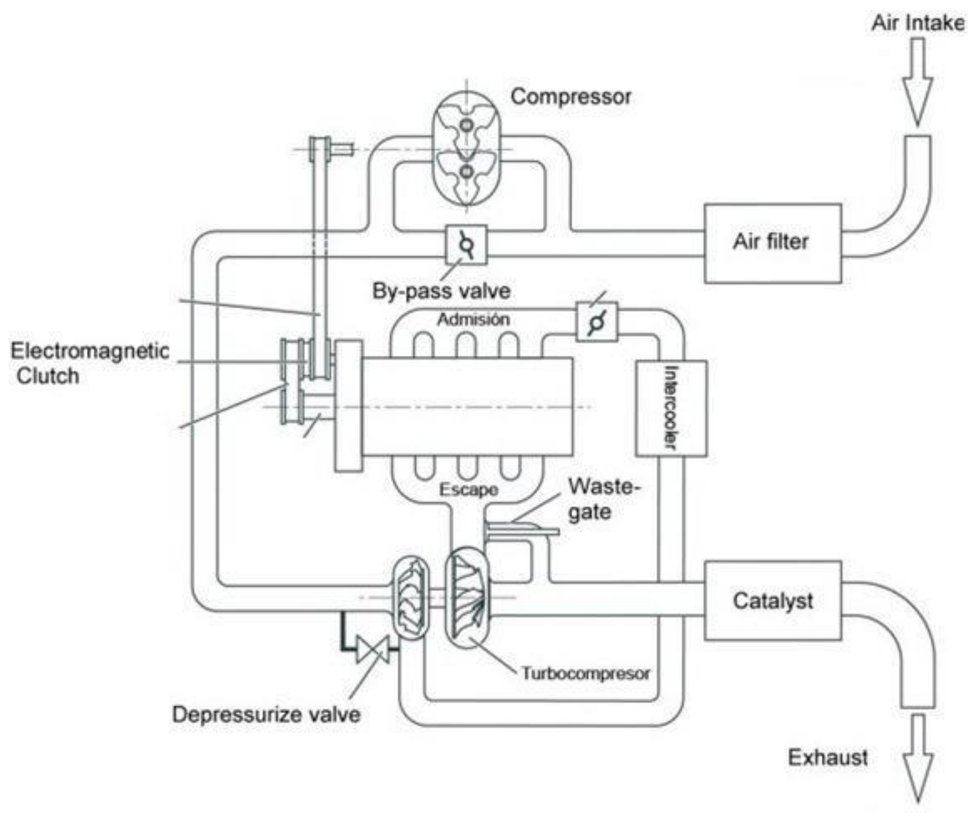

Figure 8 electrical turbocharger schematic [11]

2. EXPERIMENTAL WORK (DEVELPOMENT OF TURBO SETUP SCHEMES)

2.1 INSTALLATION SETUP

The experimental setup consists of a normal turbocharger connected in parallel with variable turbocharger. It contains split valve at each turbocharger output manifold to make sequential connection. The standard variable charger containing exhaust gas recirculation technique is used. The standard large turbo is chosen matching the engine efficiency. A standard 6 cylinder 6.0litre engine is used for the experimental setup. The intake manifold is split as 1, 3 and 5 for variable turbocharger and 2, 4and 6 is connected to standard turbocharger.[8]

The split valve and turbocharger output and input are controlled by means of sensor to measure the amount of to the engine. The exhaust manifold is directly coupled to the turbines of the turbocharger.

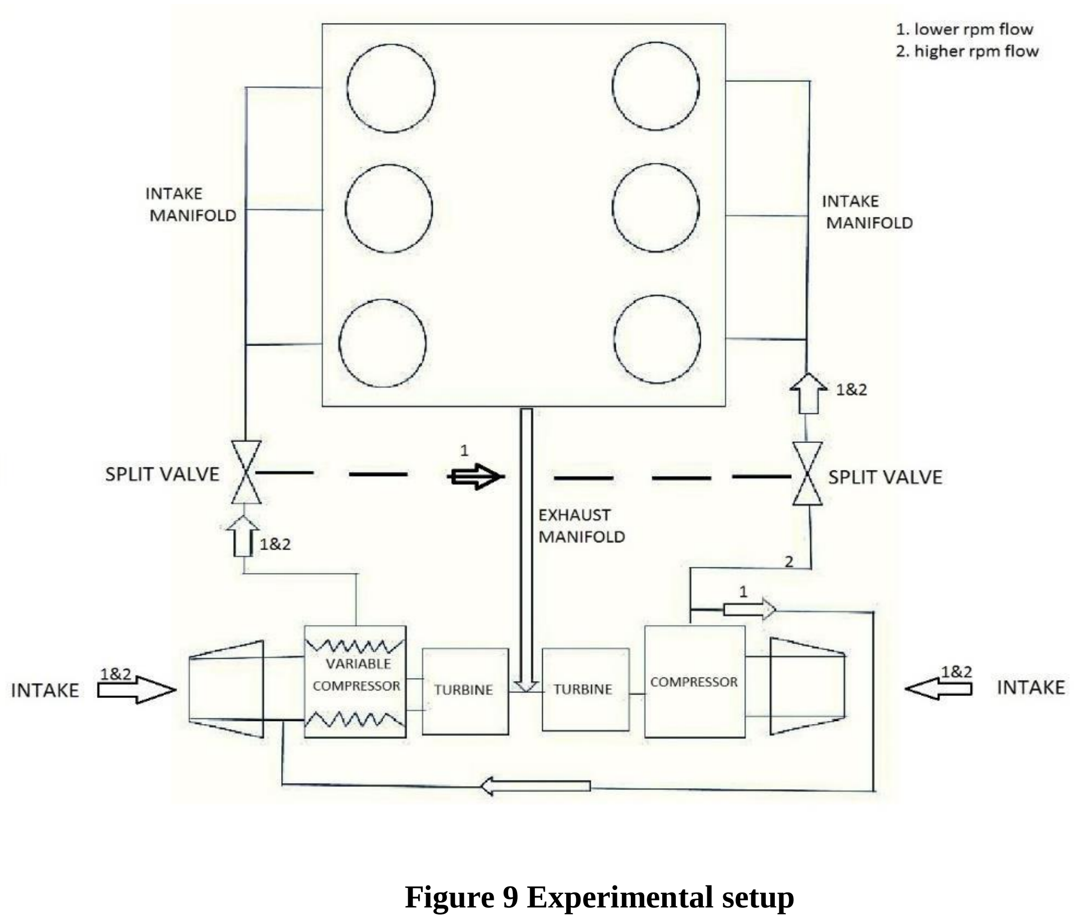

Figure 9 Experimental setup

The setup is based and calculated on sea level of pressure and temperature as initial condition. The split valve controls three ways in order to supply the amount of air depending upon the requirement.

The working of this experimental setup is based on two steps as high rpm flow and low rpm flow. The flow of air changes depends upon the running rpm and mass flow rate in the turbine. A standard waste gate is equipped in turbochargers to release the excess amount of gas. The setup contains two sets of flow lines which happens at low rpm as 1 and high rpm flow lines are marked as 2. The variable compressor used in the setup changes the A/R ratio automatically and controls the recirculation of air during lower speeds.

The turbochargers chosen for the engine setup are based everyday drivability and compromised for high performance capability. From calculated setup, the turbo is able to boost up to an average of 350 horsepower. In general, a turbo of higher upgrade is used it reduces the fuel consumption and reduces emissions.

2.1.1 LOW RPM SETUP

The setup contains two different sets of turbocharger with split valve restricting flow air depending on the rpm. At lower rpm, the variable compressor is made to directly supply air to all six-cylinder taking intake from atmosphere and from normal turbocharger which helps in increase volume of air intake. The variable turbo now converts the high volume of air in to high pressure and velocity. The use of single turbo with closed vane can produce high pressure and velocity with high density. Due to use of sequential setup at lower rpm the variable turbocharger acts as smaller turbo providing a faster response reduces the turbo lag.

At lower rpm and depending on the pressure ratio required is calculated and stored in the ECU which helps in adjusting the vane inside the variable turbocharger. The hydraulic piston in variable turbo helps in the adjustment depending on the flow of air in turbine. The low rpm setup is shown in figure 8. The minimal angle for vanes inside a variable geometry turbocharger is 30 degree which can pressurise the flow of air towards the turbine at high velocity.

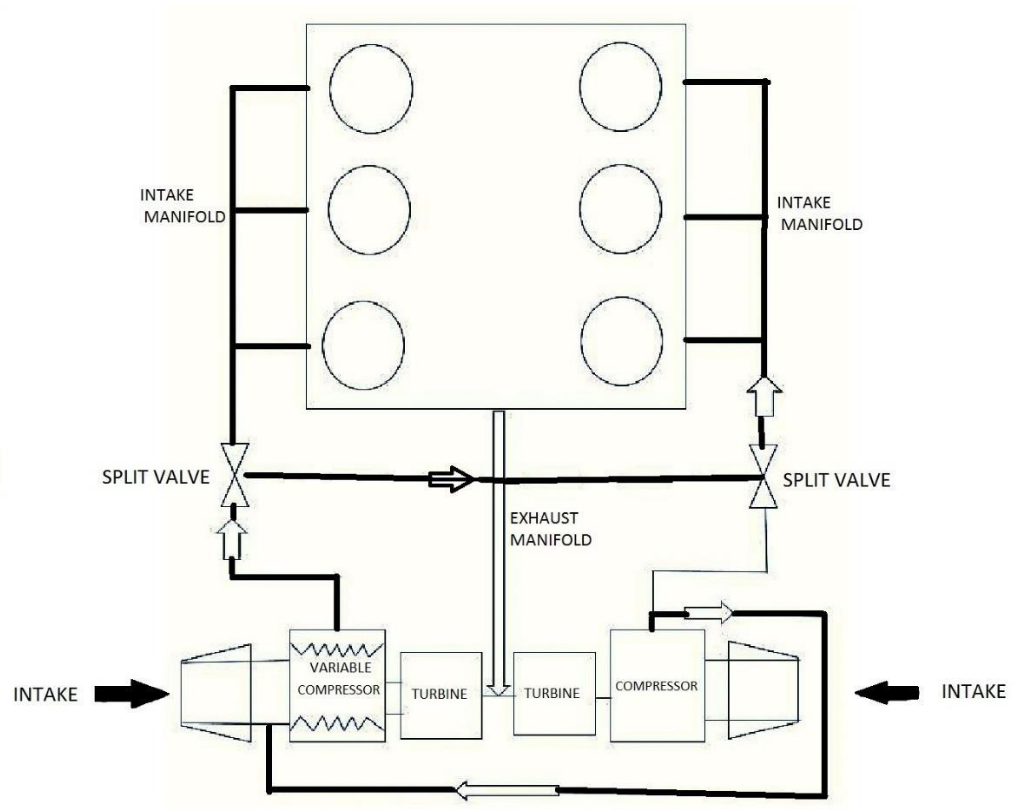

Figure 10 Schematic diagram indicating the Airflow at Low RPM

2.1.2 HIGH RPM SETUP

In high rpm, the flow valves are closed stopping the interconnections between turbochargers and the input manifold. The cylinders 1, 3 and 5 are connected to variable turbo with an open vane matching the input supplied by normal turbocharger to 2, 4 and 6. The presence of vanes in variable turbo helps in matching A/R ratio to the standard turbo. They act as parallel twin turbo setup at higher rpm.

In general, at high rpm the velocity of air supplied to the turbine is high causing the vanes inside the turbine to fully open which allows both turbine to run at full efficiency. The waste in turbocharger releases the exceeding gas. Th flow path of air during high rom is shown in figure 9.

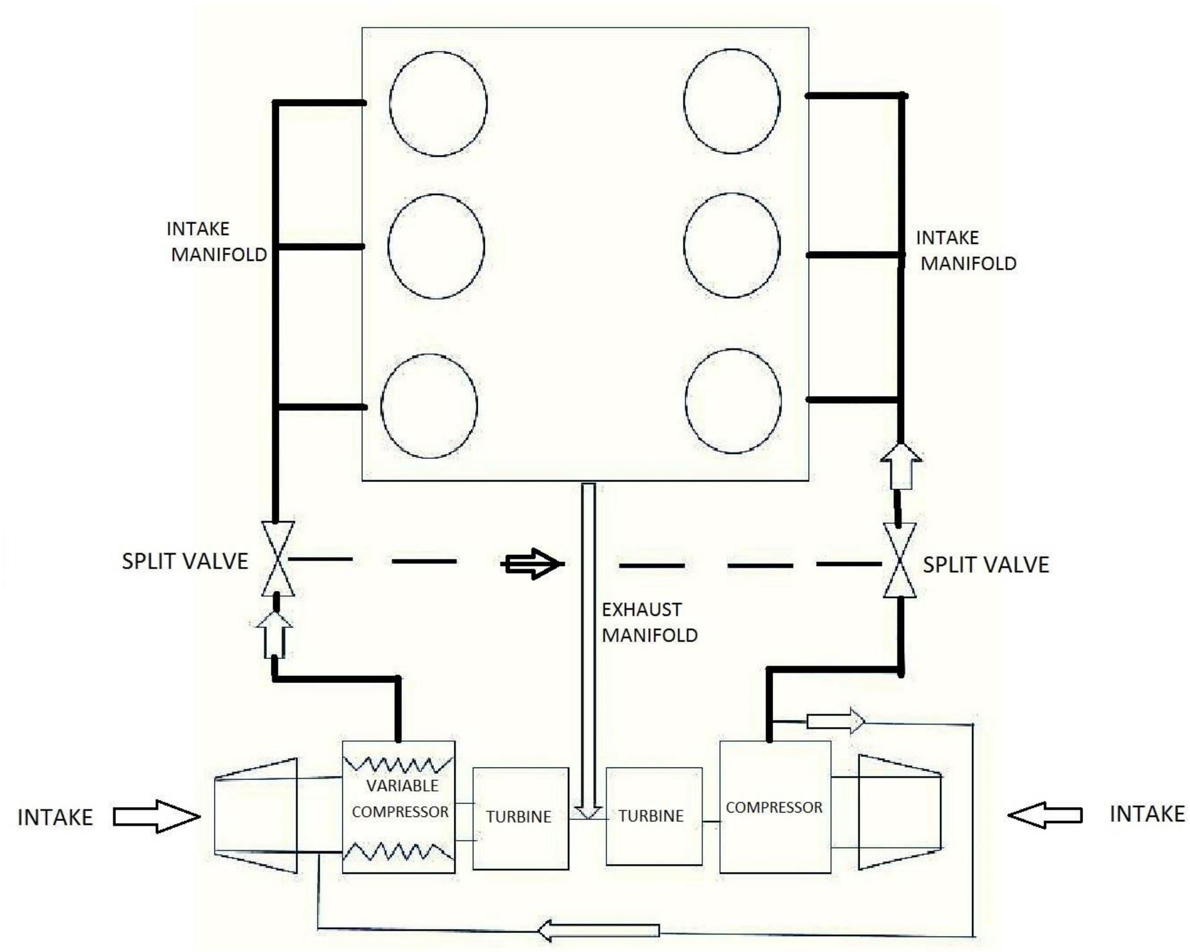

Figure 11 Schematic diagram indicating the Airflow at Higher RPM

3. CALCULATIONS

3.1 ENGINE CALCULATION

In general turbochargers are chosen depending upon the amount of horsepower required from normal base horsepower which is related to boost pressure. The mass flow rate and pressure ratio helps in calculating the compressor map of the turbocharger. [4]

3.1.1 COMPRESSOR FLOW RATE

To calculate the compressor flow, rate some general engine characteristics must be known. Compressor flow rate(Wc) is equal to cubic inch of engine displacement(CID), revolutions happening per minute and volumetric efficiency of the engine(VE).

$$W_c = \frac{\mathrm{CID} * \mathrm{RPM} * \mathrm{VE}}{3456} \quad (1)$$

The volumetric efficiency varies depending upon the engine type. In two valve per cylinder engine, Push rod engine volumetric efficiency is 80%, Four valve engine volumetric efficiency is 85% and for a four-valve engine with variable valve timing volumetric efficiency is 95%. For 3.0 litre four valve engine a cubic displacement will be 183ci and at a max rpm of 6500 the air flow rate will be 292CFM.

3.1.2 PRESSURE RATIO

Pressure ratio(PR) is generally calculated by means of ambient pressure and boost pressure. The amount of pressure required depending on the rpm is chosen from density chart.

$$PR = \frac{BP + \text{ambient pressure}}{\text{ambient pressure}} \qquad (2)$$

The ambient pressure at normal sea level is 14.7lbs and we require a boost pressure(BP) of 10 so the pressure will be 1.68. For each boost pressure the pressure ratio is calculated and plotted against the density ratio to obtain compressor efficiency. Boost pressure is the amount of required boost to meet the necessary horsepower. For a standard boost pressure of 10 pressure ratio is 1.68 but in general the turbo can exceed the amount for pressure ratio which results in good fuel burn and high volumetric efficiency.[4]

3.1.3 TURBO AIR FLOW

The amount of air turbo needs to pump is calculated by compressor flow rate and density ratio of air. The turbocharged air is then converted to lbs/min to obtain the corrected air flow.

$$W = W� * � \qquad (3)$$

The turbocharged air flow(Wa) for the engine calculated for a 1.5 density ratio(dr) will be 438CFM. The corrected mass flow is converted by multiplying cfm of turbo to standard air density (0.069) which will be 30.26lbs/min of air mass flow. Mass flow rate in lbs/min is directly proportional to 1:10 ratio of horsepower produced by the engine. The turbocharged air mass flow converted produces 300 horsepower where initial aspirated produce 20.14lbs/min which corrects to 200 horsepower.[4]

3.2 TURBOCHARGER CALCULATION

In order to choose a turbocharger, the amount of boost pressure we required is calculated by means of applying horsepower or torque. A stock engine can handle boost of 100 Horsepower(HP) depending upon the type and state of the engine.

3.2.1 MANIFOLD PRESSURE

The manifold pressure required to meet the proposed horsepower is calculated by means calculating an approximate air flow with air fuel ratio (A/F) for low smoke performance which lies between 22 to 1. The standard Brake Specific Fuel Consumption range is 0.38.

$$W = HP * \frac{A}{F} * \frac{BSFC}{60} \tag{4}$$

With a setup target of 350 Horsepower(HP) and full burn Air Fuel ratio of 22 and standard brake specific fuel consumption of 0.38 requires Air Flow of 48.77lb/min. The manifold required Pressure (MaPreq) is calculated by Air flow, intake manifold temperature (Tm) and Volumetric Efficiency (VE).[9]

$$MaPreq = \frac{Wa * R * (460 + Tm)}{VE * (\frac{RPM}{CID}) * 2} \tag{5}$$

From the calculated data and initial condition the manifold pressure requirement is 35.83 psi. In above condition R is gas constant value of 639.6 and average manifold temperature is take as 130F.

The standard pressure ratio is proportional to inlet pressure and outlet pressure. The outlet pressure(Po) is the combination of manifold inlet pressure and compressor discharge pressure (Pd). The compressor discharge pressure is the loss of discharge pressure in air filter and piping which lies between 1 to 4 Psi. The inlet pressure (Pi) is the difference between ambient pressure(Pa) and discharge pressure.

$$Po = MaPreq + Pd \tag{6}$$

$$Pi = Pa - Pd \tag{7}$$

$$PR = \frac{Po}{Pi} \tag{8}$$

The pressure ratio calculated from the above formula is used to design the turbocharger initial condition. The pressure ratio is 2.76 which is generally used in choosing a turbocharger. [9]

4. DESIGN AND ANALYSIS

4.1 DESIGN SETUP

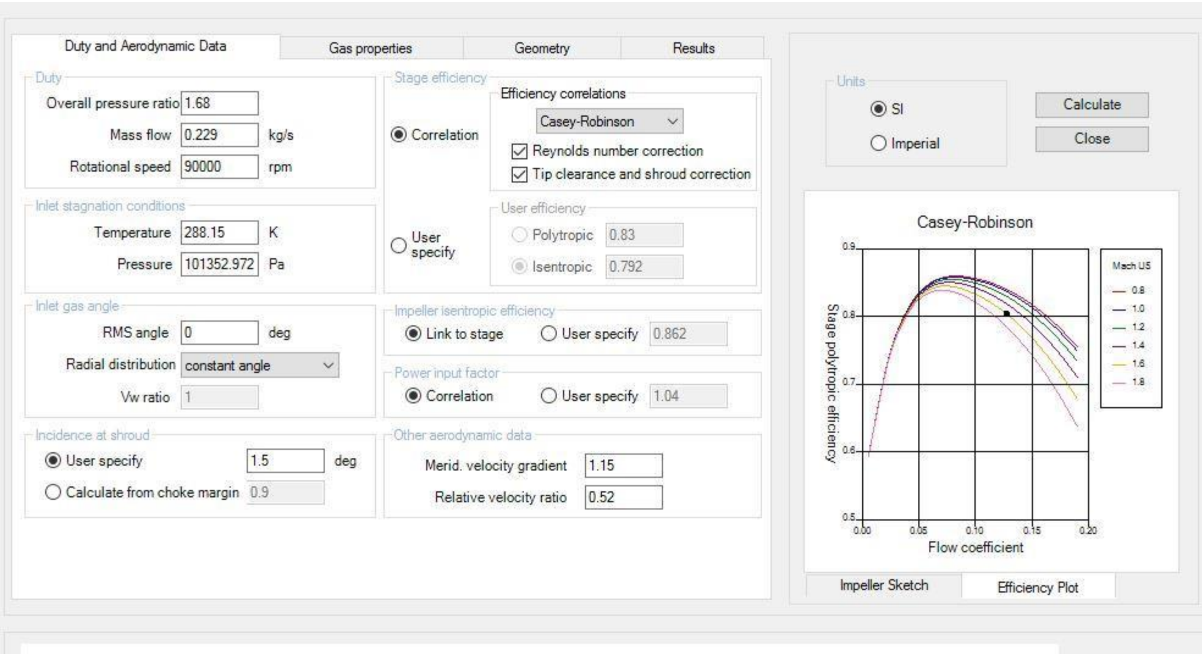

Figure 12 initial condition setup for analysis

The initial data for analysis is taken from the calculation of turbocharger and engine calculated above. The initial condition contains a 3.0litre engine running at 6500rpm at sea level. The pressure ratio is calculated by means of inlet manifold pressure and mass flow conditions. The efficiency data displayed on duty and aerodynamic data which is based on the current design indicates a various number of efficiency correlation such a casey-robinson stage efficiency, caey-marty stage efficiency correlation and Rodgers stage efficiency correlation. The efficiency plot is generated in Ansys vista CCD by the calculated data. The temperature and pressure is kept constant as normal condition. The data for centrifugal compressor is automatically generated in the result tab. The initial fluid conditions and flow angle for the air intake is given in vista centrifugal.

The blades are generated by means of blade modeler where the blade thickness and sketching angles can be adjusted. the blade can be viewed in 3d angles. The vane angle and layer between vanes are adjusted. The problems and corrections regarding design are corrected in blade modeler. The impeller sketch is generated based on the input in one dimensional sketch at bottom right of the duty and aerodynamic data.

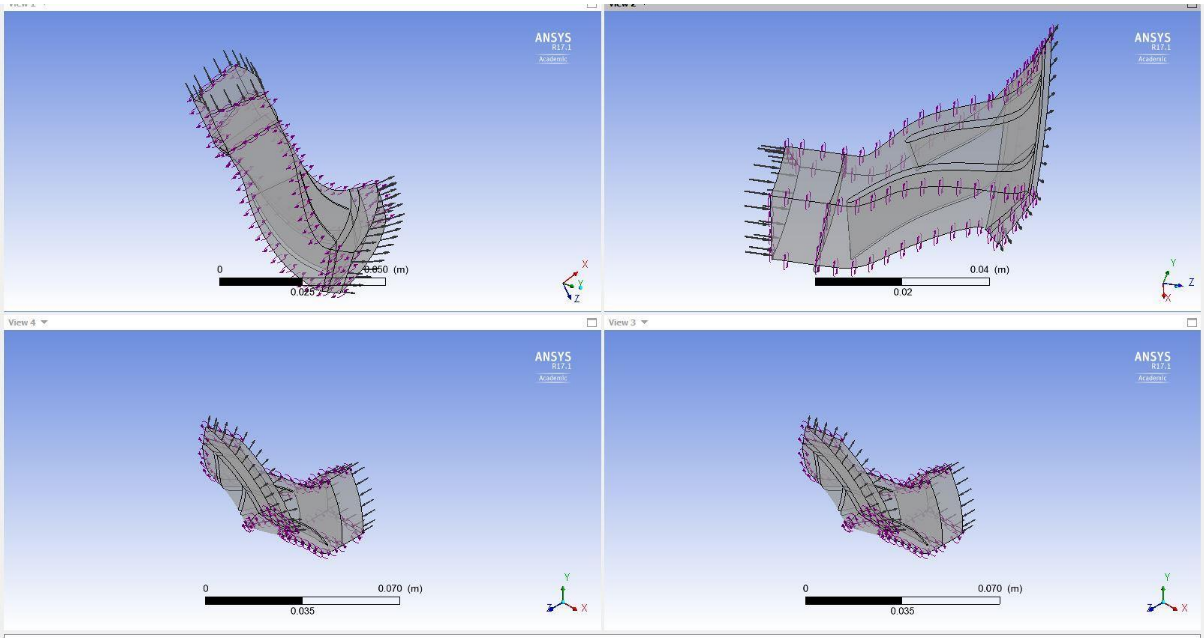

Figure 13 Initial design setup for design analysis

The turbo mesh view is used to set the initial boundary condition and flow path between the blades of the turbine. The blade alignment is reviewed for analysis. The mesh is generated. In geometry section, the test data, mass flow rate , work factor, rotational speed to measure inlet pressure and temperature are known. The iterative mode is used to adjust the generated unknowns from CCD. The parameter setting the initial condition are then adjusted like impeller tip diameter and tip width, vane angles.

The performance map in blade modeler helps in creating a efficiency chart relating to study about the turbine condition during the process. The number of speed lines required can be set and rotational speed, mass flow rate for each speed line is adjusted or automatically depending upon the requirement.

4.2 DESIGN AND ANALYSIS REPORT FOR STANDARD TURBO AT HIGHER RPM

Table 1 Performance result

Rotational Speed	-9424.7800	[radian s^-1]
Tip Diameter	0.0992	[m]
Tip Speed	467.3070	[m s^-1]
Mass Flow Rate	0.6001	[kg s^-1]
Power	78656.4000	[W]
Inlet Flow Coefficient	0.1066	
Total Pressure Ratio	2.8873	
Total Temperature Ratio	1.4529	
Total-to-Total Isentropic Efficiency %	82.1009	
Total-to-Total Polytropic Efficiency %	84.5947	
Polytropic Head	110886.0000	[J kg^-1]
Polytropic Head Coefficient	0.5078	

The stabilised rpm analysis of 90000rpm with constant inlet ambient pressure and temperature is taken in to account. Mass flow rate is initially calculated depending upon the engine characteristics and amount of boost pressure required. The ratio of input and output temperature is automatically calculated in result tab based on the initial input condition applied in duty and aerodynamic data.

Table 2 Detailed summary

Quantity	Inlet	LE Cut	TE Cut	Outlet	Units
Density	1.1305	1.0042	1.7722	1.9762	[kg m^-3]
P	90599.7000	78543.6000	191271.0000	219205.0000	[Pa]
P0 (abs)	101311.0000	102607.0000	316675.0000	292514.0000	[Pa]
P0 (rel)	101236.0000	99175.9000	82249.8000	82760.7000	[Pa]

T	279.0260	266.1880	362.4420	382.2950	[K]
T0 (abs)	288.1760	288.7260	419.2760	418.6810	[K]
T0 (rel)	288.1250	288.1340	289.8730	291.7210	[K]
H	-19207.8000	-32102.8000	64574.4000	84515.6000	[J kg^-1]
H0	-10017.7000	-9465.9400	121659.0000	121062.0000	[J kg^-1]
Ro thalpy	-10069.0000	-10060.0000	-8313.5100	-6457.7400	[J kg^-1]
Entropy	-34.1250	-28.3708	9.4285	25.3893	[J kg^-1 K^-1]
Mach (abs)	0.4018	0.6466	0.8656	0.6494	
Mach (rel)	0.9759	1.0773	0.5623	0.9214	
Cm	134.5740	196.7240	129.5230	111.4690	[m s^-1]
Cu	0.1194	3.7412	301.9340	225.4900	[m s^-1]
C	134.5770	210.0690	337.4170	255.9500	[m s^-1]
Wu	-296.4530	-286.2890	-165.3740	-342.0360	[m s^-1]
W	326.9840	348.3860	216.5640	362.8630	[m s^-1]
Flow Angle (abs)	0.0673	3.0824	25.6419	28.3734	[degree]
Flow Angle (rel)	-64.8134	-55.0354	-56.1439	-74.4652	[degree]

The end condition from the analysis shows the pressure ratio variance is increased due to higher amount of mass flow through the turbine, which results in increase of temperature between the inlet and the outlet.

4.3 VARIABLE GEOMETRY TURBOCHARGER

The study of variable geometry turbocharger based on low pressure and high pressure exhaust gas recirculation technique is considered. The standard turbocharger used in the experimental setup matches the variable turbo for high speed and low speed requirement. The speed of turbine remains constant through the entire cycle from low rpm to high rpm.

Thus, resulting a constant gas flow through the turbine. The speed of turbocharger and amount intake air is related based on engine condition.[8]

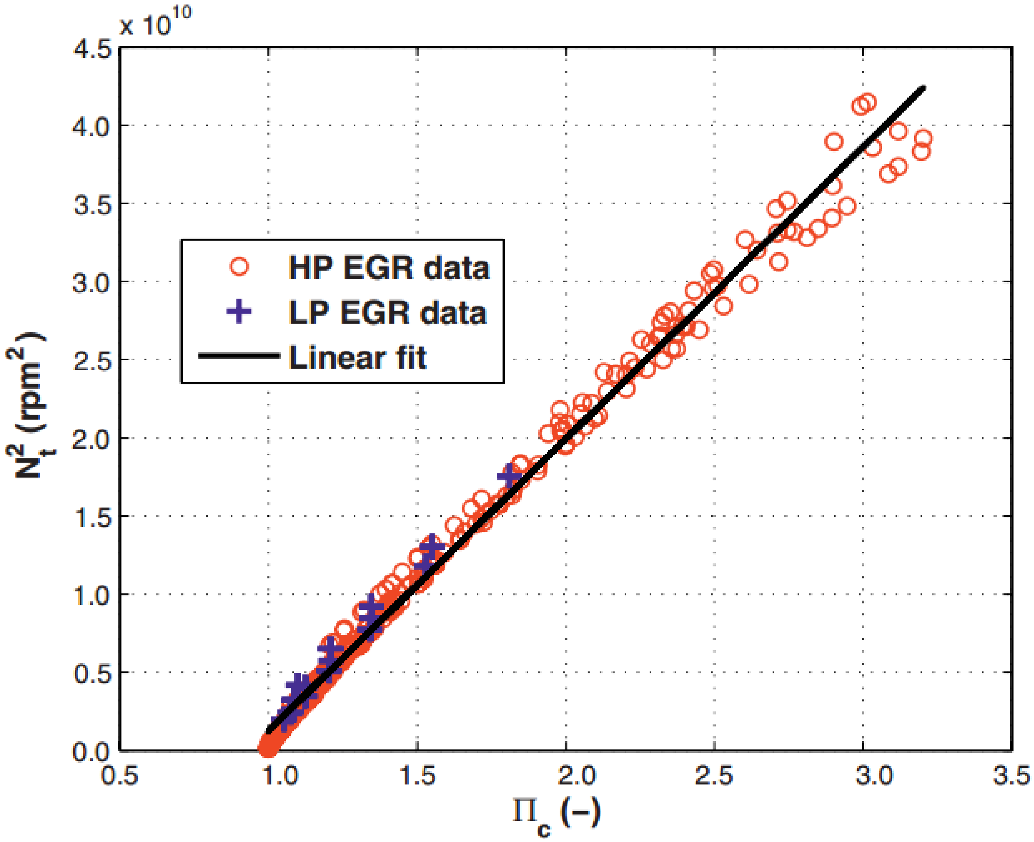

Figure 14 calibration between speed and mass flow rate

The variable turbocharger calibration depends upon the exhaust gas recycle, volume of air flowing through. The vanes inside the turbine gets adjusted based on the sensor reading of mass flow through the turbine. The higher mas flow expands the vane fully and for lower condition the vanes opens minimally. In figure the flow through turbine at several vanes opening condition is calibrated.

Variable turbocharger control strategy is mostly based on exhaust gas recycle technique and air supply management for aspirated engines. The actuator in the variable geometry turbocharger causes the turbine to stay in stable speed by adjusting the vane angle. The intake and exhaust manifold sensor helps in the adjustment of vane angle in turbine to maintain an efficient mass flow rate to the engine.[8]

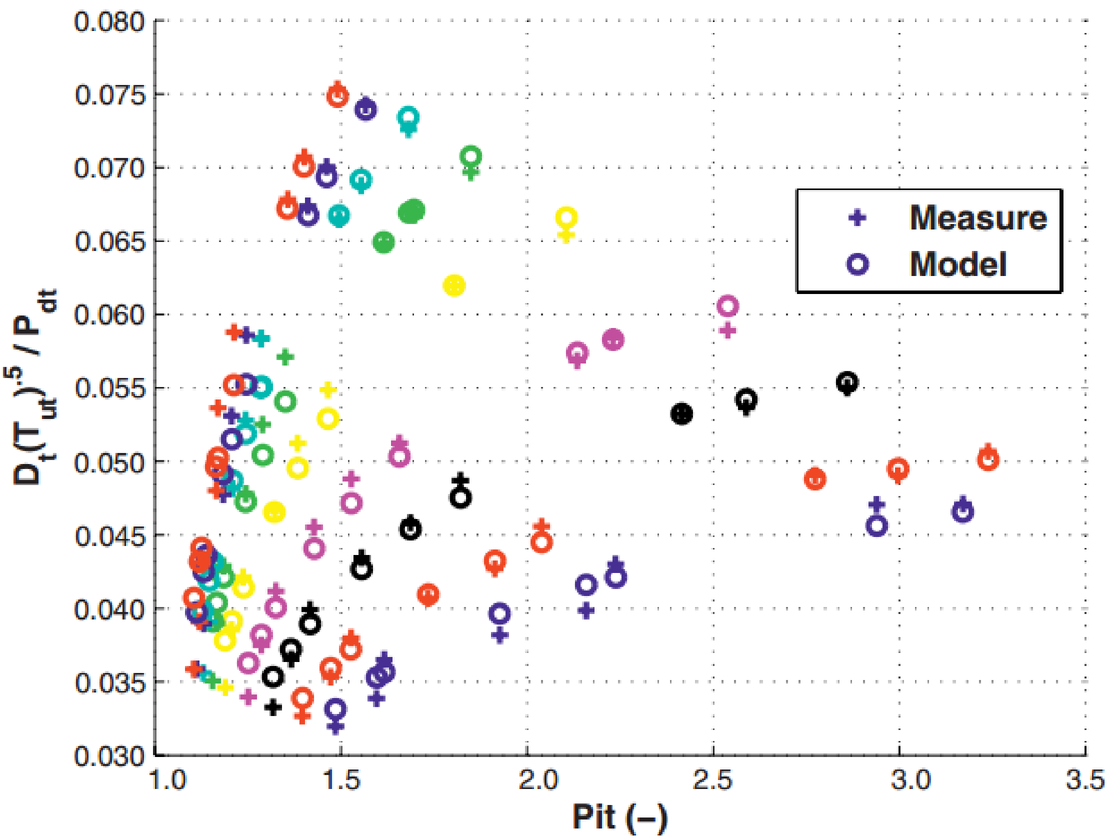

Figure 15 mass flow based on vane angle

The above graph calculated by adjusting vanes at different angles and varying mass flow rate in various angle. The exhaust gas recycle system is turned off in order to study the efficiency change of mass flow rate at different angle. The steady state system used to read points for various measure is based on engine operating condition. The study of these maps in transient condition is complicated due to altering of mass flow rate at various condition.

The measure point is studied to evaluate the efficiency of variable turbocharger. The volumetric change affects the efficiency of the turbine. The measure of efficiency in transient condition is not possible due to various operating condition.

5. RESULTS

5.1 CFD RESULTS FOR COMPRESSOR BLADES

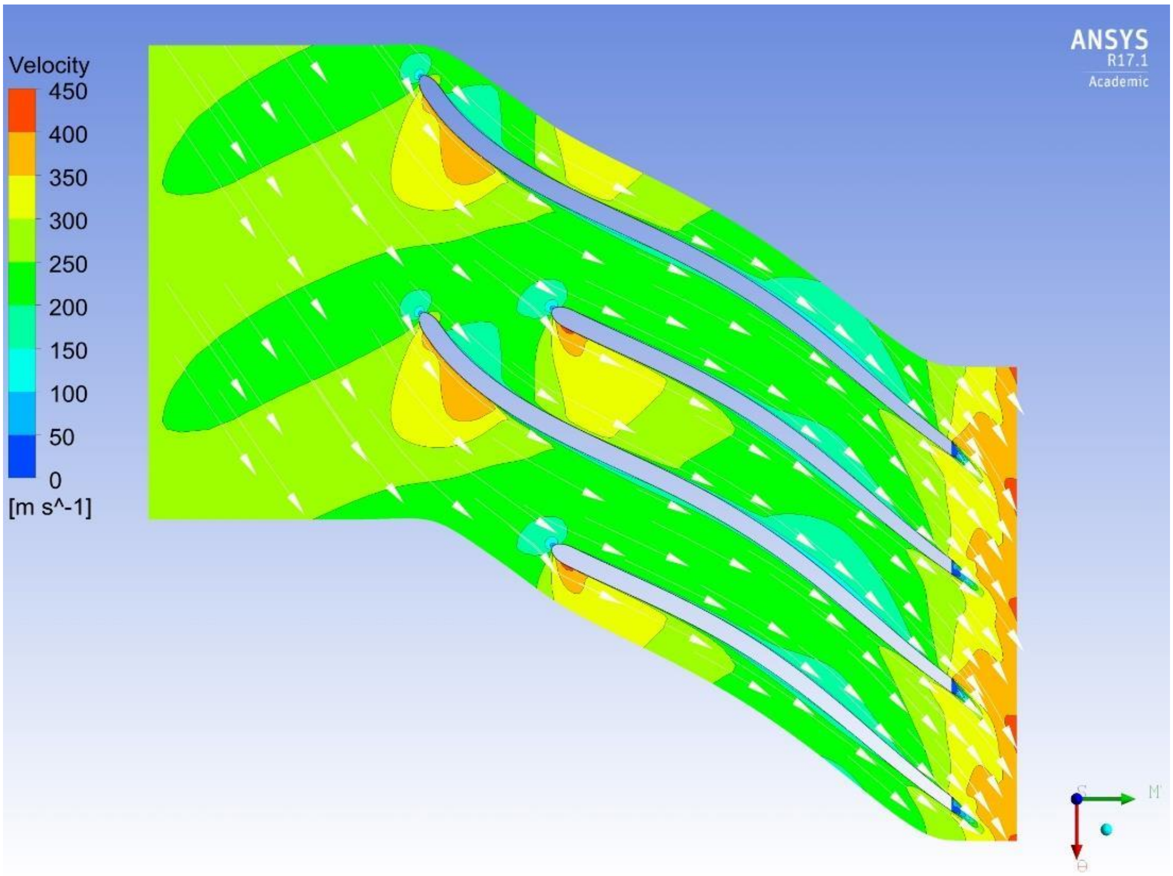

Figure 16 velocity impact at low rpm

At lower rpm, the flow of air does not impact the blades of the compressor the pressure and velocity is boosted at end of the blade. The flow of air caused by engine pump vacuum increase the flow of air. the blade angle remains constant at lower rpm. The flow of air happens from the nozzle tip to the educer. The velocity flow results help in analysing the flow path and mass flow rate compared to pressure created.

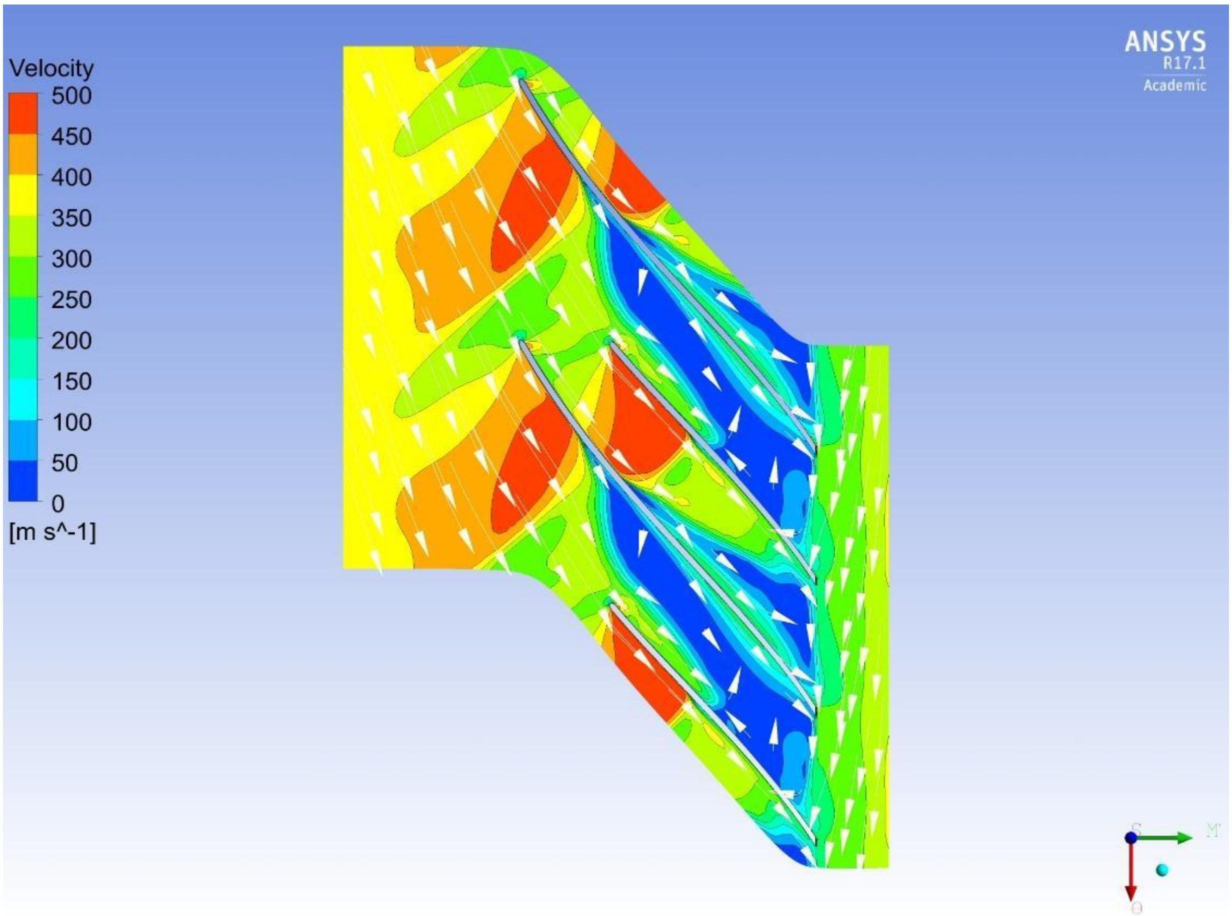

Figure 17 velocity impact at high rpm

At higher rpm, the velocity of air cause the blades to align causing a high flow rate. The change in alignment of blades creates a laminar flow of air. The laminar flow helps in causing a high amount of flow which in case increases the volumetric efficiency of the engine. the laminar helps in creating high velocity and pressure due to alignment of blades in the turbine.

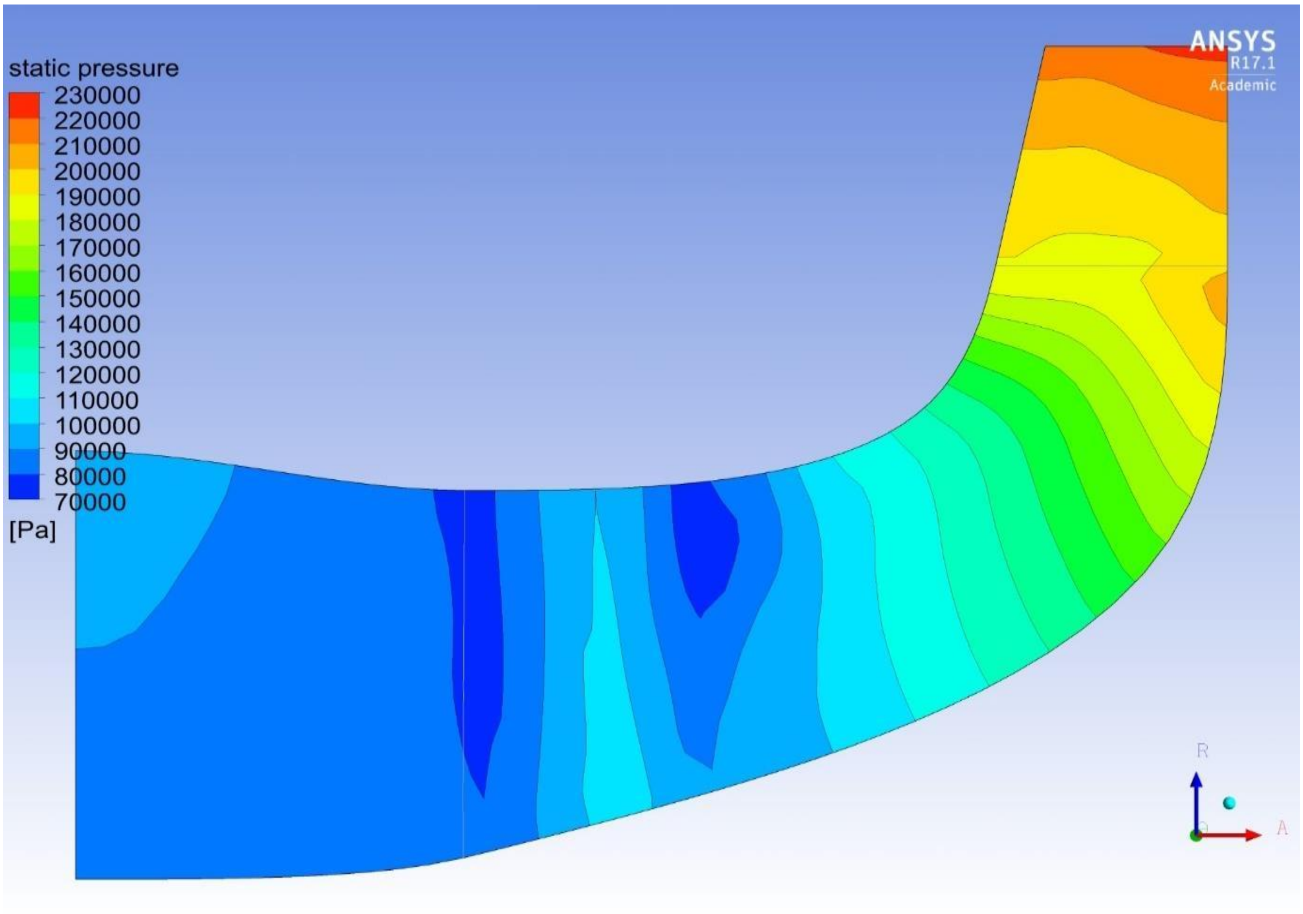

Figure 18 static pressure distribution

The static pressure analysis on blades is used to analyse the pressure distribution from entering point to the exit point. From the figure 15 it is found that the maximum pressure is developed at the inlet point and the value is 230 Megapascal. The pressure is created because of large intake of air at the inducer of small diameter.

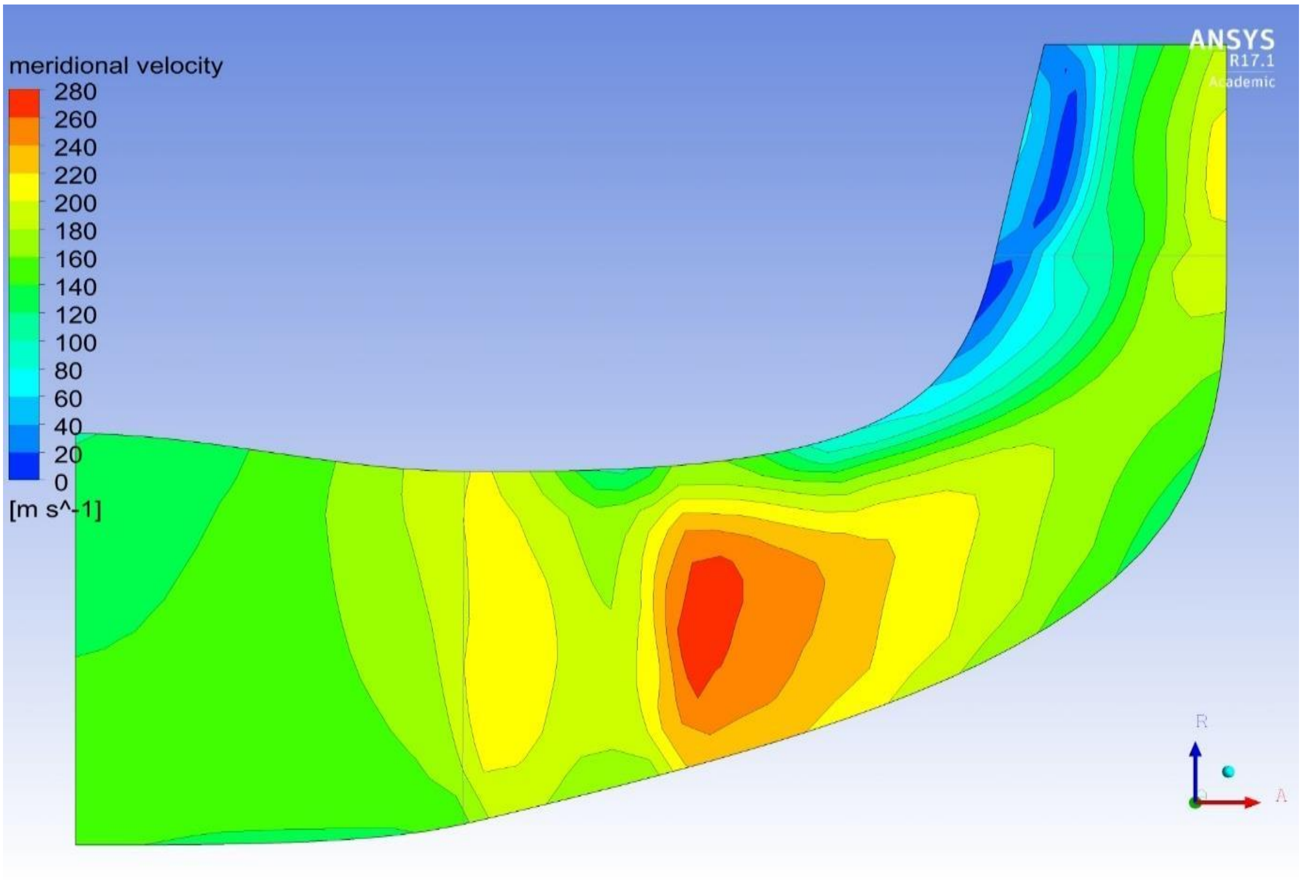

Figure 19 Impact of meridional velocity on compressor blades

Meridional velocity is the velocity that is created perpendicular to the direction of air flow. From the figure 16 it was clear that the maximum meridional velocity is created at the centre of the blade. As maximum velocity is acting at the middle of blade, the efficiency of turbo charger is increased causing a high mass flow rate. It results to high volumetric efficiency.

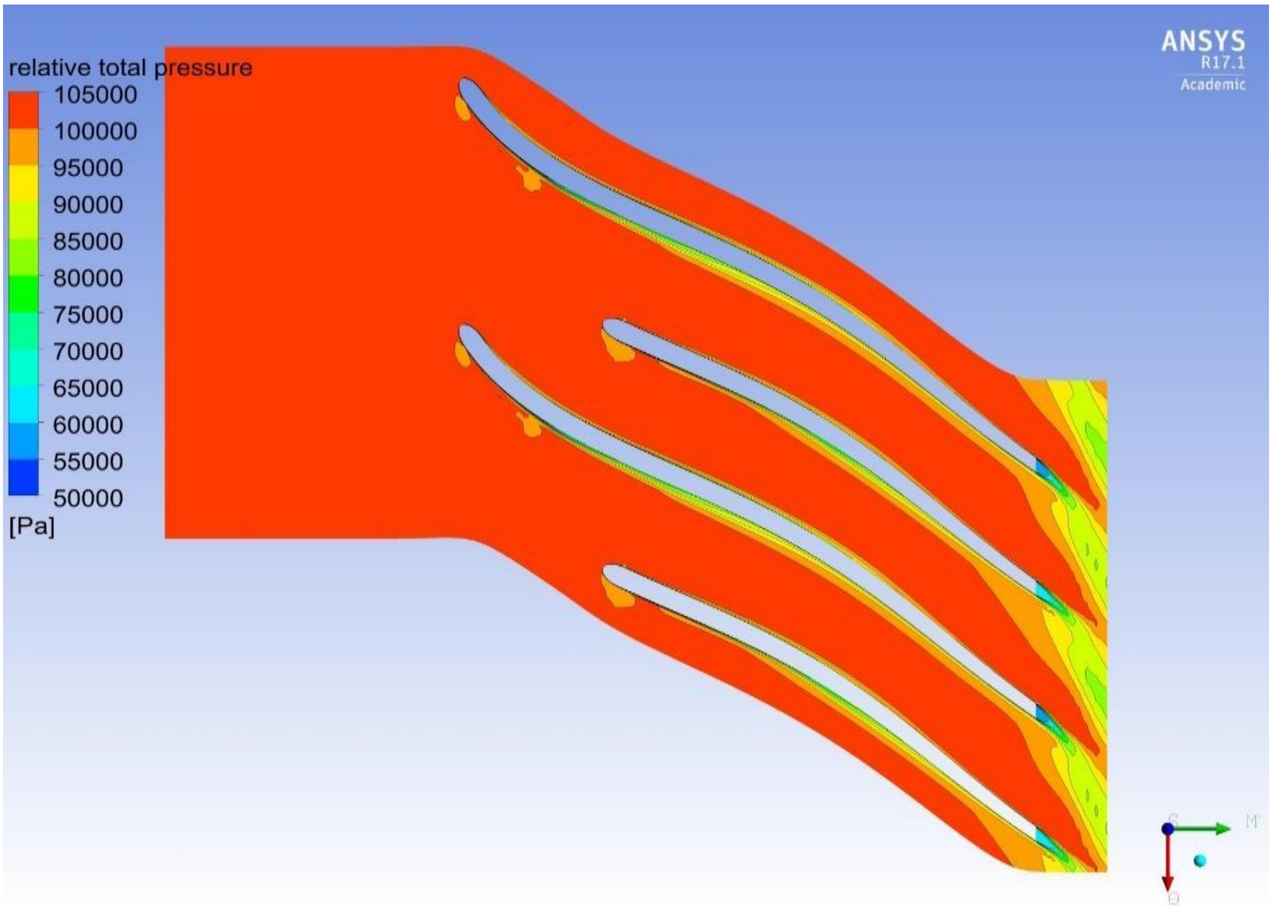

Figure 20 pressure created between blades at high rpm

Relative pressure is a parameter which determines the intake volume of air flow in to the compressor. At higher rpm, the relative total pressure generated in the blade is higher which ultimately leads to the higher intake volume of air. From the figure 17 the laminar flow of air changes the blade angle to increase the mass flow rate creating high pressure and velocity in air flow. The change of air from high volume to high velocity creates a high temperature of air flow.

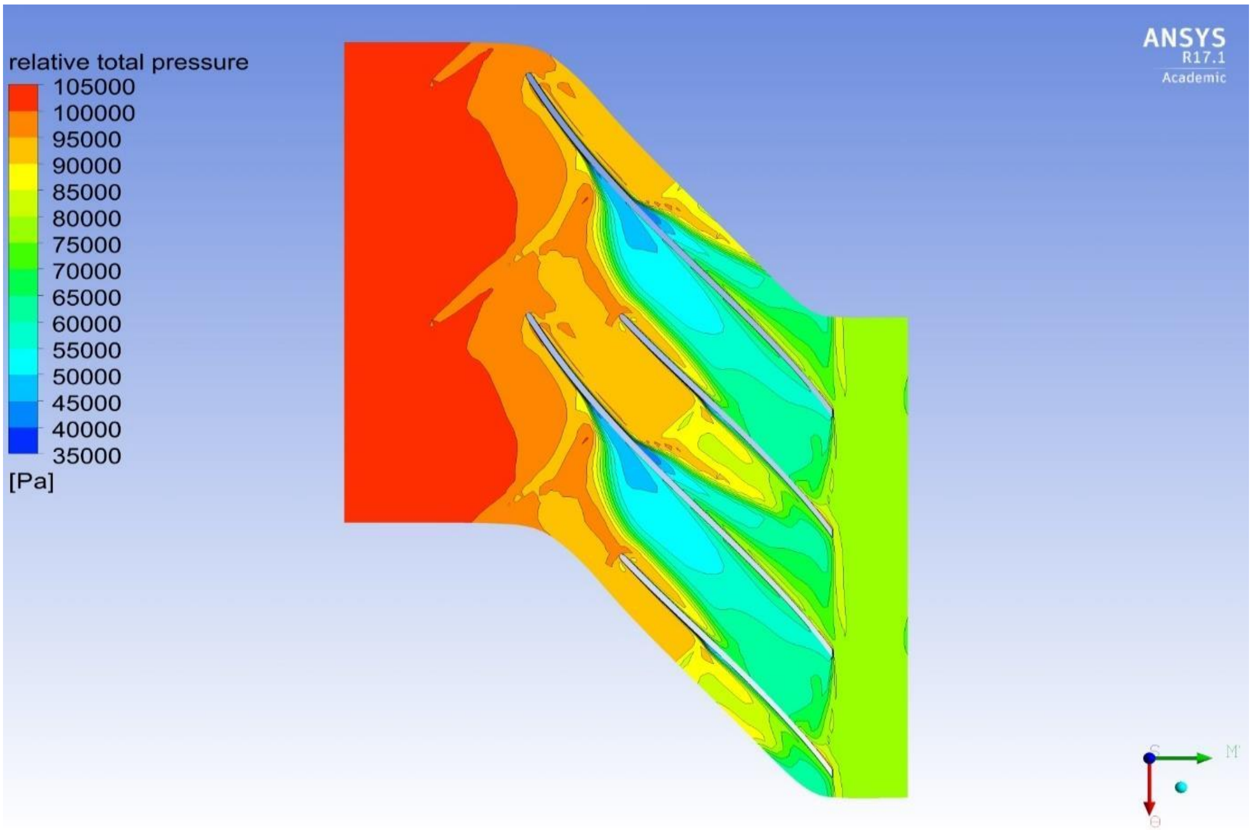

Figure 21 pressure created at lower rpm

In case of blade rotating at lower rpm the pressure developed between the blades is less. This difference in pressure reduces the intake volume of air and causing lower mass flow rate. As the mass flow rate is decreased it has the impact on the engine volumetric efficiency. So it was found that this compressor is not applicable in case of lower rpm. Hence it is used as sequential circuit to increase volume of air supplied to the variable turbocharger.

5.2 PRESSURE VARIANCE ON MASS FLOW RATE (STANDARD TURBO)

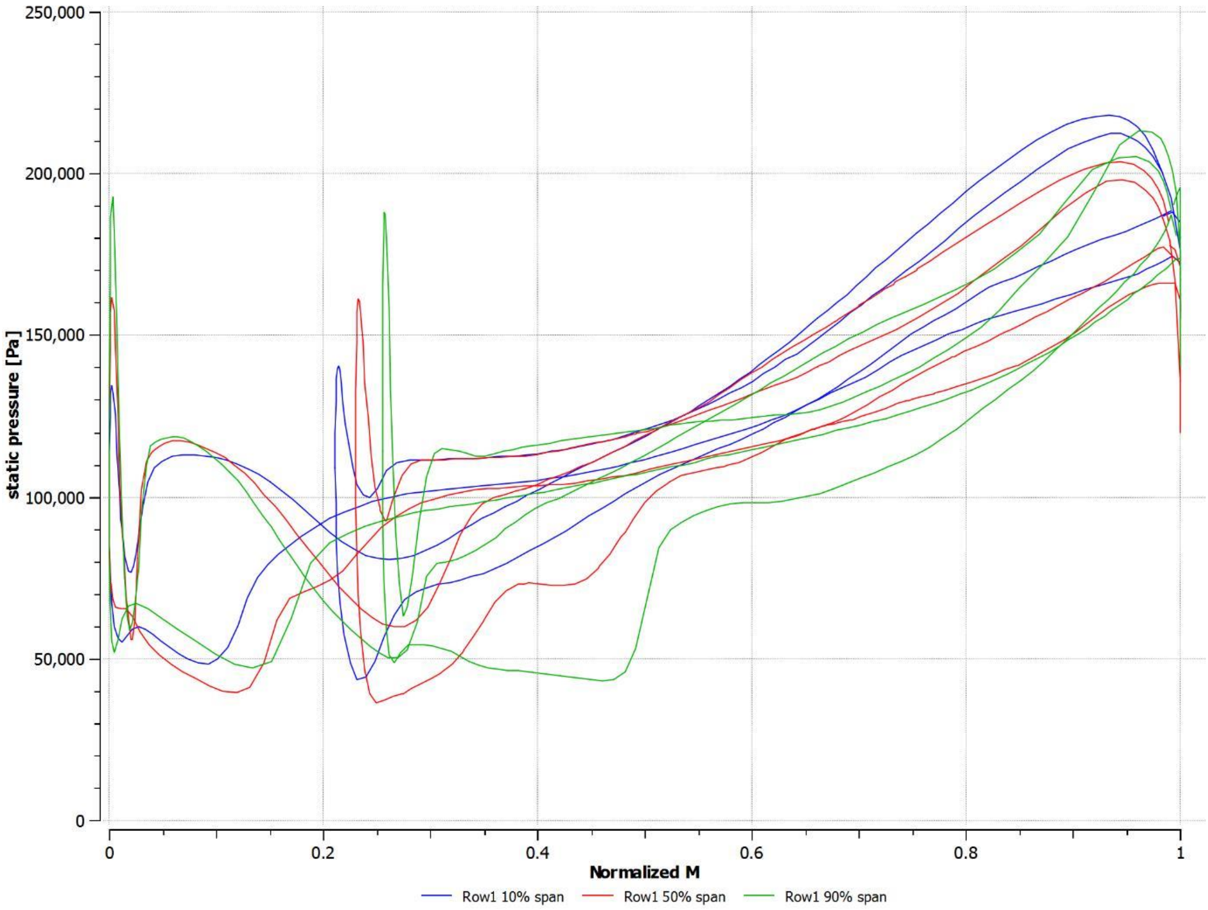

Figure 22 pressure analysis to increase rpm

The change in mass flow rate and pressure at a standard rpm increase shows a turbo lag at lower rpm. The increase in rpm gives a good boost pressure thus showing a gradual increase of temperature and mass flow rate. The standard turbocharger produces a vast turbo lag but can produce a larger expansion of mass at initial which is supplied to variable turbocharger causing a high-power supply to prevent the engine from turbo lag.

The above-mentioned graph indicates the number of iterations carried out on the compressor fines to study about the mass flow rate during different rpm. The static pressure is increased is increased during high mass flow with a increase in velocity.

CONCLUSION

a. The use of twin turbo setup as normal and variable, by controlling the flow path at lower rpm changes the setup to sequential gives a large reduce in turbo lag causing the turbo to produce a huge variance in output.

b. As at higher rpm the turbocharger performs as parallel, set of turbo supply air flow to their sequencing sides helps in keeping a standard torque through the entire speed.

c. The existing setup such as either sequential or parallel suffer from either turbo lag or engine knocking can be prevented. The analysed turbo setup is now fully compared to achieve the improved efficiency.

d. Standardised generation of torque and pressure keeps the flow to the engine constant resulting in production of maximum power throughout the entire cycle. The use of twin turbo helps in maximum downsizing of engine which result a lower fuel consumption cycle.

e. Initial acceleration is increased due to the use of twin turbo setup. The usage of new setup result in improvement of constant efficiency and a standard torque through the entire cycle.

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