IJARSE
ISSN 2319 - 8354

REVIEW ON TURBOCHARGER SYSTEM IN SINGLE/MULTI STAGE IN VARIOUS APPLICATIONS.

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ABSTRACT

The current scenario of global warming and rising sea levels pose a threat to the entire ecosystem. This has forced engine manufacturers to reduce emissions, thus resulting in the use of Turbochargers to compensate the power loss. Turbocharger is a device used to force more air in the combustion chamber. The air is made denser to achieve the goal. This paper summarizes brief history of Turbochargers and studies it in various applications. Wasted energy in the form of exhaust gases is used to provide engine with additional air for better combustion of fuel. It consists of turbine, forged steel shaft and compressor. Turbine wheel rotates as exhaust gas passes through it. The rotating assembly in turn rotates the compressor unit which draws more air and converts it from high velocity, low pressure to low velocity high pressure air. This compressed air is pushed into the engine, allowing engine to produce more power by better combustion of fuel since density of air is higher. Turbocharger units are manufactured using aluminum, cast iron. Thus energy needs are met with lower emissions and cleaner environment. A turbocharging system partially increases scavenging efficiency of an engine thus reducing oil and fuel consumption.

Keywords: Exhaust gases, Global Warming, Power loss, Scavenging, Turbocharger

I. INTRODUCTION

We have always depended on fossil fuels to suffice its energy needs. This fuel source had its own problems. Excessive use of fossil fuels is leading to a situation where regulations are put forth to reduce its emissions. This results in reduction of engine capacities or use of alternate power sources. Alternate energy sources cannot meet the demands of very high power from small energies. Turbochargers first came in the picture of engine building during 1905 in the dawn of industrialization. Need of higher power from a smaller engine made engineers tap all the energy wasted from the engine. Principle waste being the exhaust gases, it was tapped using Turbochargers. The objective of turbocharger is to increase density of air entering engine which will result in improved volumetric efficiency. This allows more power per stroke. Turbochargers can be employed where we want no substantial loss in performance when considering engine efficiency.

II. KEY COMPONENTS OF TURBOCHARGER

A turbocharger consists of three major components.

- Turbine
- Compressor
- Rotating assembly

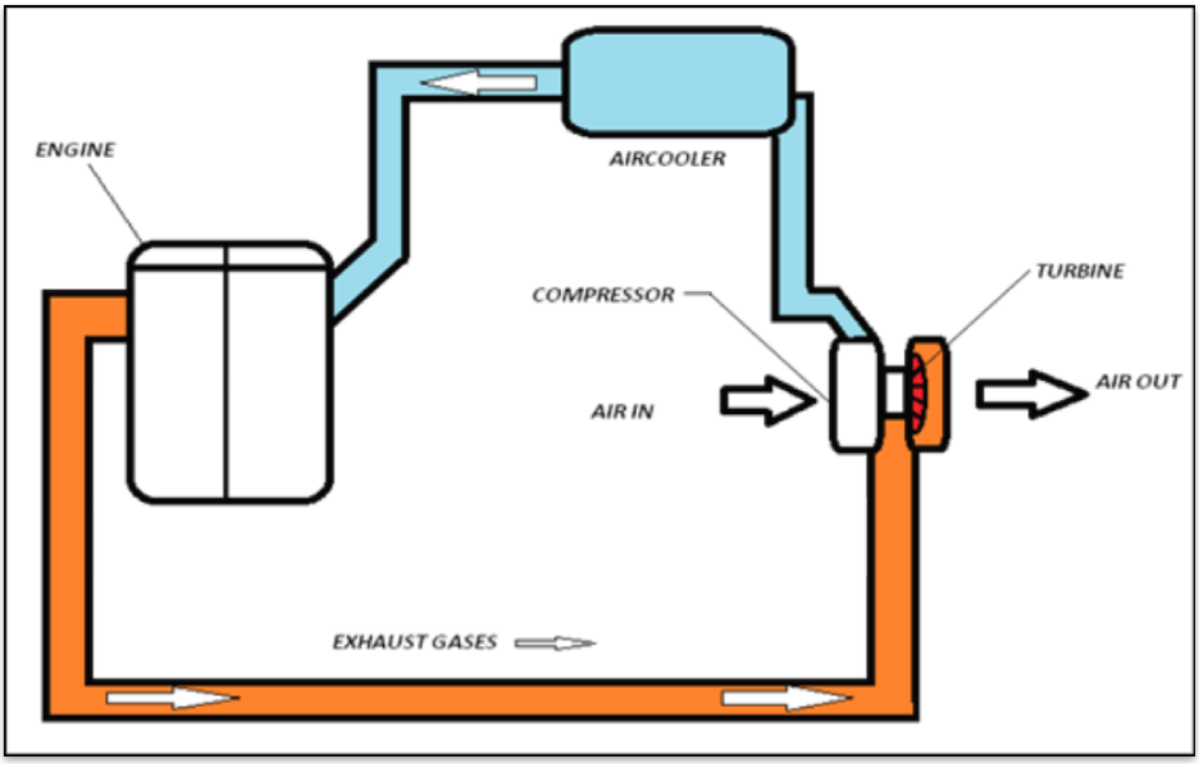

Figure 1. Schematic of Turbocharger System in Automobiles

2.1 Turbine

Turbine in a Turbocharger system is placed in turbine housing. Job of turbine is to convert the energy from the exhaust gases into mechanical energy to drive the compressor. Turbochargers are further classified in axial flow and Radial flow types. For diameters up to 160mm only radial flow type turbines are used. Both axial and radials can be used from 160 to 300, above which only axial turbines are used. The restriction by turbine housing to flow of exhaust gases results in temperature and pressure difference between inlet and outlet. This pressure drop is converted to kinetic energy by turbine which is used to drive turbine wheel. The turbines live in highly corrosive

Conditions where temperatures exceed 1025^{o}C. Corrosion in turbine can lead to failure of turbocharger. Substantial vibrational and bending stresses get imposed on the turbines during operation. Nickel based alloys are used for turbines to improve its ability to handle to stresses.

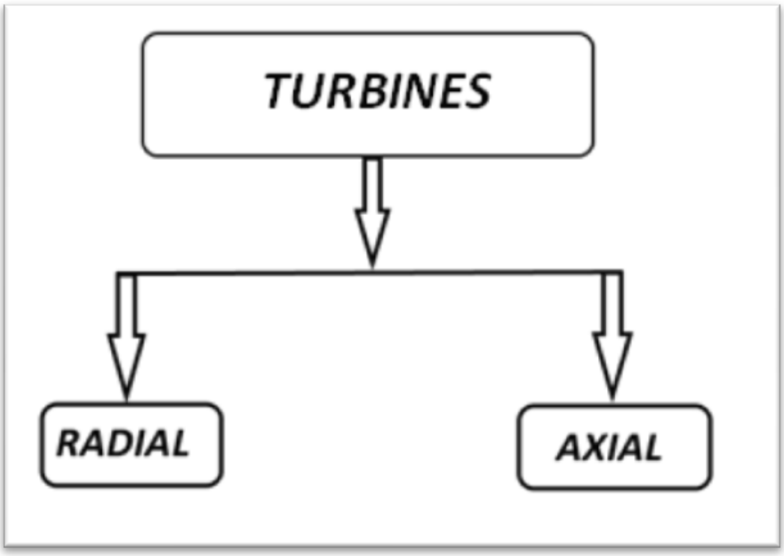

Figure 2. Classification of Turbines

2.2 Compressor

Compressor compresses the air which is to be sent through the inlet to the engine. Density of the air is increased for efficient combustion. A compressor comprises of three parts namely

1) Compressor wheel
2) Diffuser
3) Compressor Housing

Compressor wheel draws air axially, accelerates it to high velocity and discharges it radially. The compressor back plate forms a diffuser which reduces slows down the high velocity air. The compressor housing further slows down the high velocity air and thus the air is expelled out of the compressor exit. Temperature of air entering compressor is slightly higher than the ambient temperature, but there occurs substantial increase in air temperature by the time air is expelled out of it. This poses as a significant problem to the best aluminums available. 2000 series aluminum is used to manufacture high performance compressor wheels.

2.3 Rotating Assembly

A turbocharger shaft rotates at 13500 to 25000 RPMs. An ideal turbocharger should last for at least 100000 Kms under service for an automobile. Specially made bearings are used for Turbochargers to last to its corresponding lifespan. Sleeve bearings specially designed for such high stresses can be used to meet the demands.The shaft is made up of gray cast iron or aluminum. A cooling system is supplied to facilitate efficient cooling of the shaft. The bearings play an important role in smooth rotation of the shaft at peak RPMs. Bearings reduce the frictional losses incurred due to rotational movement of the shaft inside center housing. Bearings also keep in tap the axial and radial movement of the rotating shaft inside the center housing. The rotating shaft and bearings are floating on a thin film of oil to facilitate smooth rotation. If the engine using turbocharger is turn off, the heat in turbine and compressor passes into the center housing as there is no flow of exhaust gases to conduct heat out. This sudden increase in temperature with no adequate cooling device can restrict the shaft and turbocharger's life and efficiency. High centrifugal forces cause the bearing balls to lift off the inner race. Manufacturers have thus started using ceramic based bearing balls which are much more resistant to temperature fluctuations.

Turbochargers in passenger car application where gasoline is used as fuel face a higher temperature then diesel engines by 200degC to 300degC. Such turbochargers are provided with water-cool housings which works in tandem with engine's cooling system. An electric pump is employed to remove heat left in the circuit after the engine is turned off.

III. TURBOCHARGER LAG

Concept of turbo lag is a principle disadvantage of a turbocharging system. Turbo lag is the lack of throttle response due to time required for the exhaust gases to spin to turbine which turns the compressor. A turbocharger turbine rotates at RPMs ranging from 13500-25000 RPM depending upon the application. To rotate the turbine at the required RPM it requires enough boosts from the exhaust gases which cannot be attained at less than 1000 RPMs in automobile diesel engines also factors like inertia, frictional losses contribute to turbo lag. This results in noticeable hesitation in throttle response which is termed as turbo lag. Turbocharging is used where rapid change in output power is required like automobiles or in applications where no rapid surge in output power is required like ships and aircrafts. Turbocharger lag is an important design consideration in such engines where rapid surge in output power is required. Various modifications are used to compensate for the turbocharger lag. Few of them are as follows:

- Provide an electric auxiliary motor to pre boost the turbines so as the RPM required by the compressor is reached quicker than conventional exhaust gas boost.
- Use more than one turbochargers in parallel or sequential setup such that low end RPMs and higher RPMs are both handled by individual turbochargers.
- Use of anti-lag systems can help decrease turbocharger lag. A small amount of fuel is passed through intake valve. This fuel when comes in contact with red hot turbine of turbocharger it ignites giving a boost to turbine. This keeps turbine rotating even at slower engine RPMs.

IV. PRACTICAL APPLICATIONS OF TURBOCHARGER

- Marine applications
- Aircrafts
- Automobile

4.1 Marine Applications

Ships require high torque to suffice its need to break inertial standstill position and move in the said direction. The demand of high torque is fulfilled by turbocharger mechanisms. Because of low specific power and low power to weight ratio of every diesel powered engine the need of a turbocharger arises in marine applications like ships, vessels and auxiliary power units. Fuel is introduced inside a diesel engine at the end of compression stroke and it gets ignited because of the compression pressure. Thus a very high boost can be induced in a diesel engine cylinder provided the engine cylinder is able to handle the additional pressure and heat. Turbocharger is used to propel the gigantic ships at a constant speed and save diesel costs.

4.2 Aircrafts

Turbochargers are most effectively used in aircrafts. Air is less dense at higher altitudes. This produces minimum drag for the airframe; pilots use this minimum drag condition to gain speed and avoid lag due to denser air. Engines require denser air for proper combustion of fuel which is impossible to achieve at higher altitudes. A turbocharger increases air density to match the condition at sea level. The exhaust gases from aircraft engine are pushed through an impeller which rotates a compressor. The compressor increases the density of air. The density can be adjusted by electronic automated circuits with sensor in the engine sensing the required density. Turbocharging an aircraft engine allows pilots to maneuver the aircraft more precisely. It allows better safety as small aircrafts can achieve higher altitudes. This allows them to tackle mountains terrains with higher speed and minimum fuel consumption. There are two subcategories of turbochargers used in aircrafts.

- Ground boosted- These turbochargers directly increase the overall air density to achieve sea level rated power output.
- Turbo normalized-These turbochargers maintain the horsepower performance as rated at sea level.

4.3Automobiles

An automobile engine uses a turbocharger for multiple uses. Some engines are provided with a turbocharger to increase efficiency while others are provided to give the driver a sudden surge in power when required. A turbocharging mechanism can be used for both gasoline powered and diesel powered engines. The design, working and location of the turbocharger are same in both the engines. Gasoline is highly combustible and do not require extremely high pressure during introduction in combustion chamber. This makes gasoline powered engine smaller and more thus wider range of RPMs can be achieved during operation. Because of the higher RPMs petrol engine runs at an increased temperature. In case of diesel engines the Inherent problem is inability of engine to draw enough air into combustion process. This problem is tackled by using turbocharge.Fuel is not highly combustible and ignites only when sufficient pressure is provided for. This extremely high pressure makes diesel engines to be made up of harder thicker and stronger materials. This makes diesel engine heavy reducing its efficiency and power to weight ratio. To compensate for this decrease in power output a turbocharger is employed. Diesel engines create more exhaust gases and run at lower temperatures than gasoline engines. Suction of air is difficult in a diesel engine due to slower RPMs. This problem is solved by use of a turbocharger.

V. REVIEW OF SOME RESERCHERS

5.1 Ding Xianfei et al [1]-This paper studies the law governing two-stage Turbocharger in Piston aircraft engine. A piston aircraft was selected for testing. The engine of the aircraft is 4-cylinder, 4-stroke spark ignition with electronic boost control. The engine and turbocharger are matched by using appropriate turbocharger. Considering the losses incurred during operation and mass of air at 10 above sea level the total compression ratio is calculated by using;

Where P_b is Air-box pressure, P_a is the ambient pressure and η_e is the coefficient of efficiency.

$$P = \frac{P_b}{P_a \eta_e}$$

The two stage turbocharger is provided with two compressors is series and two compressors in parallel. The effectiveness is stated by comparing simulation results to testing results.

5.1.1 Material Specification

Performance data of engine-

	Performance in kw	Torque in Nm	Engine speed in rpm	Throttle position in %
Take-off power	84.5	139	5800	115
Max. continuous power	73.5	128	5500	100

5.1.2 Dimensions

Bore in mm	Stroke in mm	Displacement in ml	Compression ratio
79.5	61	1211	9:1

5.1.3 Result

- With increase of altitude the temperature and density of air decreases considerably, to compensate that intake air needs to be boosted. PID control system controls the boost pressure.
- The experiment can be used to aid design of aircrafts as it provides with the data that cannot be calculated under practical conditions.
- This model is used to test the matching between engine and turbocharger to work at high altitudes.

5.2 M.Mohammed Mohaideen Et Al [2]

In this paper two materials were selected and subjected to both theoretical and ANSYS testing. Turbine manufacturing is discussed in the paper. ANSYS software is used to test as there are human errors which occur during the analysis of materials that can be used for turbochargers. Turbine design was used as a preliminary design inputs of which are provided for next stage. The values thus obtained from the two dimensional design are subjected to further testing. It further gives us the blade co-ordinates, which are then tested, using cascade flow analysis.

The following materials were subjected to ANSYS analysis for turbine rotors are as follows.

- UDIMET-500[Ni-18Cr-17Co-4Mo-3Al-3Ti]
- INCONEL-718[Ni-19Cr-18Fe-5.1(Cb+Ta)-3Mo-0.9Ti-0.5Al]

5.2.1 Material Specifications

Properties	UDIMET-500	INCONEL-718
Yield strength(Mpa)	1104 (at 520degC)	1037.28(520degC)
Density(tonnes/mm^3)	8.22x10^{-9}	8.02x10^{-9}
Formation	Bars	Bars
Ultimate strength(Mpa)	1090(at 21degC)	1310(21degC)
Condition	Heat Treated	Heat Treated

Theoretical analysis for the same is carried out by the researcher. Thermal stresses, Hoops stresses and radial stresses are calculated using respective equations for both materials. Considering 3% error in analysis yield stresses and stresses calculated are used to obtain FOS (Factor of Safety).

5.2.2 Result and Observation

Use of ANSYS software and calculations performed by the researcher concludes UDIMET-500 is the best material out of the two selected.

5.3 Guan-Jhongh Wang et al [3]

Numerical study of Exhaust gas recirculation employed diesel powered engine using various blends of fuel was conducted in this paper. A 4-stroke Mitsubishi engine 4M424AT2 was used having an exhaust gas recirculation system built into it. Formation of carbon deposits and NO_x in the piston cylinder was analyzed. Dimensions of the engine and components were measured physically by disassembling the engine. Dynamic mesh is used to take into consideration the motion of piston, inlet and outlet valves. ANSYS generated models were used to find the injection of fuel. Transient analysis is performed by using 0.01 crank angles at 2000RPM.Turbocharger parameters were observed and compared to physical values. Simulation also gives us values like gas velocity, injection timing. A CFD model of engine is constructed. Every cycle starts from 360-1080 including every stroke. Engine is run at 2000RPM at 25% loading.

5.3.1 Result

Change in peak temperature does not affect the operation of turbocharger in the given engine. Higher oxygen levels in biodiesel help reducing thermal stresses on turbocharger as it need not work at same temperatures.

5.4 Takao Yokoyama et al [4]

This paper discusses the effect of volute cross-section on performance of radial turbocharger through experiments and CFD method. Experiments were conducted on turbocharger test-rig in London. Compressed air at 70degC is passed through the turbocharger to restrict condensation. A pulse generator is used to produce exhaust gases replicating an engine. Eddy current dynamometer is used to measure power output from the turbocharger. Two volute configuration versions were taken for testing. In volute A the aspect ratio changes from 0.8 to 2.6 at 360deg rotation against the aspect ratio of Volute B which remains constant at 1.7 throughout all positions. Turbines were analyzed in steady flow test at 30 and 40 RPMs. Flow meter is used to measure mass flow rate. Performance was analyzed at 3 different frequencies (20Hz, 40Hz, & 60 Hz) at different loads at 2 distinct speed lines.

5.4.1 Result and Observation

- Baseline volute B and volute A are compared resulting in Volute A showing higher efficiency.
- Total loss is higher in baseline volute B.
- Baseline volute B is more sensitive to pulsating flow.

5.5 Alfred Scholz et al [5]

This paper discusses the testing of turbine housing in turbocharger.Since turbine housing is the most exposed surface to the brutal forces of exhaust gases and thus suffers from constant aging and cracking therefore testing of Ni-resistant D5S is carried out. As there are several materials available for turbochargers in commercial vehicles, diesels powered engines and gasoline powered engines, proper systematic testing of material should be conducted to verify the structural rigidity and long term reliability of the materials used. Tests carried out include Lifetime assessment, material model, computational fluid dynamics, Gas stand test, finite element analysis.

5.5.1 Experiments

- Material model-

It is based on work of Chaboche. Equation is used to calculate strain value. Overall backstress is compared to the original components.

- Lifetime assessments-

It is used to calculate cycles that the material can withstand before cracking. Life fraction rule is used to determine creep and Miner's rule is used to determine fatigue that the material withstands.

5.5.2 Result

Lifetime estimation approach gives an estimated number of cycles before the material cracks. Micro crack growth method is also focused on.

VI. CONCLUSION

This review paper is focused on application of Turbocharger in various engines. Turbocharger can lead to a greener environment but not at the cost of reduced power outputs from the engine. This creates a perfect balance between power output, efficiency and emissions. Sustainability of environment and optimum use of fossil fuels needs turbochargers employed for every engine. This paper outlines the current uses and trends of turbochargers with various applications.

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