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Significance of Turbocharger on Performance of IC Engine: A Review

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Abstract: Turbochargers are used throughout the automotive industry as they can enhance the output of an internal combustion (IC) engine without the need to increase its cylinder capacity. The application of such a mechanical device enables automotive manufacturers to adopt smaller displacement engines, commonly known as “engine downsizing”. Historically, turbochargers were often used to increase the potential of an already powerful IC engine. The emphasis today is to provide a feasible engineering solution to manufacturing economics and “greener” road vehicles. It is because of these reasons that turbochargers are now becoming more and more popular in automobile applications. The aim of this paper is to provide a review on the techniques used in turbo charging to increase the engine output and reduce the exhaust emission levels.

Keywords: Intercooler, IC Engine, Turbocharger, Volumetric Efficiency.

I. INTRODUCTION

A turbocharger is a device used to allow more power to be produced for an engine of a given size. A turbocharged engine can be more powerful and efficient than a naturally aspirated engine because the turbine forces more intake air, proportionately more fuel, into the combustion chamber than if atmospheric pressure alone is used. Its purpose is to increase the volumetric efficiency of the combustion chamber. Various new technologies have been introduced to assist the turbo charging of internal combustion engine so that the volumetric efficiency may improve more. These technologies include inter-cooling of the charged air before going in to the combustion chamber so that its mass flow rate is increased. The other technology is twin charging in which firstly the engine is boosted by a supercharger then it is boosted by a turbocharger when the energy of exhaust gas is sufficient to rotate the turbine blades. There are various other technologies used for this purpose of improving the volumetric efficiency which will be discussed later in the literature review.

II. PAGE LAYOUT

HOW A TURBOCHARGER WORKS

Turbochargers are a type of forced induction system. They compress the air flowing into the engine. The advantage of compressing the air is that it lets the engine squeeze more air into a cylinder, and more air means that more fuel can be added. Therefore, we get more power from each explosion in each cylinder. A turbocharged engine produces more power overall than the same engine without the charging. This can significantly improve the power- to-weight ratio for the engine. In order to achieve this boost, the turbocharger uses the exhaust flow from the engine to spin a turbine, which in turn spins an air pump. The turbine in the turbocharger spins at speeds of up to 150,000 rotations per minute (rpm) -- that's about 30 times faster than most car engines can go. And since it is hooked up to the exhaust, the temperatures in the turbine are also very high. [2]

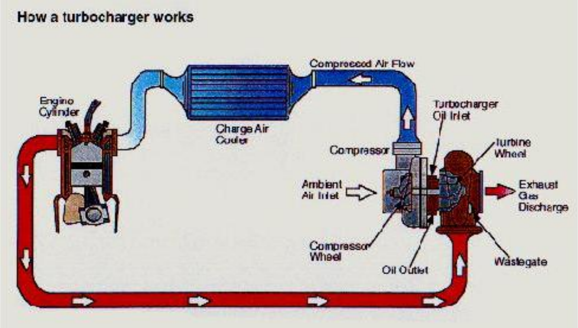

Figure 1-working of turbocharger

III. LITERATURE REVIEW

The world's first functional engine supercharger was made by Dugald Clerk, who used it for the first two-stroke engine in 1878. Gottlieb Daimler received a German patent for supercharging an internal combustion engine in 1885. Supercharger is a device which supplies high density charge to the engine by compressing it through the compressor driven by the engine mechanically. Main problem with supercharger is the loss of power used to drive the compressor from the engine output shaft. This loss can be up to 15% of engine output. To eliminate this loss of power, later on the compressor was driven by a turbine utilizing the energy of exhaust gases of the engine by passing them through the turbine blades. Then this technology became popular by the name as Turbo charging in early 1980s. From that day, various new technologies are introduced in turbo charging to improve its efficiency and this improvement was carried out as follows:

J. Cheong et. al., [2000] Power boosting technology of a High Speed Direct Injection (HSDI) Diesel engine without increasing the engine size had been developed along with the evolution of a fuel injection system and turbocharger. Most of the turbochargers used on HSDI Diesel engines had been a waste-gated type. That time, the Variable Geometry Turbocharger (VGT) with adjustable nozzle vanes was increasingly used, especially for a passenger car in European market. This study describes the first part of the experimental investigation that has been undertaken on the use of VGT, in order to improve full load performance of a prototype 2.5 liter DI Diesel engine, equipped with a common rail system and 4 valves per cylinder. The full load performance result with VGT was compared with the case of a mechanically controlled waste-gated turbocharger, so that the potential for a higher Brake Mean Effective Pressure (BMEP) was confirmed. Within the same limitation of a maximum cylinder pressure and exhaust smoke level, the low speed torque could be enhanced by about 44% at maximum. VGT is a device that can vary the flow area and flow angle between the turbine volute and rotor channel. Compared with a waste-gated turbocharger, it was possible not only to increase a boost pressure and charge air flow rate with VGT at low engine speeds, enabling a higher torque, but also to reduce fuel consumption at higher engine speeds, due to lower pumping losses with full utilization of the exhaust flow. With the use of the VGT, it was possible to increase the charge air mass by about 10 ~ 20 % at a low speed range. As a result of this, the exhaust smoke was reduced and the fuel consumption was improved with the same fuel delivery and start timing of injection.

Panting et. al., [2001] stated that turbo charging of internal combustion engines was an established technology used for the purpose of increasing both power density and in some cases the cycle efficiency of diesel engines relative to naturally aspirated engines. However, one significant drawback was the inability to match the characteristics of the turbocharger to the engine under full load and also to provide sufficiently good transient response. Under many conditions this results in reduced efficiency and leads to higher exhaust emissions. The design of turbocharger components must be compromised in order to minimize these drawbacks throughout the entire operating range. However, when shaft power can be either added to or subtracted from the turbocharger shaft by means of a direct drive motor– generator, an additional degree of freedom is available to the designer to achieve a better turbocharger–engine matching. Both engine efficiency and transient response can be significantly improved by means of this method, normally described as hybrid turbo charging. The author described the results of a theoretical study of the benefits of hybrid turbo charging over a basic turbocharged engine in both steady state and transient operation. The new system and its benefits were described and four different engine– turbocharger systems were analyzed in addition to the baseline engine. The author concluded that assist motors were capable of considerably reducing the response times of turbochargers, all other facts being constant. Resizing the turbine and re-optimizing valve timing results in a considerable increase in thermal efficiency when an engine was not compounded. The relative improvement appears to be of order 10 percent.

Rakopoulos et. al., [2004] developed a computer analysis for studying the energy and availability performance of a turbocharged diesel engine, operating under transient load conditions. The model incorporates many novel features for the simulation of transient operation, such as detailed analysis of mechanical friction, separate consideration for the processes of each cylinder during a cycle (‘‘multi-cylinder’’ model) and mathematical modeling of the fuel pump. This model had been validated against experimental data taken from a turbocharged diesel engine, located at the authors’ laboratory and operated under transient conditions. The availability terms for the diesel engine and its subsystems were analyzed, i.e. cylinder for both the open and closed parts of the cycle, inlet and exhaust manifolds, turbocharger and aftercooler. The present analysis reveals, via multiple diagrams, how the availability properties of the diesel engine and its subsystems develop during the evolution of the engine cycles, assessing the importance of each property.

Naser et. al., [2009] concluded that efficient way which was used that time was to reduce the fuel consumption was based in reduction cylinder volume of internal combustion engine and power to be same or higher. Key component was turbocharged diesel internal combustion engine. Increased compressor outlet air pressure can result in an excessively hot intake charge, significantly reducing the performance gains of turbo charging due to decreased density. Passing charge through an intercooler reduced its temperature, allowing a greater volume of air to be admitted to an engine, intercoolers have a key role in controlling the cylinder combustion temperature in a turbocharged engine. The author, through his worked out programmed code in MATLAB presented effect of intercooler (as a heat exchange device air-to-liquid with three different size and over – all heat transfer coefficient and one base) at multi-cylinder engine performance for operation at a constant speed of 1600 RPM. Author concluded that maximal temperature in engine cylinder was decreasing from 1665.6 K at SU =1000 to 1659.2 K at SU(surface area*heat transfer coefficient)=1600, sometimes engine power and volumetric efficiency was increased. Also intercooler performance was increased with increased the design parameter.

Eyub et. al., [2010] concluded that there were three main problems in automotive applications that cause environmental effect, cost and comfort problems. Therefore, internal combustion engines were required to have not only a high specific power output but also to release less pollutant emissions. For these reasons, that time light and medium duty engines were being highly turbocharged because of having negative environmental effects of internal combustion engines. Due to mentioned facts, there were studies going on to improve internal combustion engine performance. Studies for supercharging systems were also included in this range. One of the most important problems faced in supercharging systems was that air density was decreasing while compressing air. Also air with high temperature causes pre- ignition and detonation at spark ignited engines. Various methods were developed to cool down charge air which was heated during supercharging process. One of these methods was to use a compact heat exchangers called as intercoolers to cool charging air. The purpose of an intercooler was to cool the charge air after it has been heated during turbo charging. As the air is cooled, it becomes denser, and denser air makes for better combustion to produce more power. Additionally, the denser air helps reduce the chances of knock. The inter-cooling concept was introduced and performance increase of a vehicle by adding inter-cooling process to a conventional supercharging system in diesel or petrol engine was analytically studied. Pressure drops, air density and engine revolution were used as input parameters to calculate the variation of engine power output. Also, possible downsizing opportunities of the cylinder volume were presented. It was found that the engine power output can be increased 154% by ideal intercooler while single turbocharger without intercooler can only increase 65%. Also a meaningful 50% downsizing of the cylinder volume possibility achieved by means of turbo charging and intercooling.

Abdullah [2010] concluded that fuel economy and thermal efficiency were more important to all engines. Efficiency was increased with cooled air by intercooler. Most of researches regarding engineering problems generally deal with experimental studies. But, the experimental researches are quite expensive and time consuming. In the last decades, Neural Networks (NN) had been used increasingly in a variety of engineering applications. The objective of the study was to investigate the adequacy of neural networks (NN) as a quicker, more secure and more robust method to determine the effects of inter-cooling on performance of a turbocharged diesel engine’s specific fuel consumption. The data was obtained from experimental research that was performed by the author. NN based model was developed trained and tested through a based MATLAB program by using of these data. In the study, break specific fuel consumption (BSFC, g/kWh) was analyzed with inter cooling and without inter cooling. The statistical analysis was performed to explain the performance of the NN based model. NN based model outputs were also compared with the experimental results. The statistical results and the comparison demonstrated that the NN based model was highly successful to determine the effects of inter-cooling on performance of a turbocharged diesel engine’s specific fuel consumption. The overall results show that the NN based model can be used as an alternative method for estimating the effects of inter-cooling on performance of a turbocharged diesel engine’s BSFC.

Yashvir et. al., [2011] aimed at the work to increase the torque and power of the two- wheeler by supercharging the vehicle. For this purpose LML freedom 125 cc was analysed for the work and certain parameters like torque, power, and specific fuel consumption vs rpm were calculated. The data calculated was used in software Engine Analyser for analysis purpose together with the data of supercharger. It can be seen that power and torque of the engine increases from 7 to 11 KW and 9 to 13 NM at 7500 and 9000 RPM respectively.

Wladyslaw et. al., [2011] studied that the main problem in charged spark ignition engine was control of air-fuel ratio near stoichiometric values at different boost pressure in order to obtain higher torque at the same level of specific fuel consumption and exhaust gas emission. Charging of such engine was connected with the problem of knock in the medium and high values of load at low engine speeds. Higher boost pressure leads to abnormal combustion process and to knocking. Author described the boost pressure control algorithm which enables to prevent the knock, so the engine can work near the knock boundary.

Medium capacity engine Toyota Yaris 1300 cc SI engine for experimental test was equipped with variable turbine geometry(VTG) turbocharger with possibility to control mass flow rate in the turbine by using additionally waste gate(WG) system. Such approach enabled charging of the engine in wide range of rotational speeds and loads. Special computer control program in Lab view environment was written in order to analyze knock signal and regulate the opening of VGT and WG in dependence on throttle opening (engine load). High voltage of knock signal was given to the electronic control unit (ECU), where was transformed by fast Fourier transform (FFT) procedure, which gave a distribution of knock signal in the range 2000-8000 Hz. Control signal from “knock” was obtained in the range 0 – 0.01 V and was transferred to the control unit for regulation of mass flow rate of exhaust gases through the turbine by VGT and WG. When output signal from FFT was greater than 0.01 V then the valve in WG was opened much more in order to reduce mass flow rate of exhaust gases through the turbine, which decreased rotational speed of the turbocharger and thus decreased pressure ratio behind the compressor.

Kusztelan et. al., [2012] In this study, one-dimensional analysis using AVL Boost software had been carried out on a series of compression and spark ignition engines utilizing a manufacturer fitted single-entry turbocharger and a modified twin-entry variety, the latter adopting two turbine housing inlet ports. The model reconstruction using AVL Boost considers parameters that accurately represent the physical engine conditions including manifold geometry, turbocharger flow maps and combustion chamber characteristics, etc. Model validations have been made for a manufacturer single-entry turbocharger configuration to predict the maximum engine power and torque, in comparison with available manufacturer data and analytical calculations. Further studies concentrate on engine performance comparisons between single- and twin-entry turbochargers in terms of torque, shaft speed and compressor efficiency and at low engine speed conditions typically in a range of 1000-3000 RPM. It was found that on average engine response has been increased by 27.65%, 5.5%, 5.5% in terms of turbine shaft speed, engine power and torque, respectively, which implies improved “drivability” of the vehicle. This study reveals the potential benefits of adopting a twin-entry turbocharger and the findings would be useful for both industry and academic communities.

Muqeem [2012] The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing the density of the intake gas (usually air, entering the intake manifold of the engine). When the pressure of the engine's intake air is increased, its temperature will also increase. Turbocharger units make use of an intercooler to cool down the intake air. Here, the purpose of author was to bring the temperature of intake air nearer to the ambient temperature. The inter-cooling of intake air was greatly increased by installing a specially designed intercooler in which air run as hot fluid and refrigerant, of the air conditioning system coming from cooling coil fitted in the dashboard, run as cold fluid. The intake air is cooled down by the air flowing through the fins of the intercooler and the refrigerant coming from the evaporator. Here the author concluded that when normal air cooled intercooler is used to cool down the hot air before entering into the engine cylinder, the mass of oxygen being fed to the engine becomes 1.43 times but when refrigerated intercooler is used, it becomes 2.618 times. Increasing the oxygen content with the air leads to faster burn rates and the ability to control exhaust emissions. Added oxygen in the combustion air offers more potential for burning diesel.

Ghodke et. al., [2012] said that expectation in next coming years is CO2 emissions reduction for vehicles and demand for more driving comfort would be the challenges for the automobile industry. One approach to this problem is the reduction of the displacement of the combustion engine while maintaining the characteristics of large displacement engine. This method is often referred to using the term” downsizing” and requires the engine to be turbocharged and improve performance and torque. It has been demonstrated that a simple charging unit alone is not enough and it require more complex charging systems when emissions are stringent. The goals of developed in terms of the thermodynamics and operating of future passenger car viz increase in the power density of the engine, highest possible maximum torque at low engine speeds across the widest possible range of speeds, improvement of the driving response in transient operating condition like start up response and elasticity response, reduction of the primary energy consumption during testing and when driving on the road, observances of the future exhaust gas thresholds which mean a drastic reduction in the current emission levels. The latter goals can be reached through the use of smaller displacement engines. Engines with low engine displacement yield significant advantages in the test cycles with respect to fuel consumption and emissions, but the torque produced by small engine is pronouncedly less than that of a large displacement, naturally aspirated engine must be attained in terms of the steady state response and of the transient response. The author summarized review of advancements in turbocharger technology to meet the demand of high performance and low emission of passenger car vehicle application.

Shaaban et. al., [2012] said that turbocharger performance significantly affects the thermodynamic properties of the working fluid at engine boundaries and hence engine performance. Heat transfer takes place under all circumstances during turbocharger operation. This heat transfer affects the power produced by the turbine, the power consumed by the compressor, and the engine volumetric efficiency. Therefore, non-adiabatic turbocharger performance can restrict the engine charging process and hence engine performance. His research work investigated the effect of turbocharger non-adiabatic performance on the engine charging process and turbo lag. Two passenger car turbochargers were experimentally and theoretically investigated. The effect of turbine casing insulation was also explored. His investigation shows that thermal energy is transferred to the compressor under all circumstances. At high rotational speeds, thermal energy is first transferred to the compressor and latter from the compressor to the ambient. Therefore, the compressor appears to be “adiabatic” at high rotational speeds despite the complex heat transfer processes inside the compressor. A tangible effect of turbocharger non-adiabatic performance on the charging process is identified at turbocharger part load operation. The turbine power is the most affected operating parameter, followed by the engine volumetric efficiency. Insulating the turbine is recommended for reducing the turbine size and the turbo lag. Experimental data show 55% decrease of the turbine actual power at 60000 rpm due to thermal energy transfer from the turbine. The effect of thermal energy transfer from the turbine on turbine power decreases with increasing the turbine rotational speed at constant exhaust gas temperature at the turbine inlet. This decrease is due to the rapid increase in the turbine power with increasing the rotational speed relative to the amount of thermal energy transfer from the turbine.

Vishal et. al., [2012] examined the current and the future trends in the development of gasoline direct injection engine and attempts at identifying the turbocharger requirements for such systems. Predicted engine performance data from various reputable published sources were used to identify the air flow requirements and thus the turbocharger needs. A case study was considered by sizing an engine from the gathered brake mean effective pressure trends and its turbocharger requirements were simulated using a Cummins’s Turbo Technologies developed software. The software uses a steady state energy balance between the required compressor work and the extracted turbine work. The findings of the simulation and the turbocharger matching were subsequently analyzed. From the analysis of the simulation, it can be deduced that turbo charging the GDI engine offer considerable challenges to the air handling system. The report has shown that, for a wide operating speed range with a low speed peak torque, conventional turbocharger systems may not be sufficient. The parallel sequential turbocharger system provides a right solution for wide flow range and near constant pressure ratio demands. The control mechanism for the switch from the low speed turbocharger to the high speed one needs to be calibrated to ensure that during the transition, there is no loss of boost pressure and therefore loss of torque.

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CONCLUSION

From this literature review it has been concluded that from last two decades various attempts were made to improve the power output of an engine and to reduce its emissions by making some changes and installing some additional accessories like intercooler in the turbo charging technology. This will carry on in the future because in coming days there will be increase in the demand of fuel efficient engines with more power and minimum emissions and this is possible with some advancements in turbo charging technology.