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Analysis on Turbo Charging of C I Engine for Improving Performance and Emissions

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Abstract:

Turbochargers are used throughout the automotive industry to enhance the output of an internal combustion engine without increasing the cylinder capacity. The application of such a mechanical device enables automotive manufacturers to adopt smaller displacement engines, commonly known as engine downsizing. Turbochargers were often used to increase the potential of an already powerful IC engine, e.g. those used in motorsport. 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 much more popular in automotive industry applications. The aim of this paper is to provide a review on the current techniques used in turbo charging to improve the engine efficiency and exhaust emissions as much as possible.

Keywords:

Engine Performance, Exhaust Emission, Supercharger, Turbocharger, Volumetric Efficiency.

I. Introduction:

Turbochargers were originally known as turbo superchargers when all forced induction devices were classified as superchargers. Nowadays the term "supercharger" is usually applied to only mechanically driven forced induction devices. The key difference between a turbocharger and a conventional supercharger is that the latter is mechanically driven by the engine, often through a belt connected to the crankshaft, whereas a turbocharger is powered by a turbine driven by the engine's exhaust gas. Compared to a mechanically driven supercharger, turbochargers tend to be more efficient. Turbochargers are commonly used on truck, car, train, aircraft, and construction equipment engines [1] [2].

1.1 Operating Principle:

In normally aspirated piston engines, intake gases are pushed into the engine by atmospheric pressure filling the volumetric void caused by the downward stroke of the piston (which creates a low-pressure area), similar to drawing liquid using a syringe. The amount of air actually sucked, compared to the theoretical amount if the engine could maintain atmospheric pressure, is called volumetric efficiency. The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing density of the intake gas (usually air). The turbocharger's compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure. This results in a greater mass of air entering the cylinders on each intake stroke. The power needed to spin the centrifugal compressor is derived from the kinetic energy of the engine's exhaust gases. The pressure volume diagram shows the extra work done by turbocharging the diesel engine [1-9].

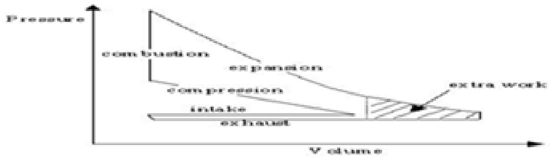

Fig 1: Pressure volume diagram of diesel engine with turbocharging [2]

II. Current Status Of Turbocharger Researches:

Turbochargers are widely used in the automotive industry to enhance the volumetric efficiency and reduce the exhaust emissions. Researchers are continuously doing advancements in the turbo charging technology to improve its efficiency and reduce the exhaust emissions of automotive to meet the environmental related rules laid down by the government of different nations. A review of novel turbocharger concepts for enhancements in efficiency by many researchers is done in the following sub-headings.

2.1 Impact of Turbocharger Non-Adiabatic Operation on Engine Volumetric Efficiency and Turbo Lag

Shaaban et al [10] studied 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. Author's 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. The research 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.

Turbocharger performance significantly affects the overall performance of turbocharged engines. Turbocharger operation involves heat transfer under all circumstances. Even if the turbocharger casing is well insulated, heat transfer takes place from the turbine to the lubricating oil [11-13] or from the oil to the compressor at low rotational speeds. Malobabic et al [14] reported that the turbocharger will operate at a considerably lower speed due to non-adiabatic operation which in turn influences the charging process. Non-adiabatic turbocharger operation can also increase the turbo lag because the time required to accelerate the turbocharger from angular velocity ω_1 to ω_2 is given by

$$\Delta t_{\text{acceleration}} = I_{\text{rotor}} \int_{\omega_1}^{\omega_2} \frac{\omega \, d\omega}{\dot{W}_T - \dot{W}_C}$$

………………… (1)

Turbo lag increases if the actual non-adiabatic turbocharger operation involves a decrease in the turbine power and an increase of the compressor power. Moreover, the turbo lag decreases if the turbine can produce the same power at smaller size (smaller rotor inertia). Rakopoulos et al [15] reported that turbocharger lag is the most notable off-design feature of diesel engine transient operation that significantly differentiates the torque pattern from the respective steady state conditions. It is difficult to measure the non-adiabatic turbine and compressor actual power due to heat transfer between the turbocharger components as well as between the turbocharger and the ambient. The high exhaust gas temperature, the very high rotational speed and the shaft motion associated with the use of the sliding hydraulic bearing are some factors that increase the difficulty of measuring the compressor torque under non-adiabatic operating conditions. Therefore, non-adiabatic turbocharger operation is investigated using either thermodynamic models or CFD simulation. Rautenberg and Kammer [16] modeled the non-adiabatic compressor performance by decomposing the amount of thermal energy transfer to the compressor into three portions.

The first portion takes place before the impeller, the second portion takes place during the compression process in the impeller and the third portion takes place after the impeller. Hagelstein et al [17] simplified the model of Rautenberg and Kammer [16] and decomposed the amount of thermal energy transfer to the compressor into two portions only. The first portion takes place before the compressor impeller, while the second portion takes place after the compressor. They considered the compression process in the impeller to be adiabatic. Cormerais et al [18] experimentally and analytically investigated the process of heat transfer inside the turbocharger. Galindo et al. [19] presented an analytical study of a two stage turbocharging with inter and after cooler. They considered the amount of thermal energy transfer in the turbine side before gas expansion in the turbine. Bohn et al. [20–21] performed 3D conjugate calculation for a passenger car turbocharger. Eriksson et al. [22] modeled a spark ignition turbocharged engine with intercooler.

They neglect the effect of heat transfer in the turbocharger. Serrano et al. presented a model of turbocharger radial turbines by assuming that the process undergone by the gas in the turbine is adiabatic but irreversible. Most of the previous publications concern with the amount of thermal energy exchange between the turbocharger components or even assume the turbocharger to be adiabatic. These investigations are important for engine modeling programs. Shaaban et al [10] investigated the probable effect of actual turbocharger non-adiabatic operation on engine volumetric efficiency and turbo lag. They modeled and estimated the actual turbine and compressor power under real non-adiabatic operating conditions. They also explored the increase in compressed air temperature due to thermal energy transfer to the compressor and estimated its subsequent effect on engine volumetric efficiency. Experimental investigations were performed on the small combustion chamber test rig of the University of Hanover as shown in figure 2.

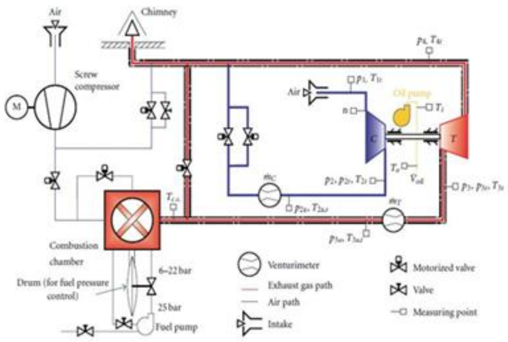

Fig 2: Schematic of the small combustion chamber test rig [10]

The investigated the effect of non-adiabatic turbocharger performance on engine volumetric performance and rapid lag. Thermostat sizeable impact of turbocharger non-adiabatic overall performance on rapid lag is diagnosed on the turbine. Experimental statistics display fifty five% decrease of the turbine real power at 60000 rpm due to thermal energy switch from the turbine. Experimental records also display that insulating the turbine drastically improves the non-adiabatic turbine overall performance. it's far therefore recommended to insulate the turbine and offer compressor cooling with the intention to improve the turbocharger non-adiabatic overall performance and hence the engine overall performance. Experimental records also show that insulating the turbine results in 2.4% boom of the exhaust gas temperature at turbine exit.

2.2 Effect of Variable Geometry Turbocharger:

Cheong et al [24] studied the effect of variable geometry turbocharger on HSDI diesel engine. Power boosting technology of a High Speed Direct Injection (HSDI) Diesel engine without increasing the engine size has been developed along with the evolution of a fuel injection system and turbocharger. Most of the turbochargers used on HSDI Diesel engines have been a waste-gated type. Recently, the Variable Geometry Turbocharger (VGT) with adjustable nozzle vanes is increasingly used, especially for a passenger car in European market.

Cheong et al described 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) is 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. In power boosting of engines, the application of conventional turbochargers could realize only a limited improvement because it is effective in a narrow flow range. Charging effect of a conventional turbocharger is too poor in a low flow range below the matching point to realize a high power output at a low engine speed region.

The waste-gated turbochargers that bypass some portion of an exhaust gas were generally used for boosting high speed Diesel engines. But, recently, VGT (Variable GeometryTurbocharger) is increasingly used in HSDI Diesel engines, which makes it possible to raise the boost pressure even at lower engine speeds, together with the reduction of pumping losses at higher engine speeds, compared with a waste-gated turbocharger. In his study, aVGT was applied to an HSDI Diesel engine, and the improvement of a full load performance over the case with a mechanically controlled waste-gated turbocharger was confirmed. The test engine was a prototype 2.5 liter direct injection diesel engine, equipped with a common rail fuel injection system with a maximum rail pressure of 1350 bar and 4 valves per cylinder. The VGT tested in this study was a Variable Nozzle Turbine (VNT) type, and the vane angle of the turbine nozzle can be varied, as shown in Fig. 3.

Fig 3: Schematic diagram of VGT [24]

Cheong et al found that 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. At low speed, over 40 % of additional torque increase was observed within the same exhaust smoke, the cylinder pressure, and the exhaust gas temperature limit, by adjusting the boost pressure and fuel delivery with the VGT. In the medium engine speed range, there was a marginal gain in the fuel consumption for the VGT, with the same fuel delivery. When the boost pressure and fuel delivery were increased, more torque could be achieved with the expense of the deterioration in fuel consumption. This is because the injection timing should be retarded not to exceed the maximum cylinder pressure limit. At high engine speed, with the same fuel delivery, the rated power can be enhanced by 3.5 %, mainly caused by the reduction of pumping loss. However, within the same boundary conditions, the power increase for the VGT could reach about 7.9 %. Cheong concluded that the application of VGT could provide HSDI Diesel engines with a great potential for full load performance, especially at low engine speed.

2.3 Availability Analysis of a Turbocharged Diesel Engine Operating Under Transient Load Conditions:

The running below transient load situations. A pc evaluation was advanced for analyzing the strength and availability performance of a turbocharged diesel engine, working under temporary load conditions.

The model contains many novel functions for the simulation of temporary operation, together with designated evaluation of mechanical friction, separate consideration for the strategies of every cylinder in the course of a cycle (multi-cylinder version) and mathematical modeling of the gas pump. This model became established in opposition to experimental records taken from a turbocharged diesel engine, placed at the authors' laboratory and operated below temporary situations. the supply phrases for the diesel engine and its subsystems have been analyzed, i.e. cylinder for both, the open and closed elements of the cycle, inlet and exhaust manifolds, turbocharger and aftercooler. The evaluation revealed how the availability houses of the diesel engine and its subsystems expand all through the evolution of the engine cycles, assessing the significance of every belongings. specifically the irreversibilities term, which turned into absent from any analysis primarily based solely on the first-regulation of thermodynamics, turned into given in element as regards temporary response in addition to the rate and cumulative terms in the course of a cycle, revealing the value of contribution of all of the subsystems to the full availability destruction.

The experimental investigation was carried out on a 6-cylinder, IDI (indirect injection), turbocharged and aftercooled, medium-high speed diesel engine of marine duty coupled to a hydraulic brake, located at the authors' laboratory. A high-speed data acquisition system was setup for measuring engine and turbocharger variables performance, under both steady-state and transient operation. The transient behavior of the engine was predicted adequately by the developed code, despite the long non-linear brake loading times and the IDI nature of the engine. From the experimental data it was concluded that the availability term for the heat loss to the cylinder walls increases substantially during the transient event (increased potential for work recovery), but the reduced term returns to the initial value after a peak in the middle of the transient event.

The availability of the exhaust gases from the cylinder increase significantly after an increase in load (increased potential for work recovery). Cylinder irreversibilities decrease, proportionally, after a ramp increase in load due to the subsequent increase in fueling, while combustion irreversibilities account for at least 95% of the total cylinder ones. Every operating parameter that can decrease the amount of combustion irreversibilities (e.g. greater cylinder wall temperature) was favorable according to second-law and can lead to increased piston work. Exhaust manifold irreversibilities increase significantly during a load increase, reaching as high as 15% of the total ones, highlighting another process which needs to be studied for possible efficiency improvement. This increased amount of irreversibilities arises mainly from the greater pressures and temperatures due to turbocharging, which have already lowered the reduced magnitude of combustion irreversibilities. The inlet manifold irreversibilities, on the other hand, were of lesser and decreasing importance during the transient event. Turbocharger irreversibilities, though only a fraction of the (dominant) combustion ones, not negligible, while the intercooler irreversibilities steadily remain of lesser importance (less than 0.5% of the total ones) during a load change.

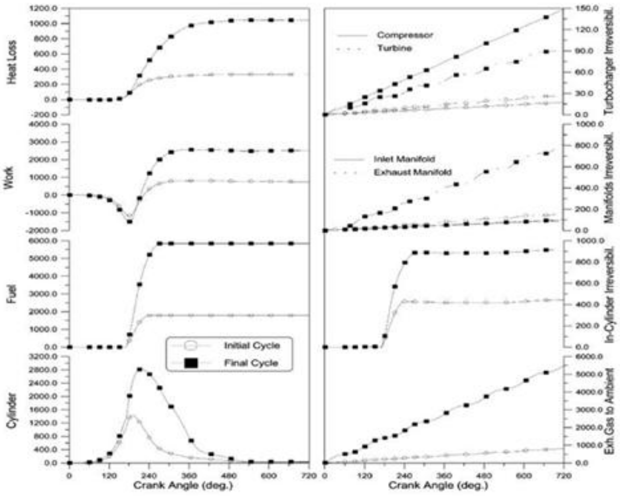

Fig 4: Development in the cumulative (J) availability terms of diesel engine and its subsystems, at the initial and final steady-state conditions. [25]

2.4 Effect of Intercooler on Turbocharged Diesel Engine Performance:

Expanded air strain outlet compressor can result in an overly warm consumption charge, appreciably lowering the performance gains of rapid charging due to decreased density. Passing price thru an intercooler reduces its temperature, allowing a more quantity of air to be admitted to an engine. Intercoolers have a key function in controlling the cylinder combustion temperature in a turbocharged engine. Naser et al [26] thru their own labored out programmed code in MATLAB provided the effect of intercooler (as a warmth alternate tool air-to-liquid with 3 extraordinary sizes and universal warmness switch coefficient and one base) at a multi-cylinder engine performance for operation at a regular speed of 1600 RPM. They presented the simulation predictions of temperature and pressure in cylinder for three types of intercoolers. also they provided the stress and temperature in consumption, exhaust manifold and other overall performance.

From the experimental statistics, the authors concluded that the maximal temperature in engine cylinder became decreasing from 1665.6 okay at SU =one thousand to 1659.2 k at SU=1600. also intercooler overall performance turned into increased by means of growing the layout parameters. Intercooler efficiency changed into 0.ninety two% at SU =1000 and zero.ninety eight% at SU=1600. Canli et al [27] also studied the intercooling effect on power output of an internal combustion engine. In his study, a diesel engine was considered and it was evaluated whether it was equipped with either a turbocharger or both a turbocharger and a super intercooler. Using thermodynamics laws and expressions, the power output of the engine was analytically examined by changing intercooling features such as pressure drop values and engine revolution at full load. Results were presented and interpreted as power (kW) and downsizing of the engine volume values (m^3).

In this study Canli et al concluded that engine power can be increased to 154% by ideal intercooler while single turbocharger without intercooler can only increase 65% engine power output. The power output of engine at different RPM is shown in the graph below.

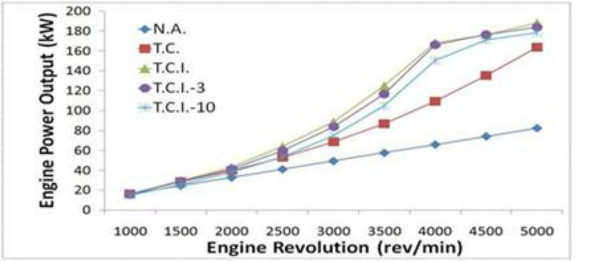

Fig 5: Power output values of the engine due to supercharging, N.A. Naturally aspirated engine, T.C. Engine with turbocharger and without intercooler, T.C.I. Engine with turbocharger and intercooler, T.C.I.3 Engine with turbocharger and intercooler and 3 percent pressure drop, T.C.I.10 Engine with turbocharger and intercooler and 10 percent pressure drop [27]

2.5 Increase in Low Speed Response of an IC Engine using a Twin-entry Turbocharger:

Turbochargers had been significantly used for engine downsizing practices as they are able to largely beautify the engines power and torque output without the want of increasing the swept extent of each cylinder. however, for turbocharged downsized diesel engines, the slower response of the turbine at low engine speeds, commonly in a variety of one thousand – 3000 RPM, appears to be a commonplace hassle. various answers were proposed and studied, including variable geometry turbochargers (VGT), -stage turbocharger and turbo-compounding strategies. each Arnold [28] and Hawley [29] found that adopting a narrow vane angle inside a VGT turbine housing at low engine speeds increases exhaust glide to the impeller, for this reason enhancing the boost overall performance of the compressor. Chadwell and partitions [30] suggested a new era known as a top notch turbo to triumph over the sluggish response of a turbocharger at low engine RPM.

This form of turbocharger can be coupled to a continuously variable transmission (CVT) that is immediately run via the crankshaft of the engine, for that reason allowing the turbocharger to behave as a supercharger boosting device at lower engine speeds. comparable increases in overall performance the usage of turbo-compounding methods are found via Ishii [31] and Petitjean et al [32]. two-degree turbocharging as discussed through Watel et al [33] uses high and low stress turbochargers working in series to overcome the consequences of reduced exhaust stress encountered at low engine speeds. One method which has no longer been completely researched is the software of a dual-access turbocharger with two turbine inlet ports. This arrangement might also lead to an progressed engine response at lower engine speeds, frequently due to the separated inlet port association, thus avoiding the interactions between the in another way pulsed exhaust gases in the manifold, and improving the strength transfer from exhaust fuel to the turbine impeller. In comparison to a single-entry turbocharger, a dual-entry turbine housing (as shown in figure 6) will higher make use of the electricity of the pulsating exhaust gas to reinforce the turbine overall performance which immediately will increase the rotational pace of the compressor impeller.

For example, a four cylinder engine with a 1-three-4-2 firing order equipped with a unmarried-entry turbocharger and four into 1 exhaust manifold will produce the subsequent situations: at the cease of the exhaust stroke in cylinder 1 (i.e. while the piston is drawing near the pinnacle useless centre (TDC)), the momentum of the exhaust fuel flowing into the manifold will scavenge the burnt gas out ofthe cylinder. inside the interim in cylinder 2, the exhaust valve is already open allowing for exhaust gas to enter the manifold as nicely. this means that the exhaust gas from cylinder 2 will have an effect on the glide of exhaust gas from cylinder 1, for that reason affecting the power switch to the turbine [34]. One way to this hassle is to adopt a dual-access turbocharger with a split-pulse manifold that keeps the otherwise pulsed exhaust gasses separate, accordingly allowing the general public of the pulsating electricity of the exhaust gasoline to be utilized by the impeller. This is not handiest greater realistic and reasonable however also offers a potential for development within the discount of gaseous emissions. dual-entry turbochargers have now been utilized in enterprise for large-size engines, however restricted studies has been undertaken for medium-sized engines. therefore extra research are important to offer in addition insight into the key advantages, or in any other case, of adopting a dual-entry turbocharger as studied through Kusztelan et al [35].

Fig 6: Turbocharger cut-away highlighting the twin-entry volute geometry, allowing differently pulsed exhaust gases to remain separate [35]

Kusztelan et al, through the AVL Boost engine simulation code,demonstrated potential performance improvements on a variety of engines due to the adoption of a twin-entry turbocharger with a corresponding split-pulse manifold. The results for the 1.5L DCi Renault engine show that the application of a twin entry volute design enhances the performance of the engine when operating during low RPM conditions, the most effectiveness being observed from 1500-3000 RPM showing a maximum 27.65% increase in turbine shaft speed and amaximum 4.2% increase in BMEP. Both engine torque and power performance also increased by 5.55% at 2000 RPM resulting in an average performance increase of 4% during the 1000 – 3500 engine RPM range. The addition of the extra torque and power was more beneficial during low engine speeds as the turbocharger delay time would be reduced making the engine more responsive to driver input. The“drivability” of the vehicle has therefore also improved.

Figure 7 shows the increment in the engine power output of a 2.0L CI engine using a twin-entry turbocharger.

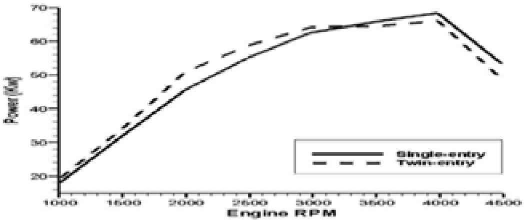

Fig 7: Increased engine power output of a 2.0L CI engine using a twin-entry Turbocharger [35]

III. Conclusion:

The literature review take a look at offered in this paper presents a fashionable outline of the advancements inside the turbocharging technology to enhance the engine performance. In last two many years diverse new advancements are done to enhance the energy output of an engine and to lessen its emissions through making a few adjustments and installing some extra add-ons like intercooler within the turbocharging generation. this may carry on in the destiny due to the fact in coming days there will be an increment inside the demand of fuel green engines with greater power and minimum emissions and this is possible with non-stop advancements in turbocharging era.

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