Advancement in Turbocharger Technologies: A Review

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Abstract

"Decreasing the waste product and increasing efficiency." Turbochargers increase the power output of the engine by allowing more air per intake to the combustion chamber to power train without increasing the cylinder capacity. The performance of diesel engine increase with a rise in compression magnitude relation exhaust gas recirculation may be a common thanks to management in-cylinder Nox production and is employed in hottest high-speed direct injection diesel engines as a result of it lowers element concentration and flame temperature of the operating fluid within the combustion chamber. The EGR system recirculates a fraction of exhaust gases into the manifold wherever it mixes with the recent incoming charge.

Keywords*: Automotive turbocharger, engine downsizing, EGR, turbocharger technologies.*

1. Introduction

Turbocharged spark ignition engines have been around since the 1970s. Their popularity in the public sector has been small until the recent advances in engine control. This lack of popularity could partly be due to the drawbacks associated with the early turbocharged engine. But with the advancement in electronic control and engine technology, turbocharging has become more reliable for consumer-grade cars. The operating principle of the turbocharger is to run a turbine by the energy derived from the exhaust gases. This turbine then pushes a greater amount of air into the combustion chamber (more oxygen) and hence more fuel is burned, and more power is produced. Therefore, a turbocharged engine can produce more power than a similar sized engine without a turbocharger.

Many new technologies have been introduced to assist the turbocharging of the internal combustion engine to improve volumetric efficiency. These advances incorporate between cooling of the charged air before going into the ignition chamber so its mass stream rate is expanded. The other innovation is twin charging in which right off the bat the motor is helped by a supercharger then it is supported by a turbocharger when the vitality of fumes gas is adequate to pivot the turbine sharp edges. The next important reason for the introduction of the turbocharger in a consumer-grade car is related to the environment. A Turbocharger paired with an exhaust gas recirculation system relies solely on the energy that was designated to be lost to the environment in the first place and uses no other external power source to run itself. This means we are reaching new heights of engine power without actually burning extra fuel as a cost for it.

Even though turbocharger has come a long way, not even about 30% of the cars in 2014 were equipped with one. But the trend is changing fast and it is expected to have about a little less than 40% of cars in 2019 to be turbocharged. As such, turbocharger technology will see many revisions in coming times. All this leads us to our current review topic where we are interested to see just how well an engine performs with a turbocharger and EGR working together against the engines of the past, the ones that were designed without turbocharger in mind. Additionally, to compare the consequences of having turbocharger now to the time it was still new and budding.

2. LITERATURE REVIEW :

Kusztelan et. al., [2012]: 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. 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

Ghodke et. al., [2012]: 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 the review of advancements in turbocharger technology to meet the demand for 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 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.

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 airflow requirements and thus the turbocharger needs.

2.1 "Airpath control of a heavy-duty EGR vgt diesel engine"[18]:

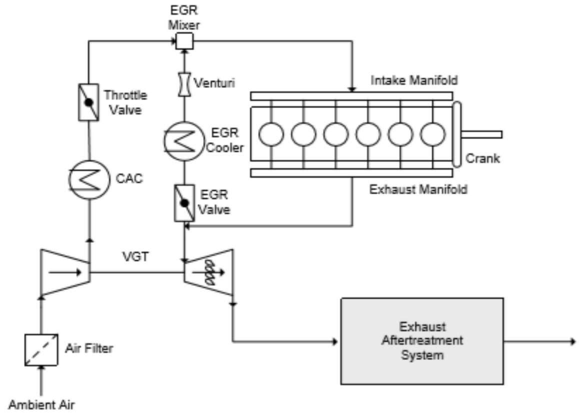

Figure 1: Schematic drawing of the Diesel engine with EGR and VGT.[18]

The review expands on the idea of controlling air pathing and we come to an understanding of concepts regarding the importance of flow of gases inside turbocharger

Ferreau et al. (2007) applied MPC to the air-path of a Diesel engine equipped with an exhaust gas recirculation (EGR) valve and a variable-geometry turbocharger (VGT), to track set-points of the fresh mass air flow (MAF) and the intake manifold pressure (MAP), and with box constraints on actuator position and rate limits. The MPC controller designed by Ferrau et al. used local linear models with operating range described in terms of engine speed, and an online optimization solver called qpOASES running on a rapid control prototyping system called dSPACE Auto box. A similar problem formulation is proposed in Ortner and Del Re (2007), but with local linear models with operating range described not only in terms of engine speed but also in terms of fuel injection, and with an explicit MPC. The control scheme proposed by Ortner and Del Re was implemented and tested on a dSPACE Auto box unit.

2.2 "A review of novel turbocharger concepts for enhancement in energy efficiency"[1]:

This review tries to expand on the various techniques and test used in industries to test turbocharger performance and efficiency, this is explained as following in the stated review

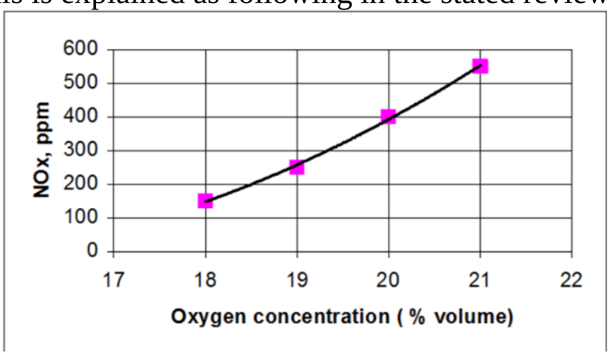

Figure 2: Effects of intake oxygen concentration [19]

Capobianco and Marelli [1] used a cold gas test apparatus to analyze the performance of a turbocharger. They found that certain areas of interest must be looked upon when undertaking such an experimental procedure. These include analyzing the compressor and the turbine characteristics over a typical operating range, similar to those used on an internal combustion engine. They also stated that the steady and unsteady feature of exhaust gas flows and their effect on engine performance are also important. Flow unsteadiness will occur due to the pulsating nature of the exhaust gases, which originates from the pumping action of the engine's combustion cycle. Therefore it is necessary to replicate this effect in the test. Capobianco and Marelli have adopted two methods (see figure 2), the first being a series of rotating valves and the second an application of a cylinder head. In the former, the opening and closing of the valves create a similar pulsating nature of air supply to the turbine. This type of setup in conjunction with an electric motor can produce a pulsating frequency similar to that of a working engine (i.e. 10 - 200 Hz).

Based on the study, it was claimed that the VGT unit will decrease the quantity of NOx in the exhaust gas emissions when compared to an FGT unit. To quantify this finding, the amount of NOx produced at varying engine speeds using a VGT unit is shown in figure 2.

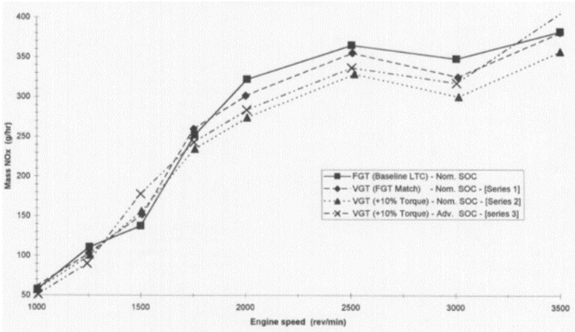

Figure 3: The NOx production over a range of engine speeds [1]

2.3 "Design of an experimental EGR system for a two-cylinder diesel engine"[19]:

This review try to explore the effect of egr on nox production such as by giving graphical data on existing models

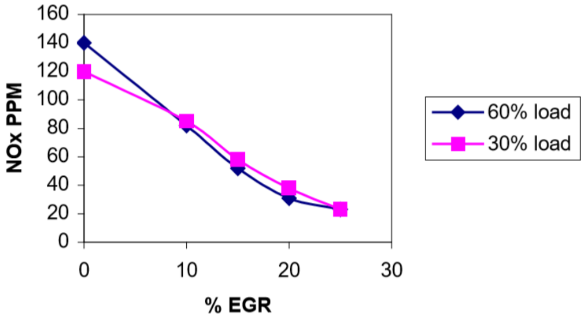

Figure 4 : Effect of EGR on NOx [19]

The local atomic oxygen concentration depends on molecular oxygen concentration as well as local temperature. Fig 4 depicts the effect of Oxygen concentration in the intake air on the concentration of NOx emissions in the exhaust.

2.4 "Evaluate the performance and emission using EGR in compression ignition engine fuelled with blend"[20]:

This review tries to explain the importance of EGR coupled with turbocharger or even as stand-alone solution

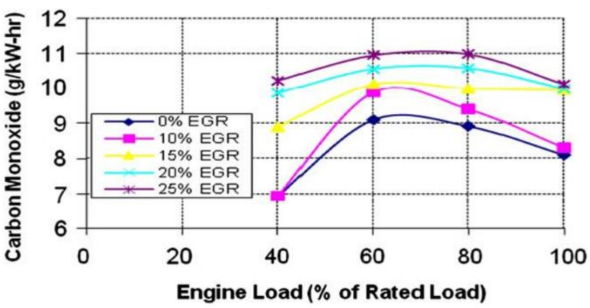

Figure 5: Carbon Monoxide v/s Engine Load[20]

Federico Millo [20] to evaluated by means of both experimental tests and numerical simulation in addition to the experimental tests, a one-dimensional fluid-dynamic engine model has been built in order to assess the potential of a Dual Moad (DM) EGR system a combination of Short Route (SR) and Long Route (LR) EGR systems. Substantial reductions of the NOx emissions have been achieved using the LR EGR layout both under steady-state and transient operating conditions a reduction. The use of a Long Moad EGR system has resulted to be extremely effective in reducing NOx emissions reduction both under steady-state and transient operating conditions a reduction of up to 15% in comparison with the conventional Short Moad system.

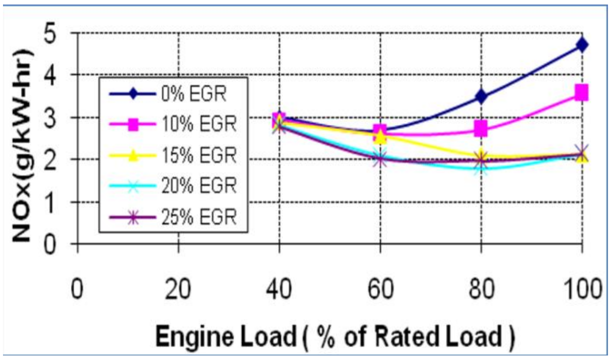

Figure 6: NOX v/s Engine Load[20]

N. Ravi Kumar, [20] the experiment was conducted on a single-cylinder direct injection variable compression high-speed diesel engine with 0%, 5% and 10% EGR. The experimental results show that with an increase in compression ratio the brake thermal efficiency increases and specific fuel consumption decreases. It was observed that with a raise in % of EGR the percentage increase in brake thermal was up to 13.5%. It was found that with raise in % EGR the NOx emissions were gradually decreased by 11% to

85% at different compression ratios due to fewer flame temperatures and low oxygen content in the combustion chamber. Smoke opacity also decreases.

2.5 "The study of EGR effect on diesel engine performance and emission- a review"[12]:

This review tries to explain the effect of NOx production specifically in the diesel engine ecosystem.

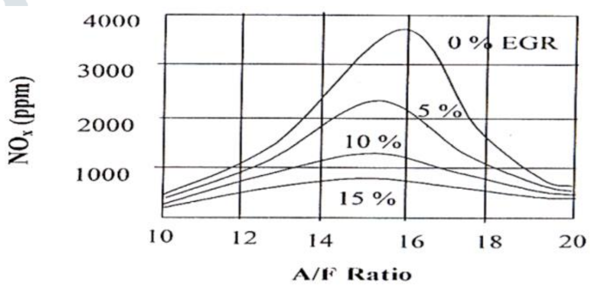

Figure 7: NOX v/s Engine Load[12]

Mukesh Rameshbhai Zala [12], in his study on "Optimization of EGR Rate on multi cylinders 4 stroke diesel engine" they conducted an experimental study on a naturally aspirated 4 cylinders, 4 stroke diesel engine with modification to run with EGR. Engine performance and emission were tested at varying EGR Rate (0- 40%) and optimum EGR Rate for the naturally aspirated engine is found out by taking the performance and emission readings at varying load conditions (0-120%) and at 1500 RPM. Brake power was measured with an electric dynamometer. The evaluation of experimental data showed that NOx emission was reduced by about 80% because of EGR.

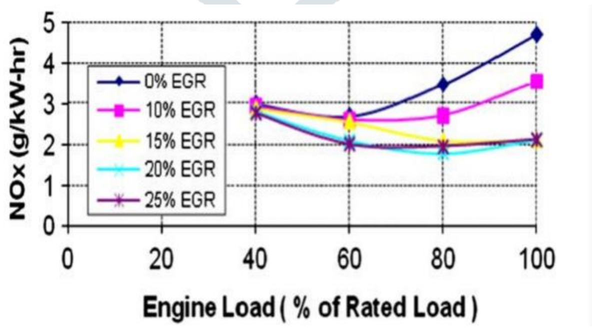

Figure 8: NOx for different EGR Rates[12]

Figure 8 shows the main benefit of EGR in reducing NOx emissions from a diesel engine. The degree of reduction in NOx at higher loads is higher. The reasons for the reduction in NOx emissions using EGR in diesel engines are reduced oxygen concentration and decreased flame temperatures in the combustible mixture. At the part load, O2 is available in sufficient quantity but at high loads, O2 reduces drastically, therefore NOx is reduced more at higher loads compared to part loads.

3. Turbochargers

Turbochargers essentially have an exhaust side and a fresh airside. The main component, known as the core assembly, comprises the bearing housing, the bearing system itself and the rotor shaft on which the turbine wheel and compressor wheel are located. The compressor wheel is located on the fresh air side, while the turbine wheel is located on the exhaust side.

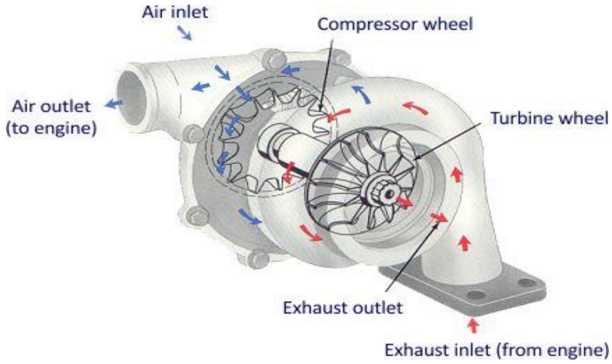

Figure 9: Turbocharger construction and flow of gases(Source: Schwitzer)

3.1 Turbocharger operating principle

When operating, hot exhaust gases are emitted from the engine and fed to the turbocharger via the exhaust manifold. Depending on the exhaust gas volume, the exhaust gases generate a rotary movement at the turbine wheel and this is transmitted via a shaft 1:1 to the compressor wheel. The compressor draws in fresh air via the intake duct, compresses it and passes the air via the intake duct into the engine's cylinder at the resulting overpressure. A turbocharger is a device used to assist the engine in producing more power for an engine of given size. Its purpose is to increase the volumetric efficiency of the combustion chamber; A Turbocharger is a device that increases the power output of the engine by allowing more air per intake to the combustion chamber of the powertrain. The main purpose of turbocharging technology is increasing the power of the engine without an increase of piston displacement.

3.2 There is two type of connections for turbocharging:

- Parallel
- Sequential

3.2.1 Bi-turbo/twin-turbocharging (parallel connection)

Biturbo or twin-turbocharging involves a parallel arrangement of two turbochargers. The two chargers are used over the entire load and speed range. In the case of a six-cylinder bi-turbo engine, each turbocharger only has to fill three cylinders. In the case of a V8 engine, each turbocharger supplies one bank of cylinders. With this form of turbocharging, smaller turbochargers can be used in place of one larger turbocharger and hence have lower moments of inertia to overcome. This results in improved response. The turbocharger turbines are thus supplied with half the exhaust gas volume. Each turbocharger has its wastegate. The total volume flow and charge air pressure result from the supplied and compressed air from both compressors. This means that each turbocharger has its charge air cooler and the cooled air flows are combined in a Y-shaped intake pipe before the butterfly valve. With bi turbocharging, achieving approximate turbocharger synchronization presents a challenge. Therefore, the designs of the two turbos frequently differ. By the way, this essentially affects the entire intake and exhaust gas system due to the different situations on the left and right-hand sides of the engine bay. A turbocharger can even help to compensate for the differences in the overall system by being calibrated differently.

3.2.2 Two-stage Turbocharging (series connection)

In the case of two-stage turbocharging or series connection, two turbochargers are connected one after the otherthan This differs from register turbocharging in that there is permanent interaction between both turbochargers. One high-pressure turbocharger and one low-pressure turbocharger are used. The exhaust energy is passed to the turbine side of the high-pressure turbocharger in the lower speed range. The wastegate and the bypass valve are closed. The smaller high-pressure turbocharger takes over compression almost on its own. The wastegate is opened at medium speeds, the low-pressure turbocharger is supplied with exhaust gas. This compresses the air and passes the recompressed air over the suction side of the high-pressure compressor, which acts as a booster. If the maximum charge air pressure is reached, limiting takes place by opening the bypass valve and the wastegate, which is already open. This allows a large proportion of the recompressed air from the low-pressure turbocharger to bypass the high-pressure turbocharger, feeding it directly to the engine. To summarize, this means that regulation takes place on the exhaust side and the fresh airside.

3.3 E-Booster in Turbocharger

The e-booster eliminates it by augmenting the turbocharger. It's driven by electricity, so it spins up to 70,000 rpm in just three-tenths of a second, providing a boost until the turbocharger gets up to speed. BorgWarner says the cantaloupe-sized device, combined with a standard turbocharger, improves torque by 85 percent at 1,500 rpm, and by 55 percent at 2,000 rpm.

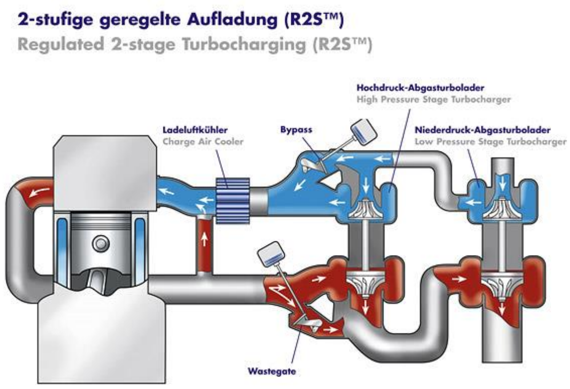

Figure 10: SCHEMATIC OF THE R2S[13]

Features:

- Equipped with a permanent-magnet motor
- Available as a 48V and a high-voltage version
- Features the necessary power electronics – a controller is also available
- Benefits
- Up to 11 kW continuous power and 17 kW peak power
- Lowers emissions and enhances fuel economy
- Improves transient response

3.4 Electrically assisted turbocharger (EAT)

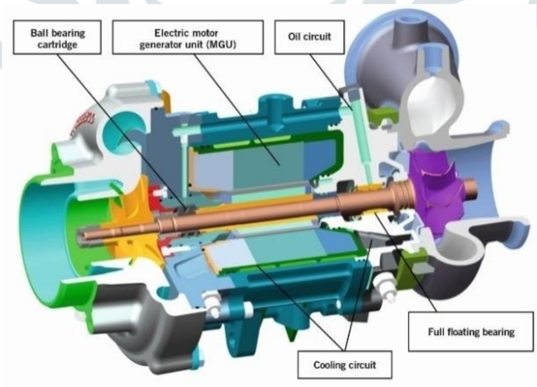

Figure11: Electrically Assisted Turbocharger[15]

The electrically aided turbocharger (EAT) is a high-speed electric machine is interconnected between the turbine and the compressor.

During low engine speeds, the electric machine purposes as a motor providing supplementary torque to the compressor producing higher boost pressure with a faster transient response.

While during high engine speeds, the electric machine produces power, which can be transferred to energy storage.

It can also restrict the turbine to exceed its speed limit. However, this might also cause high backpressure effect to the ICE, which can neutralize the energy reclaimed from the exhaust gas.

3.5 Electric compressor (EC)

The electric compressor (EC) is the energy for actuating the compressor is solely rendered from electric energy storage so that it has more flexibleness in terms of control. Also, the compressor can be operated at its optimal operating point assuring high efficiency. The electric components are expected to have high power output compared to other topologies. This topology does not have the capacity of energy generation itself but the regenerative braking system or integrated starter generator (ISG) can be consolidated to provide electrical energy to the energy storage. The torque/inertia ratio can be achieved if an electric machine with large power density and low inertia.

3.6 Hot inside V Engine (Mercedes)

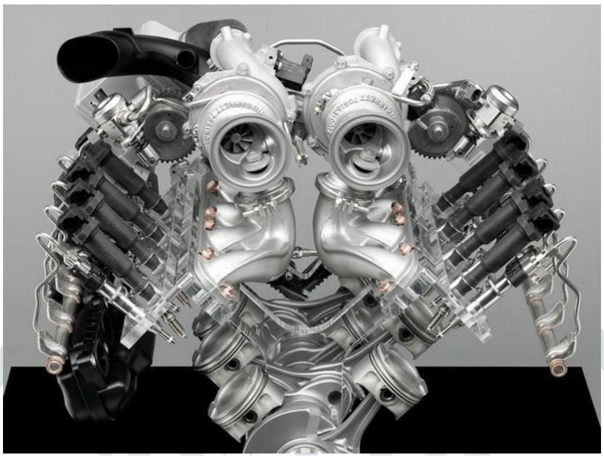

Figure12: Hot inside V Engine[16]

A hot inside V turbocharger design puts the turbo or turbos inside the valley between the motor banks. Mercedes-AMG offers this on its twin-turbo V-8 motors, while BMW and Audi offer hot V arrangements on some of their items too. The advantage to such an arrangement is, that the fumes gas has a shorter way to spill out of the complex. They're perched over the ventilation systems. This considers a considerably more limited bundle put in the engine. Other than the short way, the fumes side of the turbochargers stays more sizzling than if the turbos were outside of the V. The motor experiences far less slack as the short way for the fumes gases and the warmth mean vitality is utilized all the more productively, which keeps the turbos on help. The motor being referred to, Mercedes-AMG's 4.0-liter twin-turbo V-8, likewise gives top torque at a lower rpm, and it offers a magnificently wide pinnacle torque zone. The hot inside V is a brilliant arrangement that is being utilized in a ton of the top of the line sports and extravagance autos. The bundling and warmth maintenance perspectives are progressively proficient, and an increasingly effective motor is one that can create its capacity all the more effectively

3.7 Exhaust Gas Recirculation

In the process of exhaust gas recirculation, a fraction of exhaust gas is re-circulated to the engine. When the temperature inside the combustion chamber exceeds the critical temperature, the molecules of nitrogen and oxygen combine forming the oxides of nitrogen. When incoming air is mixed with re-circulated exhaust gas, it cuts off some percentage of the oxygen going into the combustion chamber and lowers the adiabatic flame temperature.

Due to the presence of exhaust gas, the specific heat of the mixture increases and the peak combustion temperature lowers. NOx formation progresses faster at higher temperatures. EGR serves to limit the formation of NOx. EGR is very effective in reducing the oxides of nitrogen, but it also has adverse effects on engine efficiency. As exhaust gas contains a lot of particulate matter, it may also contaminate the lubricating oil and can also foul the intake manifold. Intermixing the incoming air with recirculated exhaust gas, lowers the adiabatic flame temperature and reduces the excess oxygen. The exhaust gas increases the specific heat of the mixture and lowers the peak combustion temperature. NOx formation progresses faster at higher temperatures. EGR serves to limit the formation of NOx.

3.8 Mechanism of NOX formation

The principal issue in understanding the mechanism of generation of NOX and restraining is that combustion is highly heterogeneous in compression ignition engines. NO and NO2 are lumped mutually as NOX and there are some notable differences among these two pollutants. Both gases are considered toxic, but NO2 has a level of toxicity more prominent than that of NO. NO is formed during the post flame combustion process in a high-temperature zone. The most extensively accepted mechanism was suggested by Zeldovich. The principal source of NO formation is the oxidation of nitrogen already in atmospheric air. The nitric oxide formation reactions are initiated by atomic oxygen, which develops from the severance of oxygen molecules at the high temperatures during the combustion process.

$O + N_2 = NO + N$

$N + O_2 = NO + O$

N + OH = NO + H

3.9 The most frequent causes of loss of performance:

1. Sticky adjustment vanes on the VTG turbocharger. The charge air pressure setpoint/actual comparison is outside tolerances, the ECU switches to limp mode.
2. Defects in the charge air pressure control circuit (leaky pressure capsule, vacuum hoses that have slipped off or broken, broken electrical connections).
3. Defective wastegate valves. The turbine is not receiving the full exhaust gas flow.
4. Rotor shaft blockage caused by a lack of oil (see also chapter 8.3).
5. Defective turbine wheel caused by damage due to foreign objects or overloading (see chapter 8.5).
6. A damaged compressor wheel caused by foreign objects (see also chapter 8.6).
7. Leaks between the intake manifold and the turbocharger. The charge air pressure is lost. This results in hissing and whistling noises.
8. Blocked exhaust or intake system.
9. A defective injection system.

3.10 EGR technique for NOX reduction

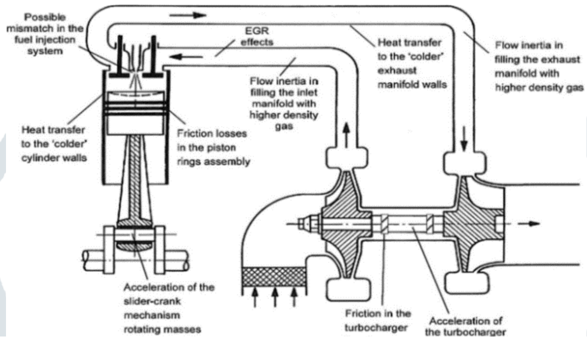

Figure 13: A presentation of the major contribution to the system delay during transient response of a turbocharged engine [14]

Exhaust gas consists mainly of CO2, N2 and water vapour. When a part of this exhaust gas is re-circulated to the engine cylinder, it acts as diluents to the combustion mixture. This, in turn, reduces the concentration of O2 in the combustion chamber. The specific heat of EGR is much higher than fresh air; hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber. EGR percentage is defined as % EGR = Volume of EGR * 100 / Total intake charge into the cylinder. The popular explanations for the effect of EGR on NOX reduction are increased heat capacity, dilution of the intake charge and ignition delay. The increased heat capacity lowers the peak combustion temperature due to non-reacting matter present during combustion. According to the dilution theory, the effect of EGR on NOX is caused by increasing the amount of inert gas in the mixture reduces the adiabatic flame temperature. The ignition delay hypothesis asserts that became EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing.

3.11 Volumetric Efficiency and Turbo Lag

In internal combustion engine, it is defined as the ratio of the mass density of air-fuel mixture drawn into the cylinder at atmospheric pressure to the mass density of the same volume of air in the intake manifold Turbo delay is the time between pressing the throttle and observing the rush of torque from a turbocharged engine. The delay comes from the time it takes the engine to generate enough exhaust pressure to rotate the turbo and pump compressed intake air into the engine and is greatest when the engine is in a low rpm, low load cruising condition.

4. Variable Geometry Turbocharger

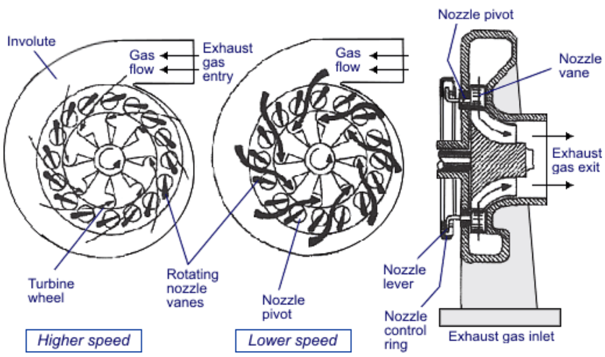

Figure 14: Variable Turbocharger schematics [17]

Variable geometry turbocharging embodies a large division of the technology present in today's vehicles. VGT technology (also known as VNT-Variable Nozzle Turbocharger) is employed in a huge range of applications, such as in commercial on- and off-highway, passenger, marine and rail internal combustion engine applications. Aside from the emissions and engine downsizing elements, other key developmental drivers include increased transitory response, improved torque characteristics, over-boosting restriction and greater fuel economy.

4.1 Limitation of FGT

Spark ignition (SI) engine is hard to coordinate with turbochargers because of the more extensive speed range and need to painstakingly control burning planning to stay away from thump. SI engine frequently work at decreased pressure proportions to counteract pre-start and farthest point thump; this makes eco-friendliness investment funds more earnestly to accomplish utilizing a turbocharging. CI engine likewise face troubles in coordinating turbochargers and engine, especially for the temporary reaction.

5. Advantages

Compared with equally powerful naturally aspirated engines, turbocharged engines use less fuel. The space required by a turbocharged engine is smaller than by a naturally aspirated engine of equal power. The altitude behavior (e.g. power delivery in alpine regions) of the turbo engine is considerably better. A naturally aspirated engine loses considerable amounts of power as a result of the decreasing air pressure at altitude. In turbo engines, the turbine power increases as there is a fairly large pressure drop between the almost constant pressure before the turbine and the lower ambient pressure. The lower air density at the compressor inlet is thus largely compensated. The engine loses hardly any power. Compared with a naturally aspirated engine, the turbo engine is also quieter as the turbine and compressor wheel act as silencers.

6. Shortcomings

Engine blocks, crank mechanisms, and pistons have to withstand higher loads in the case of turbocharged engines. The operating temperatures are higher (up to 1,050°C). Older turbocharger applications suffered from a poor response in the lower rpm range (turbo lag). The oil supply is more expensive. Contaminants in the exhaust system reduce turbocharger service life (source: Struck Turbotechnik, Cologne).

7. Expected Outcomes

Having bumped into a wall after the power and size an engine came to an apparent halt due to the nature of work and fuel consumption consideration, turbocharger brought a breath of fresh air to the system and made the realization of even higher engine power without the cost of extra fuel or engine size problem.

But, ever since its introduction turbocharger has gone through a lot of iteration, making it cost-effective or more efficient or just plain out more reliable and to this day it continues to grow more every time a new addition or change is made to it.

Thus, a turbocharger is a component that has a lot for it in the future where it will become a staple for every vehicle across the world.

8. Conclusion

There remains significant potential for further optimization with the application of variable valve actuation and turbocharger control system. We realize through the comparison, that Turbocharger not only increases the power of the given engine by 15-25%, but it also avoids the common problem of increasing fuel consumption or engine size, which is normally associated with power incremental of engine. Consequently, a turbocharged 4-cylinder engine can be used in place of a larger 6-cylinder engine. Also if we use a pattern of turbocharger effectively such as parallel and sequential we get better performance characteristics and to deal with disadvantages such as turbo lag we can implement to use E-booster in Turbochargers.

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