COMPREHENSIVE REVIEW ON TURBO LAG REDUCTION SYSTEMS IN A DIESEL ENGINE

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Abstract

Turbochargers are used throughout the automotive industry to improve the overall efficiency of an internally fired combustion engine. This helps the manufacturers to improve the power output of the vehicle without actually increasing the size and cylinder capacity of the engine. This is termed as "downsizing". Turbochargers have proved very crucial in the field of motorsports. But turbochargers fail to provide an initial boost which gives a sluggish feel during the start and an instantaneous kick in the power as the exhaust gas reach the threshold power. This disadvantage is commonly known as "Turbo lag". The aim of this paper is to provide an insight on turbo lag and current techniques adopted by manufacturers to reduce its effect.

Keywords: Turbochargers, Turbo lag, Efficiency Downsizing, Threshold power, Supercharger, Performance.

Introduction

Turbocharger is a turbine driven forced induction device installed to improve the overall efficiency of the engine. This is modification over the naturally aspirated and supercharged engines. The working principle is to increase the amount of air intake during the suction stroke using a compressor followed by increased amount of fuel in the combustion chamber resulting in high power-to-weight figures. Construction of simple turbocharger consists of a turbine and an air compressor mounted on same shaft.

Superchargers were first used over naturally aspirated engines in 1902 by Louis Renault. The energy required to run the air compressor was derived by connecting it to the crankshaft with the help of a chain, belt or gear. This increase in air density is accompanied by more fuel supply in the combustion chamber improving the overall power output. Turbocharger is basically a modified supercharger. It initially was coined "Turbo-supercharger". The main difference between the two is that supercharger was mechanical driven and used power from the engine itself for its working. This was the major disadvantage which was overcome using a turbocharger.

The exhaust gases carry a certain amount of thermal energy as they exit through the exhaust. This energy is utilized by the turbocharger to rotate the turbine which in helps in running of the air compressor. Compression of air results more amount of air being drawn into the combustion chamber. So burning of this air fuel mixture helps to increase the power. Larger air fuel mixture greater is the explosion and finally greater "boost". The crankshaft is connected to the transmission through a drive shaft and a differentials and finally to the driving wheels.

Let us now consider the throttle now to be closed during the initial state. So the density of air entering the combustion chamber is very low and subsequently the exhaust gases. The turbines basically have some mass which the exhaust gases have to overcome in order for the inertia to take place. So there is lack of force to rotate it. As turbine the and compressor are connected with the same shaft, the air intake process through the compressor will be very slow. So no extra air intake no boost. Now as we open the throttle we allow more air to be flowing through the chamber which finally results on more exhaust gases after combustion. This gases help in rotating the turbine which then facilitates more air to be sucked after each exhaust cycle. This is required boost we expect from a turbocharger. But the process from air to be sucked till exhaust gas reaches turbine needs time. This time gap in the engine is nothing but turbo lag. This is a major disadvantage as it reduces the throttle efficiency of the engine i.e. power is not delivered in the required manner and also there is an instant hop in the amount of power as the turbo kicks in. It is defined as the time lapse between the operating of the throttle and the rush of the torque from the engine [1][2].

Variable Geometry Turbocharger

VGT is the next generation of Turbocharger usually plan to allow required aspect ratio of turbo which allows significant flexibility over the pressure ratio across the turbine .this is done because the aspect ratio of engine changes with the change in speed of engine i.e. the effective aspect ratio of low speed engine is very different from the effective aspect ratio of high speed engine. Aspect ratio is nothing but the ratio of area to radius.

Fig 1: Schematic diagram of Variable Geometry Turbocharger

If the Aspect ratio of turbo is less we will get high performance or efficiency at low speed but it will suffer at higher speeds as the turbo will not get required boost on the other hand if the Aspect ratio of turbo is high we will get high Overall efficiency at high speed but there will huge amount of lag at lower speeds. So as the best alternative of Fixed Geometric Turbocharger EGLI developed an idea in 1958 about variable geometric turbocharger (VGT) also known as variable nozzle turbocharger (VNT) to get the optimum aspect ratio by altering the geometry of turbine with the help of actuators which control the variable vanes to restrain exhaust flow against the turbine blades .VGT are commonly used in diesel engine as it has lower exhaust temperature means they are less liable to failure. In diesel engine there are many advantage of using VGT over other turbochargers such as it improve the low Speed-Torque characteristics and has the no throttle loss as it does not require waste gate but the main advantage of VGT is it reduced the turbo lag considerably due to the aspect ratio being variable, A/R ratio can be kept low at low speeds, and as the engine speed increases, the A/R ratio can also be increase which improves the performance. In India, VGTs are commonly used in well-known diesel cars such as the Hyundai Verna and Maruti Swift.

WORKING:-

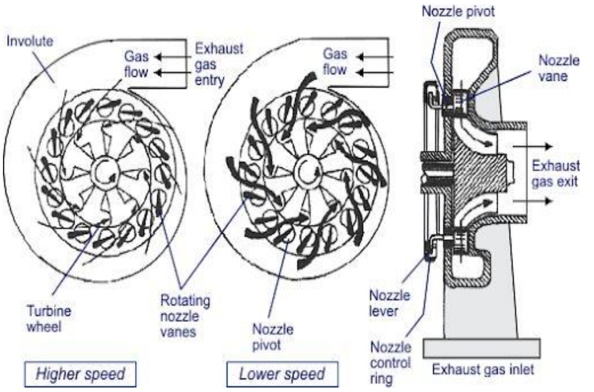

Fig 2: Working of VGT

Variable geometry turbo use vanes to alter the air flow path of the exhaust gases to maximize boost across the entire rev range.it has movable vanes or fins to obtain the optimum aspect ratio by adjusting the angle of vanes via actuator works on the hydraulic or pneumatic pressure.

Angle of vanes controlled remotely thus it does not need the waste gate. During low boost operations, the vanes create a narrow path to the exhaust turbine. As the rpm increases kinetic energy of exhaust gases develops, an actuator rotates the vanes, increasing the area of the path to the turbine, and allowing for greater flow, thus increasing boost at higher RPM which optimizes the behavior of turbine and reduces lag time to spool up. [3][4][5]

Electronic Turbo

In this method, electrical energy is used to reduce turbo lag in modern diesel engines. We know that, the exhaust gases don't have enough energy to drive the air compressor and give required power at initial running of engine. So to provide required initial power to engine this method is used. The basic principle of this technique is that, an electric motor is used to run the air compressor at start and through lower revolutions. And when engine attains higher RPM there is enough volume and energy of exhaust gases, so electric motor is cut-off and compressor runs on the power developed by turbocharger. The electric motor requires a DC supply for its running. This supply is given to the motor from a DC source i.e. battery. This battery is charged a generator which derives power from turbocharger.

This technique is now mainly used in Audi's latest model i.e. Audi SQ7 TDI. So, here is the review on how this technique is implemented in this specific model and it's improved performance over the other models without electric turbo. This system contains following important components or subsystems.

Electrically powered compressor (EPC): This EPC is used for the first time in production vehicles. This EPC

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mainly supports the engine at the time of starting off and accelerating by giving required boost with no turbo lag. EPC is placed in the air path downstream the intercooler. The operation of EPC is controlled by a by-pass valve installed in an air path. This compressor is run by a compact electric motor. The motor used for the purpose delivers power to the compressor as per requirement .The maximum power requirement of compressor can be up to 7kW. The compressor wheel spins up to 70,000 rpm.

Electrical system: Power is provided to the motor through a 48-volt lithium-ion battery. The battery has nominal energy content of 470 watt-hours and peak output of about 13kW. The required power that is stored in the battery can be provided by a more powerful and highly efficient generator. The efficiency of generator used is about 80 percent and can provide power upto3kW. The generator used is a MOSFET type generator which has minimum electric losses.

Audi Valve lift System (AVS): For expected working of the whole electric turbo system, a specially designed cam shaft and valve mechanism is used. There are basically two inlet and two exhaust valves per cylinder. The inlet and exhaust cam shafts each have two cam contours per valve. This specific shape of cam helps to operate each valve as per the requirement. On the inlet side, one cam contour helps the engine while starting off, while other helps the engine during acceleration or high power requirements. On the contrary, the exhaust side contours enables the second exhaust gas turbocharger.

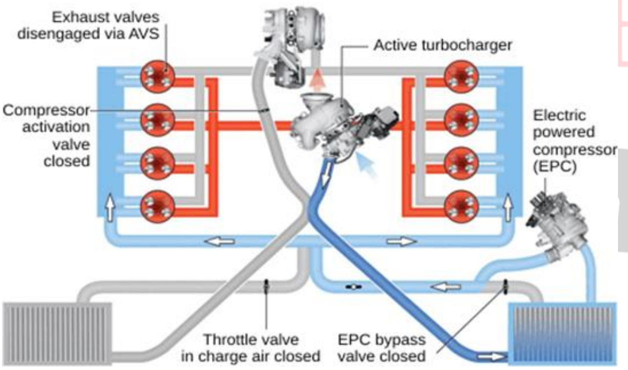

Fig 3: Schematic diagram of an electric turbocharger

Turbochargers: To fulfil peak power requirements two turbochargers are used in this system. At low load conditions, all exhaust is send to the only active turbocharger through one valve as other remains closed and the other turbocharger remains in a idle position as there is no need of both turbochargers for low load. When load on engine increases, the cam contour actuates the exhaust valve and some exhaust is sent to second turbocharger also. Now as both turbochargers are operating, air intake can be increased and more power is developed.

Working: As the engine is started, initially intake charge pressure is developed by a single turbine only (up to @800rpm), this is also called mono-turbo mode. The air pressurized by the turbocharger is passed through the intercooler to reduce its temperature increased due to compression. One electrically operated compressor is placed in downstream air path from the intercooler. This compressor is actuated by a by-pass valve placed in air path so that, air from intercooler passes through the compressor and again the pressure is developed and air is send to the inlet manifold. Due to additional increase in pressure of air by the electrically driven compressor, required boost is obtained (upto@1500rpm). When the first turbocharger becomes able to develop the required pressure on its own, the compressor is made shut off with the help of by-pass valve.

Now the engine again starts operating on mono-turbo mode that is compressed air is supplied to engine from one turbocharger only such that it fulfills the power requirement up to @ 3000rpm. When there is requirement of more power or more torque, the second exhaust valve per cylinder is actuated by the AVS, so that another exhaust flow starts through second exhaust valve to second turbocharger.
Due to this, both turbochargers causes more and more air flow to the inlet manifold and the power requirement is satisfied. This condition when both turbochargers are operating is called bi-turbo mode. This mode lasts upto@5000rpm. [6]

Table 1 Benefits of Audi SQ7 (latest model) over Audi Q7 (first version)

S.NO	PARAMETER	AUDI Q7	AUDI SQ7
1	Engine displacement	4134cc/4.134L	3995cc/4.00L
2	Power output	322Hp/240KW	429hp/320kw
3	Maximum torque	760N-m @1800-2500rpm	900N-m @1000-3250rpm
4	0-100kmph	7.4 sec	4.8 sec

VOLVO'S POWER PULSE

Everyone driving a turbo powered diesel vehicle appreciates the impressive torque available. But for getting even a better performance on tap Volvo came up with an ingenious solution which they call "power pulse" reducing turbo lag by delivering instant response. This is mainly used mainly on a twin turbo and a sequential turbo diesel engine of their own production. An electrically operated compressor and a pressurized air tank are added to the power train. Power pulse takes the fresh air form the intake port through air filter. The air is compressed and stored in a pressurized tank of capacity of two liters. As this air is taken directly from the air filter fresh air is used for combustion. When the driver decides to accelerate the vehicle rapidly a valve opens and the compressed air is forced into the exhaust manifold which feeds the turbo. This improves the response time and you don't have to wait for the exhaust gases to spool up the turbo. In the sequential turbo the exhaust gases help rotate a smaller turbo which then rotates a larger turbo in order to have a good power range across all rpm range. This instant power pulse creates an instant boost of the turbine. The compressed air in the tank is filled automatically making sure that power pulse is available whenever required to deliver a new boost. The pressure inside the tank reaches value of up to 12 bar (174psi) which is maintained by a magnetic valve controlling the system's action phase. This aids the drive-E technology better starting results. The rapid acceleration gives the driver superior acceleration without losing on the clean drive-E efficiency. The power pulse (compressor and pressure tank) for Volvo's 4-cylinder D5 engine weighs about 10kg and fits snugly behind the V90 wagon's headlamps.

The "PowerPulse" is a cheaper alternative for a 48-V hybrid which was a electrically driven turbocharger to rapidly spin turbo at lower engine rpms. The engineers at Volvo took over three years to develop the PowerPulse in the same manner as used in a D5 engine. This engineering marvel was first installed on their 2.0L 4-cylinder direct injection system. The power and torque figures respectively as claimed by Volvo are: 173kW (232hp) and 480Nm (354lb.ft). This helps the V90 wagon attain a 0-100 km/h (62mph) in only 7.2 seconds considering the massive 1817kg dry weight of the car. It uses a 8-speed automatic transmission.

Company's powertrain program manager Fredrik Ulmhage said that the PowerPulse is entire in-house production. Engineers at Volvo claim that the system reaches its peak 150000rpm in just 0.3s firm idle. When tested against the competitor's 6 cylinder from rest their new 4 cylinder PowerPulse assisted vehicles were found to 50-60m ahead during the test. PowerPulse adds roughly 10kg (22lbs) to the base engine however test are being conducted to use lighter materials to be used for greater efficiency. And reduce weight of the pressure tank.

Now Volvo also assure that by the year 2019 that they will electrify their entire line up which means that there will be at least one electric motor in each circuit. They will still use the regular diesel and gasoline powered engine but they will add an electric system in their setup. This will definitely help in reducing the turbo lag. One example of this is their "T8 TWIN ENGINE AWD". They have installed both supercharger and turbocharger in the engine resulting in an immediate response and good low end torque by the supercharger and the turbocharger to maintain the high torque on higher rpms. This also has an electric motor powered by a lithium ion battery. This is a plug in hybrid which is both supercharged and turbocharged. This engine provides a total of four riding modes on tap namely "PURE, HYBRID, POWER, OFF ROAD". So we don't feel the turbo lag as it is eliminated by the instant power delivery by the supercharger and the electric motor. Volvo has a series of high priority technology programs which emphasizes on using hybrid technology to bring gasoline powertrain engines much closer to the diesel fuel combustion potential. [7]

Fig 4: Schematic representation of a Volvo V90 engine

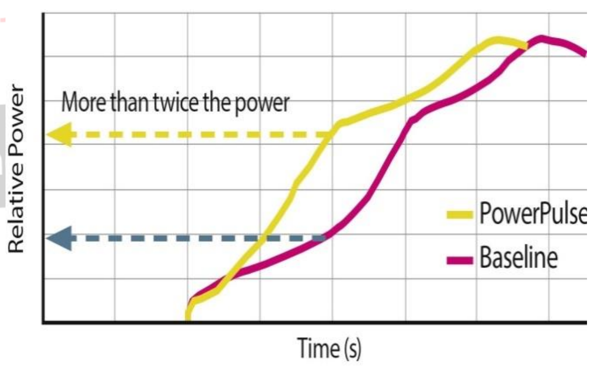

Fig 5: Relative power of a PowerPulse system (Relative power vs. time)

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Conclusions

The review study presented in this paper provides an overview to no. of techniques used in modern vehicles to reduce turbo lag and increase power output. We studied different types of turbo lag reduction systems namely variable geometry turbocharger , electric turbocharger and Volvos power pulse technology and reviewed there working and advantages over traditional turbocharger systems. These systems will make throttle response more quicker thus making cars more enjoyable to drive.

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