Despite the Turbo-Lag, Turbochargers are preferred to Superchargers by the Manufacturers

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***Abstract*—With the recent innovations since five decades in the automotive industry the most prominent and imprinting ones are the turbosuperchargers (or commonly called as turbochargers or turbos) and the superchargers. They are air compressors that work on the principle of forced induction that force the compressed air into the combustion chamber of the IC engine via the intake manifold and proportionately more fuel is injected which is going to result in the increment of the power and torque of the engine without increasing the displacement. This helps smaller engines to make more power and torque than they were making when aspirating naturally. This paper is an attempt to bring out the facts and theories that why turbochargers are used more than superchargers despite the turbo lag and their complex installation.**

Keywords—turbochargers, superchargers, compressor, turbine, intercooler, thermal efficiency, power.

I. INTRODUCTION

The turbochargers as well as superchargers have the same job to do and have the same goals to achieve, which is to send in more air into the combustion chamber through the intake manifold. Due to this additional air added without increasing the displacement of the engine proportionately more fuel would be injected, and more combustion would take place within the volume which in turn would increase the power and torque of the engine. [2] This is going to increase the power to weight ratio of the vehicle which is a positive and much needed nowadays. They both are centrifugal air compressors which work on the principle of forced air induction. [3] In order to find out the reason why the turbochargers are used more instead of superchargers despite the turbo-lag, first we need to understand their construction and working. In the next section their working and construction has been discussed. [1]

II. TURBOCHARGERS

A. Construction

The main components of a turbocharger incorporate:

- a turbine; which is usually a radial inflow turbine, but axial inflow turbines are used for large diesel engine
- turbine housing; which accommodates the turbine
- a compressor; which is generally a centrifugal compressor
- compressor housing; which accommodates the compressor
- a shaft; which connects the turbine and the compressor
- bearings; which are usually fluid bearings and support the shaft connecting the turbine and the compressor
- an intercooler; which sits between the compressor and the engine
- wastegates; which keeps a check on the flow of the exhaust gases to the turbine and if the boost is too much, they open, and the exhaust gases directly go to the catalytic converter without entering the turbine
- blow-off valves; they release the pressure off the turbocharger when the throttle is released suddenly

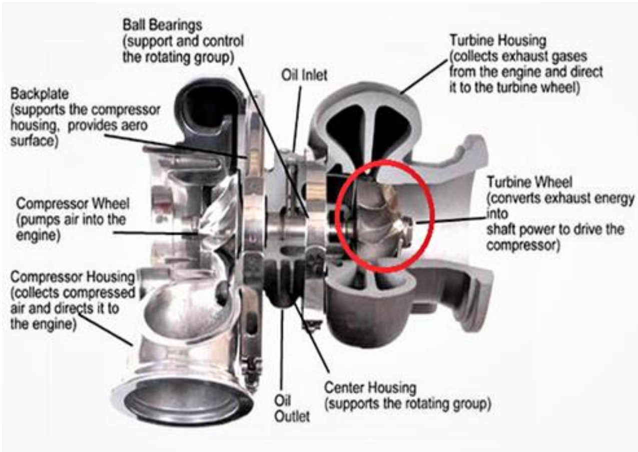

Fig.1. Construction of a turbocharger

B. Working

Turbocharger extracts the energy from the exhaust gases that are being expelled from the combustion chamber after the fourth stroke, i.e., the exhaust stroke. The turbocharger is installed in such a way that the turbine remains in proximity of the exhaust manifold while the compressor to that of the intake manifold. The exhaust gases rotate the turbine and due to which the compressor starts rotating since they both are connected via same shaft. The turbine utilizes the kinetic energy of the exhaust gases to provide rotary motion to the compressor. The turbine during this, pipes over the exhaust gases towards the catalytic converter for the way out. While the compressor sucks in air through its inlet and compresses the air to send it to the intake manifold through its outlet. [5]

But, according to Gay-Lussac's law;

$P \propto T$; (when the volume is kept constant)

Where,

P is the pressure, and

T is the temperature

Which means that when the air is compressed by the compressor the pressure as well as the temperature of the air will rise and which in turn will reduce the density of air as well and less dense air would not be of any use in the combustion chamber and might also cause knocking in the engine if used and this will reduce the volumetric efficiency of the engine too. [12] In order to make the air dense, an intercooler is introduced between the compressor and the intake manifold of the engine. [10] The intercooler is an air-to-air heat exchanger which cools the air down and makes it denser before it enters the engine. [9]

The turbochargers are designed to rotate at over *150,000 rpm* and can go right up to *250,000 rpm*. In turbochargers we get high end power boost, i.e., at higher rpms. The reason for this is that, in order to spin the turbine in the first place by extracting the kinetic energy of the exhaust gases there has to be a *threshold exhaust energy* which has to be provided to the turbines. So, this signifies that at low rpms the turbochargers would be of very little (insignificant) or of no use but as soon as the threshold is reached, and the turbine gets into action there would be a significant boost that would get the engine going hard and make more power and torque. But in order to get this boost we have to wait for some instance which is referred to as the *turbo-lag.* This lag is there because the turbochargers rely on the build-up of the exhaust gases to drive the turbine.

C. *Performance*

The boost is very much clear from the dyno graph (shown below) which the turbo provides to the engine. There is a huge boost in both the power as well as in the torque of the engine [8].

It is quite evident from the graph that the low-end power is missing but there is abundance of high-end power available this is mainly because of the exhaust threshold and the turbo-lag but when the revs climb, the high-end boost comes into play as the turbine is now spinning at a very high rpm and so is the impeller which in turn is going to suck in more air and send it to the intake manifold [7].

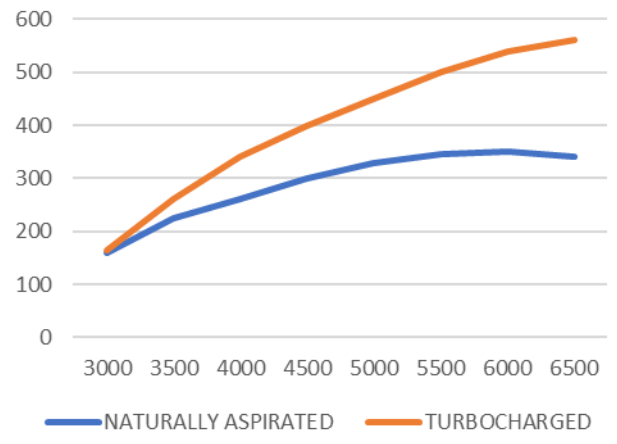

Fig. 2. Dyno graph of power (in hp) vs engine rpm of a naturally aspirated engine against a turbocharged engine

D. *Disadvantages of a turbocharger*

- *Threshold exhaust:* There has to be a threshold exhaust energy in order to get the turbine going so that the turbocharger starts working and the compressor gets into action. This means that turbochargers would not work on low rpms, say, below 2000 rpm but this also depends on the size of the turbo. If the turbo is big then greater threshold boost is required for its functioning, and if the turbo is small then it might even get to work at 2000 rpm.
- *Turbo-lag:* There is a time difference when we press the throttle and when we get the boost from the turbocharger which is known as the turbo-lag or boost-lag. It is because when we rev the engine it takes some time for the exhaust gases to spin the turbine and the compressor to deliver the boost. Sometimes turbo-lag is often mistaken with the threshold exhaust or boost but they both are totaly different things. Nowadays manufacturers are trying to reduce the turbo-lag as much as they can by using and implementing different technologies like modifying the aspect ratio of turbine, reducing the losses due to friction at bearings, using an anti-lag system, using multiple turbos be it parallel or sequential, using a spool valve to increase the speed of the exhaust gases, increasing the compressor discharge, etc.
- *Turbocharger lubrication and cooling:* While its operation the turbochargers need to be lubricated in order to reduce the friction and wear and tear in its components which in turn will also increase its life. The main problem prevails in how it is lubricated; from where it gets the lubricant, the answer is the engine. Turbochargers consume the engine oil for their lubrication, which means frequent monitoring has to be done of the engine oil level so that the turbo isn't running out of the lubricant and it also consumes more lubricant. Besides lubrication, turbos also need cooling because of their high operating temperatures so this asks for additional hoses and hardware [7].
- *Throttle miscommunication:* There is a throttle miscommunication in case of turbochargers. When we press the throttle, we don't get the power at that same instant but after some time, but when the rpms are high and we release the throttle, the large turbo boost kicks in unexpectedly and surprises the driver. This is kind of annoying and is not feasible. The deeper we push the throttle the more we would feel this miscommunication since turbos need time to spool up. [11]
- *Cost:* This is not that much of a deal breaker, but the turbochargers are not that economical. They are difficult to install and maintain or repair which will spike up its maintenance and installation charges. The reason for this is because turbos are installed deep down in the engine compartment where the exhaust manifold ends, which makes it a difficult place to reach for and hence affects the cost.

III. SUPERCHARGERS

There are commonly two types of superchargers:

1. *Dynamic compressors*: they depend on increasing the speed of the air (high speed, low pressure) and then by using a diffuser to make it low speed and high-pressure air. They work just like turbos which means they are not very responsive at low rpms.

2. *Positive displacement*: these are the ones that compress the air themselves and don't need a diffuser and can deliver air at all speeds. We are going to consider superchargers of this type only since the dynamic ones are similar to turbos.

Positive displacement superchargers are of following types:

- Roots (they are just simple blowers since they don't compress the air)
- Lysholm twin-screw
- Sliding vane
- Scroll-type

Among these twin-screw and Roots superchargers are the most popular ones. [18]

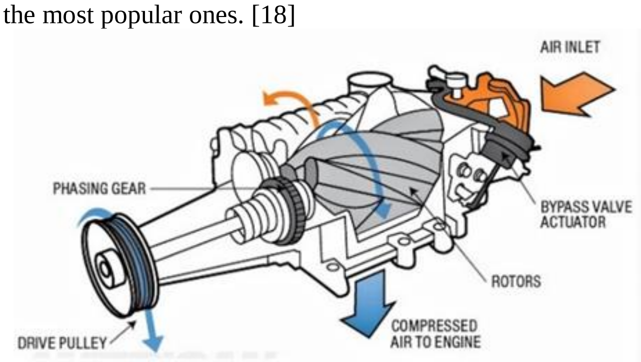

Fig. 3. Construction of a supercharger

A. *Construction*

The main components of a supercharger incorporate:

- Twin-screws; the most important part which rotates and compresses the air. The lobes are generally three with the helix angle of 60 degrees. Besides this there are superchargers with even four lobes, with the helix angle of 170 degrees for high performance vehicles.
- Central housing; which accommodates the twin screws
- transmission; which manages the speed of the compressor that it gets from the crankshaft of the engine. It is a step-up gear ratio.

B. *Working*

The working of a supercharger is not very different from that of a turbocharger. The supercharger derives the power for its operation directly from the crankshaft of the engine via a mechanical drive, which can be a belt-drive, a chain-drive, or a gear-drive; generally, it is a belt and a pulley. Now since the superchargers are mounted just on top of the engine block so that they remain in proximity of the crankshaft, their intercooler is also present just above the engine intake manifold. Out of the two screws, one is male while the other is female. The rotary motion of these screws sucks in air and compresses it and send it to the intake manifold via the intercooler.

The speed of the superchargers is generally limited to 50,000 to 60,000 rpms because it is directly connected to the engine and due to mechanical factors, there has to be an upper limit for the speed to keep the engine parts safe from getting damaged. In order to increase the speed a step-up gear ratio is used. A supercharger clocking at 50,000 rpm can translate a boost of about six to nine pounds per square inch (psi).

For example, a performance mod company called *Roush* has a supercharger (twin-screw) especially for *Ford Mustang* which has four lobes with the helix angle of 170 degrees. This supercharger could boost up to 2650 cubic centimeters (cc) of air in just a single revolution of the compressor, i.e. 360 degrees.

C. *Performance*

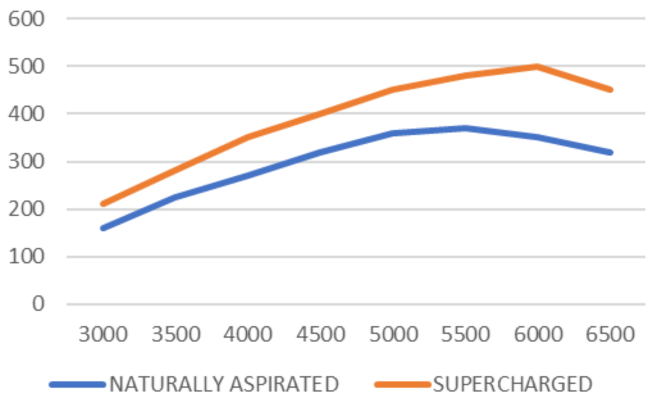

Fig. 4. Dyno graph of power (in hp) vs engine rpm of a naturally aspirated engine against a supercharged engine

In the graph, it can be seen that the power distribution is very uniform throughout the whole rpm range. The supercharger kicks in right from the beginning, right from the moment we press the throttle this is because it is connected to the crankshaft mechanically so lag being zero unlike the turbochargers which depend on the exhaust gases for their operation. But in superchargers, we don't get that much of a boost at high rpms that we do get in turbos though we have the low grunt that is missing in case of a turbocharger.

D. *Disadvantages of a supercharger*

- *Efficiency:* Since superchargers are mechanically driven by the crankshaft of the engine via belt and pulley (generally) or any other drive system like chain-drive or gear-drive, they consume quite a fraction of the total power generated by the engine and this fraction can be as much as 1/3 of the total crankshaft power. This in turn reduces the volumetric and thermal efficiency of the *engine* as well as that of the *supercharger*. This is much evident when the revs climb high as the supercharger consumes more power of the engine. For an instance suppose, an engine gives out 600 hp without being supercharged while it makes 800 hp when supercharged and say the supercharger consumes about 150 hp. Therefore, a boost of about 350 hp (600 – 150 + 350 = 800) is what we have but we get only 200 hp of it, so the net gain being 200 hp. This is the main drawback of a supercharger. The engine has to work extra or burn extra fuel in order to drive the supercharger [16] [17].
- *Fuel economy:* The second main drawback of the superchargers is the fuel economy. Since the engine has to burn extra fuel in order to drive the supercharger, this very drastically affects the fuel economy of the vehicle. Though it increases the density of air at the intake manifold and the power-to-weight ratio, this all comes at the cost of increased fuel consumption which is not very desirable.

IV. Conclusion

They both do the same job but differently and have different factors that are to be kept in mind in order to choose one over the other and these factors are discussed in detail below. The main factor which plays a vital role in deciding which one to go for is that what is one's requirement and the main objective of turbocharging or supercharging the vehicle and would money in any manner be a constraint.

- *Power delivery:* For instant power delivery one should definitely go for a supercharger since the lag is zero. When we are on throttle, we get the boost and when we are off the throttle, we get no boost, it is as simple as that.

  Second thing is that the power delivery is very linear in supercharger unlike the turbos where it is non-linear. On top of it if we want to tune the supercharger it is much easier, and we can tune it for a wider range of rpm than we could in case of a turbocharger which can be tuned in mid and high range rpm only [17]. The turbos also lack the low-end grunt unlike the superchargers but, they are very effective as the revs climb up. In turbos what sometimes happens is when we are on throttle say 40% we get a certain amount of power so we think that this is the power that we will get at this point but some additional power (turbo boost) comes after some instance which surprises the driver and this can also lead to the loss of control of the vehicle.

- *Installation and maintenance:* In this case, the supercharger takes away the cake because it is very much easier to install and maintain unlike the turbos which require lubrication and cooling throughout, and installation is quite a job.

- *Fuel economy:* For this, turbochargers are the clear winner; the reason has been discussed in detail earlier in the paper. The turbos use the waste exhaust gases that were earlier thrown out of the exhaust manifold but now being used by them to do some useful work of pulling in more air and send more dense air to the intake manifold in order to not only increase the power-to-weight ratio of the vehicle but also increasing the fuel economy of the vehicle because now the vehicle is making more power in the same amount of fuel. [16]

- *Efficiency:* In this case also, turbocharger is the clear winner since it is much more efficient than a supercharger. The superchargers also decrease the thermal and volumetric efficiency of the engine hence in this case superchargers are not at all desirable to be used. [6]

The main answer for the topic of this paper is that because of the *federal laws and requirements* the manufacturers have to use the turbos rather than the superchargers. In spite of the better performance of the superchargers, turbos are used just because of the *federal rules and regulations*. According to which, the vehicle should have *higher fuel economy, higher efficiency and should emit less harmful emissions.* [4] Since the turbos use the waste exhaust gases to power themselves and utilize kinetic and thermal energy of the exhaust to get the boost, it reduces the emissions by quite a margin by reusing these gases to produce useful work. Secondly turbos increase the *fuel economy* of the vehicle; this is what everybody wants in their vehicle, high kmpl. Thirdly turbos also have higher *efficiency* than that of the superchargers. They also increase the thermal and volumetric efficiency of the engine because after being turbocharged the engine is now producing more power without burning any extra fuel, i.e., higher power-to-weight ratio. [14] Using this point in their favour and profit manufacturers nowadays are downsizing the engine and turbocharging it, because this is going to increase the *fuel economy* as well as the efficiency further. [15] In this way they are not only cutting their manufacturing cost in manufacturing smaller engines but also spiking up the efficiency and the mileage of the vehicle. In this way they are not cutting or sacrificing the power figures of the vehicle since the turbo will compensate the power of the downsized engine, which in other terms is a *replacement for displacement.* [13]

All this does not by any means imply that the superchargers are not used. The superchargers are used where instant, accurate and precise power delivery is needed, such as in drag race competitions, or in high low-end diesel torque, or in top end supercars, etc. Several muscle cars such as *Chevrolet Chevelle, Camaro, Dodge Challenger, Charger, Supercharger hellcat, Ford Mustang, etc.* All these muscle cars come with superchargers and some supercars and luxury cars are there on the list too like *Cadillac CTS-V, Jaguar F type, Porsche Cayenne, Audi A6, Volvo XC 90, Lamborghini Huracan, etc.*

Afterall they both serve their purpose at their respective positions, but superchargers are the one that we would go for and according to many automobile experts and enthusiasts superchargers should be chosen over the turbos due to obvious reasons that have already been discussed in detail earlier in the paper.

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