

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

***A Brief History of the Turbocharger, including key
developments in Automotive Applications***

Academic Skills (ACHA4005)

Luca Minchella

2405260

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1 Introduction

This report aims to provide the reader with an insight into the history and development of the turbocharger within the automotive sector. Present in the report are several key details on the turbocharger including its history, composition, function, purpose and its implementation. There is also discussion on key innovations relating to the turbocharger and its performance.

2 Research/Background

Before discussing the turbocharger or 'turbo' itself it's paramount to establish its aim and purpose. Turbochargers were created using the principal of 'forced induction'. As discussed by Marshall (2024) Forced Induction describes the process of forcing more air or air with a high density into an engine's cylinders. As a result, more air will be available for combustion within said cylinders to create a larger overall power output.

The turbo was not the first device created to utilise the benefits of forced induction. Several configurations of large, high-powered pumps which force air into an engine known as 'Superchargers' were designed in the early-1800s with the Roots Blower being the first (Knutsson et al., 2017). These early superchargers were welcomed in the wake of the first Industrial revolution, enabling primitive engines to produce a higher peak power output. In his book 'Supercharged!' Bell (2001, p.87) describes 'The Screw Compressor Supercharger'. 'Its design was credited to Henrich Krigar and enabled engines to move air at low rotating speeds more effectively. This was especially important at the time due to the fact that piston engines and electric motors were both in their infancy'. Naturally, the Supercharger was not initially developed with the automotive sector in mind as the Benz Motorwagen wasn't constructed until roughly 25 years after the Roots supercharger was patented (Rootsblower.com, 2019). Early superchargers saw implementation in industrial and locomotive engines.

While superchargers had many configurations, they carried inherent flaws. Marshall summarises "these early superchargers were bulky and relatively inefficient. They sapped power from the engine and were limited by their outputs being in direct proportion to crankshaft speed." Thus, the demand for a new style of forced induction device was presumably high.

In 1905 Alfred Büchi patented the 'Turbosupercharger', now known as the Turbocharger (Alfano, 1986). This radical new design abandoned the large design of traditional superchargers in favour of a more efficient, turbine-centred construction. Therefore, an appeal was created for the device in small, higher revving engines such as those found in planes of the time. Miles (2005) explains that the design was a great success. A 1920 test showed a biplane equipped with a turbo reaching a record height as it was now able to produce more consistent power at a higher altitude. This is possible to the turbo's ability to consistently deliver high density air to the engine even where atmospheric density was low.

With its history and principals now established, we can look at how a Turbo functions.

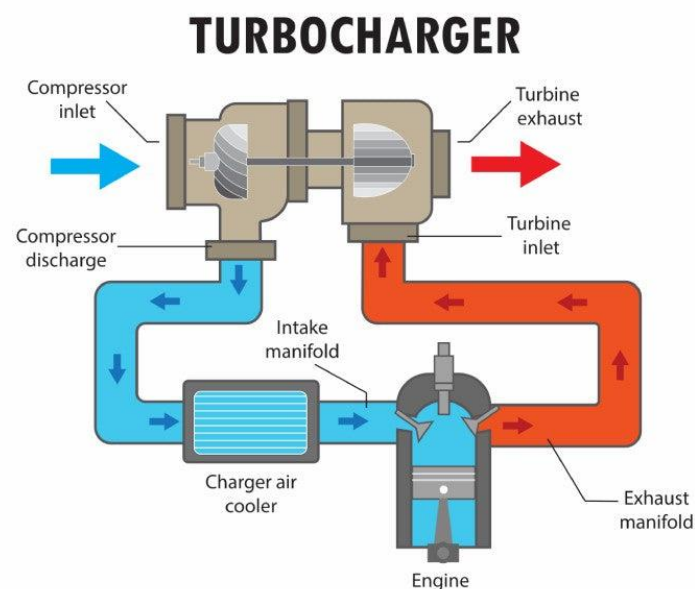


Figure 1- A Simplified Diagram Showing How a Turbo Functions

A Turbo is comprised of a hot side, and a cold side. With reference to Figure.1 the hot side is on the right and the cool side is on the left. A turbocharger functions by utilising the exhaust gasses produced by the engine which would ordinarily be a waste product. The Engine's exhaust manifold connects to an inlet on the hot side of the turbo. Within the hot side is a turbine wheel which is rotated by the spent exhaust gasses from the engine. The turbine wheel is connected to a compressor wheel located in the cold side of the turbo via a shaft. This means that when the turbine wheel spins, so does the compressor wheel. When the compressor wheel spins, high volumes of air are sucked in, the air molecules are compressed, the air

becomes denser and the air increases in pressure. This air then makes its way toward the engine intake. This diagram includes an intercooler which is fitted to lower the high temperature of the compressed air. This prevents preignition and also means the air will achieve a favourable, even higher density after cooling. The air then makes its way to the engine's intake manifold ready for combustion. All processes carried out by the turbo and its associated parts cause the air to be at both a higher density and a higher pressure upon reaching the engine. This allows the engine to create a larger power output thanks to the increased availability of oxygen molecules during the process of combustion.

Much as the turbocharger was a success early on in its lifespan, like the supercharger it saw quite a long period before being applied to automotive engines. However, the potential for turbocharged cars was realised quite early on. In 1939 W.H Paul discussed the theoretical benefits of charging automobile engines to increase economy and efficiency. At this time superchargers were fitted to cars engines purely to boost performance. Paul's ideas foreshadowed the future, with turbo-diesel engines now considered commonplace due to their increased efficiency and performance over naturally aspirated diesel engines.

Table 1- Figures Taken from Paul's Report

Fuel-Air Cycle	Supercharged	Unthrottled
Compression Ratio	6.2	8.2
Work per Cycle	476 B.t.u.	540 B.t.u.
Thermal Efficiency	32.4	36.8
Mean Effective Pressure	266	213
Expansion Ratio	9.2	13.65
Initial Volume	11.5	15.6
Air-Fuel Ratio	12.8	12.8

3 Discussion

The potential for automotive engines equipped with turbochargers was very apparent from early on in the 20th century. Yet several modifications and solutions would need to be implemented to fully realise the benefits of turbocharging. This section will detail key developments within turbocharging technology and their significance.

A significant addition to the turbocharged ecosystem is the wastegate. The wastegate was implemented to ensure that a turbo doesn't exceed its maximum boost pressure. It does so by allowing excess exhaust gasses to escape prior to reaching the turbine wheel. As a result, the turbine wheel will only be able to turn at a predetermined speed to prevent an uncontrollable and theoretically indefinite rise in pressure which would cause both the engine and turbo to fail. As seen in Figure.2 below the wastegate's construction is rather basic. 'It is controlled by a diaphragm containing a spring. As the boost pressure increases beyond its desired level the spring will begin to compress opening the wastegate. The higher the pressure, the more the spring compresses and a higher volume of exhaust gasses will escape via the wastegate' (Mezger, 1978). The wastegate is a highly significant piece of equipment. With most modern turbos coming equipped with an internal wastegate, their importance cannot be understated. Alternatives such as blow off valves are also available to relieve pressure, though unlike wastegates, they act on the compressor wheel rather than the turbine.

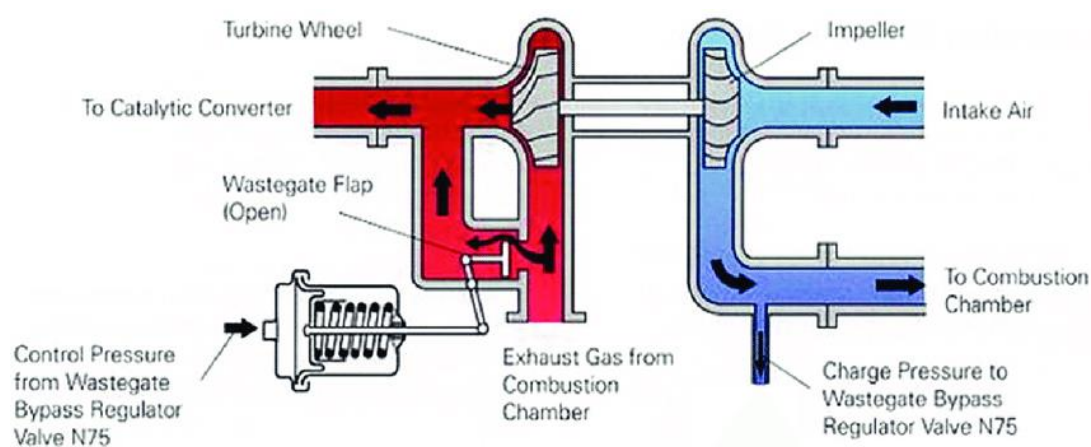


Figure 2- A Diagram of a Turbo with a Wastegate

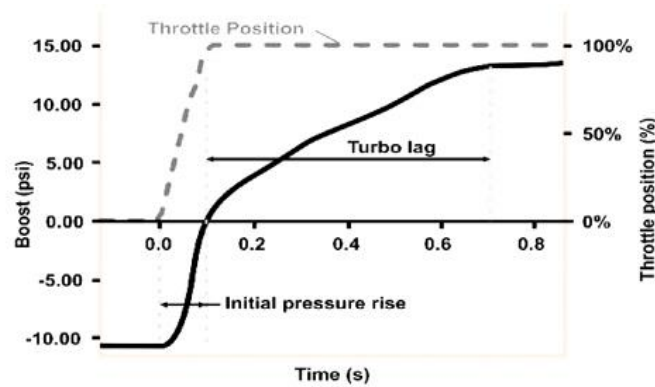


Figure 3- A Graph Showing Turbo Lag

A rather noticeable phenomenon found in some turbocharged cars is ‘turbo-lag’. Turbo-lag describes the lack of acceleration response at low RPM in some turbocharged cars. The effect occurs due to the lack of exhaust gas pressure at low RPM which is required for the turbo to function and the turbine wheel to spin. As a result, a driver will feel an underwhelming throttle response followed by a sudden surge in acceleration as engine revs begin to climb and boost pressure rises. Although some enjoy the sensation, with highly regarded cars such as the Porsche 930 Turbo and Ferrari F40 becoming synonymous with lag, it is generally viewed as negative. Several efforts have been made to reduce the effects of turbo lag with degrees of success across the approaches. An expensive option found in high-performance turbocharged cars is sequential twin-turbocharging. This is the process where two turbos are installed in an engine. Only one turbo is utilised in the low RPM range. If the turbos are of different size, then the smaller one will be used first as it can be activated more quickly. As the revs climb, either the larger turbo will take over or both turbos will be utilised depending on the configuration. This option offers not only a decrease in lag when compared to traditional turbocharging but also a boost in speed and performance, making it an expensive but effective option for reducing lag.

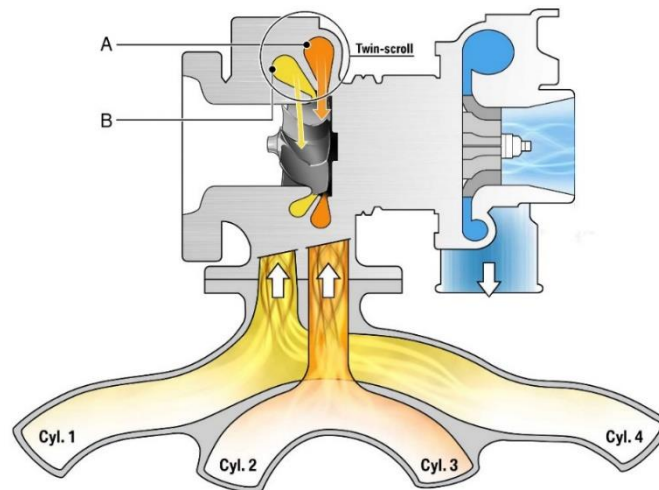


Figure 4- A Drawing Showing a Twin Scroll Turbo's Configuration

Solutions such as twin scroll turbos offer a relatively simple fix. As seen in Figure.3 the twin scroll turbo simply has separate channels or scrolls for exhaust gasses to enter the turbine through. These channels direct the gasses to specific parts of the turbine wheel allowing it to spin faster in less time, which in turn improves boost response. Twin Scrolls are therefore an effective yet simple way to decrease turbo lag as the modifications are primarily to the turbo itself rather than the entire engine layout (as seen in the twin turbo option).

When comparing twin scroll technology to twin turbo implementation in the context of reducing lag then installing a twin scroll turbo would be the more basic and arguably more logical option for most. It's a more cost-effective solution which would also present less issues during the installation process when in comparison to creating a twin turbocharged engine. However, if the goal is also to boost overall performance, then the twin turbo setup would likely be the more fitting choice. Despite its complexity and higher cost compared to the twin scroll, the performance created by a twin turbo setup is undeniable. As proved by the readings in Figure.5 a turbo setup of any kind can drastically increase vehicle power and performance.

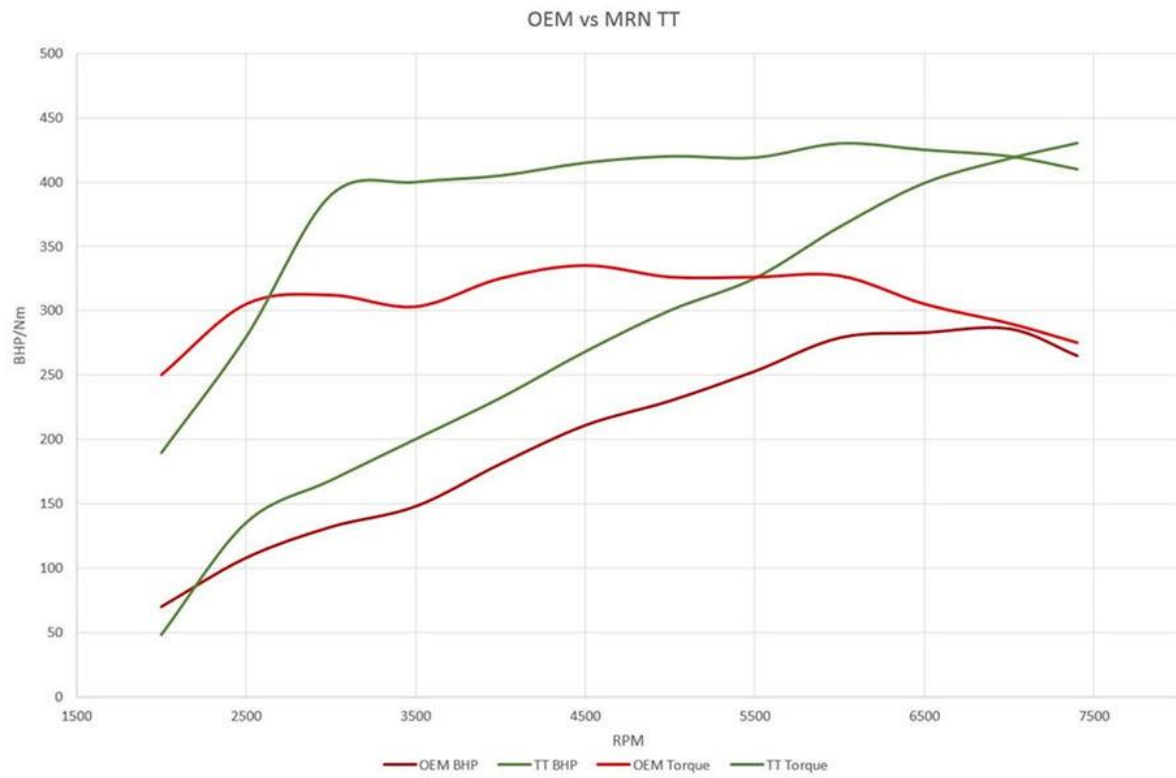


Figure 5- A Graph Showing BHP in a Porsche 987 With and Without a Twin Turbo Setup

4 Conclusion

To Conclude, the turbocharger is now a highly significant device in the automotive and wider engineering fields. Though the key principle remains the same, the turbo has drastically evolved since its 1905 inception, becoming a reliable and efficient method of delivering forced induction. The future of the turbocharger appears secure. With many new road cars coming equipped with turbochargers and smaller engines, the turbo's relevance is increasingly growing. In an industry that is constantly trying to lower its carbon emissions, the turbocharger is a valuable asset as it can both reduce emissions and improve fuel economy. Ongoing developments, such as electric turbocharger prototypes, suggest that the turbocharger still has much to offer.

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