Turbo-diesel

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Turbo-diesel, also written as **turbodiesel** and **turbo diesel**, refers to any diesel engine equipped with a turbocharger. Turbocharging is common in modern car and truck diesel engines to produce higher power outputs, lower emissions levels, and improved efficiency from a similar capacity of engine.[1] Turbo-diesels in automobiles offer a higher refinement level than their naturally aspirated counterparts.[2]

A diesel engine turbocharger

Contents

History

The turbocharger was invented in the early 20th century by Alfred Büchi, a Swiss engineer and the head of diesel engine research at Gebruder Sulzer engine manufacturing company in Winterthur. Büchi specifically intended his device to be used on diesel engines. His patent of 1905 noted the efficiency improvements that a turbocharger could bring to diesel engines [3][4][5] which in 1922 had first been developed for use in road transportation.[6]

At the time, metal and bearing technology was not sufficiently advanced to allow a practical turbocharger to be built. The first practical turbodiesels were marine engines fitted to two German passenger liners - the *Danzig* and the *Preussen* in 1923, each having two 10-cylinder engines of 2,500 horsepower (the naturally aspirated version of the same engine produced 1,750 HP). By the late 1920s, several diesel engine builders were making large turbodiesels for marine and stationary use, such as Sulzer Bros., MAN, Daimler-Benz, and Paxman.[7][8]

Turbocharger technology was improved greatly by developments during World War II and subsequent development of the gas turbine. It was now possible to use smaller turbochargers on smaller, higher-speed engines. Diesel locomotives with turbodiesels began appearing in the late 1940s and 1950s.[9][10]

In 1951 MAN presented a turbocharged version of their MK26 truck, although it was never put into mass production.[11] Series production of turbocharged diesel trucks commenced in 1954, when both MAN 750TL1 and Volvo Titan Turbo were introduced to the markets.[12] The building of the Interstate Highway System in the USA from 1956 made long-distance road transportation of goods more attractive. To keep up with general traffic, more powerful engines came in increasing demand. Cummins, Detroit, and CAT all had turbo-charging as an option by the late-1960s. In Europe, legislation was introduced in Germany mandating a minimum power-to-weight ratio for trucks; by the late 1960s, a 38-tonne consist had to have at least 304 hp.[13] Most manufacturers met these requirement with large-displacement natural aspiration engines, some with the option of large-displacement or turbo-charging, while Scania and Volvo where among those that only provided turbocharged trucks that met the demands. Turbo-charging was not preferred initially as the engines were perceived to be less reliable, however the method won a decisive victory by the mid-1970s as the 1973 oil crisis increased fuel costs. The last market to see the absolute penetration of turbo diesels was Japan, where legislation on particle emissions effectively mandated natural aspiration engines until effective particle filters became available.

Experiments with smaller turbodiesels of a size suitable for an automobile were carried out in the 1960s. The Rover Company (already a builder of industrial gas turbines) built experimental 2.5 liter 4-cylinder turbodiesels (including versions with an intercooler) in 1963, but did not put the design into production. The first turbodiesel production car was the Mercedes-Benz 300SD (series W116, engine OM617.950), introduced in May 1978.[14] It used a Garrett AiResearch turbocharger, and was produced only for the United States. In Europe, the first turbodiesel was the Peugeot 604 in early 1979 (model year 1978). Turbodiesel cars began to be widely built and sold in Europe during the late 1980s and early 1990s, a trend that has continued to the present day.[15][16] In France, due to a tax structure which gave turbodiesels a comparative advantage, sales shot up earlier, reaching 33,000 passenger car sales in 1983 (1.6 percent of the overall market).[17][18]

Characteristics

Improvements in power, fuel economy, and noise, vibration, and harshness in both small- and large-capacity turbodiesels over the last decade have spurred their widespread adoption in certain markets, notably in Europe where they (as of 2014) make up over 50% of new car registrations.[19][20] Turbodiesels are generally considered more flexible for automotive uses than naturally aspirated diesels, which have strong low-speed torque outputs but lack power at higher speeds. Turbodiesels can be designed to have a more acceptable spread of both power and torque over their speed range or, if being built for commercial use, can be designed to improve either torque or power at a given speed depending on the exact use. Naturally aspirated diesels, almost without exception, have a lower power output than a petrol engine of the same capacity whilst the same time requiring stronger (and thus heavier) internal components such as the pistons and crankshaft to withstand the greater stresses of the diesel engine's operating cycle. These factors give naturally aspirated diesels a poor power-to-weight ratio. Turbocharger units weigh very little but can offer significant power, torque, and efficiency improvements. Fitting a turbocharger can bring a diesel engine's power-to-weight ratio up to the same level as an equivalent petrol unit, making turbodiesels desirable for automotive use, where manufacturers aim for comparable power outputs and handling qualities across their range, regardless of the type of power unit chosen.

Turbochargers are in many ways more suited to operation in diesel engines. The smaller speed range that Diesel engines work in (between 1000 and 5000 rpm for a passenger car, and as little as 500-3000 rpm for a larger unit in a commercial vehicle) mean that the turbocharger has to change speed less, reducing turbo lag and improving efficiency. Diesel engines do not require dump valves (see the turbocharger article for more information). Perhaps most significantly, the diesel engine is immune to detonation because the fuel is not injected until the moment of combustion. Therefore, the compression ratio does not have to be reduced, or other anti-detonation measures taken, as would be necessary for a turbocharged spark-ignition engine. The turbodiesel engine can also help with the amount of torque it can give out. Commonly used in trucks, it helps improve the towing capacity of a truck, as well as fuel economy.

A Mazda3 with a modern common rail 1.6 liter turbodiesel engine (PSA) with variable geometry turbocharger, intercooler, 16 valves, double overhead camshafts and piezo controlled 7-stage direct injection.

Turbochargers vs superchargers

A turbocharger is generally more desirable than a supercharger unless outright power is required. Turbochargers offer increased power without the same decrease in fuel economy. In both a turbo- and a supercharged engine, power is increased by providing air under pressure to the engine's cylinders. This allows an increased amount of fuel to be burnt, producing more power. However, this inevitably increases fuel consumption.

A supercharger is driven directly from the engine and thus its boost output is directly related to engine speed. A turbocharger is more directly controlled by the pressure of the exhaust gases which, as well as increasing with engine speed, also vary significantly with engine load.

When a diesel engine is put under a load there is greater resistance to the expansion of combustion gases in the cylinder. This increases combustion pressure and temperature which, in turn, increases the pressure and temperature of the exhaust gases. A turbodiesel engine under a heavy load will thus drive its turbocharger at a greater speed than if the same engine is run at the same rpm under little or no load.

This has the effect that a turbocharger delivers boost, thus increasing power (and fuel consumption) only when such a power increase is demanded by putting the engine under a heavy load. A turbodiesel-powered vehicle accelerating from rest, for example, will put its engine under a heavy load, thus causing high boost pressures to be delivered by the turbocharger. This is detected by the fuel injection system which delivers more fuel to provide more power. Once the vehicle reaches a constant speed and constant engine rpm, the load decreases significantly, and the pressure of the exhaust gases through the turbo drop. Boost and fuel delivery decrease, thus lowering fuel consumption to near the same levels as a naturally aspirated diesel engine. If, say, the vehicle starts climbing a gradient, the engine load increases and the turbocharger and fuel system provide more power. Extra fuel is delivered only when needed.

A supercharger delivers near-constant boost pressures, and so fuel consumption suffers. Superchargers have the advantage of having no boost threshold (an rpm-level below which a turbocharger does not operate effectively) and almost no lag. Superchargers only need to be connected to the engine's intake system, thus making installation easier and reducing to some extent the increase in internal temperatures that occurs with turbocharging.

Even in engines operating under a constant load (such as electrical generators), turbochargers have advantages over superchargers. The main advantage is that a turbocharger does not take power from the engine to the same extent that a supercharger does. A supercharger takes power directly from the engine's crankshaft to drive it. Large units can draw up to 10% of the engine's total power when at full boost, although of course, they provide a power increase much greater than this. Turbochargers are driven by the engine's exhaust gases. Only a relatively small power loss is caused by the turbocharger's turbine restricting the flow of exhaust gases and increasing back-pressure. In a gasoline engine, this power loss is much more pronounced. It is commonly referred to as turbo lag and is experienced at lower engine speeds. However, since these speeds are where a diesel is most efficient, the turbo spools (spins up) very quickly and lag is almost nonexistent. The diesel's torque output is increased and a broader range of engine speeds can be used.

Turbodiesels in the United States

A Land Rover 2.5-litre 4-cylinder turbodiesel engine is typical of 'first generation' automotive turbodiesels, with mechanical indirect injection, 8 pushrod operated valves and no intercooler. The turbocharger itself is visible in the upper centre of this picture.

During the 1990s, turbodiesel engines were mainly used in the United States for light trucks. An example is the Ford Power Stroke engine series, mounted on Ford F-Series Super Duty pickup trucks, the E-series vans and the Excursion sport utility vehicles. In 1989, Dodge started making light duty trucks with a 5.9 liter Cummins turbo-diesel engine.

As demand for diesel engines in standard sedan and station wagon cars in the United States has traditionally been much lower than in saloon and estate cars in Europe, the development of smaller automotive turbodiesels has (in general) been led by European manufacturers in recent years. Diesel fuel in the USA (prior to late 2006) had a significantly higher level of sulphur than the fuel used in Europe, which meant that diesel cars from European makers had to either be fitted with specially developed fuel and emissions control system for the (prohibitively small) North American market, or simply could not be sold in that market.

After ultra low sulphur diesel was introduced in the United States in October 2006, automakers began to offer turbodiesel models which could take advantage of it to reduce emissions. Manufacturers such as Volkswagen, BMW, Audi, and Mercedes-Benz have been releasing cars with four- and six-cylinder turbodiesels. Chrysler marketed the Jeep Grand Cherokee with a Mercedes-Benz-supplied CRD engine for the 2007-2008.5 model years. Porsche released the Cayenne Diesel in the U.S. for the 2013 model year, and has announced that the Macan will have a turbodiesel available in the 2016 model year.

Availability of turbodiesel models increased in the 2014 model year, as a few more manufacturers introduced passenger cars and sport utility vehicles powered by turbodiesel motors. GM began selling the 2014 Chevrolet Cruze Clean Turbo Diesel in 2013. The 2014 Jeep Grand Cherokee with the 3.0L EcoDiesel V6 engine was made available at the end of 2013. This marked the return of a turbodiesel option after a five-year absence. In addition, manufacturers have started marketing vans and light-duty trucks with turbodiesels again. The 2014 Ram 1500 has an EcoDiesel engine option.

The 2015 Ford Transit van is available with a 3.2L I-5 Power Stroke turbodiesel option. Mazda is developing a U.S.-spec SKYACTIV-D engine for the Mazda6. As of September 2014, there is no ETA. The Chevrolet Colorado and GMC Canyon midsize pickup trucks will have a 2.8L Duramax Turbo-Diesel engine available as an option starting with the 2016 model year.[21] They will be the first U.S.-market midsize trucks with an available turbodiesel engine. The next-generation Nissan Titan pickup truck will have a Cummins-sourced 5L V8 turbodiesel available.[22]

See also

- Common rail
- Diesel engine
- Injection pump
- Intercooler
- Turbocharger
- Variable geometry turbocharger

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