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Introduction To Turbochargers For Modern Diesel Engines

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ABSTRACT
CO_2 emissions reduction for vehicles and demand for more driving comfort are the challenges for the automobile industry today. One approach to this problem is the reduction of the displacement of combustion engine while maintaining the characteristics of large displacement engine. This method is often referred to using the term" downsizing" and requires the engine to be turbocharged to improve its performance and torque. It has been demonstrated that a simple charging unit alone is not enough and more complex charging systems are required when emission norms are stringent. The goals of a developed engine in terms of the thermodynamics and operation of future passenger car are increase in the power density of the engine, highest possible maximum torque at low engine speeds across the widest possible range of speeds, improvement of the driving response in transient operating conditions like start up response and elasticity response, reduction of the primary energy consumption during testing and driving on the road, observances of the future exhaust gas thresholds which mean a drastic reduction in the current emission levels. The latter goals can be reached through the use of smaller displacement engines. 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 attained in terms of the steady state response and of the transient response. This paper summarizes review of advancements in turbocharger technology to meet the demand of high performance and low emission of passenger car vehicle application.

Keywords- Emission, performance, turbocharger, VNT, VTG

I. INTRODUCTION

The thermodynamic demands placed on modern charging systems for diesel engines in passenger cars result mainly from the target values of the steady-state and transient characteristics of the charged engine. A higher power and torque density result in shift in the direction of the steady-state power and intermediate pressure generally require an additional injection of a large amount of fuel in the cylinder and therefore a correspondingly higher air mass flow rate i.e. higher charging pressure. The initial approximation of the increase in the air mass flow rate required across the entire operating range of the diesel engine is equal to the realizable increase in performance and intermediate pressure. An important demand placed on the charging system is therefore to make a constant high pressure level available across the widest possible range of engine speeds. High charging pressure at low engine speeds permits high intermediate pressures (Steady-state) to be attained relatively quickly, which in turn contribute to the amount of surplus torque available and therefore the acceleration response of the engine.

The airflow required for the rated output range can only be produced by charging device of a corresponding large design. The design for a high charging pressure even at low engine speeds means that the compressor and turbine designs need to be relatively smaller. An ideal yet impossible to realize reduction to this conflict is charging device for the compressor and turbine that is continuously variable on the housing and rotor sides. A real possibility that is already the state of the art is the well known method of designing the charging device with variable elements. Another significant advance will be made possible by corresponding optimized multistage charging systems. Selected multistage systems with different performance features will be prepared in addition to single stage units to fulfill the future demands on diesel engines for the passenger cars.

II. MODERN TURBOCHARGER DESIGN FOR PASSENGER CAR DIESEL ENGINE

2.1 Single stage charging systems.

In general, modern diesel engines place particularly high demands on the charging system in terms of the air flow required at various engine operating conditions. The map width of flow compressor however becomes increasingly smaller as the pressure ratio increases so that the problem of having enough useable map width arises, especially for high performance turbocharged engines. In the single stage charging method, the selection of the compressor must therefore be based on the torque or rated output of the engine. In the former case, the selected compressor can only deliver a high rated output over limited range, which in the latter case there will not be enough steady state torque available at low engine speeds. The limited useable compressor map width therefore represents an important and decisive restriction for an improvement across the entire intermediate pressure curve. This means that an entirely vertical shift of the intermediate pressure curve of the diesel engine to higher values is not possible with these simple units.

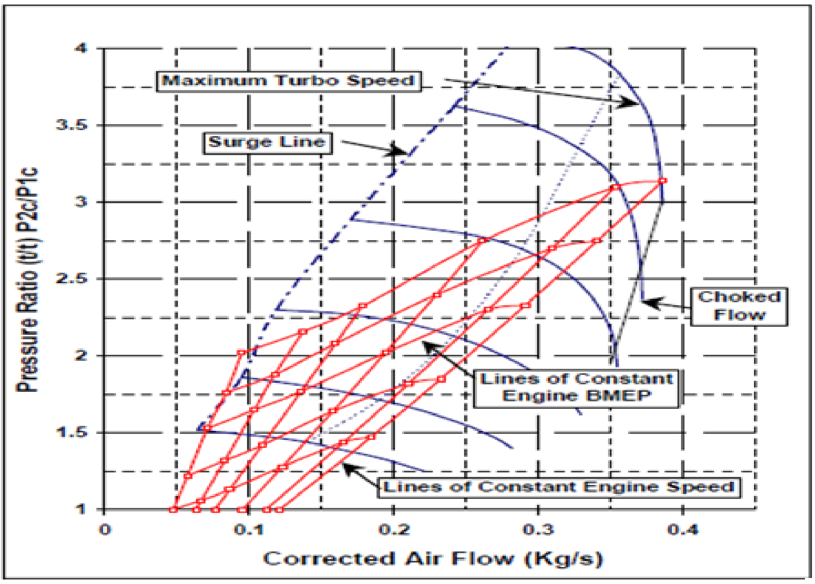

Figure No 1: Single stage charging system

2.2 Variable turbine geometry charging system

In single stage charging units, turbochargers with variable turbine geometry are primarily used for passenger car diesel engines in addition to modern and economical turbochargers with boost pressure control valves. The waste gate turbocharger was developed especially for charging small combustion engines and designed to meet the requirements of variable turbine geometries. The turbochargers in this type can also be equipped with a boost pressure control valve, depending on the requirements of performance and emissions. Fig.2 shows a turbocharger with rotary blades (VTG) known for its use in the production of passenger car diesel engines.

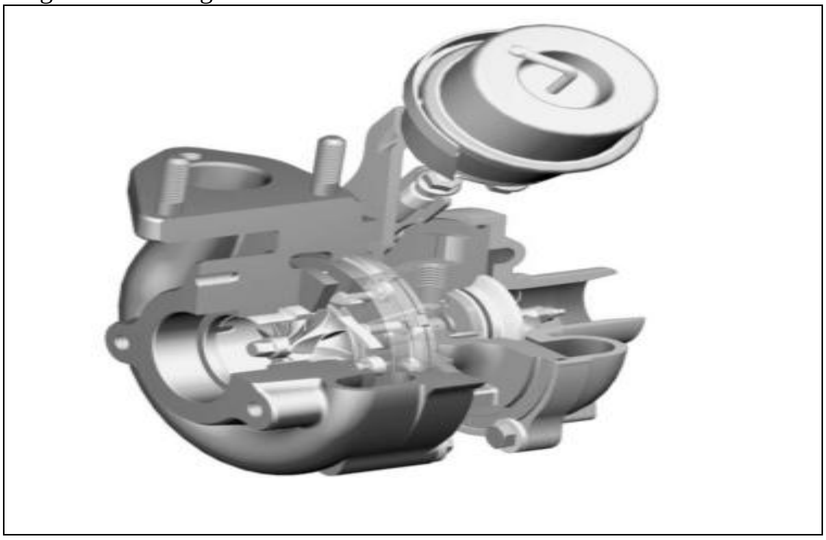

Figure 2: Turbocharger with Variable Blades (VTG)

An interesting alternative to the VTG with rotary blades, especially for small displacement passenger car diesel engines, is the VST turbocharger with variable slider ring turbine. In this design there is a bypass valve integrated into the turbine housing for the upper operating range of the engine. At low engine speeds only the left duct of the double-flow turbine housing conducts exhaust gas. The efficiency of single flow, unregulated housing is reached in this manner. As the exhaust gas mass flow increases, the right channel is constantly actuated by a regulating valve that moves axially. At the highest range of engines speeds, one control edge of the regulating valve opens a bypass from the right channel of the turbine housing to the housing outlet. The yoke of a control rod converts rotational motion introduced from outside of the housing to the axial motion of the regulating valve. The control rod can be controlled by a pneumatic control box supplied with pressure. To provide electrical motor drive power to the turbocharger a suitable electric motor is integrated into the turbocharger shaft, for example between the turbine wheel and compressor impeller shown in figure 4. This integrated system results in a noticeably improved transient response at operating points where there is not much exhaust gas available in spite of the increase in the mass moment of inertia of the rotating blades. The potential for improvement in the transient operating characteristics depends primarily on the amount of electric power available and the electrical infrastructure of the vehicle. There are limits however to this approach since improvements in the steady-state torque curve can only be achieved within the given compressor map limits due to the single stage processing of the system. The potential for improvement with this concept is therefore limited when compared to other concepts.

2.3 Electrically driven flow compressors in combination with turbochargers

This charging system was specially developed to improve the transient response at low engine speeds and that, in addition to other goals, makes a significant contribution to the development of the future small displacement engines with a transient torque response that approaches that of large displacement, naturally aspirated engines. Fig. 6 & 7 show the basic design. The e-Booster can be placed before or after the turbocharger, although placing it before the turbocharger compressor shown in figure 6 provides more flexibility in terms of the mounting position, while placing it after the exhaust turbocharger compressor shown in figure 7 allows for shorter cable lengths.

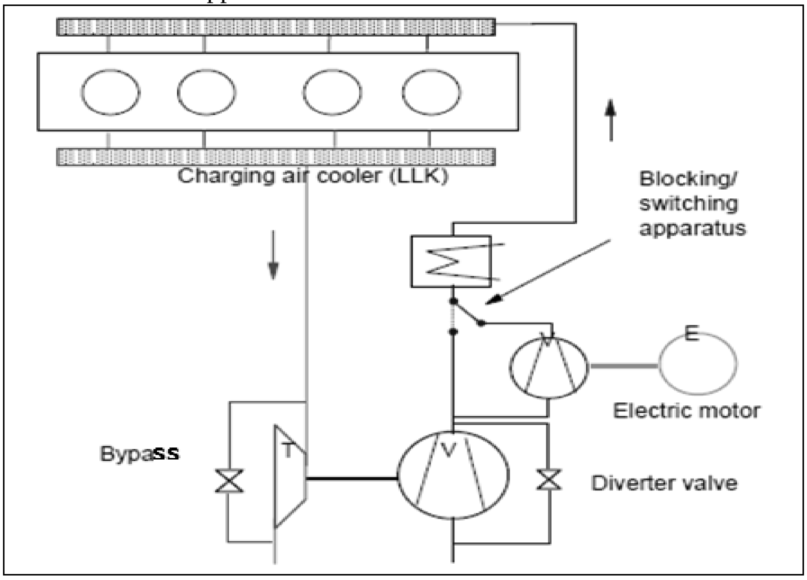

Figure 6: Basic Schematic of e-Booster before the Exhaust Turbocharger

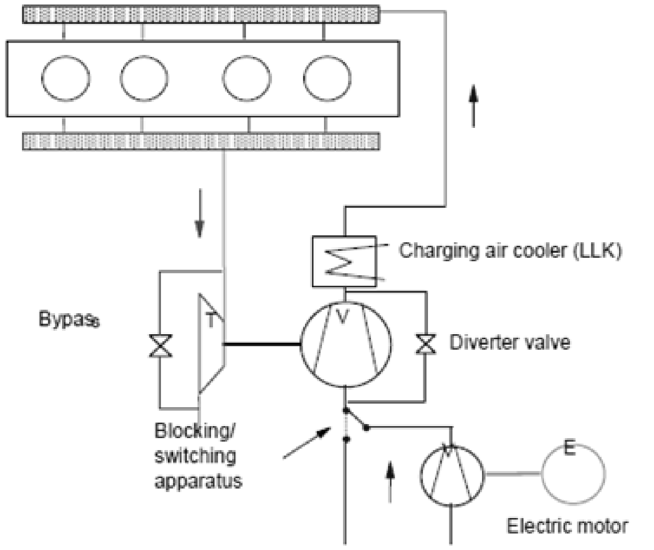

Figure 7 Basic schematic diagram of the eBooster after the exhaust turbocharger

The concept is based on a regulated, two compressions in which an electrically driven compressor (e-Booster) is connected in series with an exhaust turbocharger. At operating points where there is little exhaust gas available, the two stage compression reaches a higher overall charging pressure level faster.

Significant advantages result from the separation of the turbocharger and electrically driven charger when compared to other approaches. Thanks to its electric drive, the e-Booster is completely independent from the turbocharger and the thermal energy of the exhaust gases. The electrical system of the vehicle is the only component that determines the maximum amount of energy available. The advantages that can be gained using the e-Booster system in terms of the transient response are only limited by the amount of electrical power made available. An increase in the steady-state torque at low engine speeds is possible, in contrast to the electrically driven turbocharger, if the electrical power required can be made available permanently by the vehicle electrical system. While the e-Booster and turbocharger combination supply the necessary charging pressure at the engine speeds below 2000 rpm, the turbocharger alone supplies the charging pressure at the engine speeds above this value.

Since two centrifugal compressors are combined in this system, their maps can be combined, which then substantially increases the total map width. The separation of the turbocharger and electric motor results in a significant improvement in the transient response since only the compressor impeller and the rotor need to be accelerated with the e-Booster, and a turbine wheel with a comparatively high density and therefore a high mass inertia does not have to be accelerated. Numerical simulations show that the power consumption of the e-Booster system is about 30% lower than that if the electrically driven turbocharger. The e-Booster can also be mounted at location where it is not subject to a thermal load from the turbocharger turbine or a mechanical load from the operation of the combustion engine.

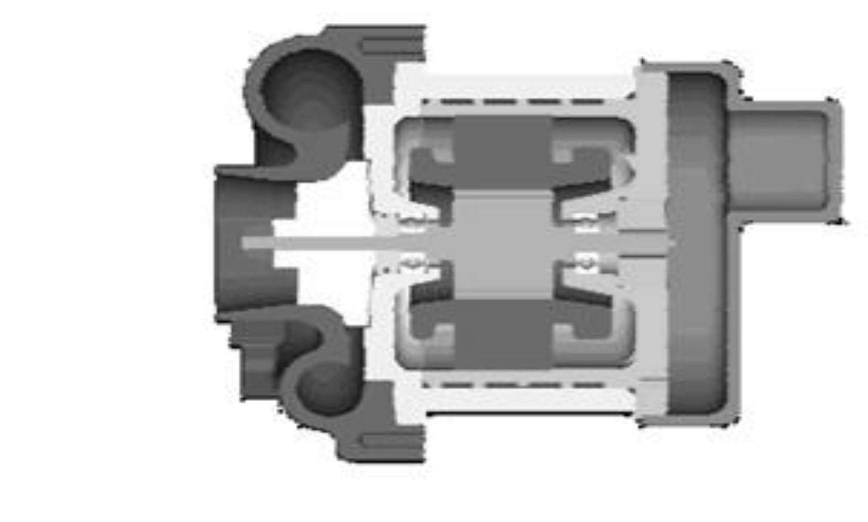

Figure 8 : Cross-section of the eBooster (prototype)

2.4 Two-stage regulated Turbocharging

The main advantage of two stage charging systems over the single stage units is that two different sized compressors can be connected in series, parallel & mixed way so that an optimized map is available for each airflow rate range. This then circumvents the restriction of the limited useable compressor map.

The two stage regulated charger consists of two exhaust turbochargers of different sizes connected in series shown in figure 9 .The advantage of this type of charging system over the single stage version is the increase in the rated output while simultaneously improving the steady state torque at low engine speeds and the acceleration response of the passenger car diesel engine by quickly building up charging pressure.

The entire fresh air flow is compressed first by the low pressure stage in this design. In the high pressure stage, the charging air is compressed further and then cooled. Due to the pre-compression process, the relatively small high pressure compressor can reach a high pressure level so that it can force the required amount of air flow through the system.

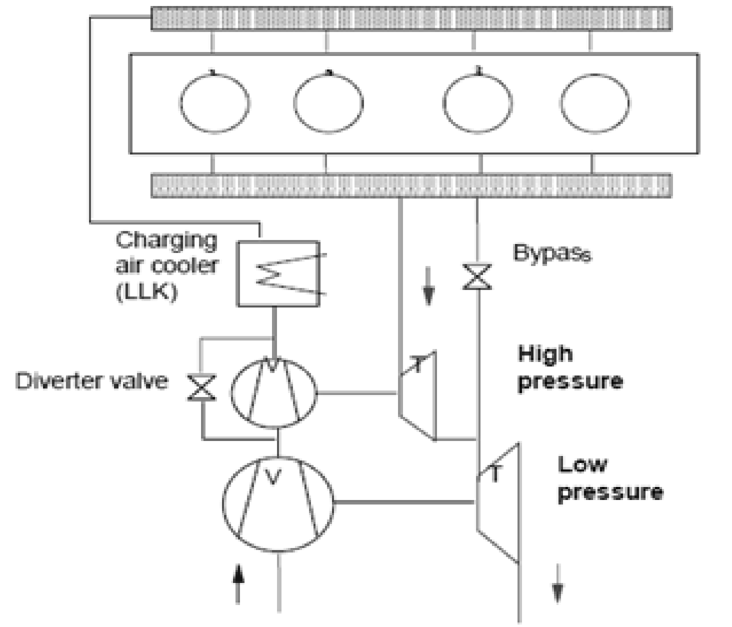

Figure 9 : Basic schematic of two-stage regulated charging

Structural design of a two stag regulated charging system on a passenger car diesel engine is shown in figure 10.

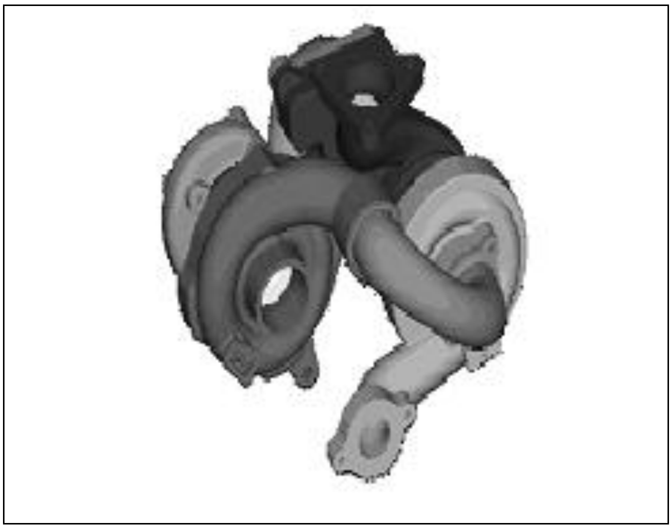

Figure 10: Two-stage regulated charging system

With the use of a bypass on the exhaust side, for example a waste gate valve (German Abbreviation is LRK), it is possible to expand the entire exhaust mass flow using the high pressure turbine or to redirect some of the mass flow to the low pressure turbine located downstream.

At low engine speeds, meaning when the exhaust mass flow rate is low, the bypass remains closed and the entire exhaust mass flow is fully expanded by the small high pressure turbine. This yields a high charging pressure that is built up quickly. As the exhaust gas mass flow increases, the work of expanding the mass flow is constantly transferred to the low pressure turbine by increasingly opening the bypass. Two stage regulated charging therefore allows for continues, variable adaptation of the turbine and compressor to the actual requirements of the operating engine.

Fig-11 shows a comparison of the measured intermediate pressure curve of the passenger car diesel engine with two stage regulated charging to that of passenger car diesel engine charged by a turbocharger with the variable geometry turbocharger (VTG) with the same rated output. The potential of downsizing with two stage regulated charging can be seen in figure 11.The plot of a standardized torque curve of two passenger car diesel engines with VTG turbochargers is compared to that with two stage regulated charging .

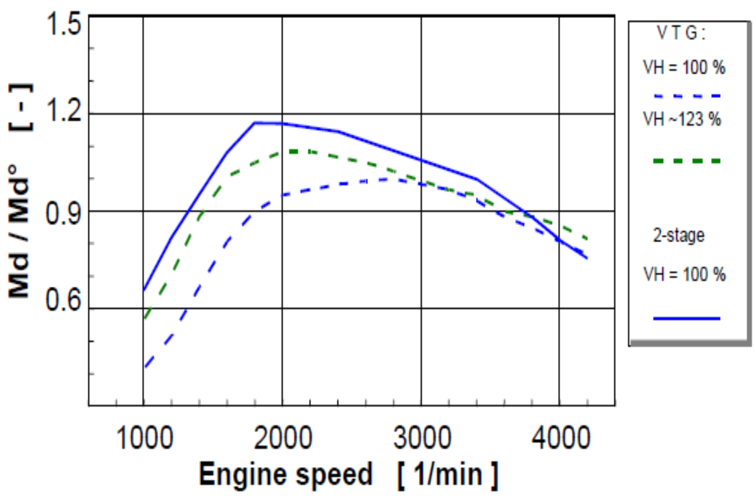

Figure 11 : Standardized torque curve of passenger car diesel engines : Comparison of VTG to two-stage regulated charging

III. EVALUATING THE CHARGING SYSTEM FOR PERFORMANCE

An evaluation scheme for the various charging concepts can be created from the thermodynamic requirements. The requirements result primarily from the steady state response and the transient response of the turbocharged passenger car diesel engine.

With respect to the steady state response, the higher output density of the engine targeted requires a parallel vertical shift of the entire power curve/intermediate pressure curve to higher values. Consequently, an important evaluation criterion is whether or not a charging system can shift the entire intermediate pressure curve upwards and if so, how far it can be shifted upwards.

There are some other important parameters from transient operations to be used in the comparison. These parameters are the amount of startup (low speed) torque the engine supplies at 1000 rpm, the acceleration performance from 0-100 km/h and the acceleration performance when in the upper gears (acceleration from 60-100 km/h and from 80-120 km/h).

3.1 Startup torque at an engine speed of 1000 rpm

There is no increase in the startup torque to be expected when a VTG or VST exhaust turbocharger is used when compared to the basic version, but a satisfactory potential is offered by two stage regulated charging when the high pressure turbine is designed accordingly.

The electrically driven designs have significant advantages over charging system driven only by exhaust gas in terms of a high start up torque. The eu-ATL permits an improvement within the limits of its compressor map. The greatest potential for improvement can be seen in the e-Booster concept. Realize charging pressure depends mainly on the amount of electrical power supplied.

3.2 Acceleration from 0 to 100 km/h

The performmance of a vehcile accelerating from 0 to 100 km/h primarily depends on the rated output of the motor, which in turn depends on the amount of air availble in the motor and therefore on the map of the turbocharger compressor.

Assuming the compressor impellers are the same in the VTG/VST exhaust turbocharger, in the eu-ATL and in the exhaust turbocharger of the e-Booster system, the same rated motor output is obtained in an initial approximation for all engines charged in this manner. This means that all of the designs stated also have about the same potential in terms of the acceleration from 0 to 100 km/h. However, it must be kept in mind that the current design of the e-Booster unit is only active at engine speeds below about 2000 rpm. Since the limitation of a single compressor map is not present in two-stage regulated charging, this charging system offers the greatest potential for increasing the rated output and therefore for improving the acceleration from 0 to 100 km/h.

3.3 Acceleration from 60 to 100 km/h and from 80 to 120 km/h

A very important criterion used to evaluate an engine is its elasticity, which is usually assessed using the acceleration performance from 60 to 100 km/h and or 80 to 120 km/h. In this case, turbochargers with variable turbine geometries (VTG or VST) achieve perfectly satisfactory improvements in comparison to the turbocharger with the waste gate (LRK). However, a substantially greater potential for increasing the elasticity driven systems and two-stage regulated charging, although the advantage of the electric system increases as the amount of readily available extra power from the vehicle electrical system increases.

IV. SUMMARY AND CONCLUSION

The thermodynamic demands placed on modern charging systems for diesel engines in passenger cars result mainly from the criteria relating to the steady state and transient characteristics of the charged engine. The increasing demands placed in the future on exhaust emission values must also be met, even when charged. A higher output and torque density initially leads to the demand to shift the entire power curve/intermediate pressure curve of the charged passenger car diesel engine to higher values.

Higher rated output and higher effective intermediate pressure require the injection of a large amount of fuel into the cylinder and a corresponding high air mass flow rate, which is achieved through a higher charging pressure. An important demand placed on future charging systems is therefore to make a high pressure level available continuously across the widest possible range of engine speeds. A higher air flow for the rated output range always requires a correspondingly large turbocharger in order to handle high mass flow rates at high efficiency levels. Desire for a high charging pressure even at low engine speeds means that the compressor and turbine designs need to be relatively small. In order to fulfill both these contradictory demands, turbo suppliers are refining the designs of existing charging concepts with variable turbine geometries with the goal of designing a single stage unit that operates at the limits of what is technically possible.

Other leading modern charging concepts for passenger car diesel engines result in systems that are too complex according to the current state of art. Expansion is possible with two stage systems (i.e. an e-Booster in combination with an exhaust turbocharger and two stage regulated charging, the known limits of single stage turbochargers, which results from a compressor map from just one single compressor). In connection with the increase in the pressure ratio, these systems provide important characteristics that can be used to meet the high demands placed on the future diesel engines.

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