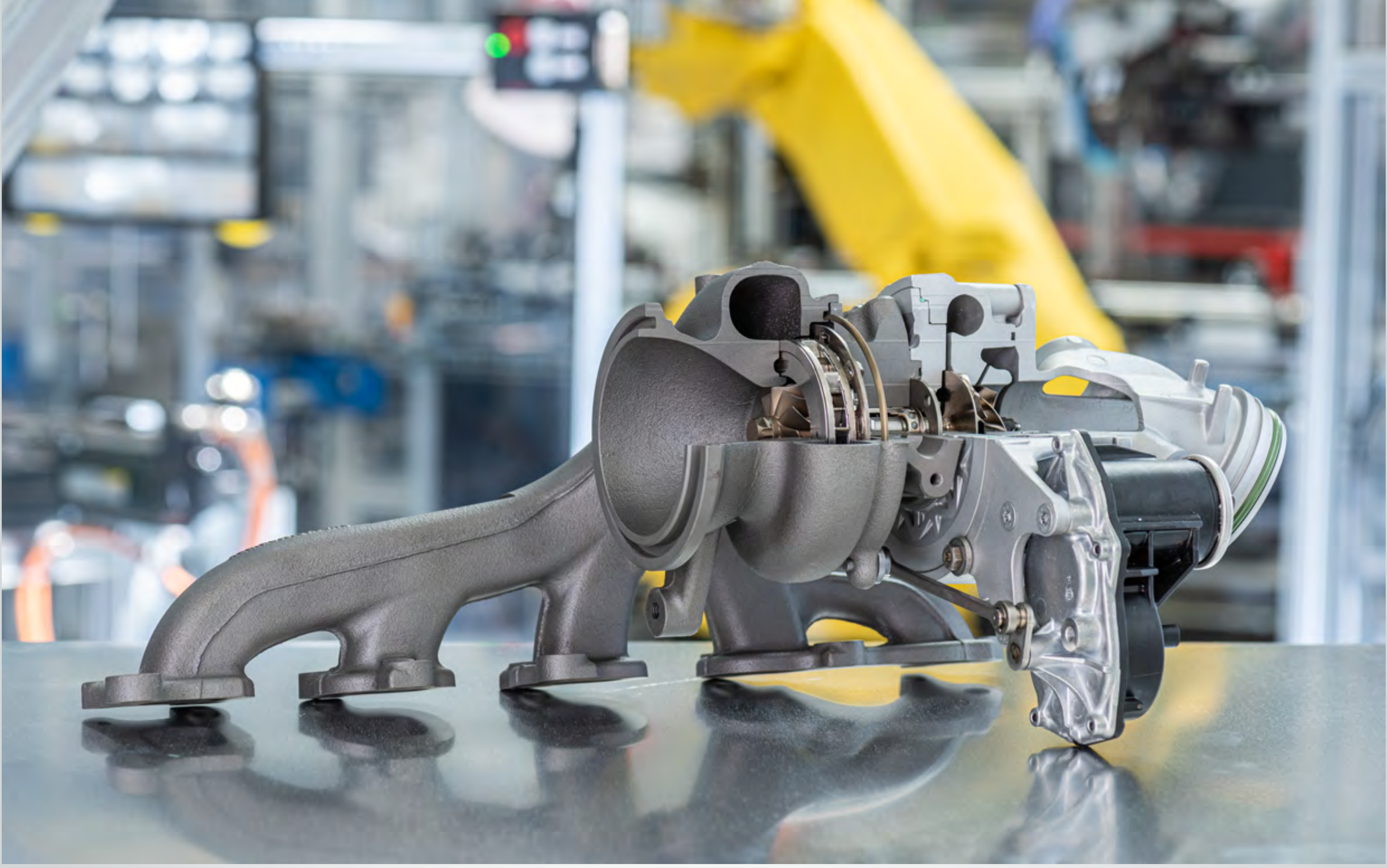

Combustion Hybrid

BorgWarner

Turbochargers with Variable Turbine Geometry (VTG)

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BorgWarner Turbochargers with Variable Turbine Geometry (VTG)

Hybrid concepts require maximum efficient internal combustion engines to achieve a significant reduction in CO_2 emissions. Miller/Atkinson-cycle gasoline engines are showing excellent progress in striving for the reduced CO_2 levels that EU carmakers must comply with by 2030. BorgWarner's VTG turbochargers are an ideal charging system for this process.

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Introduction

In addition to the electrification of the powertrain, alternative propulsion concepts based on highly efficient internal combustion engines are necessary in order to achieve even stricter CO_2 targets in the future. The hybridization of the powertrain offers possibilities for integrating the electrical support of the charging system and at the same time new design strategies for exhaust turbocharging. The common goal of these concepts is to extend the spread from increasing efficiency in fuel-relevant operating areas of the engine and to display the stoichiometric motor operation in the entire motor characteristic field at full load. This increase in engine efficiency is presented by Miller/Atkinson combustion, for which the turbocharger with variable turbine geometry (VTG) is the perfect charg -ing solution. BorgWarner's VTG turbocharger offers additional efficiencies through improved flow geometry in the turbine and reduced friction performance by using ball bearings instead of journal bearings.

Gasoline Engine Development

A number of adjusting screws are available to increase the efficiency of the gasoline combustion engine: higher geometric compression ratio, charge dilution, Miller/Atkinson cycle and various combinations of these measures. The growing range of full and plug-in hybrids justifies the development of internal combustion engines optimized for hybrid operation. Turbocharged gasoline engines with Miller cycles achieve a higher specific power density with improved consumption compared to hybrid-optimized naturally aspirated engines.

In addition to the higher requirements for charging pressure due to charge dilution and intermediate expansion, the increase in efficiency of internal combustion engines also brings new challenges. Here, the VTG turbocharger for the gasoline engine offers a better system efficiency compared to the classic Wastegate technology. In addition to an increase in performance from 15 to 20 kW compared to the Wastegate turbocharger, the VTG turbocharger for gasoline allows a reduction in fuel consumption. This is done by the possibility of increasing the Miller rate using the entire exhaust gas enthalpy. The VTG turbocharger can achieve a temperature gradient between the engine outlet and the entrance into the exhaust aftertreatment system,

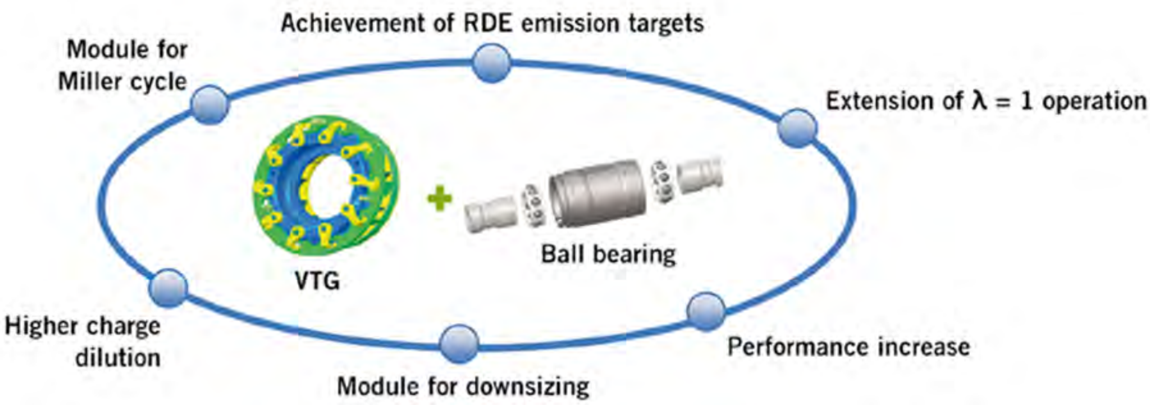

Figure 1. Benefits of the VTG turbocharger and ball bearings for gasoline engines

which is about 25 °C higher compared to Wastegate turbochargers. At the same time, it remains at a constant low-speed torque, enabling RDE (Real Driving Emissions, RDE) compliance up to power classes above 100 kW/l (Fig. 1).

Further consumption potential is offered by charge dilution in the middle partial load. The corresponding potential is limited by the efficiency of the boosting system. The optimized design of the aerodynamic components and the use of ball bearings instead of the classic oil lubricated journal bearings ensures an increase in turbocharger efficiency of up to five percent compared to the Wastegate turbocharger. In addition, the use of ball bearings helps to compensate the delayed load build-up caused by the new combustion process. Compared to traditional Wastegate technology, the combination of an optimized Miller cycle with cooled exhaust gas recirculation and reduced dynamic support of the P2 module can reduce CO_2 emissions by up to 3%.

VTG Turbocharger Development

VTG technology, first introduced for diesel engines in 1997 (Fig. 2), has advanced to be the preferred turbocharging system for passenger car diesel engines. This rise in popularity is now expanding to gasoline engines with the introduction of the Miller/Atkinson cycle. A BorgWarner turbocharger for the Porsche 911 Turbo 3.6 l engine marked the first series application of the gasoline VTG in 2006. Once the Miller cycle

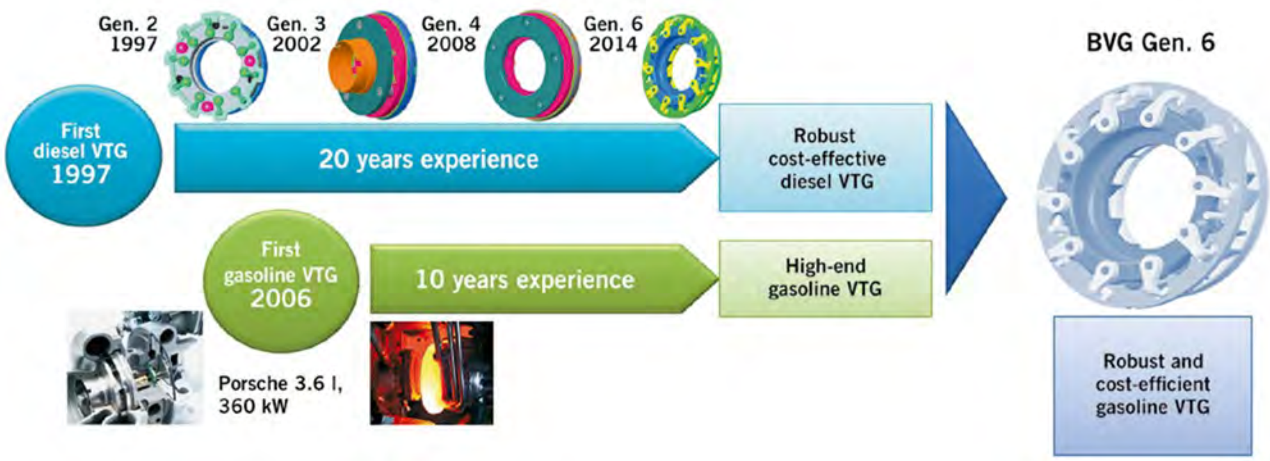

Figure 2. Evolution of BorgWarner VTG technology

was introduced, this technology quickly moved into the mass market, where prior experience with the diesel VTG enabled considerable cost optimization.

Advanced Performance Design

The aerodynamic setup of the turbine is comprised of the adjustable stator blades and the turbine wheel. The VTG uses an adjustable stator vane ring (VTG cartridge) upstream of the turbine wheel to control exhaust gas mass flow and provide improved efficiencies for the turbine across a wider engine operating range. Because of the high demands of the VTG cartridge materials, the system was initially limited to use in diesel engine applications at exhaust gas temperatures of up to around 860°C. BorgWarner was able to use experience gained from the high-temperature Porsche 911 Turbo gasoline engine application to further technical development of the VTG. Considerable advancements in material and cost, along with the Miller/Atkinson combustion technique at exhaust gas temperatures of up to 950°C, have combined to make VTG technology very attractive for use with gasoline engines now being developed for use in next generation hybrid systems.

The enhanced aerodynamic efficiency and control of the VTG turbine is achieved through adjustable inlet guide vanes, which allow a flow rate spread of more than twice that of fixed-housing turbines with wastegate control at comparable wheel diameters. The wide efficiency plateau is made possible by a unique combination of blade angles of the inlet guide vanes and wheel. The turbine provides high flexibility in creating turbine backpressure and turbine power output, ensuring boost pressure control. This contributes to substantial CO_2 reductions while also effectively adapting to efficiency characteristics for the engine in use.

Design of the aerodynamic components is especially important in effectively influencing the VTG efficiency parabola. BorgWarner turbines are adapted to the position of the connecting flanges of engine and exhaust gas system to optimize flow for each customer application. The volute is designed to have a surface that is wetted minimally by exhaust gas and to fit in a small installation space. Both components are aligned aerodynamically to produce a directed flow to the inlet guide vanes.

The innovative flow guidance of the VTG turbocharger reduces thermomechanical deformation of the cartridge and, along with the design of the vane itself, works to minimize the inlet guide vane side clearances (Fig. 3). This allows for high efficiencies at the knee torque of the engine. The tubocharger's inlet guide vanes feature BorgWarner's patented S form to ensure that low-loss flow deflection and the torque on the guide vanes is as low as possible, while maintaining the fail-safe function to open at all times. The cartridge is designed as a modular system, offered in various sizes to meet the optimum thermodynamic mapping objectives for all relevant passenger car gasoline engine displacements. Additional turbine wheel family options also allow adaptation of the efficiency parabola to meet different engine targets.

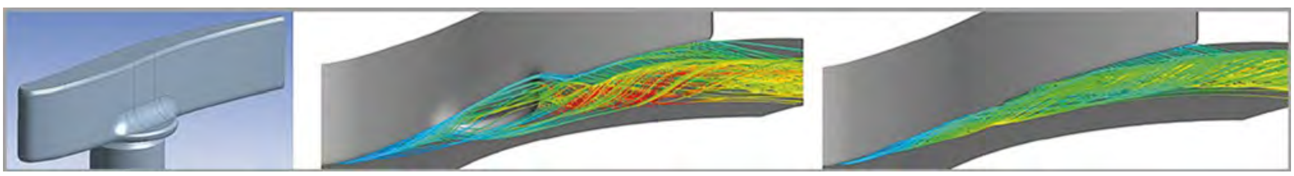

Figure 3. Patented blade design for high stream efficiency

Figure 4. High flow VTG turbine wheel design

Because gasoline engines require a lower turbine backpressure and an enlarged flow rate to avoid knocking, BorgWarner uses radial wheels in VTG turbines. Higher efficiencies are also necessary at small turbine flow rates, around 30-40 % of its maximum, for improved engine response and knee torque. The response behavior of the VTG turbine, similar to fixed-casing turbochargers with small inertia-optimized wheels, is achieved through improved efficiencies and a 10-20% reduction in the moment of inertia of the turbine wheel compared to earlier BW VTG generations for diesel applications. The VTG turbine wheel is designed for high flow rates, with the mechanically optimized wheel disk reducing stresses to provide long service life at a reduced moment of inertia (Fig. 4).

More efficient turbochargers with ball bearings

Mechanical losses in turbochargers with ball bearings are reduced considerably compared to those using journal bearings of the same size. Overall efficiency of a ball bearing turbocharger is further increased by enhanced rotor stability which allows contour clearance reduction on both the compressor and turbine sides (Fig. 5).

This unique ball bearing concept optimizes the acoustic transmission path and shaft motion stability during both ramp-up and ramp-down of the rotor. The higher stiffness of the ball bearings requires optimized vibration transmission paths which are effectively transferred to the surroundings. Special attention is also paid to use low-viscosity oils (HTHS ≈ 2,0 mPa s) at relatively low oil pressures to achieve the optimum balance between maximum bearing stability and reduced vibrations.

This optimized design ends in a ball bearing cartridge floating in oil film within the bearing housing (Fig. 6). A squeeze film damper is used to ensure the system damping of the rotor. BorgWarner uses a patented system of decoupling rings to ensure buildup of the damping oil films, while allowing the cartridge to be centered in the bearing channel, improve the balancing and consequently acoustic behavior. The rings also seal off the pressure area of the damper from the rest of the bearing housing. This controls the oil flow rate and reduces

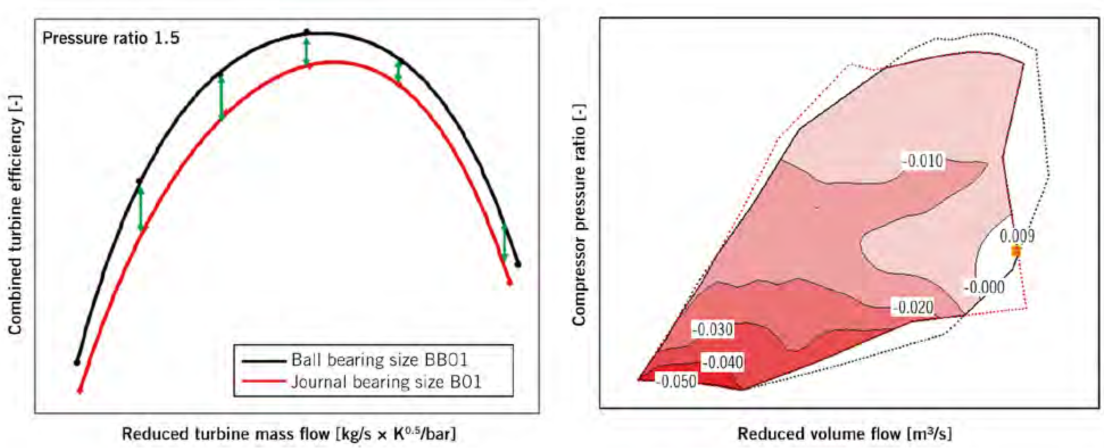

Figure 5. Ball bearing vs. journal bearing turbine efficiency parabolas (left) and overall turbocharger efficiency (right)

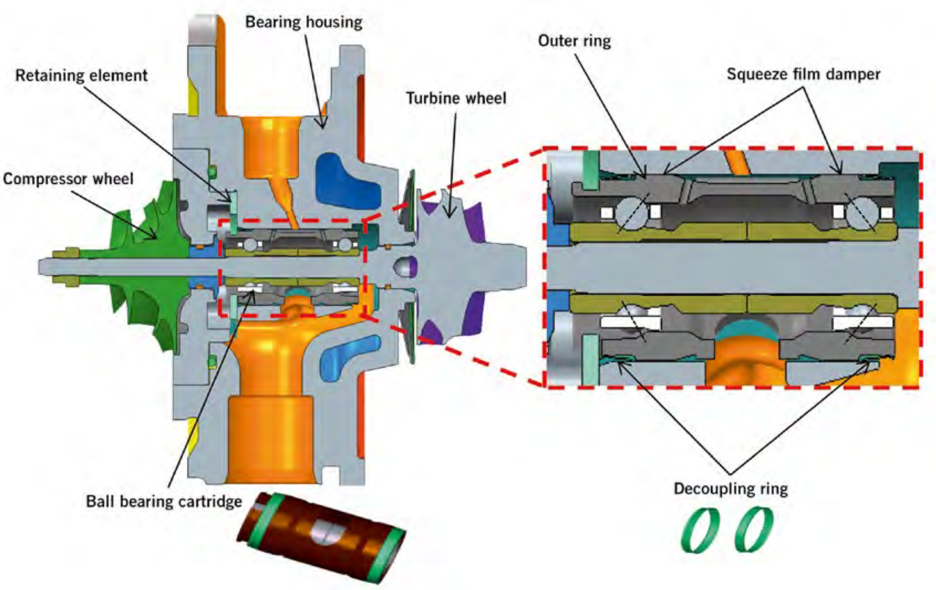

Figure 6. Cross section of a ball bearing centre section

churning losses, while allowing the bending eigenmode of a ball bearing to be countered by the squeeze film damper.

Summary

With the introduction of the Miller/Atkinson combustion cycle and further hybridization of the drivetrain, optimized turbocharging with a gasoline VTG has emerged as a significant contributor to progress being made in meeting specified CO_2 goals for gasoline engines. VTG development, initially driven by the diesel field, is now being advanced by many enhancements on the turbine side. BorgWarner gasoline VTGs are available for all typical passenger car displacements, mainly to comply with "λ=1 operation" for highly boosted gasoline engines, along with a comprehensive portfolio of ball bearings for better efficiency.

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