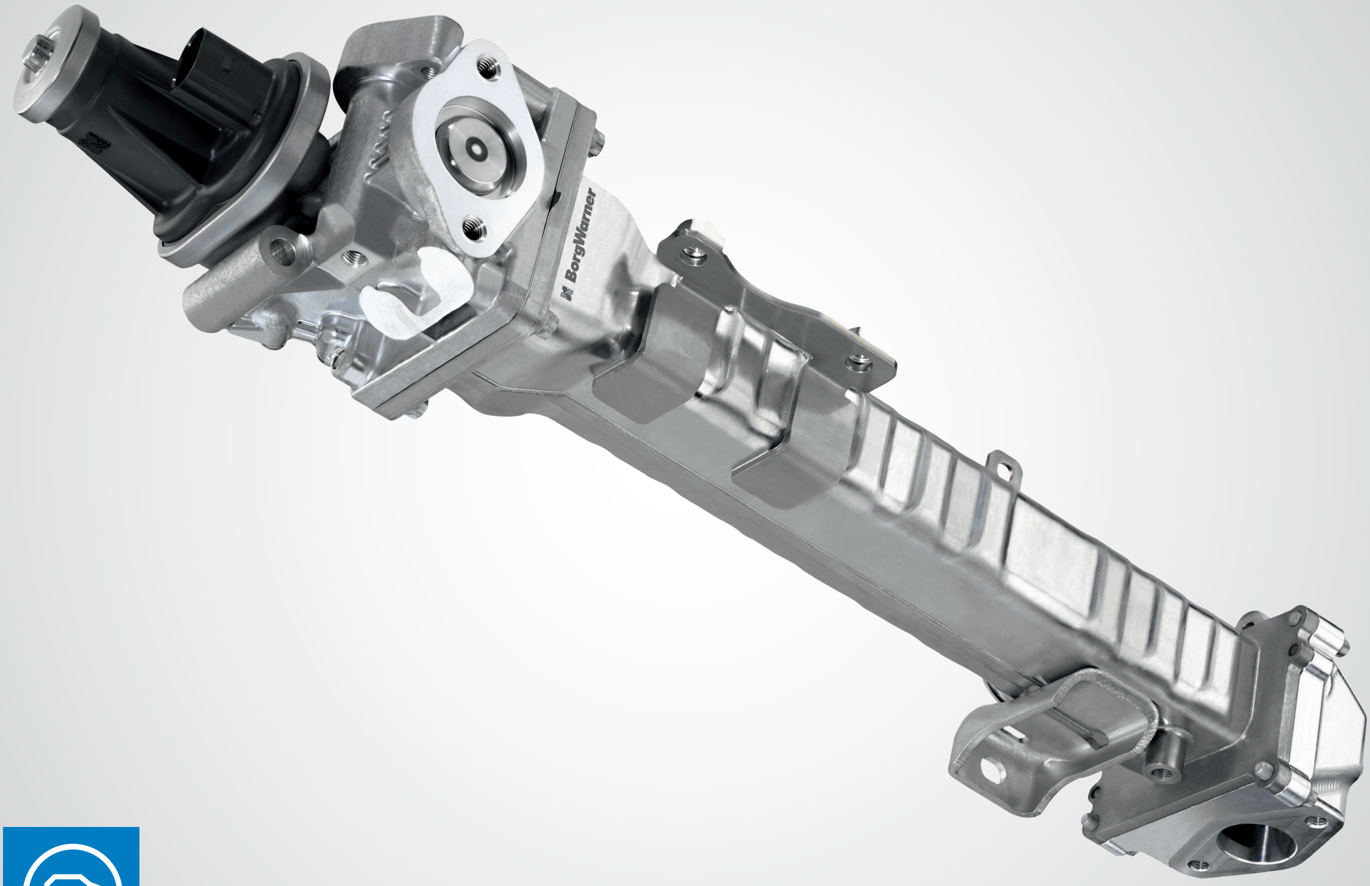

Combustion

“Plug And Cool” Compact Floating Core EGR Coolers for Commercial Vehicles

Knowledge Library

borgwarner.com

BorgWarner

BorgWarner "Plug And Cool" Compact Floating Core EGR Coolers For Commercial Vehicles

Featuring a water-cooled, flexible thermal damper directly integrated into the inner core, BorgWarner's new generation of floating core EGR coolers provides improved robustness against thermal stresses and mitigates the impact of transients. The company developed four standard designs.

Dipl.-Ing. José A. Grande is Senior Product Engineer at BorgWarner Emissions Systems in Vigo (Spain).
Dipl.-Ing. Manuel J. Dieguez is Senior Product Engineer at BorgWarner Emissions Systems in Vigo (Spain).
Dipl.-Ing. Julio A. Carrera is Senior Product Engineer at BorgWarner Emissions Systems in Vigo (Spain).

Commercial vehicle EGR systems for emissions control

Exhaust gas recirculation (EGR) is an in-cylinder emission control technology that reduces NO_X formation for most types of diesel engines in commercial vehicle (CV) applications. It works by recirculating a portion of the engine's exhaust gas back to the engine cylinders. The recirculated exhaust gas is mixed with intake air and introduced into the cylinder for combustion. This mixture of air and exhaust gas has a reduced oxygen content and contains a high amount of CO_2. By thus promoting the reduction of peak temperatures in the combustion chamber, EGR reduces the engine's NO_X production.

The durability of the EGR systems has been a big concern for several automakers on the commercial vehicle market. In order to support its customers in this regard, BorgWarner has put a special focus on the development of an EGR cooler that operates reliably even under the worst possible combination of conditions to be found in the field.

Commercial vehicle EGR cooler design features

During the design process of an EGR cooler for a commercial application, it's important to take the lifetime requirements into account. This means that parts need to be able to operate for up to 1.5 million kilometers or 20,000 hours at exhaust gas temperatures of up to 700 ºC for diesel engines and of up to 800 ºC for CNG systems.

BorgWarner developed the compact floating core (CFC) solution in order to generate a design with a high degree of standardization that is able to cover a wide range of specifications while being durable enough to withstand the roughest possible conditions.

Market volume and design standardization

Usually, EGR systems are specifically designed for a certain engine application. However, this means that a new system has to be developed and validated for every new application. Especially in the commercial vehicle market with its low sales volumes, this approach is not very efficient.

For this reason, the challenge posed by the development of an EGR cooler for commercial vehicles is to create a robust design that can be adapted for use in different applications. This allows design, validation and costs to be reduced.

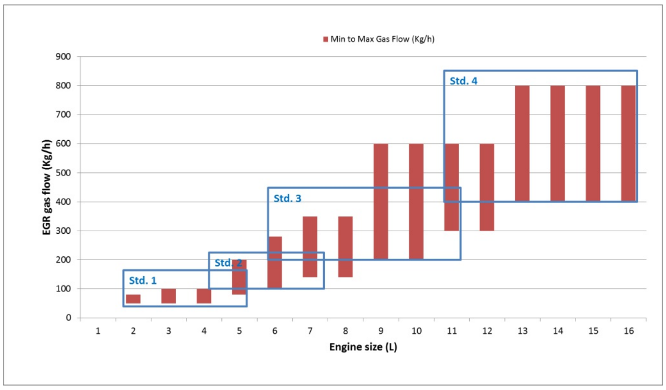

Figure 1. Gas flow value ranges depending on engine displacement, grouped by standard design.

BorgWarner prepared the system for integration into applications using alternative fuels like compressed natural gas in addition to adjusting the design to withstand the worst conditions. Depending on engine size, manufacturer specifications and emissions legislation (from Tier III, EU IV and US 07 until today), each application needs to be able to handle a variety of gas flow values (Figure 1).

BorgWarner engineers defined four standard designs (Figure 2). Each of these is able to operate at a design point with a gas flow of between 50 and 100 percent. In some regions, two standards can overlap. If that is the case, the appro-priate design is chosen based on the available gas dP.

Improving resistance to boiling

Coolant fluid boiling doesn't necessarily occur because of a global lack of coolant, instead being more typically related to the non uniform local coolant distribution or stagnation. Whenever it occurs, boiling produces high thermal stress within the cooler and can thus lead to early malfunctions.

On the other hand, nucleate boiling, meaning the generation of small bubbles on the hot skin of the cooler core components, is generally not an issue. Since BorgWarner's standard design concept is intended for use in a variety of applications, it must be even more robust against boiling under given reference working conditions.

The critical areas in terms of boiling risk are usually located very close to the hot side header and at the inner tubes. Film boiling can be prevented by ensuring sufficient coolant velocity around each section of the cooler core. To accomplish this, BorgWarner engineers' first step was to define the worst possible operating condition for each of the four standard designs. As a result, a combination of maximum flow and temperatures on the gas side with low coolant flow and pressures from the coolant side must be used.

By utilizing intermediate baffles correctly positioned and designed using CFD simulations, the design was optimized to facilitate a sufficiently high coolant velocity in all parts of the component and avoid any hot spots inside the EGR cooler. In fact, the same design is able to operate with gas and coolant both in parallel flow and counter flow (Figure 3).

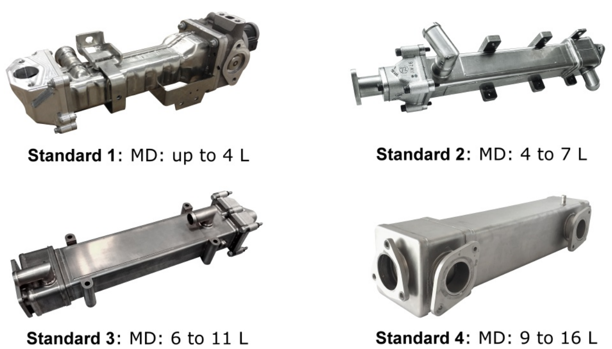

Figure 2. BorgWarner's four standard compact floating core EGR cooler designs.

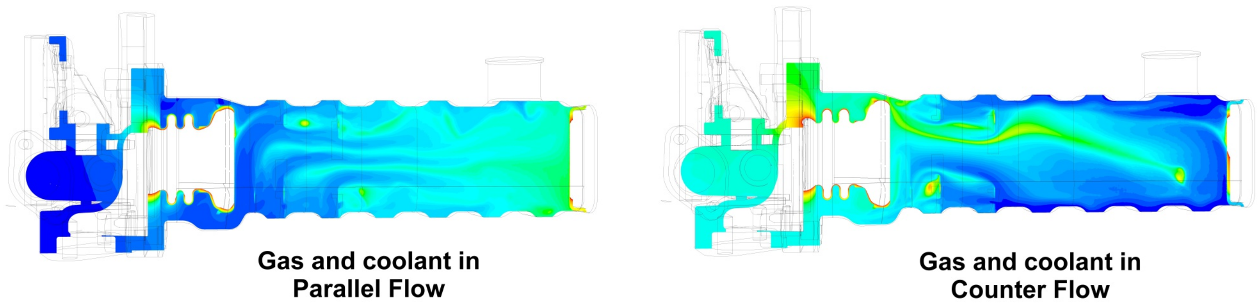

Figure 3. Coolant side optimization.

Optimizing thermal robustness

Thermal fatigue is the most important and challenging issue in the design of EGR systems for commercial vehicles, as it causes the most component failures for customers. While it is commonly caused by load variations, which result in fluctuations of both gas and coolant flow and temperatures during engine operation, thermal transient phenomena may increase thermal stress on the component even more.

Commercial applications are sensitive to thermal fatigue due to their high design life requirements and loads. This means that the components used must be as robust as possible, and a certain degree of flexibility has to be added to the inner core and/or the outer shell, which are the main components of the EGR cooler involved:

- The shell
- The gas entry side header and cone
- The inner tubes

Thermal stress is induced primarily through the differences in thermal expansions among these components, so it is important to use components with a similar thickness and thermal inertia.

The shell's temperature typically reaches a very similar level to that of the coolant over time. As it has to be stiff enough to withstand the coolant pressure pulsation, it restricts the longitudinal elongation of the inner core once the latter heats up.

The floating core is a different solution altogether. Here, the outer shell and the inner tubes are decoupled and thus allowed to expand and contract independently. The concept itself has been utilized in the industry for more than 13 years, typically by including O-rings into the design. These work as a seal between the inner core and shell while allowing longitudinal displacement between the two components (Figure 4).

This solution has its limitations, however. For one thing, the maximum operating temperature of the O-rings can be insufficient for some applications. In addition, a ring-based design is unable to absorb angular displacements. For these reasons, O-rings were not used in the design presented here. Instead, the thermal damper is a metal component with the following advantages:

- Total decoupling of shell and inner core
- Ability to absorb longitudinal and angular displacements
- Gas temperature is reduced by the thermal damper at the inlet before reaching the inner core

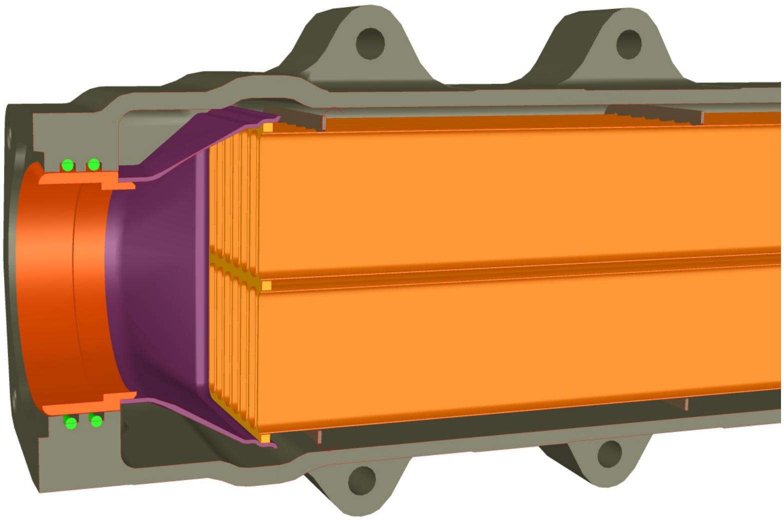

Figure 4. Detail of a floating core featuring O-rings.

The thermal damper is located at the gas inlet and has no temperature limitation (Figure 5).

With its reaction force of only 1,000 N for a compression displacement of 0.3 mm (a reduction of 50 percent when compared to previous floating core solutions featuring O-rings), BorgWarner's compact floating core EGR cooler family is highly flexible. As a result, the innovative system is significantly more resistant to harsh thermal fatigue cycles than other technologies (Figure 6).

Finally, the optimal positioning of the thermal damper right at the entry of the EGR cooler

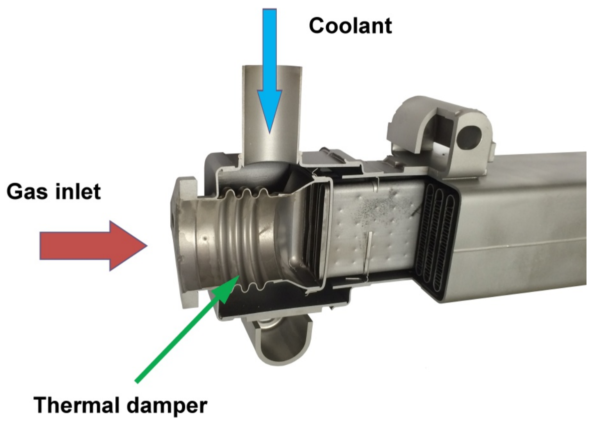

Figure 5. Compact floating core cooler thermal damper design.

provides 2 additional functions which increase the component's robustness against thermal fatigue:

- Improvement of the gas distribution to the cooler core by introducing a degree of disturbance into the gas path at the entry
- Cooling of the inlet gas box using cooling fluid. This attenuates the conse quences of any transient effect because the thermal inertias are very low.

During the development of the compact floating core EGR cooler family, BorgWarner engineers based the definition of the validation condition for thermal fatigue on the application of an accelerated test covering a wide range of applications. Each of the proposed standard designs was shown to be able to survive the accelerated thermal fatigue test required for its top range application.

Summary

By introducing the four EGR cooler standard designs, BorgWarner presents an innovative family of solutions that cover a wide range of engine sizes with a minimum of changes.

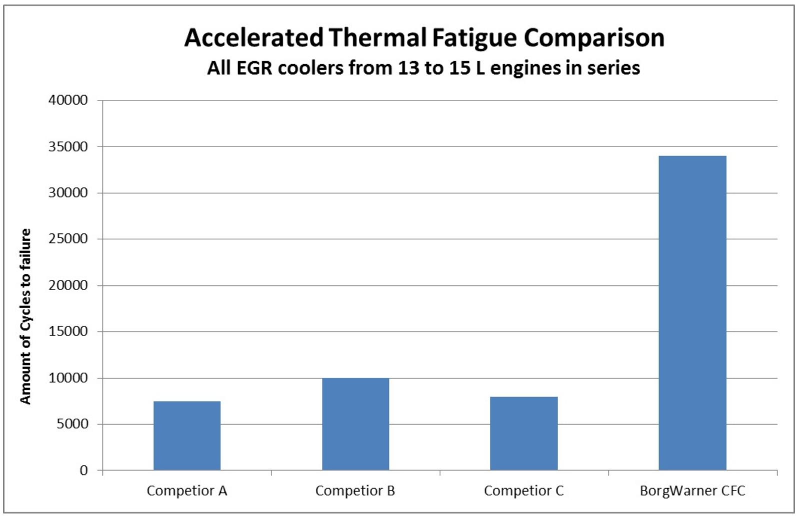

Figure 6. Thermal fatigue comparison.

Featuring an optimized coolant distribution, the new technology avoids boiling issues completely. Skin metal temperatures of the inner core are also limited. Combined with the thermal damper, which drastically reduces thermal stresses, this increases the system's robustness against thermal fatigue when used in both parallel and counter-flow arrangements.

References

[1] n. n.: Dieselnet. Online: www.dieselnet.com/tech/engine_egr_emissions.php, access: October 2017

[2] Carrera, J.: An Empirical methodolog y for the Prediction of the Boiling Limits of EGR Coolers. In: SAE International Journal mater 9 (2016), no. 2, pp. 338 – 34 4

[3] Grande, J.; Carrera, J.; Dieguez, m.: Design Procedure For Robust Design Of CV EGR Coolers Against Thermal Fatigue. SAE Technical Paper, 2017

[4] Carrera, J.; Navarro, A.; Paz, C.; Sanchez, A.; Porteiro, J.: Fatigue Life Calculation under Thermal multiaxial Stresses in EGR Coolers. In: SAE International Journal mater 8 (2015), no. 3, pp. 6 32– 6 39

[5] Holland, B.; McKinley, T.; Storkman, B.: Modeling Approach to Estimate EGR Cooler Thermal Fatigue Life. In: SAE International Journal Engines 8, (2015), no. 4, pp. 1724 –1732

[6] Carrera, J.: Thermal Fatigue Accelerated Life-Testing and Field Damage Analysis in EGR Coolers. SAE Technical Paper, 2016

Contact
Email: technology@borgwarner.com
For more information please visit
borgwarner.com