FEV GmbH
Neuenhofstraße 181
52078 Aachen · Germany

Phone +49 241 5689-0
Fax +49 241 5689-119
marketing@fev.com
www.fev.com

Advanced Diesel Engine Concept with superior Power Density

Within the last couple of decades, the modern DI diesel engine has proven to be an economical and attractive offer in the modern passenger car segment. This is attributable to its higher fuel efficiency and impressive torque characteristic. The recent rise in consumer acceptance of the DI diesel engine is a result of improved drivability and acoustic appearance, which has contributed substantially to the reduction of fleet fuel consumption. This has been achieved by maintaining its traditionally low fuel consumption, while also fulfilling stricter emission regulations. The combination of recent indications of climate change, that are linked to the use of fossil fuels and the rising fuel prices, has brought fuel consumption stronger into the limelight for the entire spectrum of all OEM's and their development teams.

One widely discussed approach for fuel consumption improvement within passenger car applications is to incorporate the downsizing effect. The correlating impact on fuel consumption is well-known. To maintain the high full-load performance of a modern diesel powertrain, an increase of the specific power has to be considered when facing future downsizing concepts.

FEV analyzed all design parameters of the diesel combustion system in detail and evaluated them for future demands. The solution became the development of the FEV combustion system, labeled **HECS** (**H**igh **E**fficiency **C**ombustion **S**ystem), which was designed initially. A specific power of up to 85 kW/l with a balanced layout regarding performance, emission and NVH is achievable with a maximum cylinder pressure of 190 bar.

The initial HECS-layout contains the following elements:

- Optimization of mixture formation (fuel injection and swirl)
- Improved cylinder filling with optimized gas exchange (boosting, manifold layout and flow)
- Highly capable boosting system, in conjunction with a combined high pressure and low pressure EGR system
- Adjustment of the key elements of the combustion chamber (geometry and compression ratio) to the air and fuel system capabilities
- Intensified and refined cooling (Air and EGR)
- Implementation of high performance glow plug system

Based on this layout, which is capable of the EU-6 NOx emission level without active DeNOx system up to an inertia weight class of 1700 kg and 80 kW/L, FEV investigated the possibility for a further significant increase of the specific power.

Thus, the following are the primary elements of the optimized combustion system layout to achieve higher power output:

- Enhanced High Pressure Fuel Injection system (with increased hydraulic flow rate, while maintaining reasonable emission performance)
- Optimized concept of serial turbocharging architecture with VGT, FGT and external bypass
- Increased maximum cylinder pressure capability

With higher degrees of turbocharging due to an improved boosting system in conjunction with higher fuel injection and cylinder peak pressures, a steady increase in specific power can be achieved when increasing the hydraulic flow rate of the injector nozzle from 310 to 520 $cm^3/30s$. For these conditions (cylinder peak pressure of 200 bar), the remarkable maximum power density of 100 kW/L is achieved on the base of a 1.6 L downsized HSDI Diesel engine.

In view of the EU 6 emission legislation, the performed investigations indicate, that the required NOx target can be still achieved. As drawback, an increase in particulate emission needs to be accepted. Due to the increased nozzle hole diameters, the spray break-up and vaporization behavior is deteriorated. Thus, mixture preparation is worsened which leads to higher soot emissions. Estimation of the NEDC cycle performance shows, that PM increase by a factor of 3 is evident (s. Fig. 1); however, due to the excellent HECS emission performance, this emission level (PM ~40 mg/km) can still be handled by a conventional DPF with slightly shortened regeneration intervals. Without consideration of the latter, significant differences in CO_2 emissions cannot be observed.

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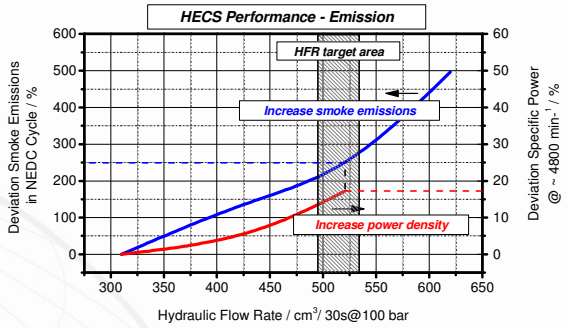

Fig.1: Assessment of power density and PM emissions vs. hydraulic flow rate (p_{max} = 200 bar)

In order to achieve highest boost pressures, the charging system depicted in Fig. 2 is necessary. The two turbocharger stages operate in serial manner. To enable a high starting torque at low engine speeds, the setup features a fixed geometry turbine in the low pressure stage and a variable geometry turbine in the high pressure stage. The architecture takes the excess exhaust gas out of the manifold before entering the HP stage. Such an arrangement offers exhaust pressure benefits if the efficiency maps of HP and LP turbine are well matched, achieving a boost pressure level at 1500 rpm of 3.5 bar and 3.75 bar from 2500 rpm to 4500 rpm.

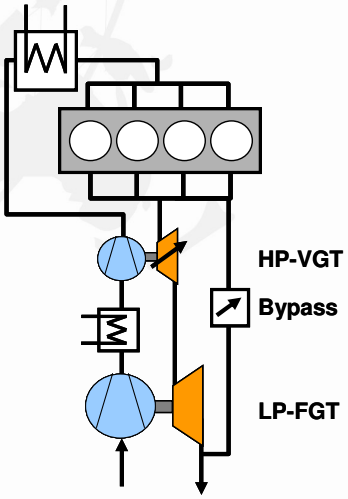

Fig.2: Two stage serial turbo-charging architecture for achieving highest power density

With all measures applied: Increased peak pressure, adapted nozzle, advanced boosting conditions, the impressive specific power of 105 kW/l can be obtained. For this performance, an increased cylinder peak pressure of 220 bar combined with a compression ratio of ε=15 is required (s. Fig. 3).

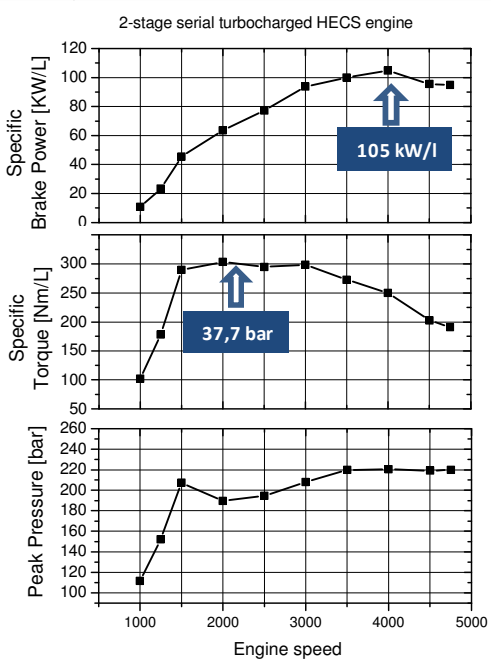

Fig.3: Balance between peak firing pressure and specific power output (Full Load Point @ 4000 rpm)

We are continuously working on a variety of projects to provide further increases in fuel efficiency and reduced emissions for diesel engines, in order to facilitate the customer's individual mobility. Apart from innovative concept vehicles and demonstrator vehicles, we are working on a large variety of production development programs for the worldwide automotive market. We look forward to assist you in achieving your future goals.

Contact: Dipl.-Ing. Thomas Körfer
FEV GmbH
Neuenhofstraße 181
52078 Aachen, Germany
Phone: +49 241 5689-827
Fax: +49 241 5689-507
I-Fax: +49 241 5689-7-827
E-Mail: koerfer@fev.de
Internet: http://www.fev.com

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