Boosting the Future -
Concept Layout and Design of Advanced Charging Systems

One of the key technologies for future Diesel and gasoline engines will be concepts based on advanced boosting systems.

Downsized S.I.-engines will be charged, especially in combination with direct injection, to combine their fuel saving potential with driving fun, as the FEV TurboDISI shows.

With regard to Diesel engines, the trend towards higher specific power outputs lead to an increasing need for charging systems, which can provide sufficient boost pressure over a wide engine speed range at full load. More stringent emission regulations will lead to increased EGR-rates at higher speeds and loads than today, also requiring new charging concepts.

FEV has built up extensive knowledge in the field of charged engines for more than 20 years. During this time, FEV has developed a large number of turbocharged Diesel and S.I.-engines as well as supercharged engines to series production, from smaller engines for passenger cars to heavy duty Diesels for railway applications.

The first step in the development of a charged engine is the layout of the overall charging system. Due to the very stringent package restrictions of modern engine and vehicle designs there is a big challenge to find the right compromise between performance, durability and arrangement in the engine compartment. Meanwhile the main challenge for the design is to find tailor-made solutions for every engine/vehicle concept.

The work tasks must solve very specific questions, which e.g. include the adaptation of the turbocharger housing to the exhaust manifold. Overall, the following advantages can be achieved with those design solutions:

- compact design
- elimination of gaskets and bolts
- elimination of possible leakage areas
- weight optimisation
- cost reduction

Here some tools and methods shall be discussed, focusing on the development of advanced charging systems like:

- exhaust manifold integrated T/C,
- hybrid charging concepts,
- 2-stage T/C concepts.

The layout of the gas exchange system is supported by gas dynamics simulation tools. FEV mainly uses GT-Suite by Gamma-Technologies, supported by its own in-house developed subroutines for inter- and extrapolation of turbocharger data. A database of T/C and S/C data helps setting up simulation models very quickly.
Using these tools, different hybrid charging concepts have been evaluated in numerous projects. The graph below shows for example the load response of a gasoline engine with a combination of T/C and Roots-S/C.

By detailed analysis, the matching of engine and charging device of this system was optimized in advance.

The performance prediction was finally confirmed in a demonstrator vehicle.

As described in the introduction, future diesel engine charging technologies will have to be developed towards higher boost pressure levels and wider operation range. But today’s state-of-the-art VTG turbocharger is a thoroughly developed high-tech component. Further improvements are rather expensive and the potential, especially in terms of boost pressure ratio, is limited. Therefore, also for diesel engine applications the hybrid charging or 2-stage charging is a cost-efficient way to optimize the overall performance of an engine.

For 2-stage charging systems, it is important to note that at least in case of passenger cars, this does not really mean compressing the air twice, but instead refers to two turbochargers of different size e.g. in serial configuration. At lower speeds, the smaller, high-pressure stage is working while the low-pressure compressor is bypassed. In a transition range, the exhaust flow is partly bypassed around the high-pressure turbine, building up power in the low-pressure stage. At higher engine speeds, the high-pressure stage is completely bypassed. This is illustrated in the next graph, showing the pressure ratios and operation lines of a 2-stage turbocharger system at full load.
One of the main tasks of the development work is the matching of the two stages in steady-state and transient operation, focussing especially on a smooth transition between both stages.

The following graph shows the full load torque curves of two different diesel engine charging concepts, which were laid out by FEV, compared to a scatterband of state-of-the-art diesel engines and the BMW 6-Cylinder in-line engine with Variable Twin-Turbo, which was introduced in 2004.

In case of complex configurations like 2-stage charging systems, it is important to take the flow situation into account. By means of CFD calculations, the exhaust flow from manifold to first stage can be optimized. Also, the flow between the stages and through bypasses can be simulated, aiming at uniformal flow to the turbine housings, low pressure losses and reduction of flow disturbance. This task still is challenging, for example concerning definition of boundary conditions for such calculations or prediction of the effect on turbine and compressor efficiency.

Therefore, individual solutions must be investigated for each customer. An example is shown in the following figure. Moreover, engine testing of prototype systems is to be carried out to validate any simulation work.
With the new charging concepts and the resulting high specific engine power output the exhaust manifold becomes a high loaded part caused by exhaust gas temperatures of more than 1000°C. The high gas temperatures lead to high material temperatures which, in combination with restraint expansion capability, lead to the main fatigue mechanism for exhaust manifolds - TMF (Thermo-Mechanical-Fatigue).

Though a best possible temperature distribution is desirable for TMF assessment, for existing designs early temperature measurement by thermoscan or thermal paint methods can be performed.

The changing thermal stresses are generated in the exhaust tube branches as a result of restraining high temperature parts against the "cold" cylinder head. These stresses can produce premature cracks and high deformation of the manifold. For short development times FEA became one of the most important tools to predict fatigue mechanisms where before heat-cycle endurance tests over a long period of time had to be conducted. Lifetime prediction within short time periods now is possible.

In combination with computerised structural optimization we earn further potential for reduced development time by eliminating classic "handmade" iteration loops. The shape optimization tool controls the closed loop cycle of thermal, mechanical and pos. fatigue analysis and provides an optimized model for each automatic iteration loop until the design corresponding to the supposed optimization target is reached. Possible optimization targets can be fatigue life, strain and weight.

CONTACT: Dipl.-Ing. Oliver Lang
FEV Motorentechnik
Neuenhofstraße 181
52078 Aachen, Germany
Phone: (+49)241 5689-652
Fax: (+49)241 5689-507
E-Mail: Lang_O@fev.de
http://www.fev.com