

Cylinder Head Design for High Peak Firing Pressures

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ABSTRACT

Torque and performance requirements of Diesel engines are continually increasing while lower emissions and fuel consumption are demanded, thus increasing thermal and mechanical loads of the main components. The level of peak firing pressure is approaching 200 bar (even higher in Heavy Duty Diesel engines), consequently, a structural optimization of crankcase, crank train components and in particular of the cylinder head is required to cope with the increasing demands.

This report discusses design features of cylinder head concepts which have the capability for increasing thermal and mechanical loads in modern Diesel engines

INTRODUCTION

The development of modern Diesel engines is characterized by combined increases in specific power and torque. In passenger car applications, engines with specific values of 75kW/L and more than 200 Nm/L are already in series production, engines with higher specific values are under development. Naturally, all other engine characteristics have to be improved simultaneously as well. Because of the great importance in public discussion today, the reduction of fuel consumption and the connected CO₂ emission have to be considered in parallel to all emission levels, but, all other characteristics such as cost, reliability, NVH behaviour or comfort are very important for the success of modern engines.

One important reason for the higher specific power in passenger car Diesel engines is the development of downsizing concepts; these allow the reduction of CO₂ emissions without losing performance. In parallel, the peak firing pressure and the thermal loading is increasing. Beside the crank case and the crank train, particularly the cylinder head is affected by this development

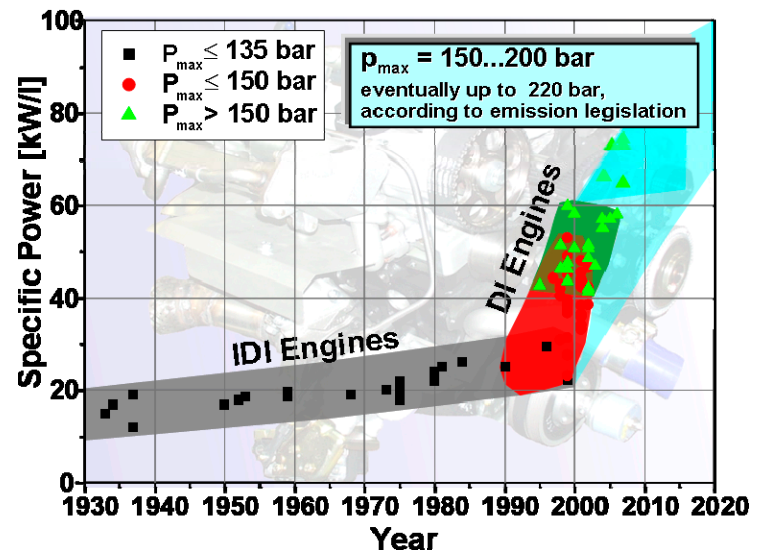


Figure 1. Development of Specific Performances and Peak Pressures of Passenger Car Diesel Engines

In this connection, an important question is how a cylinder head should be designed to cover the higher demands. To answer this, FEV performed an internal R&D project where various kinds of concepts have been designed and compared. The target was to identify cylinder head architectures that meet the demands of the harsher boundary conditions best.

The concept comparisons were supported by intensive FEM structural analysis. In particular, the designer is searching for a procedure to find good design solutions in a very early stage of the design process, this, when the CAD models are not finally detailed. Such an early solution helps to minimize effort, time and cost.

In this paper the concept work is presented and selected designs are compared. The result delivers design solutions for the cylinder head that meet the high demands regarding peak firing pressure and thermal load.

DESIGN CONCEPTS

The increasing peak firing pressure and thermal loading lead to higher mechanical loads of modern cylinder heads:

- Increased operating forces as product of projected combustion chamber area and peak firing pressure. This also dictates a higher pressure will be more important and more critical with larger bore diameters.
- Increased bolt forces of the cylinder head bolts, which have to guarantee sufficient compression of the cylinder head gasket when applying higher peak firing pressures.
- Increased thermal stress and deformations as a result of higher temperature gradients inside the head. The temperature gradient will be higher due to local temperatures at the combustion-chamber side are increasing more than at the cooled side due to the higher heat flow.

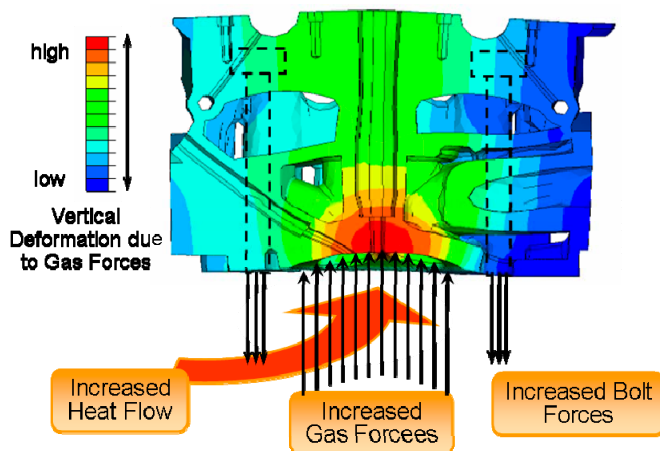


Figure 2. Cylinder Head Loads due to Increased Peak Pressures and Heat

To achieve a functional, qualitatively good, robust, production feasible and economic design also under the tightened boundary conditions, appropriate design measures to compensate the higher loads are required, such as:

- In principle, increasing of the overall structural stiffness by additional walls or ribs or an optimization of their location or dimension.
- Utilization of material with higher Young's modulus.

- Achieving a homogeneous distribution of stiffness and avoiding high gradients.
- Optimization of all fillet radii
- Stiffening of hollow areas with structures which can carry forces and loads considering the impact on cooling.
- Utilization of structures which reduce the bending of the flame deck under gas pressure.
- The need for the structure to expand shouldn't be restricted to avoid excessive strains.
- Realization of good cooling by an appropriate form of water jacket. In parallel, a sufficient coolant flow and velocity must be guaranteed, - at hot spots in particular. Target of this measure is to reduce the temperature gradient, strains and maximal temperature.
- Utilization of material with higher heat conductivity.

The incorporation of the listed measures cannot be realized without compromises. All required design elements such as ports, injector, glow plug, water jacket, valves, valve train, camshaft, oil passages and seals have to be arranged in a limited space. Simultaneously, the requirements regarding low weight and all casting and production boundary conditions have to be met.

Figure 3 depicts concepts investigated at FEV where the listed design measures have been realized. The concepts were designed for passenger car applications. In principle, however, the results can be transferred to bigger engines when the respective boundary conditions are considered.

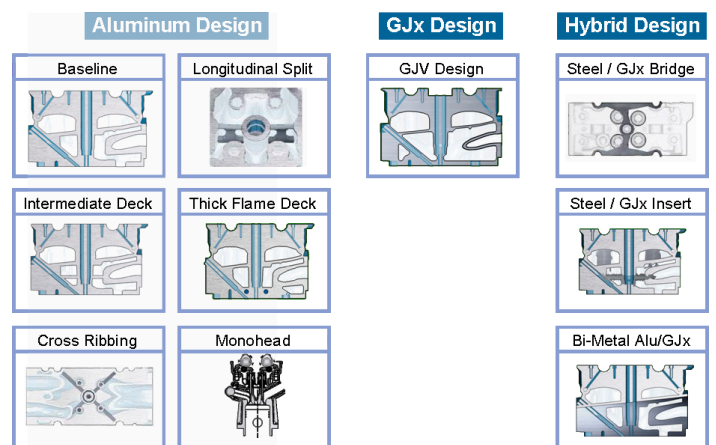


Fig. 3: Cylinder Head Concepts for high PFP

The design of the concepts was performed based on the requirements of future Diesel engines. Important conditions such as casting, machining, assembly or suitability for serial production have been considered. An individual concept design was continued with even when drawbacks in one or more area became obvious. Many different variants, including unconventional ones, were investigated and have been assessed.

The concepts can be subdivided regarding the utilized materials into the categories “aluminum alloys”, “iron alloys” and “aluminum – iron hybrids”. The base for the investigations and comparison has been a 4 valve aluminum head utilizing a single core water jacket (Fig. 4). Such a concept is very popular today for passenger car Diesel applications and therefore an appropriate starting point.

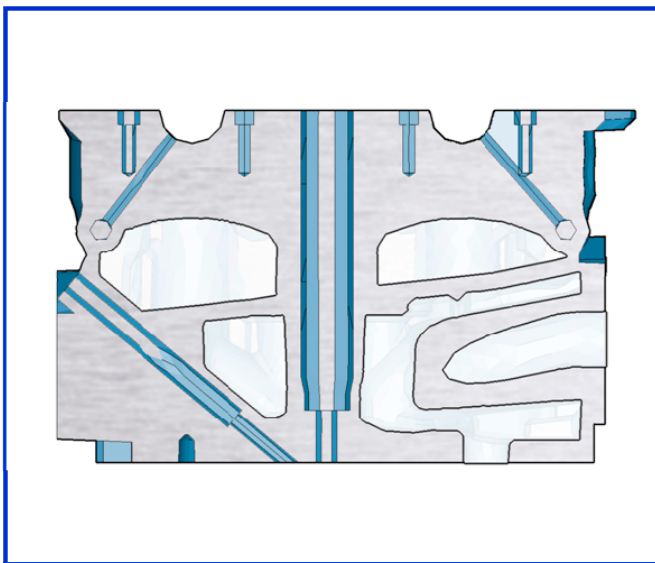


Fig. 4: Base Concept

To increase the component strength, the first option is to change the material, i.e. to use a material with a higher Young's modulus. The first choice in this regard would be the utilization of grey cast iron (GJL), or, for even higher requirements, compacted graphite iron (GJV or CGI) (Fig.5). Compared to an aluminum design, these materials, even considering the higher loads and requirements, would initially have the advantage to decrease the wall thicknesses at many locations inside the head. This results, theoretically, in more freedom and advantages in the water jacket design and therefore better cooling conditions. Unfortunately, the gains can be realized only limited in reality, because a production feasible casting process dictates wall thicknesses of 3 to 3.5 mm. So, resultant wall thicknesses are over dimensioned from the strength point of view at many locations in the head. Cylinder heads manufactured in cast iron material have a big weight disadvantage compared to those in aluminum, in particular for smaller diesel engines.

A GJV (CGI) head variant has been investigated to assess if there are significant advantages regarding the thermo mechanical loading capacity which could compensate the weight drawback.

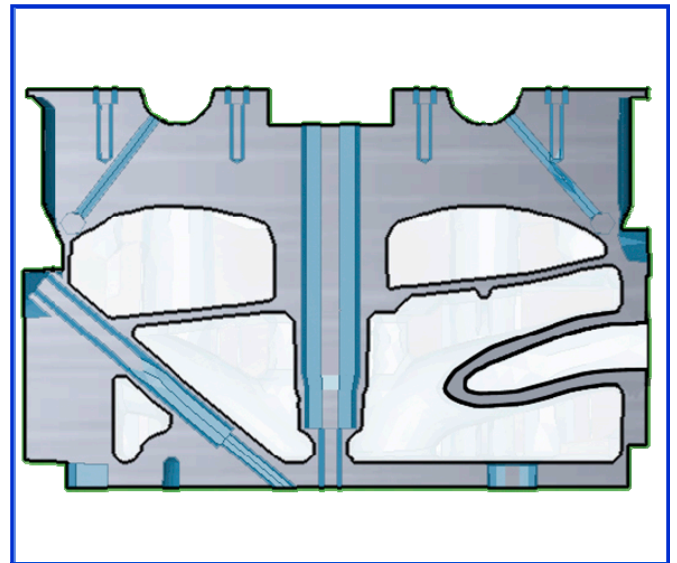


Fig. 5: GJV (CGI) Concept

Two further approaches are developed from the fact that the strength advantage of the iron alloys is only helpful in a few critical areas of the head, therefore, it could be useful to substitute the aluminum locally by GJL or GJV (CGI).

A first result is a hybrid-concept, where, the bottom part including the water jacket (which is loaded by higher peak firing pressure and heat flow) will be made from GJL or GJV (CGI) (Fig. 6). To keep the weight in acceptable limits, the upper part will still be made from aluminum.



Fig. 6: Bi-Metal Head Al/GJx