Prozesse und Tools für die detaillierte Auslegung und Optimierung von VCR-Systemen
Processes and tools for the detailed layout of VCR-Systems

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Abstract

The increasing demand for further lowering fuel consumption of combustion engines increasingly makes systems attractive that allow the adjustment of the compression ratio (variable compression ratio VCR). First manufacturers already announce the introduction of such systems into series production.

After a short introduction into the FEV VCR-technology this publication describes the development status of realized systems. Based on the example of a small displacement engine with high cylinder pressure, the design as well as the development tools and –methods for the application of VCR-systems will be described. Finally, opportunities for the further development indicate the potentials of a series application of such systems.

Main results

VCR-systems can be classified according to their different working principles. FEV has a long development history in various VCR systems. The experiences from these developments have shown that such systems are especially attractive which can be integrated into the base engine with only minor modification efforts. Otherwise, the benefit may appear too small and may not justify the effort.

The two-stage VCR system of the FEV is characterized by ease of modification to the basic engine, figure 1. A variable con rod length is adjusted by an eccentric at the piston pin.

The system design and function has been described in detail in [1, 2]. Gas forces on and mass forces of the piston respectively may enforce the eccentric to rotate once the hydraulic system allows the corresponding support piston to move. This ‘free-wheeling’ is provided through a 3/2-way valve which may be actuated externally. Oil supply from the bearing into the system is given through oil channels and check valves.

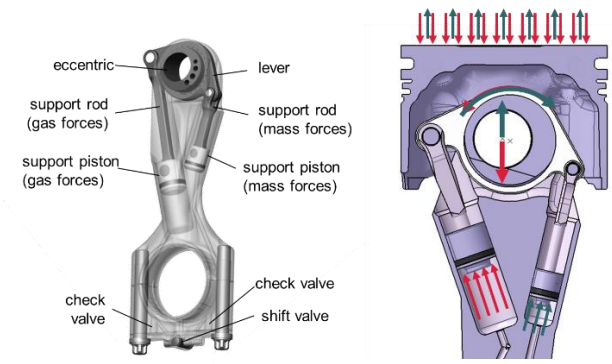

Fig. 1: FEV's 2-Stage VCR System - Working principle

The two-stage VCR system of the FEV has been investigated and further developed within numerous internal and customer projects. Besides SI engines, the applications also comprise Diesel passenger car engines, heavy duty Diesel engines and large bore engines, figure 2.

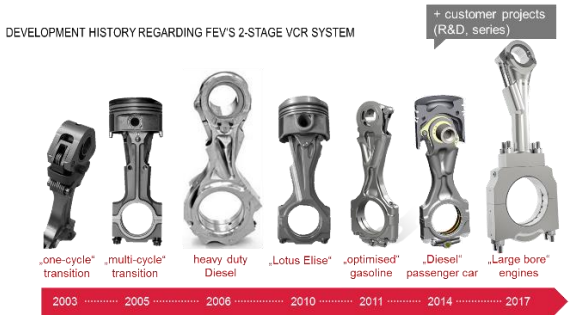

Fig. 2: FEV's 2-Stage VCR System – Development history

In order to assess the VCR-systems limitations and to demonstrate the potential even under stringent package and load conditions, a small displacement CNG TC-DI engine was set-up with the VCR-system based on Ford´s award-winning EcoBoost 1L engine. The high cylinder pressure of >160 bar here requires a robust con rod design which was accomplished through the consequent use of CAE-frontloading.

It could be shown that even under such conditions, the VCR-system can be integrated into the engine with only minor modifications to the base engine.

Typical design features of the VCR con rod are shown in figure 5. Besides the main body and the eccentric, both, the support system and the hydraulic system are to be adapted to the high load demands. All con rod components are validated through finite element analysis (FEA).

Fig. 5: Design features of the VCR con rod

Intensive CAE frontloading is applied in order to optimize the system according to the requirements, figure 6.

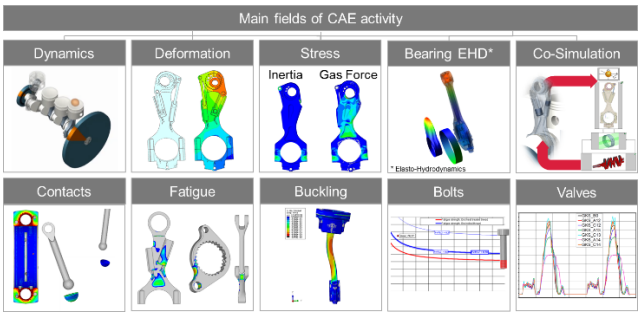

Fig. 6: CAE frontloading

Comprehensive understanding of such a VCR-system is generated through VCR con rod pulse testing, shown in figure 7. Measurement of pulse force, oil pressures, and the eccentric angle allow the subsequent model validation.

Among the advantages of such a pulse test are that 1) the investigation can be carried out under defined operating conditions, 2) easy access for hardware options, such as e.g. to the switch valve is given and 3) it represents a minimal invasive measurement of chamber pressures up to 600 bar which is feasible but represents a challenge but is feasible.

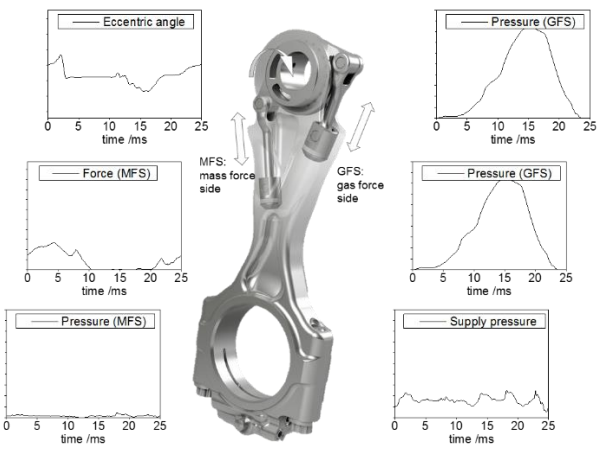

Fig. 7: VCR con rod pulse testing

Based on the VCR-system development process applying CAE and mechanical testing, significant improvement could be derived. As can be seen in figure 8, for example a notable weight reduction is achieved so that the remaining offset in oscillating mass compared to the base non-VCR rod is only 16% with potential to be lowered slightly further.

Future development steps of the 2-stage VCR-system are primarily focused on the system optimization with regard to manufacturing / industrialization and cost.

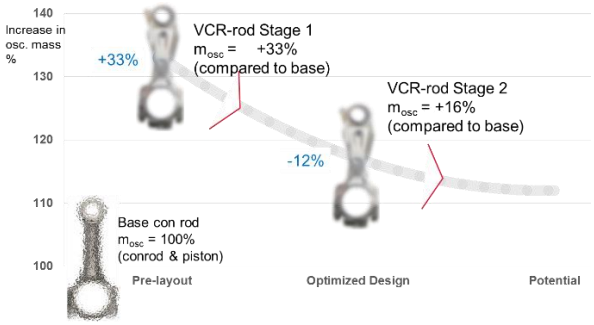

Fig. 8: VCR con rod pulse testing

Conclusions and Summary

Variable Compression Ratio (VCR) has notable benefits in regard to fuel consumption reduction as well as other aspects such as e.g. NVH, reduction of peak firing pressure, and flexfuel-capability. The 2-stage VCR-system can be integrated into the base engine with only minor modification effort and has a reasonable cost/benefit-ratio. It is mature for production. Realized on a Ford Ecoboost engine with 71,9 mm bore for CNG operation, the system has demonstrated it´s potential even for small displacement and high cylinder pressure demands. Development processes for the design and validation of VCR-systems by means of simulation and testing have been derived. These generic tools can be applied independent of the VCR system.

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