

Two-Stage Variable Compression Ratio with Eccentric Piston Pin and Exploitation of Crank Train Forces

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ABSTRACT

By variation of the compression ratio the fuel consumption of high boosted gasoline engines can be reduced, due to operating with higher compression ratios at low load compared to an engine with fixed compression ratio. The two-stage VCR-system enables a high share of fuel saving potential relative to full variable systems.

Considering a low cost manufacturability and a beneficial integratability into common engine architectures the length-adjustable conrod using an eccentric piston pin in the small eye has proved as the best concept. The adjustment is performed by a combination of gas and mass forces.

This article describes the design of such a two-stage VCR-system as well as the functional testing under motored and fired engine operating conditions.

INTRODUCTION

MOTIVATION AND POTENTIALS

POTENTIAL FOR SI COMBUSTION PROCESSES

The benefits of variable compression have already been widely acknowledged and documented [1, 2, 3, 8, 9, 11]. Its major benefits can be summarized as follows:

Under full load conditions, a compression ratio adapted to load demand is capable of reducing knock susceptibility, thus improving full load performance and efficiency. Further, the risk of pre-ignition, the potential for mega-knocking effects as well as a disposition to engine jerking due to retarded combustion phases can be reduced. In addition, as a contribution to component temperature protection, a variable CR offers further potential to control the exhaust gas temperature.

Under part load conditions, a fuel saving potential as shown in figure 1 can be achieved.

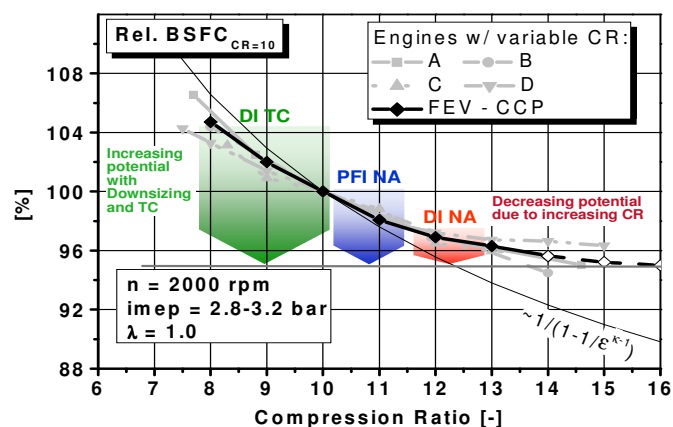


Figure 1: FC reduction through VCR (part load)

For the naturally aspirated engine, the increased compression facilitated by gasoline direct injection diminishes the potential of CR variability. Through downsizing in tandem with charging, however, the benefits of VCR can be enhanced: due to the required compression ratio reduction necessitated by high boost ratios, the fuel saving potential is increased by up to 5 to 10%.

In addition, a high compression facilitates a higher combustion stability, even under unfavorable thermodynamic conditions (e.g. high amount of residual gas, relative air-fuel ratio), so that the idle speed can be reduced, the valve overlap be increased, and, if applicable, lean burn limits be extended. For auto-ignition combustion processes based on the gasoline engine, the auto-ignition operating range can be extended at both higher and lower engine loads.

In principle, when calibrating the engine, variable compression can also be utilized to positively influence the engine's acoustic behavior.

Figure 2 shows the fuel saving potential of charged engines for various driving cycles in dependence on (mean) driving speed as well as at constant-speed driving. At low driving speeds, benefits of well over 10% can be achieved, whereas at higher vehicle speeds a benefit of approx. 6% is still possible. The consumption reduction does not only depend on the VCR system, but also, of course, on the characteristics of both engine and vehicle.

For a two-stage VCR system, due to the fact that the compression ratio cannot be operating point-optimized as well as due to hysteresis effects, the fuel economy potential is slightly reduced.

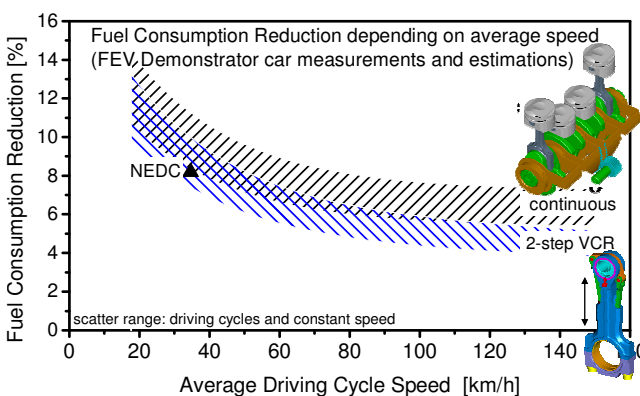


Figure 2: FC reduction through VCR (on-road)

In Figure 3, the calibrated compression ratio in an engine map is displayed. In large areas of the part load range, it is calibrated at its maximum. Even at constant-speed driving at 140 km/h, the compression ratio remains at a comparatively high value of 14. The maximal possible adjustment position is required only for full load accelerations with maximum boost pressure. The

adjustment of the compression ratio was integrated into the torque structure in such a way that it shows a torque-neutral behavior and remains inconspicuous while driving. The currently adjusted compression ratio is shown in a bar-graph display, which is located in the centre console of the passenger compartment.

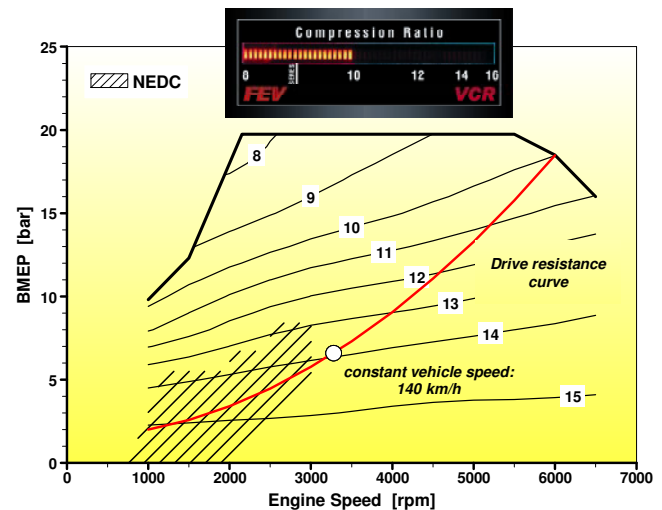


Figure 3: Compression ratio in operation map

Thus, not only can variable compression be applied in combination with modern SI combustion processes, but it also facilitates the development of new combustion technologies.

POTENTIAL FOR PASSENGER CAR DIESEL ENGINES

In view of the current carbon dioxide debate, the development efforts for the combustion process are more than ever directed towards fuel consumption reduction. As has been shown in [5] and [6], downsizing, especially in combination with high-pressure supercharging, is an effective measure to accomplish this goal. In order to achieve a high degree of customer acceptance, however, performance and torque must remain at the current high levels. In order to compensate for the reduction in displacement, then, the specific power output and the maximum BMEP have to be raised, which can be achieved by an increase in boost pressure. At a constant compression ratio, however, the higher boost pressure can only be effectively utilized in conjunction with an increased peak firing pressure.

Deciding on a compression ratio, a balance must be found between emission output and full load performance. The compression ratio typically used for a passenger car diesel engine lies in the range between 15 and 16.5. A higher CR would result in a better combustion stability and an attendant reduction in CO and HC emission in the low-load range (especially at low engine and ambient temperatures), but also in a less favorable particulate/NOX trade-off, which is due to a shorter ignition delay and a concomitant increase in peak firing pressure.

mix combustion. In addition, there are significant disadvantages in respect of full load behavior, as the higher CR at a constant permissible peak pressure needs to be balanced by a later start of injection or a reduced boost pressure.

Comparing current production engines, it was not possible to demonstrate a better start-up behavior of high-CR systems at very low ambient temperatures. At low ambient temperatures, fuel ignition is largely due to the glow plug, and not to the compression-induced heat, which is CR-dependent. Conducting cold start tests at -29 °C on a demonstrator vehicle with a reduced CR of 14.8 and a temperature-controlled glow system (metal), FEV was able to demonstrate reproducible start-up times of under two seconds. Investigations on start-up behavior as reported in [7] have shown that even a high CR of 18 cannot substitute for an adequate glow system (failed start-up at temperatures below -5 °C).

A reduced CR of below 15 is not only problematic with regard to stable engine operation at low ambient temperatures, but also adversely affects the engine's part load behavior, especially under low and medium load conditions.

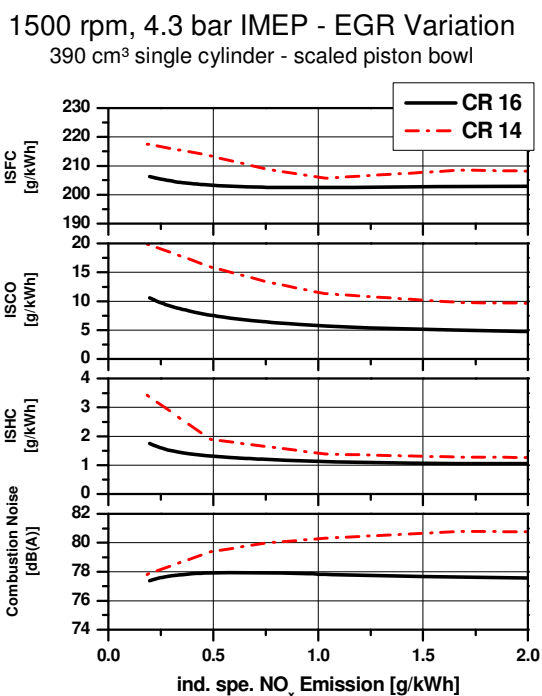


Figure 4: EGR variation at CR = 14 and CR = 16

Figure 4 shows EGR variation curves at the 1500 rpm / BMEP = 4.3 bar operating point for compression ratios of 14 and 16. Both test runs were conducted on a one-cylinder engine with adapted combustion chamber recess under equivalent combustion conditions, and both test runs show a largely homogeneous combustion without significant soot formation (Bosch smoke number

< 0.3). Obviously, the lower compression ratio results in a significantly higher fuel consumption as well as higher CO and HC emissions. Further, the engine-radiated noise turns out to be higher.

Basically, CR variability on a diesel engine can be used to increase or decrease the compression ratio according to demand. Defining the maximum CR (CR-high), however, its impact on the maximum possible combustion chamber recess volume has to be taken into account. Increasing the maximum CR beyond 16.5, a slight benefit at low loads may be achieved, but the free spray lengths as well as the k-factor are very low due to the small chamber recess – an effect which is especially marked if a lower CR is adjusted. All in all, such a design is not favorable, as small benefits in a small area of the engine map are more than counterbalanced by the negative effects elsewhere in the map.

A far greater potential can be demonstrated for a concept which features a conventional recess and combustion chamber geometry and which makes use of the variability to reduce the compression ratio. Taking only the combustion process into account, such a design facilitates an improved part load behavior, as full load characteristics have not to be considered for the determination of the compression ratio. As an example, figure 5 shows the design of a two-stage system for a downsizing concept.

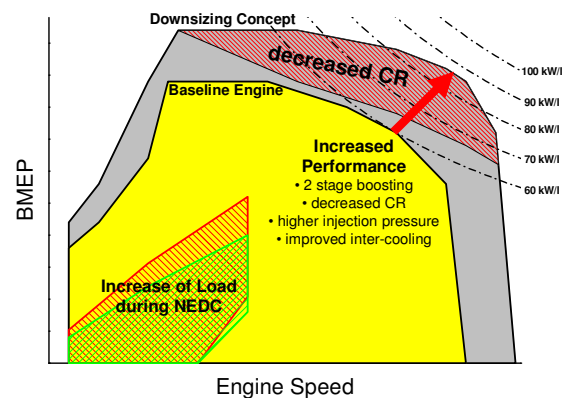


Figure 5: Downsizing concept with VCR

As the high compression ratio is optimized with regard to part load and warm-up behavior, a value close to the upper limit of the commonly applied range can be selected. Due to the variability there are no negative effects on the combustion process, as the combustion chamber geometry does not differ from that of a conventional (i.e. non-VCR) system.

The low compression ratio (CR-low) is utilized in the full load range, especially at high engine speeds. Even though it results in an enlarged squish, for modern combustion strategies with their optimized air utilization it