CONSTRUCTIVE SOLUTIONS FOR VARIABLE COMPRESSION RATIO ENGINES

Drd. ing. Adrian GABOR
Universitatea „Transilvania" din Braşov

REZUMAT. Se crede că, în viitorul apropiat, raportul variabil de comprimare (VCR) va furniza industriei auto o gamă largă de strategii pentru a putea fi produse motoare puternice, cu un consum redus de combustibil, ceea ce va duce la autovehicule atractive care se vor conforma celor mai exigente norme de poluare. Totuşi apare următoarea întrebare: în actualul context legat de poluarea mediului înconjurător şi de resursele de petrol tot mai puţine, de ce producătorii de autovehicule nu folosesc deja motoarele cu VCR? Producerea motoarelor cu VCR reprezintă o adevărată provocare tehnologică ce implică schimbări majore în mecanica unui motor obişnuit. Acest articol prezintă câteva soluţii recente de motoare cu VCR şi caracteristicile lor, sarcina fiind identificarea şi studiul soluţiei care îndeplineşte toate caracteristicile indispensabile pentru producerea în masă a motorului în termeni de funcţionalitate, rezistenţă şi fiabilitate, totodată având costuri de producţie rezonabile.

Cuvinte cheie: raport de comprimare variabil VCR, motor, eficient, combustibil.

ABSTRACT. We think that in the near-future, Variable Compression Ratio (VCR) will provide to the automotive industry a wide range of efficient strategies to produce fuel-efficient, powerful engines which will result in attractive cars that will conform to most stringent emissions standards. Then the question is: as present, environmental and energy context cannot be more suited to such a strategy, why don't carmakers already produce VCR engines? For all carmakers producing VCR engines represents a real technological challenge which implies big changes in engine's mechanical definition. This article presents some of the actual solutions of VCR engines and their characteristics, the task being to identify and study a design that fulfils all indispensable features for a mass-produced engine in terms of functionalities, reliability and durability while presenting reasonable production costs

Keywords: Variable compression ratio VCR, engine, fuel-efficient.

1. INTRODUCTION

The rapid deterioration of our environment and uncertainties concerning future energy supplies are the consequences of our current lifestyles based on personal comfort and mobility. For the future we will have to rapidly develop high energy efficient technologies in all sectors and make them available to each and every consumer. This condition will be essential to have a real impact, both on European and global level. In this context the low energy efficiency of today's cars is a source of concern. And it will be necessary to commercialize cars that consume less fuel as quickly as possible. This must, however, be done, while respecting a certain number of conditions. In order to remain popular, future cars must maintain their high performance levels, and in order to continue to be mass consumption goods, they must remain affordable.

To ensure strong impact, the price that the final customer pays per kilometer must remain low, taking into account the purchase price of the vehicle, its fuel consumption and its resale value. Good performance levels, low fuel consumption and reasonable purchase prices remain indispensable qualities for future cars.

2. THE APPLICATION OF VCR ENGINES

Designing high performance vehicles that are fuel efficient and clean is difficult since we also want them to remain inexpensive. It is therefore necessary to find simple, low cost and effective solutions, and that is the whole strategy of the Variable Compression Ratio (VCR) engine producers. Far from being a revolution, VCR engines are a major evolution of conventional engines.

The concept of variable compression ratio (VCR) promises improved engine performance, efficiency, and reduced emissions. The higher cylinder pressures and temperatures during the early part of combustion and small residual gas fraction owing to higher compression ratio give faster laminar flame speed. Therefore, the ignition delay period is shorter. As a result, at low loads, the greater the compression ratio, the shorter is the combustion time. Time loss is subsequently reduced. Therefore, it seems reasonable that fuel consumption rate is lower with high compression ratios at part load.

The VCR can make a significant contribution to thermodynamic efficiency. The main feature of the VCR engine is to operate at different compression ratios, depending on the vehicle performance needs. A VCR engine can continuously vary the compression ratio by changing the combustion chamber volume. In a VCR engine, thermodynamic benefits appear throughout the engine map. At low power levels, the VCR engine operates at a higher compression ratio to capture high fuel efficiency benefits, while at high power levels the engine operates at low compression ratio to prevent knock. The optimum compression ratio is determined as a function of one or more vehicle operating parameters such as inlet air temperature, engine coolant temperature, exhaust gas temperature, engine knock, fuel type, octane rating of fuel etc. In a VCR engine, the operating temperature is more or less maintained at optimum, where combustion efficiency is high.

3. A SUMMARY OF VCR CONCEPTS

Historically, every mechanical element in the power conversion system has been considered a way to achieve variable compression ratio. Designs presented solutions which modifies the compression ratio by:

- moving the cylinder head;
- variation of combustion chamber volume;
- variation of piston deck height;
- modification of connecting rod geometry;
- moving the crankshaft axis;

In many cases, the deviation from conventional production engine structure or layout represents a significant commercial barrier to widespread adoption of the technology.

4. LATEST ENGINES CONCEPTS

1. Named **SVC** (**Saab Variable Compression**), the engine implement VC by an innovative and interesting method - slidable cylinder head and cylinder. As can be seen in the picture below, the SVC engine have a cylinder head with integrated cylinders - which is known as monohead. The monohead is pivoted at the crankcase and its slope can be adjusted slightly up to 4 degrees (Fig. 1), in relation to the engine block, pistons, crankcase etc. by means of a hydraulic actuator, therefore the volume of the combustion chamber ,when piston is in compressed position, can be varied.

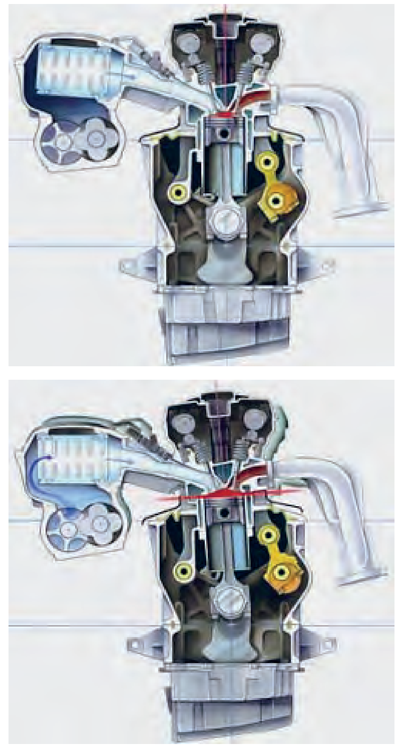

Fig. 1. SAAB VCR engine (1).

SVC is cleverer than any previous patents for variable compression ratio engines because involves no additional moving parts at the combustion chamber or any reciprocating components, so in theory is simple, durable and free of leakage. The monohead is self-contained, that means it has its own cooling system. Cooling passages across the head and the cylinder wall. There is a rubber sealing between the monohead and engine block. The VC allows the Saab engine to run on very high supercharging pressure - 2.8 bar. So high that today's turbochargers cannot provide. Therefore it employs supercharger instead. At other speed, the VC is adjustable continuously according to needs - depends on revs, load, temperature, fuel used etc., all decided by engine management system. Therefore power and fuel consumption can be optimized at any conditions. The prototype is an inline 5-cylinder with 4-valve head with a displacement of 1598 cm^3. Compression ratio can be varied between 8:1 and 14:1. With the supercharger, it output a maximum 225 hp and a torque of 305 Nm, with a very low fuel consumption. Saab claims it saves 30% compare with equally powerful conventional engines. In terms of specific output, it achieve 150 hp per liter. At the same time, the emissions of carbon dioxide are reduced proportionately to the fuel consumption, while the CO, HC and NO_x emissions enable the SVC engine to fulfill the EU4 emission regulations. The engine management system detect the fuel grade and decide the most appropriate compression ratio to be used (1).

2. Based on the combination between a rod-crank mechanism and long-life gears, the **MCE-5** (Fig. 2) is a VCR technology that integrates both power transmission and compression ratio control. Its conservative combustion chamber and its totally conventional and invariable piston kinematics allow making combustion and performance control. The compression ratio is from 7:1 to 20:1. Its long-life gears and roller-guided piston which is no longer subjected to radial stress and piston slap, makes the MCE-5 to have a high durability, robustness and reliability. MCE-5 VCR has a rigid engine block which integrates a rigid crankshaft to ensure high reliability and long lifespan to hydrodynamic bearings.

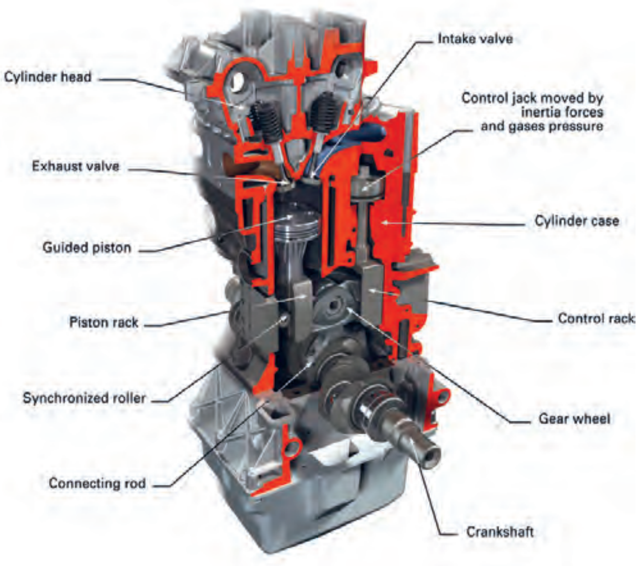

Fig. 2. MCE-5 engine parts (2).

The MCE-5 VCR engine block has no impact on other engine parts or vehicle components and needs no additional component for connection to gearbox, intake and exhaust pipes, peripherals and can be easy to fix it into all vehicles. Having reasonable production costs, future engines based on MCE-5 technology could provide to automotive industry a wide range of efficient strategies to produce fuel-efficient, powerful and attractive cars which conform to most stringent emissions standards. MCE-5 VCR-I technology brings together in the same engine the advantages of both Diesel and gasoline engines. An MCE-5 engine offers a higher low-end torque than does a Diesel engine, which gives it a low engine speed with comparable fuel consumption and range. Its noise and vibration emissions are identical to those of a conventional gasoline engine, with the same quiet and smooth operation. Its purchase price is much lower than a Diesel's. As it is more sophisticated, the MCE-5 engine is nevertheless more expensive than a conventional engine for an entry-range vehicle but nonetheless remains very viable since it is paid off in less than 60,000 km. For mid-range to top-of-the-range vehicles, the MCE-5 is less costly than the conventional engines used today and, in addition, proposes much better fuel-efficiency. The MCE-5 engine emits fewer pollutants than does a conventional gasoline engine since its variable compression ratio enables it to make better use of its 3-way catalytic converter. In the very near future, MCE-5 vehicles will benefit from the qualities of Diesel and gasoline vehicles without inheriting their faults (2).

3. Nissan has developed a new engine mechanism that enables high power of turbo engine and low fuel consumption of non-turbo engine. The newly developed piston-crank mechanism enables optimum compression ratio control, the fuel economy of a non-turbo engine and the power output of a turbocharged engine can be achieved in one engine. Significant vibration reduction has been obtained by the ideal piston motion of multi – link and by applying multi-link mechanism, significant improvement of engine vibration coupled with friction reduction have been obtained. In addition, function of variable compression ratio control under engine running condition has been achieved. The highest compression ratio is used in city driving to increase thermal efficiency for improved fuel economy. The system shifts to a low compression ratio for super charging when accelerating or climbing hills. This enables also higher turbocharging for much power while suppressing engine knock. Piston motion in the conventional mechanism is essentially asymmetrical, with rapid motion occurring at top dead center. That unbalance deteriorates engine vibration in the case of conventional 4-cylinder engines. With the multilink VCR mechanism, the piston's reciprocal action achieves ideal simple harmonic motion, resolving the unbalance. This enable low vibration property of in-line 4 cylinder engine close to that of V type 6 cylinder engines.

4. The Cortina engine is the only **Variable Compression concept** that slides the entire reciprocating assembly toward and away from the cylinder head. The advantage of this approach is that there is no complication to the workings of the reciprocating assembly itself, nor is there any complication outside of the engine. The way this is accomplished is by sliding the reciprocating assembly on a splined output shaft that is positioned perpendicular to the typical engine's output orientation. In other words the output shaft is inline or parallel with the sweep of the pistons such that the cylinders can be arranged radially around it. There are two ways this can be accomplished. One: (Fig. 4) by using a conventional crankshaft mounted in an internal sub-housing with bevel gears to shift the rotational force 90 degrees. This method uses a more tried and true crankshaft approach, but has more parts and lacks features compared with the barrel cam concept.

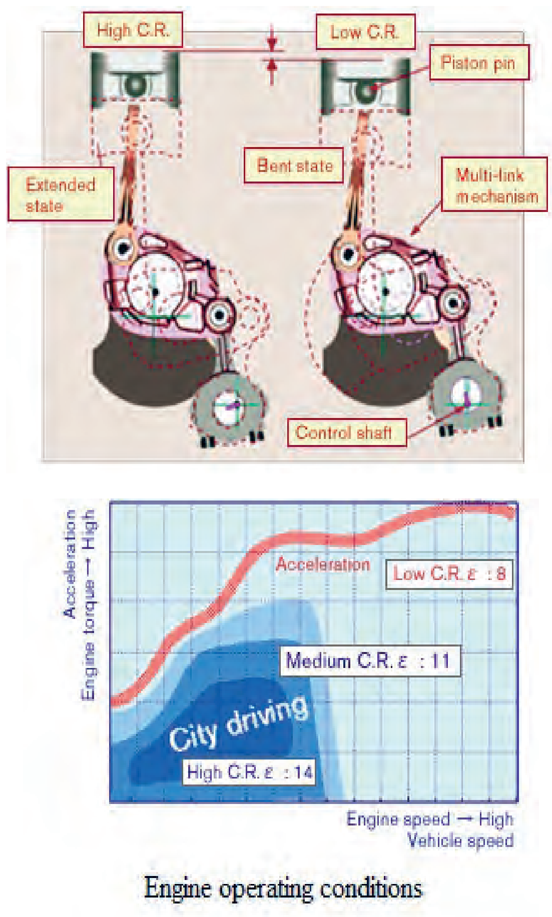

Fig. 3. Nissan VCR engine (3).

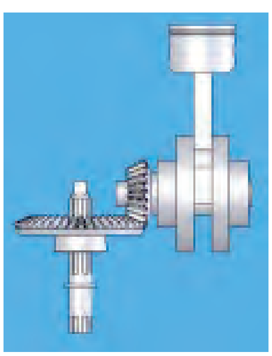

Fig. 4. First solution (4).

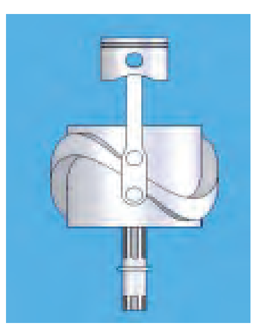

Fig. 5. The second solution (4).

And two (Fig. 5): by the use of a barrel cam. The barrel cam uses fewer parts and adds the option of a true Atkinson cycle. It also has a more favorable leverage curve that a traditional crankshaft. Since the connecting rods stay strait with a barrel cam cycling the pistons it also is possible to box in the lower cylinder for use as an internal supercharger. For these reasons this method would be preferred if the durability proves adequate. For a barrel or cylindrical cam to survive the high stress environment of cranking an internal combustion engine a cam with an external rib with complicated variable thickness would be necessary. This style of cam is just now becoming common in industrial machinery (4).

5. CONCLUSIONS

Worldwide pressure to reduce automotive fuel consumption and CO_2 emissions is leading to the introduction of various new technologies for the spark ignition engine. So far, variable compression ratio (VCR) engines have not reached the market, despite patents and experiments dating back over decades. VCR offers the largest potential improvement in part throttle fuel efficiency and CO_2 emissions when compared to other competing technologies, if applied to highly pressure-charged downsized engines. The main obstacles to adoption of VCR are incompatibility with major components in current production and difficulties of combining VCR and non-VCR manufacturing within existing plant. As environmental pressure on the automobile increases and investment plans for new products are put in place, the justification for VCR will become more evident.

VCR technology could provide the key to enable exceptional efficiency at light loads without loss of full load performance.

Acknowledgement

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOPHRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/88/1.5/S/5932

6. REFERENCES

[1] **Rodrigues de Sousa Ribeiro, B.,** *Thermodynamic optimisation of spark ignition engines under part load conditions*, University do Minho, 2006.
[2] http://www.mce-5.com/ - 30/06/2010.
[3] http://www.nissanglobal.com/EN/TECHNOLOGY/ INTRODUCTION/ DETAILS/VCR - 05.07.2010
[4] http://cortina-engine.weebly.com/ - 02.07.2010