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VARIABLE COMPRESSION RATIO (VCR) ENGINE- A REVIEW OF FUTURE POWER PLANT FOR AUTOMOBILE

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ABSTRACT

Increasingly stringent emission and fuel economy standards have long remained a source of challenges for research in automobile engine technology development towards the more thermally efficient and less polluting engine.

Variable compression ratio (VCR) technology has long been recognized as a method for improving the automobile engine performance, efficiency, fuel economy with reduced emission. The main feature of the VCR engine is to operate at different compression ratio, by changing the combustion chamber volume, depending on the vehicle performance needs.

This paper takes review of all the geometric approaches and solutions used to achieve VCR with its unique features, considers the results of prior research and its corresponding commercial barriers.

Keywords: compression, ratio, polluting engine, emission

1 INTRODUCTION

Worldwide pressure to reduce automotive fuel consumption and CO_2 emissions is leading to the introduction of various new technologies for the automotive engine.

The concept of variable compression ratio (VCR) promises improved engine performance, efficiency, and reduced emissions.

VCR is identified as the key enabling technology of downsized engines. The search for a feasible VCR engine has been driven by the compromise between WOT (Wide Open Throttle) and part-throttle which exists on any fixed CR engine.

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.[1]

2. NEED FOR VCR

One of the key features affecting thermal efficiency is the compression ratio, which is always a compromise in fixed compression ratio spark ignition (SI) engines. If the compression ratio is higher than the designed limit, the fuel will

pre-ignite causing knocking, which could damage the engine.[2]
Generally, the operating conditions of SI engines vary widely, such as stop and go city traffic, highway motoring at constant speed, or high-speed freeway driving.

Unfortunately, most of the time SI engines in city driving conditions operate at relatively low power levels under slow accelerations, low speeds, or light loads, which lead to low thermal efficiency and hence higher fuel consumption. As the engine load decreases, the temperature in the end gas drops, so that high compression ratio could be employed without the risk of knocking in naturally aspirated or boosted engines. Raising the compression ratio from 8 to 14 produces an efficiency gain from 50 to 65 per cent (a 15 per cent gain), whereas going from 16 to 20 produces a gain from 67 to 70 per cent (a 3 per cent gain). Figure 2.1 shows the effects of compression ratio with respect to thermal efficiency.

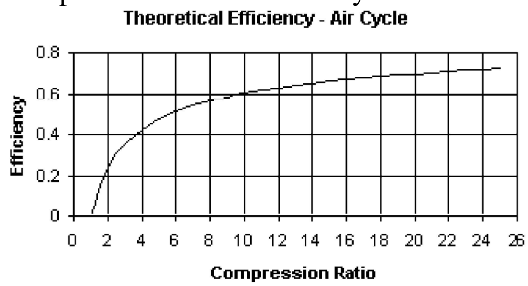


Fig.2.1 Effect of compression ratio on thermal efficiency

3. VARIOUS VCR APPROACHES

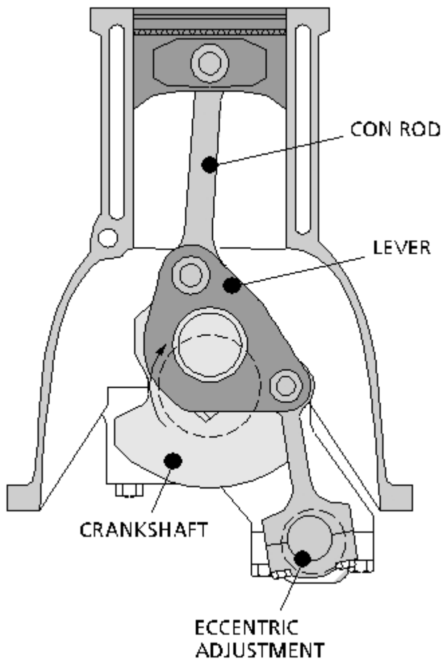
Designing and successfully developing a production practical, VCR engine has long been a challenge to the automobile industry. Many innovative patents have been filed and different designs developed to modify the compression ratio. A few approaches are discussed below:-

3.1 Moving the Crankshaft Axis

FEV, Germany has chosen to alter the position of the crankshaft. In their engine, crankshaft bearings are carried in an eccentrically mounted carrier that can rotate to raise or lower the top dead centre (TDC) positions of the pistons in the cylinders The compression ratio is adjustable by varying the rotation of the eccentric carrier. Mounting the crankshaft on eccentric bearings is simple in that the reciprocating assembly itself is unchanged. In fact, the engine requires an offset fixed-position output shaft; a coupling is required between the movable crankshaft end and the fixed output shaft. The compression ratio is adaptable from 8 to 14 approximately by varying the rotation of the eccentric carriers through 55° [4].

3.2 Modification of the connecting rod geometry.

The Nissan project uses a multi-link system to achieve VCR by inserting a control linkage system between the connecting rod and the crankshaft, and connecting this to an actuator shaft, so that the compression ratio can be varied. This project was incorporated in a four-cylinder engine without major modification of the engine block. The shorter crank throw allowed room for the link system, which was anchored by an eccentric rotary actuator. Compression was varied from 10 to 15 approximately by a 70° rotation of the actuator, while at TDC, the piston position was changed by 3.1 mm Examining the details of multi-link system operation reveals some advantages. The most striking advantage is that of maximum piston accelerations. Tension forces acting through the connecting rod and piston at TDC represent one of the factors limiting piston speed, so a geometry that reduces the peak piston acceleration would allow either an increase in sustainable engine speed or an increasing stroke, either of which is useful in terms of increasing power output [5]



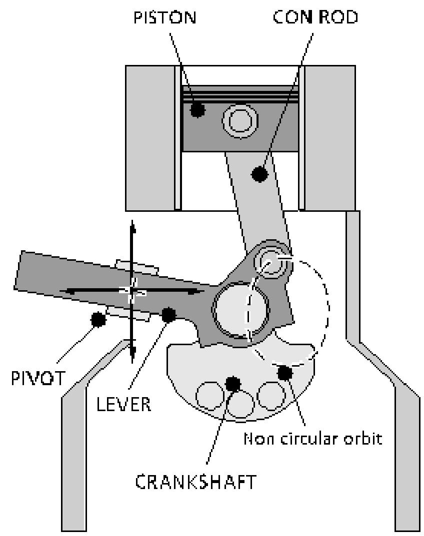


Fig.3.2.1 Nissan VCR Engine

Fig.3.2.2. Mayflower e3 VCR Engine

3.3 Moving the cylinder head

The moving head concept (Saab Automobile AB) combines a cylinder head with cylinder liners into a monohead construction, which pivots with respect to the remainder of the engine. The lower half of the block includes the crankcase and engine mounts, and carries the crankshaft, gear box, oil cooler, and auxiliaries. The upper half includes the cylinders, their liners, camshafts, and an integrally cast cylinder head. This part is referred to as the monohead. Saab has enabled a tilting motion to adjust the effective height of the piston crown at TDC. The linkage serves to tilt the monohead relative to the crankcase in order to vary the TDC position of the piston. By means of actuator and linkage mechanism the compression ratio can be varied from 8 to 14. A screw type supercharger provides a 2:1 boost pressure when wide open throttle conditions occur [5]. This system gives wide fuel flexibility, with reduced CO_2 emissions proportional to fuel consumption. Saab recognized that the fuel efficiency of the VCR engine would be low without high-pressure supercharging.

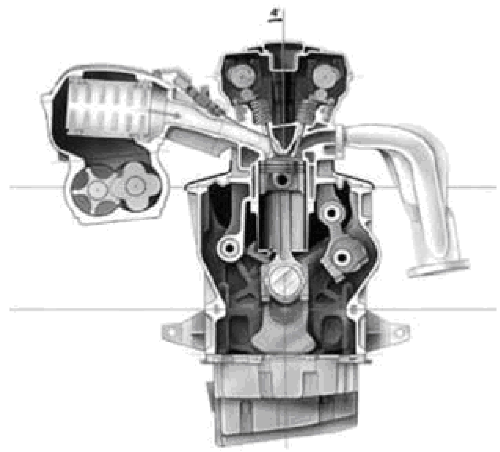


Fig.3.3.1. The Saab VCR Engine

3.4 Variation of Combustion Chamber Volume Using A Secondary Piston Or Valve

Ford has patented a means to vary combustion chamber volume by using a secondary piston or valve. The piston could be maintained at an intermediate position, corresponding to the optimum compression ratio for a particular condition. The volume of the combustion chamber is increased to reduce the compression ratio by moving a small secondary piston which communicates with the chamber [5], however, this would require a finite length bore in which the piston could travel, which raises questions of sealing, packaging, and durability.

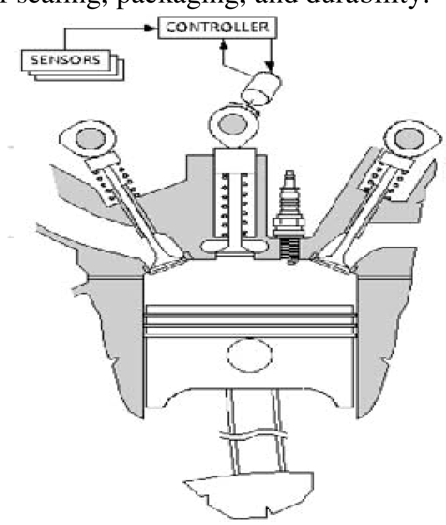
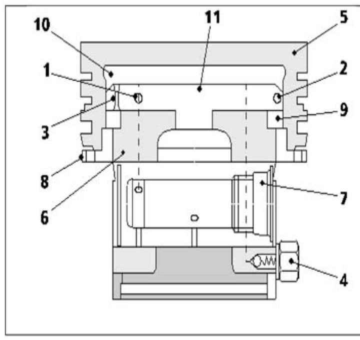


Fig.3.4.1 Ford VCR Engine

Varying combustion chamber geometry compromises the area available for intake and exhaust valves, while moving the cylinder head and barrel is feasible in a research engine but harder to accomplish in a production vehicle. The cylinder head cooling needs to be improved by an efficient cooling system and the auxiliary piston needs proper lubrication for efficient functioning of the VCR engine.

Variation of piston deck height

The Daimler-Benz VCR piston design shows variation in compression height of the piston and offers potentially the most attractive route to a production VCR engine, since it requires relatively minor changes to the base engine architecture when compared to other options . Unfortunately, it requires a significant increase in reciprocating mass and, more importantly, a means to activate the height variation within a high-speed reciprocating assembly.



1	one way valve
2	one way valve
3	orifice
4	pressure relief valve
5	outer piston
6	inner piston
7	piston pin
8	buffer ring
9	lower oil chamber
10	upper oil chamber
11	valve mounting device

Fig.3.5.1 Daimler Benz VCR Piston

This is typically proposed by means of hydraulics using the engine lubricating oil; however, reliable control of the necessary oil flow represents a major challenge. This is claimed to reduce the peak firing loads so that the compression ratio variation becomes self-acting rather than externally controlled. A side-effect would be the momentary variation in clearance volume during the combustion event, which would, in turn, increase, then reduce the volume available to the expanding gases.
The University of Michigan developed a pressure-reactive piston for SI engines. The pressure-reactive piston assembly consists of a piston crown and a separate piston skirt, with a set of springs contained between them

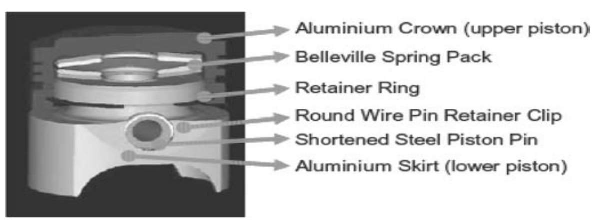


Fig.3.5.2. Pressure Reactive Piston Cross Section

This piston configuration allows the piston crown to deflect in response to the cylinder pressure. As a piston crown deflects, the cylinder clearance volume increases, lowering the effective compression ratio and reducing peak cylinder pressure. This mechanism effectively limits the peak pressures at high loads without an additional control device, while allowing the engine to operate at high compression ratio during low load conditions [8], It can be easily adapted to the conventional engine with only changes to piston and connecting rod design. Brake specific fuel consumption improvements of the pressure-reactive piston engine over baseline engine at light loads ranges from 8 to 18 per cent. The pressure-reactive piston shows higher heat transfer losses because of higher surface-to-volume ratio and produces higher hydrocarbon emission at part load owing to higher compression ratio and more crevice volume (piston crown design).

3.6 Moving the crankpins

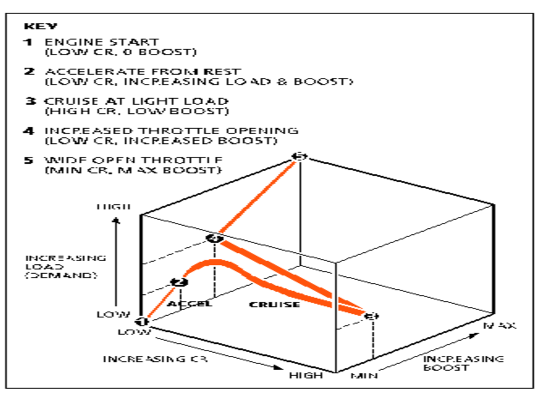
Gomecsys has proposed to move the crankpins eccentrically to effect a stroke change at TDC. Figure 3.6.1 shows the Gomecsys VCR engine in which moveable crankpins form an eccentric sleeve around the conventional crankpins and are driven by a large gear.

Fig 3.6.1. Gomecsys VCR Engine

Differences in the TDC position may vary up to 10 mm with a rotation of the ring-gear of only 40°. By rotating the ring-gear slightly to the right or to the left, while the crankshaft is at the TDC position at the end of the compression stroke, the position of the eccentric can be lifted or lowered. Note that lifting the eccentric at one TDC automatically causes the other TDC to be lowered accordingly. In order to effectively downsize the engine, a two-cylinder inline engine is a perfect solution for small cars; the two-cylinder Go Engine concept is small and lightweight, and total power train costs are comparable with a small four-cylinder engine. Applications involving staggered crankpin geometry would be less elegant, requiring multiple gear drives.

4. CONTROL STRATEGY FOR VCR

Fig 4.1 presents a 3-D representation of the Prodrive strategy for boost and CR response to variations in load (driver demand).



Points 1, 2, 4, 5 lie on the plane of low compression. Point 3 lies on the plane of high compression. The engine is started at low CR and zero boosts (point 1). When the driver accelerates, load and boost increase to point 2.When the driver throttles back into a light load cruise (point 3), load and boost reduce and CR increases. When the throttle is re-opened from this condition, CR reduces as boost and load increase, reaching point 4 and, ultimately, point 5 (WOT).For simplicity, the figure assumes only 2 available CR values (high and low). The same logic can be applied to intermediate values of CR by considering the transition between intermediate planes of CR.

5. BENEFITS OF VCR

Hence the important benefits of the VCR engine can be summarized as follows: —

1. Optimum combustion efficiency in the whole load and speed range.
2. Low fuel consumption and low exhaust emissions.
3. The VCR provides better control over pollutant generation and after-treatment than a conventional fixed compression ratio (FCR) engine, also extends the life expectancy of a three way catalytic converter.
4. As the geometrical volumetric ratio is under control on VCR engines, the engine always operates below the knock limit, whatever the load.
5. The VCR engine provides excellent fuel flexibility, since the compression ratio can be varied and adjusted to suit the properties of the fuel, and therefore the engine will always run at the compression ratio best suited to the fuel being used for bi-fuel (compressed natural gas (CNG)/gasoline) power-trains, the realization of VCR is of specific interest. High fuel flexibility, with optimal combustion efficiency.
6. Very smooth idle and full load accelerations are achieved.
7. It provides better indicated thermal efficiency than that of FCR engines.
8. It allows for a significant idle speed reduction because of reduced misfiring and cyclic irregularities, resulting in low vibration levels.
9. Reduction in low-frequency noise because of constant peak pressures.
10. Smoother combustion because the rate of heat release is the same (short) both at low and high compression ratios.
11. Cold starting emissions can be reduced greatly by early catalyst warm-up in the catalytic converter.
12. Improvement in the low end torque of a petrol engine without the risk of detonation.
13. Potential technology for future high-boosting super lean burn engines.
14. Low CO_2 emissions by down-sizing for the same power output.
15. Good idling performance at low ambient temperatures.
16. Constant frictional losses owing to almost constant peak pressures.

6. COMMERCIAL BARRIERS

Variable compression ratio engines have not yet reached the market, despite patents and experiments dating back over decades. Indeed, several prototypes of VCR engines and vehicles have been tested. In many cases, the deviation from conventional production engine structure or layout represents a significant commercial barrier to widespread adoption of the technology. Some of the commercial barriers are listed below:-

1. The available methods require major changes to the base engine architecture or layout and represent significant commercial barriers to widespread adoption of the technology.
2. Introduction of additional elements within the crowded combustion chamber environment threatens to compromise ideal geometry and layout of the valves and ports.

3. Engine-out emissions performance is likely to be undermined by additional crevice volumes which obstruct complete burning, thereby increasing hydrocarbon emissions.
4. There is a significant increase in reciprocating mass in the case of a variable height piston.
5. Some approaches lead to an increase in vibrations owing to intermediate members in the connecting rod.
6. In some cases, reworking of the entire engine structure is necessary.
7. Variable compression ratio designs consist of multilink rod-crank mechanisms, which may also present a near-to-sinusoidal motion unfavorable to cylinder filling at low speeds and fine-scale turbulence.

7. ECONOMICS OF VCR ENGINE

Choosing an appropriate VCR technology is a decisive step to determine the cost of VCR implementation in future vehicle. The different available VCR technologies have to be compared by focusing on all the positive and negative impacts on engine components and their operations. The benefits of VCR also include increased power density, reduced number of cylinders, sophisticated injection technologies, and complex after-treatment Indeed, to be marketable, the VCR technology has to present indispensable features such as robustness, durability, easy integration into all vehicles and low noise and vibration levels.

The real potential of VCR engines will be realized when they are used in combination with down-sizing and supercharging.

CONCLUSION

The VCR engine has great potential for improving part-load thermal efficiency, more efficient operation, ability to down size the engine, multi fuel flexibility. and reducing the harmful emissions. when compared to other competing technologies. 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.
The Potential of these technologies needs to be evaluated by a trade -off between cost and consumption benefit. It is potentially one of the profitable sources to investigate for the automotive industry.

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