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Design and Analysis of Variable Compression Ratio Connecting Rod

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Abstract: ***Making the variable compression ratio a magnificent innovation which is already generating fine results. The remains of this discovery are what we will strive to develop. The compression ratio plays a vital role in bringing the exceptional control over the engine's efficiency and performance. In the conventional I.C engines, the compression ratio remains fixed and its performance lays between the conflicting requirements. The most important aspect is that the drive units present in the vehicle should successfully operate at various speeds, loads and different conditions. In the SI engines, the variable compression ratio efforts the control over peak pressure of cylinder, improves the low load operation and cold start capability, which enables the multi fuel capability, increase of fuel economy, and emissions reduction. Hence, after the completion of this project, the VCR can be made as a key enabling technology of the future automobile industry.***

Keywords: VCR, Connecting Rod, Compression ratio, fuel economy.

I. INTRODUCTION

The variable compression ratio engine is nothing but altering the compression ratios of the engine depending on the conditions of the drive. Now-a-days, there are many alternative fuels coming in the market, but they are not in real time use because of their lack of efficiency in the fuels. Mainly the two wheelers need a smart engine where it can both reduce the fuel consumption and the emissions of the vehicle. In this type of Engine, there will be only two driving conditions, one at part load and other one at full load. At part load, the compression ratio of the engine will be higher i.e., 16:1 and at full load, the compression ratio will be low i.e., 8:1. The technology used in this engine will be a multi-link connecting rod. This connecting rod can be made to adjust at two different positions in the engine's chamber with the help of an actuating arm which will be controlled by the harmonic drive, whose inputs will be given by the ECU of the vehicle.[12]

At starting conditions i.e., at part load, the SI engines will have low speed and low power output and indeed low thermal efficiency which is inversely proportional to the fuel consumption. therefor efforts should be made to develop better engines so that the fuel consumption of the vehicle will be reduced and thus reducing the emissions of the vehicle.

On the other hand, when increasing the SI engine's compression ratio, there are lot of chances of auto-ignition. To avoid this detonation, the spark ignition is made advanced.[13]

So, to overcome these such problems, the Engine is made in such a way that, it will alter the compression ratio and the spark timing depending on the drive condition of the vehicle.

A. Compression Ratio

1. The compression quantitative relation may be a single range which might be accustomed verify the performance of any engine.[14]
2. The compression quantitative relation of an inside combustion engine is briefed because the relationship between the entire cylinder volume and the combustion chamber volume.[14]

$$\text{Compression ratio} = \frac{\text{TOTAL VOLUME}}{\text{CLEARENCE VOLUME}}$$

engines have a limit on the foremost pressure throughout the compression stroke, once that the Air-fuel mixture cascades inlet pressure.

Overall pressure ratio and compression ratio are interconnected as follows:

C.R	1:1	3:1	5:1	10:1	15:1	20:1	25:1	35:1
Pressure ratio	1:3	2:3	10:3	22:3	40:3	56:3	75:1	110:3

Table 1: Compression ratio and Overall pressure ratio

In typical engines, this compression ratio is mounted and ends up in compromise also with pressure ratio. However currently VCR technique will eliminate this compromise by varying the volume of the combustion chamber.[15]

B. Importance of VCR

The typical gasoline engines are designed in such a way that under full load conditions, no uncontrolled combustion i.e., knocking occurs which limits the combustion ratio. At the throttled conditions, the gasoline engine is under compressed which may reduce the engine efficiency. Gasoline engines are over compressed to increase the cold start ability.

The gasoline engines which are warmed up is also a lot of economical if they need lower compression ratio. Therefore, the variable compression ratio engines are often operated underneath completely different conditions to vary the engine compression ratio.[15] The internal combustion engines performance can be improved by various factors which has scope of improvement in the future.

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In those factors, one of the most promising factors is variable compression ratio engine according to the change in conditions.[17]
As the gasoline engines have low part load efficiency compared to the diesel engines, some technology must be developed for improving the fuel efficiency of gasoline engines to get higher efficiency with low fuel consumption in all working loads which can be achieved by variable compression ratio.
The sources of inefficiencies or losses within the spark ignition combustion engines are given in Table 2, wherever many technical solutions are associated with minimize those losses. The table conjointly shows the method those technologies will improve engine performance by reduction of the referred losses.[15]

9	CVCR	VVA	Turbocharging	Water injection	Over expansion	downsizing	Turbulence Generation
pumping		✓	✓		✓	✓	
Friction						✓	
Exhaust to Ambient	✓	✓	✓	✓	✓	✓	
Crevice effects and leakage	✓					✓	
Incomplete combustion	✓			✓			✓
Exhaust blow Down	✓	✓	✓		✓		
Heat Transfer				✓	✓	✓	✓

Table 2: Methods those improve Engine performance

C. Con rod linkages:

It is one of the most famous way of VCR engine. It is made to change the normal conventional con rod and to replace it with two-piece con rod where the upper part of the con rod is connected to the piston and the lower part of the con rod is connected to the crankshaft. Because of the shorter crank throw, the link system which is operated by an eccentric actuator can be enclosed in that free space.[18]

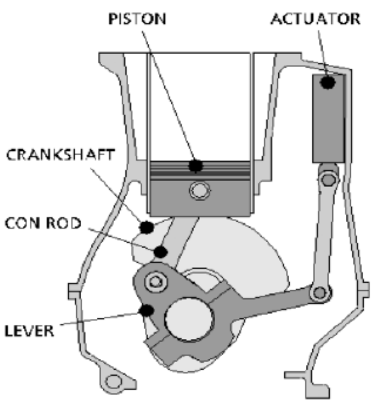

Fig.1 Peugeout VCR Engine

D. Varying the HEIGHT OF PISTON DECK

The Daimler-Benz VCR piston model gives the change in the compression height of the piston and it also offers significantly the best route to production of many VCR engines, because it only requires a minor change in the basic engine's architecture when compared to other various options.

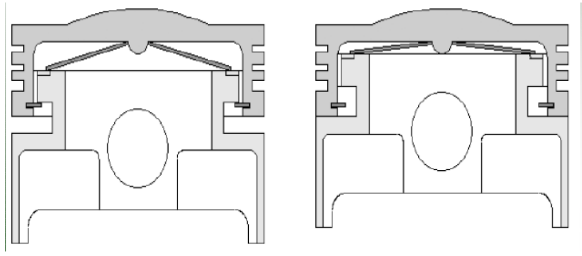

Fig.2 Ford VCR Piston

E. Varying the combustion chamber volume

The variation of combustion chamber can be done by using a secondary piston. The piston is placed at an intermediate position which corresponds to optimum compression ratio for a particular condition. The compression ratio is reduced when the combustion chamber volume is increased which can be done by moving the small secondary piston in which it will communicate with the combustion chamber.

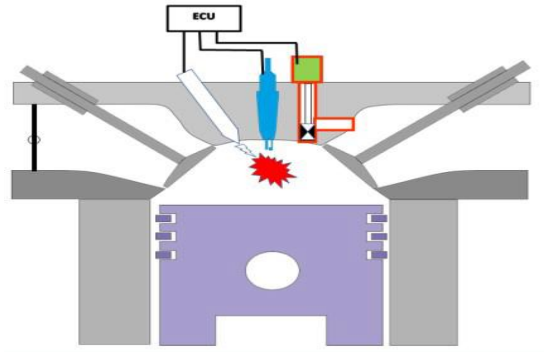

Fig.3 VCR Combustion chamber volume

F. Moving the crank shaft axis

In this type, the eccentric mounted carrier carries the crankshaft bearings that can rotate to raise or to lower the pistons top dead center (TDC) in the cylinder. The compression ratio can be adjusted by just altering the rotation of the eccentric carrier.

Fig.4 Geomesys VCR Engine

G. Locomote the cylinder head

The idea of moving cylinder head results in combining the cylinder head and liners into single mono block construction, in which it pivots according to the remaining part of the engine.

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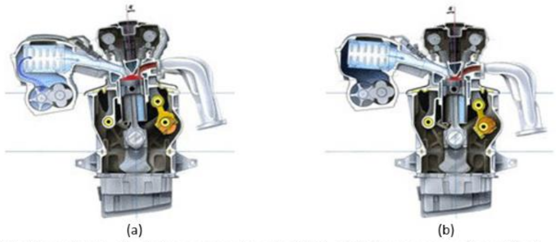
The SAAB has incorporated a tilt in motion to alter the height of the piston head at TDC. so as to vary the TDC position of the piston, the linkage tilts the monohead several to the housing. By exploitation the mechanism and also the linkage mechanism, the compression quantitative relation is altered from 8 to 14.



• Working principle of variable compression ratio (VCR) a) minimum compression ratio of 8:1 b) maximum compression ratio of 14:1.

Fig.5 SAAB VCR Engine

II. LITERATURE REVIEW

Savita Tomar el at [1] explains about attaining the Variable compression ratio using the connecting rod which is comprised with pistons in the connecting rod and how the variable compression ratio can be attained with respective to less fuel consumption and less emissions. It concludes that variable compression ratio is efficient in operation, flexibility in fuels, to enable down size of engine and to control the emissions with the variable length connecting rod.

Martyn Roberts at [2] thought of Probable aids of VCR spark ignition engines are presented, based on an inspection of the association between Brake mean effective pressure(BMEP), Compression Ratio and spark advance at low load and heavy load. Utterly other ways of executing VCR are Showed and inspected.

GVNSR Ratnakara Rao [3] passed out trials on a one cylinder four stroke variable compression ratio diesel engine to get finest compression ratio. Trials were dispensed out at compression ratios of 13.2, 13.9, 14.8, 15.7, 16.9, 18.1 and 20.2 results on thermal efficiency because of varied compression ratios are strategized on graph.

Ibraheem Raza Khan et al [4] In this paper, he studied about the variable compression ratio and the advantages of using a variable compression ratio engine. He mainly described about the type of VCR engines out there and about the principles and characteristics of the engines.

Radivoje B. Pesic et al [5] Reviewed about the variable compression ratio engine with diesel as its fuel. He made a conclusion that a VCR engine has the potential to increase the efficiency of the combustion and to reduce the emissions by Changing the load and speed conditions. He also concluded that high compression ratio increases the thermal efficiency but decreases the mechanical efficiency. The pressure in the cylinder and the mechanical loses will increase with increase in the both engine load and compression ratio.

Somnath Chattopadhyay et.al [6] A connecting rod is one in all the foremost automatically stressed parts in internal combustion engines. The target of the activity is to pick the acceptable material for a rod wherever the constraints are to create the product as lightweight and low as possible and yet strong enough to hold the height load while not failure in high cycle fatigue. The fracture toughness additionally must be on top of a minimum worth. An extra demand is that the connecting rod mustn’t buckle throughout operation. These constraints are wont to choose associate applicable cross section and material for construction.

Karsten Wittek et.al[7] His work showed results of a production engine to that a 2-stage Variable Compression Ratio (VCR) system was applied. The engine had minor modifications, remaining well original. The engine was tested with compression ratios of 9.56:1 and 12.11:1 through associate engine operational map up to 4000 revolution per minute whereas fueled with regular RON 95 fuel at ratio operation.

Ashok M.P et.al 2007[8] The work deals with figuring of a good compression ratio for the C.I engine at variable load and constant speed operation. The compression ratio of an external combustion engine or internal combustion engine can be a value that signifies the ratio of the total volume to clearance volume. It’s an essential condition for numerous common combustion engines. Experimental results showed that there’s a tiny in brake power, brake thermal and specific fuel consumption efficiency when put next with diesel. Moreover, it entirely was resulted that there’s a decrease in smoke, oxides of the chemical element, unburned organic compound, CO and ignition delay together with increase in greenhouse gas.

Mahesh Nikam [9] This project is to analyze the compressive stress acting on functioning on rod at completely different loading condition and to explore weight reduction opportunities for a production solid steel connecting rod. Foremost a correct Finite Element Model is developed using software CATIA V5. Then the FEA is done to determine the stresses in the existing connecting rod for the given loading conditions using FEA software. Supported on the observations of the static FEA and also the load analysis results, the load for the improvement study was elite.

Anil kumar [10] He worked on the optimization in weight and scale back the inertia force on the prevailing connecting rod, by changing some variables. The load of the rod was conjointly reduced by 0.004 kg which wasn’t important however reduces the inertia forces. Fatigue strength plays the fore most important role (design driving factor) with in the optimization of this rod. Optimization was performed to cut back weight of the prevailing rod. This optimization even be achieved by changing the forged steel rod into other materials like as C-70 steel etc.

A. Benefits of a VCR engine:

Once the fuel / air mixture detonates instead of burns, the gasoline engines have a limit on the most pressure throughout the compression stroke. A high portion of fuel should be burned in order to understand higher power outputs at the same speed, and so a lot of air is required. In order to do this, superchargers or turbochargers are used to increasing the inlet pressure.

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This could lead to air - to - fuel mixture detonation unless the compression ratio is lowered, i.e. the volume higher than the piston created bigger. This will be done to a more significant or lesser extent with a massive increase in power being doable. The downside of this may be that the engine may lack power and torque under light weight loading. The answer is that the inlet pressure can be changed and the compression ratio adjusted to the appropriate value.[14]

This gives the simplest of worlds, but a small economic engine that acts precisely as a popular family engine turns on demand into an extremely tuned one. The Variable Compression Ratio (VCR) is becoming more fascinating as the cost of oil increases and the interest of car consumers in fuel economy increases. In addition, the international community needs action on global climate warming. It means more stringent limits on the emissions of cars, mainly carbonic acid gas. One way to achieve these goals effectively is the variable compression ratio. Furthermore, VCR allowsthe free use of different fuels in addition to gasoline, e.g. Ethanol or LPG. The cylinder head is changed using a mechanism that is connected to the crankshaft and responds to the load and acceleration required.[14]

B. External energy is not required:

The VCR system depends on forces and moments associated with the piston movement to regulate the eccentric for altering of compression ratio. With its distinctive style, as well as two hydraulic pistons at intervals a corresponding chamber, the FEV system achieves CR transition at intervals 0.2 to 0.5 seconds.

III. DESIGN METHODOLOGY

The VR/LE consists of following:

1. Piston
2. Connecting rods
3. Crankshaft
4. Eccentric sleeve (barrel)
5. Crank pin

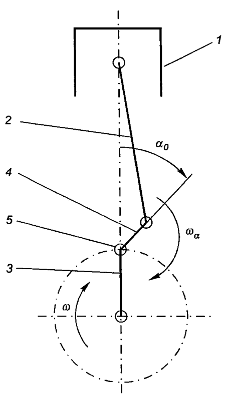

Fig.6.1
Engine Crank Mechanism

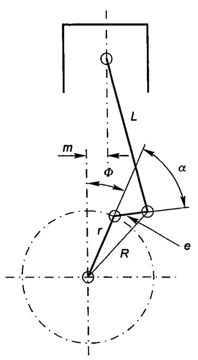

Fig.6.2
Engine General Kinematics

Eccentric sleeve is placed between crank pin and connecting rod.

The compression ratio adjustment is obtained by the angular shift α° of the eccentric with respect to crank pin. The α_0 phase angle is measured at the position of crank parallel to cylinder axis. The α_0 phase angle can be varied in the range 0 to 360. It can be performed irrespective to continuous rotational motion of the eccentric ω_α.[16]

C. Geometric relations

The piston motion (Fig.6) is described by the following general equation:

$$x = \left[\left(1 \div \frac{1}{2} \div \sigma\right)^2 - \zeta^2\right]^{\frac{1}{2}} + \\ -\frac{1}{\lambda}\sqrt{1-\lambda^2[(\sin\phi)+\sigma\sin(\alpha_t+\phi)-\zeta)]^2} \div \\ -[\cos\phi+\sigma\cos(\alpha_t+\phi)] \quad (1)$$

Where x- Piston displacement from top dead centre(TDC),Φ-Crank angle and λ,σ and ζ are the following dimensions parameters:

$$\lambda=\frac{r}{l}, \ \sigma=\frac{e}{r}, \ \zeta=\frac{m}{r} \quad (2)$$

For zero cylinder azis cylinder axis offset(m=0),equation(1) can be simplified as follows:

$$x = r\left\{\frac{1}{\lambda^2} - \sqrt{\frac{1}{\lambda^2} - [\sin\phi+\sigma\sin(\alpha_t+\phi)]^2} + \sigma[1 - \\ \cos(\alpha_t+\phi)] - \cos\phi + 1\right\} \quad (3)$$

The actual eccentric angular displacement (α_t) is the sum of two angles:

$$\alpha_t = \alpha_0 + \alpha \quad (4)$$

where the angle α results from the turning motion of the eccentric with respect to the crankpin, with the angular velocity ω_α.[16]

D. Eccentric rotational speed

The three eccentric rotational speeds can be considered: $\pm\frac{1}{2}\omega$

Case I: ω_α=0, therefore α=0,$\alpha_t = \alpha_0$

In this case, eccentric does not rotate, and compression ratio can be adjusted with respect to the changing phase angle. As in this case, eccentric does not rotate as per crank pin. So, only solution of adjusting phase angle is not feasible due to lubrication and wear problems.

$$x=7.213*10^{-4}\text{m}$$

Case II: ω_α=:$\pm\frac{1}{2}\omega$

In this case, eccentric rotates as per crank pin where the velocity is half to that of crankshaft. The eccentric rotation sense can be determined by plus and minus signs. The actual crank radius continuously changes due to eccentric rotational n=motion. This leads to the change in TDC piston position and the length of every stroke of piston.

This implies that, engine thermodynamic cycles differ for various phase angles. [16]

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Φ	α_t	x(m)
45^0	67.5^0	0.0166
50^0	67.5^0	0.0196
55^0	67.5^0	0.0225

Table 3: x values at different Crank angle and constant α_t

Φ	α_t	x(m)
45^0	22.5^0	$5.129*10^{-3}$
50^0	22.5^0	$5.972*10^{-3}$
55^0	22.5^0	$6.815*10^{-3}$

Table 4: x values at different Crank angle and constant α_t

In this case III: ω_α= :$\pm\omega$
eccentric rotates as per crank pin where the velocity is equal to that of crankshaft. This can be practical in application to slow speed engines, but it can create problems to high speed engines with designing the eccentric driven mechanism.

Φ	α_t	X
45^0	90^0	0.01195
50^0	90^0	0.00837
55^0	90^0	0.00907

Table 5: x values at different Crank angle and constant α_t

Φ	α_t	X
45^0	0	$4.23*10^{-3}$
50^0	0	$5.04*10^{-3}$
55^0	0	$6.40*10^{-3}$

Table 6: x values at different Crank angle and constant α_t

The above design methodology and calculations are taken as reference in the designing of the variable compression ratio connecting rod.

IV. CONNECTING ROD DESIGN

I. Principle:

A connecting rod which is moved by eccentric gudgeon pin suspension in which it takes its forces as input from the crank train to move the pistons in the connecting rod. This phenomenon is called as variable connecting rod. The pistons in the connecting rod are moved by using hydraulic pressure where super imposed gases will be used to give pressure to the pistons to move up and down.[4]

II. Construction of Connecting rod:

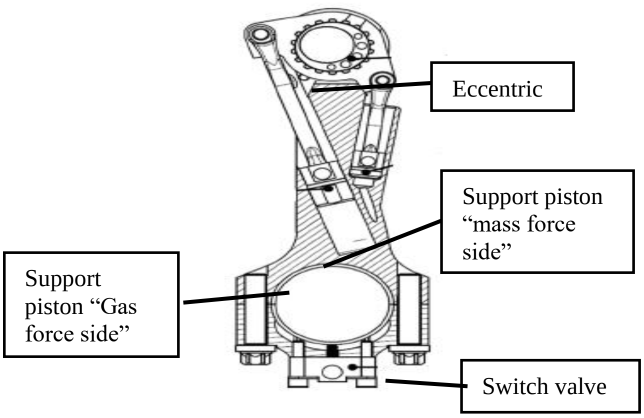

Fig.7 VCR Connecting Rod front view

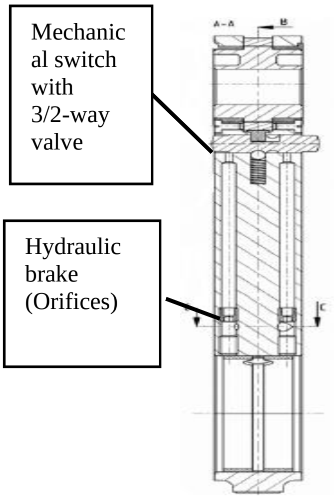

Fig.8 VCR Connecting Rod side view

III. Working:

There will be one piston each on each sides of the connecting rod, where they are embedded in the connecting rod. These pistons can be made to move because of hydraulic pressure by using oil. The two hollow chambers are having connection with the oil passages with one check valve each. The passage of oil can be released into the crankcase by using a 3/2 check valve which is located at the bottom of the small end of the connecting rod. This will result one piston to move more into the hollow chamber so that by doing so, the other hydraulic chamber is being filled with the oil. The eccentric can only be rotated in single direction. The mechanical switch i.e., the 3/2 check valve can be operated as a switch so the eccentric can be made to move in reverse direction. By actuating the two cams in such a way that the valve is moved either to lower compression or higher compression. This actuation phenomenon can take place within one engine revolution. In this way the compression ratios of high and low can be attained.[4]

IV. SOFTWARE DESIGN CONNECTING ROD:

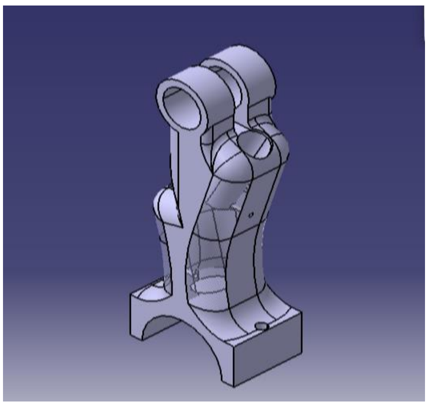

FIG.9 CONNECTING ROD

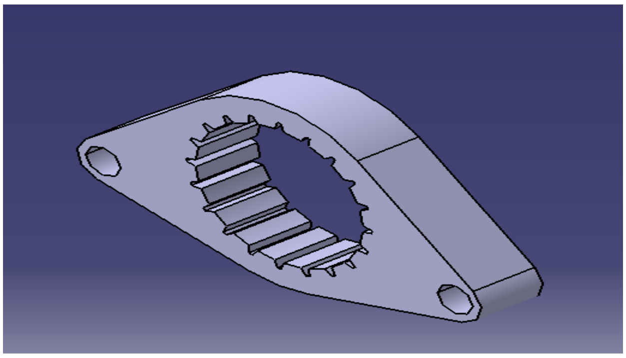

Fig.10 Eccentric Bush

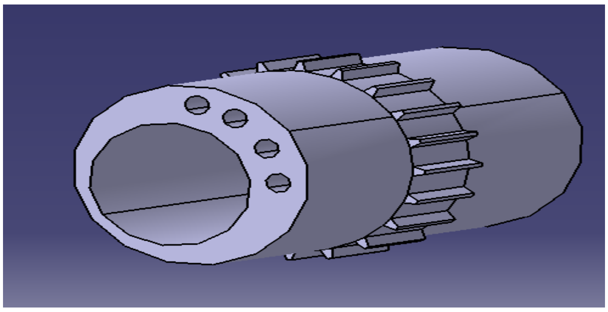

Fig.11 Eccentric Ring

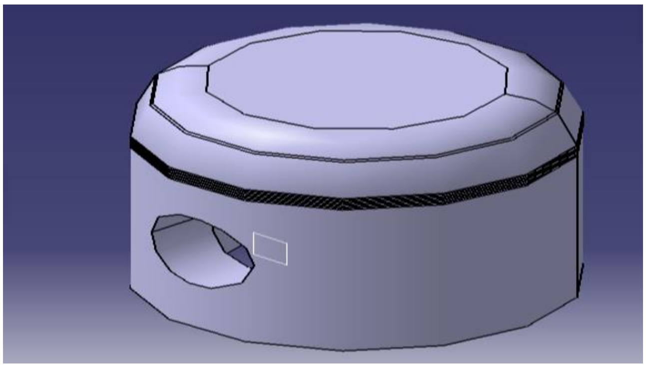

Fig.12 Supporting Piston

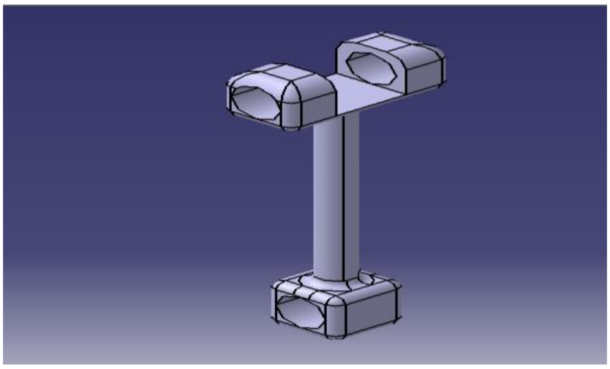

Fig.13 Supporting Connecting Rod

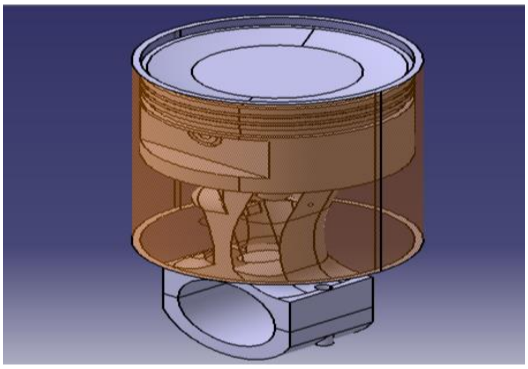

Fig.14 3D assembly of VCR Connecting Rod

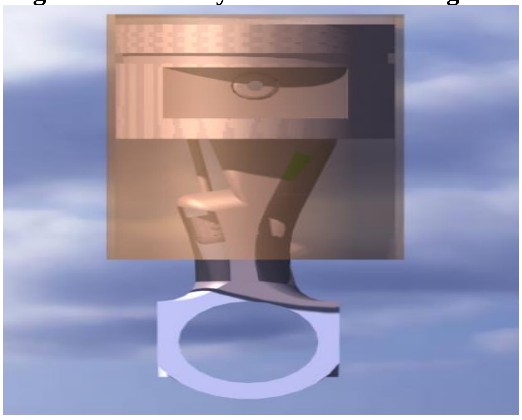

Fig.15 Front view of VCR Connecting Rod

V. RESULTS:

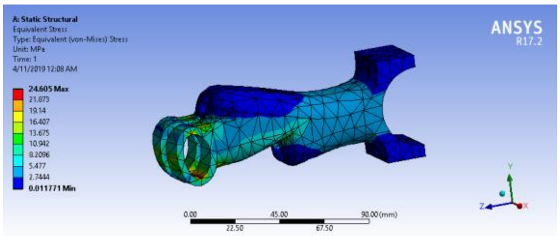

Fig.16 Equivalent stress of Connecting Rod

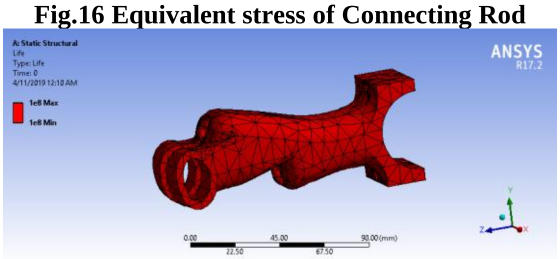

Fig.17 Fatigue (life) of Connecting Rod

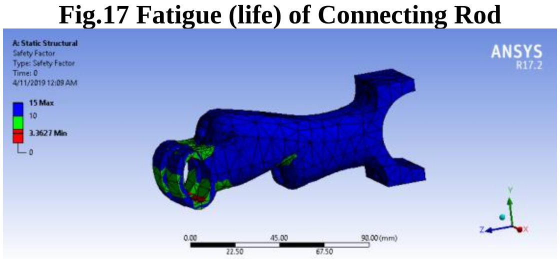

Fig.18 Fatigue (safety factor) of Connecting Rod

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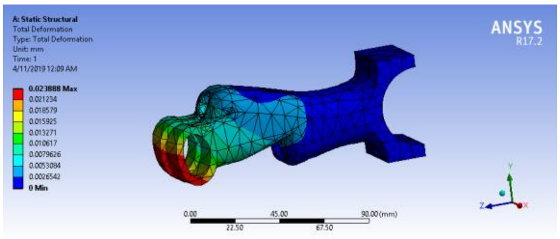

Fig.19 Total deformation of Connecting Rod

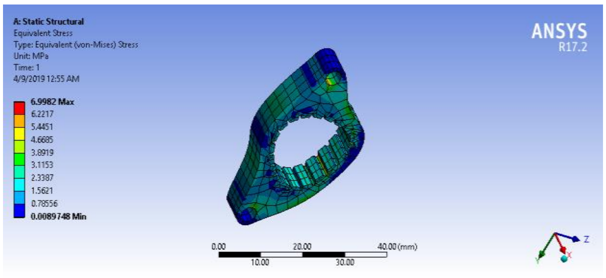

Fig.20 Equivalent stress of Eccentric Bush

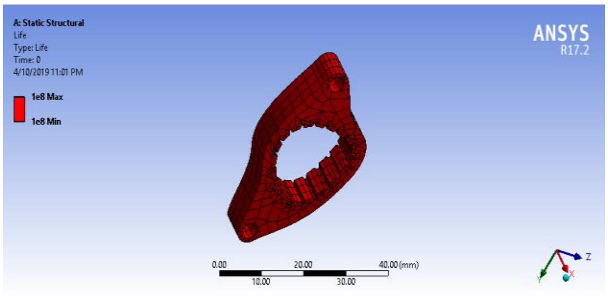

Fig.21 Fatigue (life) of Eccentric Bush

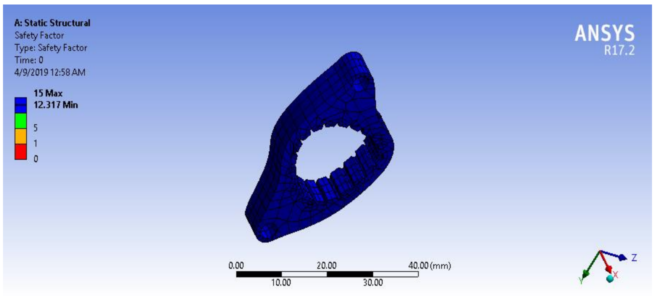

Fig.22 Fatigue (safety factor) of Eccentric Bush

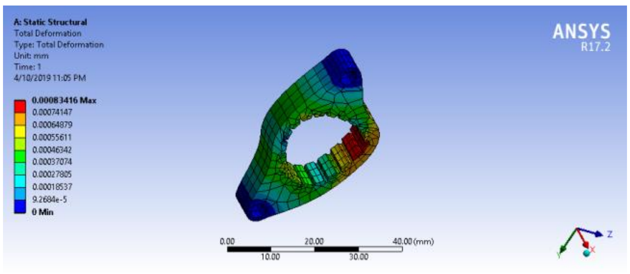

Fig.23 Total deformation of Eccentric Bush

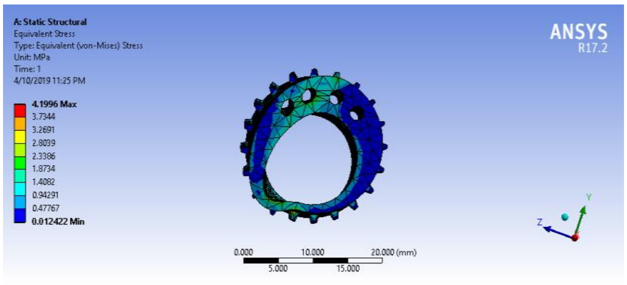

Fig.24 Equivalent stress of Eccentric Ring

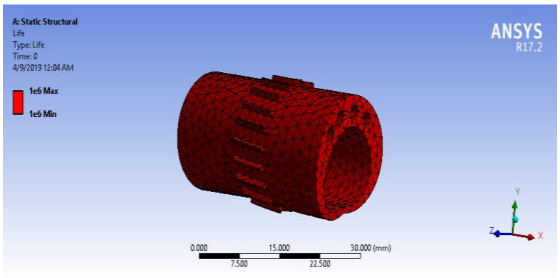

Fig.25 Fatigue (life) of Eccentric Ring

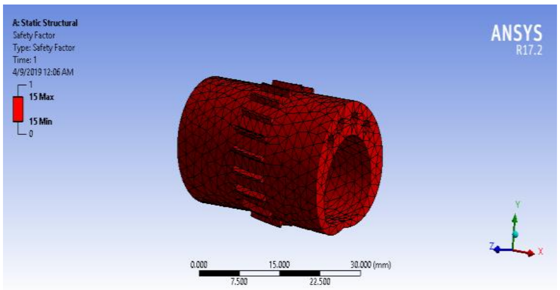

Fig.26 Fatigue (safety factor) of Eccentric Ring

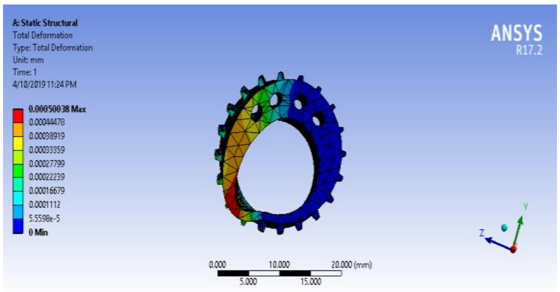

Fig.27 Total deformation of Eccentric Ring

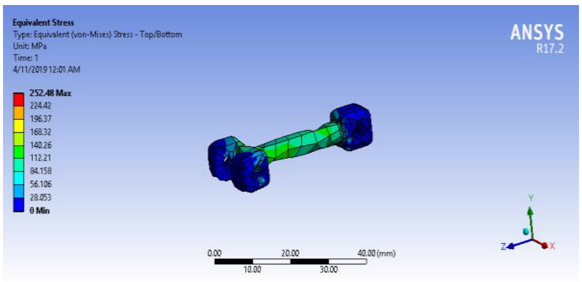

Fig.28 Equivalent stress of Supporting Connecting Rod

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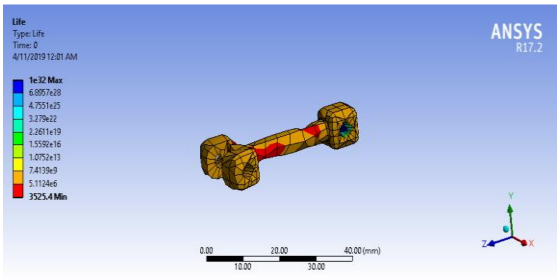

Fig.29 Fatigue (life) of Supporting Connecting Rod

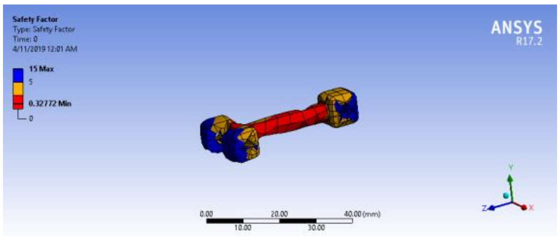

Fig.30 Fatigue (safety factor) of Supporting Connecting Rod

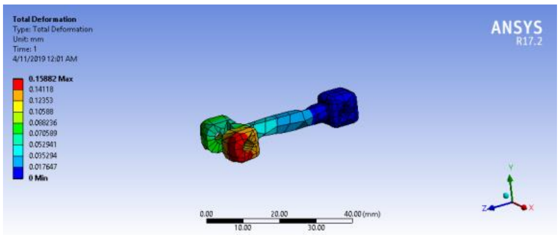

Fig.31 Total deformation of Supporting Connecting Rod

	Equivalent Stress (MPA)		Total Deformation (mm)	
	Max	Min	Max	Min
Connecting Rod	24.605	0.01171	0.023888	0
Eccentric Bush	6.9982	0.008974	0.00083416	0
Eccentric Ring	4.1996	0.012422	0.0005003	0
Supporting Connecting Rod	252.48	0	0.15882	0

Table 7: Results of Static Structural Analysis-Equivalent Stress and Total Deformation

	Fatigue Life		Fatigue Safety factor	
	Max	Min	Max	Min
Connecting Rod	1e8	1e8	10	3.3627
Eccentric Bush	1e8	1e8	15	12.317
Eccentric Ring	1e6	1e6	15	15
Supporting Connecting Rod	1e32	3525.4	15	0.32772

Table 8: Results of static structural Analysis -Fatigue life and Fatigue Safety Factor.

Based on design methodology of varying the compression ratios, a static study analysis is done on individual components of newly developed con rod. In Table 7 and Table 8 shows the Static Structural Analysis of each component and observed that the values of each component are with in considerable range based on the material properties and other parameters.

VI. CONCLUSION

Variable compression ratio engine is one of the best ways to attain fuel efficiency and to reduce the emissions. In this paper we have referred to a design methodology of VCR system, based on which we have observed the similar changes in compression ratio which could enhance the fuel efficiency and improve the emission capabilities of the vehicle. As there is no separate linkage attached to the connected this design model could preferably provide better mechanism to vary the compression ratio. The analysis of the developed model provides the enough proof the holding the enough loads generated by from the combustion chamber. For the connected no addition of a connecting rod is designed in such a way that it is comprised with hydraulic pistons on each side which can attain different two stage compression ratios. The connecting rod with this efficient design can be used in normal engines with slight modification of the engine. The VCR jointly provides additional potential for managing the temperature of the exhaust gas to help protect the temperature of the component. The performance associated with an engine's efficiency with a compression ratio that is related to load demands can reduce the susceptibility to knock under full load conditions.

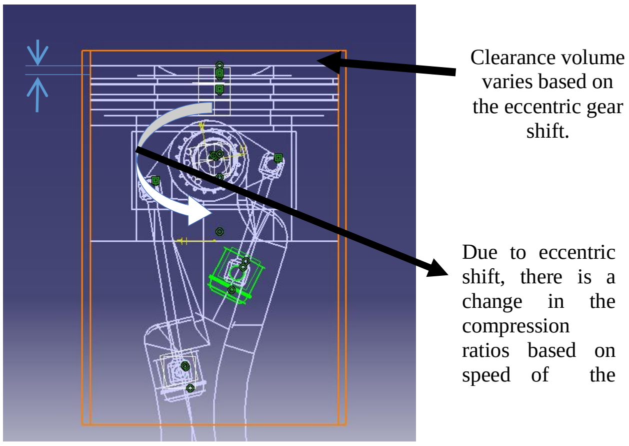

Fig.32 Identification of change in CR using new connecting rod

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