Method of achieving Variable Compression Ratio in Internal Combustion Engine

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Abstract - *Engines are widely used to convert chemical energy into mechanical energy for power generation. They can be classified into Spark Ignition and Compression Ignition Engines based on the nature of combustion. In both engine types, air-fuel mixture is compressed before ignition, and the compression ratio determines the extent of compression. Higher compression ratios generally result in increased power output.*

While several parameters such as fuel-air ratio, valve timing, and spark timing can be controlled to enhance engine performance, there are limited options for dynamically adjusting the compression ratio during engine operation. This research aims to develop a method for modifying the compression ratio of an engine to achieve optimal performance.

The proposed approach involves connecting the piston to a primary connecting rod, which, in turn, connects to a first slider joint. The crankshaft is connected to a secondary connecting rod, which is linked to a second slider joint. Both slider joints can slide along a pivoted slider arm, enabling adjustment of the leverage around the pivot point.

By employing this variable compression ratio method, it becomes possible to achieve various performance and emission improvements in the engine. Additionally, a single engine can accommodate the combustion of different fuel types such as petrol, diesel, CNG, and hydrogen, among others.

Key Words: Variable Compression Ratio, Constant Clearance Volume, Internal Combustion Engine, Linkage Mechanism, Kinematic Simulation.

1. INTRODUCTION

Engine converts various forms of energies into mechanical power and enables the mobility and transportation. Engines are categorized based on the parameters like type of combustion, fuels being used, etc. Achieving efficient and clean energy conversion has always been a challenge while improving the performance of engine. Multiple parameters like spark timing, air-fuel ratio, valve timing etc., are explored in the research work done by many researchers to improve performance and reduce emissions from engine. Compression ratio is one of the significant parameter which greatly influences the performance and emissions of Spark Ignition (SI) and Compression Ignition (CI) engines. Compression ratio describes the ratio of cylinder's total volume when the piston is bottom-most position with the clearance volume when the piston is at top-most position. With the help of higher compression ratio in engine, it is possible to extract maximum energy from fuel during the combustion process and thermal efficiency can be improved. Fuel consumption can be reduced, and desired combustion temperatures can be achieved with the help of optimum compression ratio. Also expansion cycles can be extended, mechanical power output can be increased, and exhaust temperatures can be lowered by optimizing compression ratio.

Gasoline fuel is used in SI engine, and it is described with the parameters like Octane number, which is measurement of fuel's resistance to detonation or preignition inside the engine.

Higher-octane fuels exhibit greater resistance to autoignition under higher combustion pressure and heat. Similarly, the cetane number measures the combustion quality of diesel fuel or the ignition delay. Higher cetane numbers indicate shorter ignition delays and better fuel quality. Both gasoline and diesel fuels exhibit variations in performance and emissions depending on the compression ratio. However, the conventional construction of engines imposes limitations on achieving a variable compression ratio suitable for a variety of fuels. The fixed linkage of the connecting rod between the piston and crankshaft using rotary joints at both ends restricts the piston's travel to the rotation of the crankshaft, resulting in a constant compression ratio.

Overcoming the challenges posed by conventional engine construction, a few attempts have been made to achieve a variable compression ratio. These attempts include altering the piston stroke using hydraulic or electric actuators within the connecting rod, dynamically adjusting the piston-to-crankshaft distance, modifying the cylinder or piston height, among others. However, no attempts have been observed to achieve a constant clearance volume while varying the piston position to achieve the desired compression ratio with or without continuous changes in the distance between the piston and crankshaft.

This research presents a novel method for achieving variable compression ratio in engines, thereby maximizing performance and increasing compatibility with a variety of fuels. Proposed construction of mechanism includes existing piston and crankshaft configuration, with the connecting rod divided into three components which are primary connecting rod, slider arm, and secondary connecting rod. Compression stroke of the piston can be varied by adjusting the position of slider arm which enables the desired compression ratio. Wide range of performance and emission variations can be achieved from the engine by using this method for adjusting compression ratio. Also with the help of varying compression ratio, a single engine can facilitate the proper and efficient combustion of various fuel types such as petrol, diesel, compressed natural gas (CNG), hydrogen, etc.

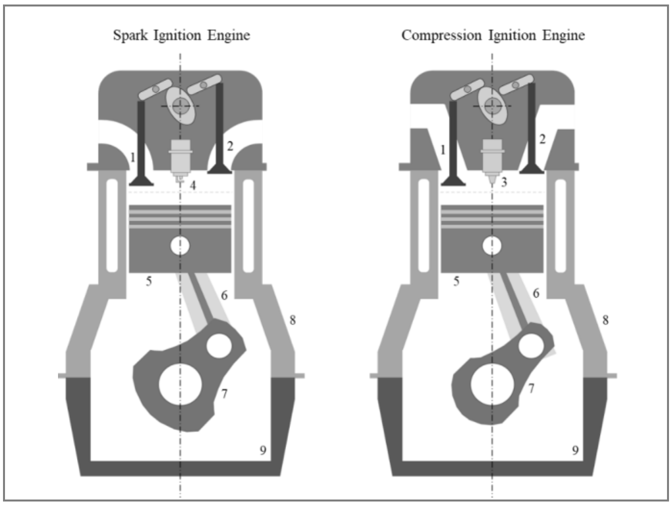

Fig -1: Construction of Conventional SI and CI Engine

Table -1: Components in Fig 1

Sr.No.	Name of Component
1.	Inlet Valve
2.	Exhaust Valve
3.	Fuel Injector
4.	Spark Plug
5.	Piston
6.	Connecting Rod
7.	Crankshaft
8.	Engine Housing
9.	Oil Sump

2. METHODS

2.1 An Outline of the Methods

Dedicated arrangement is provided between the piston and crankshaft to achieve a variable compression ratio in an internal combustion engine. This arrangement can selectively adjust the piston's bottom dead center position while ensuring that the clearance volume at top dead center position remains consistent across achieved compression ratios. Maintaining a constant clearance volume while changing compression ratios is necessary to meet specific combustion process parameters and to avoid issues like knocking, etc.

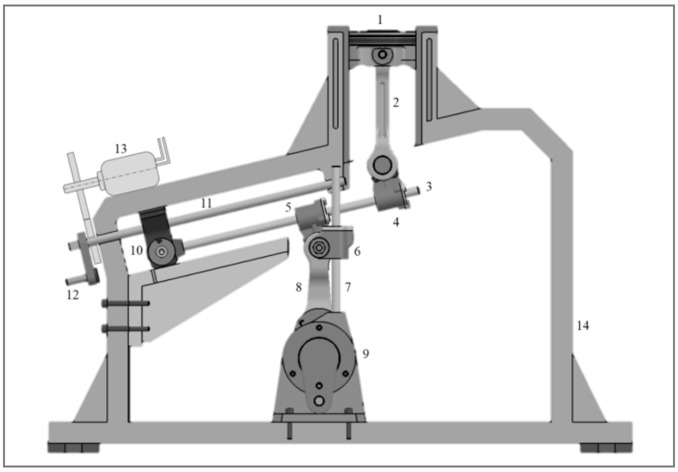

Fig -2: Mechanism to achieve Variable Compression

Table -2: Components in Fig 2

Sr.No.	Name of Component
1.	Piston
2.	Primary Connecting Rod
3.	Slider Arm
4.	Slider Joint 1
5.	Slider Joint 2
6.	Slider Joint 3
7.	Vertical Guide
8.	Secondary Connecting Rod
9.	Crankshaft
10.	Slider Pivot Assembly
11.	Leadscrew
12.	Handle Lever Assembly
13.	Motor
14.	Engine Housing frame

2.2 Major components of the Mechanism

1. Piston: In this design, the piston is similar to conventional pistons, but with an anti-rotation feature for the piston pin. This prevents any rotation between the piston and piston pin, creating a rigid joint with the connecting rod. Unlike conventional construction, there is no rotary joint between the connecting rod and piston.

2. Primary Connecting Rod: Unlike conventional engine construction with a single connecting rod, this design incorporates multiple connecting rods. It features a primary connecting rod connected to the piston and a secondary connecting rod linked to the crankshaft. This arrangement allows the connecting rod to move in a straight line concentric to the piston/cylinder due to a rigid joint connection.

3. Slider Arm: The slider arm, connected to both the primary and secondary connecting rods through slider joints, facilitates the transfer of motion between the piston and crankshaft. With a pivot end assembly on one end, the slider arm can rotate in the plane of piston movement, enabling efficient operation.

4. Slider Joint 1: Slider Joint 1 incorporates a linear bearing that allows it to slide along the slider arm. This joint ensures the primary connecting rod can move vertically in a linear manner, unaffected by the rotational motion of the slider arm.

5. Slider Joint 2: Slider Join 2 is also equipped with linear bearing which slides on Slider Arm and also connected to Secondary Connecting Rod. The purpose of the Slider Joint 2 is to maintain the linear vertical movement of the Secondary Connecting Rod irrespective of the rotary motion of the Slider Arm.

6. Slider Joint 3: Slide Joint 3 is also equipped with linear bearing and slides on Vertical Guide which helps to maintain linear vertical movement of the Secondary Connecting Rod.

7. Slider Pivot Assembly: Slider Pivot Assembly is connected to Slider Arm and able to slide between the channels created in Engine Housing frame. Slider Pivot Assembly allows Slider Arm to rotate in a plane of Piston movement with the help of rotary joint. Slider Pivot Assembly got internal threading and is mounted on Leadscrew which can move it forward and rearward.

8. Leadscrew: Leadscrew is a threaded pin which is mounted with reference to Housing and can move the Slider Pivot Assembly forward and rearward with the help of screw type connection. Leadscrew may be equipped with handle lever for manual operation or gear motor connection for electrical operation.

9. Vertical Guide: Vertical Guide is installed in Engine Housing frame and provide guiding direction to Secondary Connecting Rod with the help of Slider Joint 3.

10. Secondary Connecting Rod: Secondary Connecting Rod is connected to Crankshaft as per conventional construction and also connected to Slider Joint 2 and 3 using rotary joint. Slider joint 2 transfers the motion received from Slider arm to Secondary Connecting Rod and vice-versa. Slider Joint 3 guides the Secondary Connecting rod along the direction of Vertical Guide.

11. Crankshaft: Crankshaft is similar to conventional crankshafts except the stroke is optimized to suit the Variable compression ratio and packaging requirements of mechanism.

12. Engine Housing frame: Engine Housing frame provides rigid framework for the functioning of whole mechanism. It includes cylinder for guiding of Piston, provides sliding arrangement for Slider Pivot Assembly, location for leadscrew, location for vertical guide and provides mounting arrangement for crankshaft like conventional construction.

2.3 Experimental Procedure

3D CAD software is using for preparing and simulating the CAD model. For Kinematic Simulation following are the steps used

1. Create Mechanism

    a. Create Joints: Joints define the type of movement expected between two parts

        i. Rigid joint connection is applied to all stationary parts

        ii. Revolute joint connection is given between Crankshaft and Housing, Crankshaft and Secondary Connecting Rod, Connecting Rod and Slider Joint 2, Slider Pivot assembly and Slider Arm, Slider Joint 1 and Primary Connecting Rod, Leadscrew and Engine Housing.

        iii. Cylindrical joint connection is given between Slider Joint 2 and Slider Arm, Slider Joint 1 and Slider Arm, Piston and Engine Housing, Slide Joint 3 and Vertical Guide, Slider Joint 3 and Secondary Connecting Rod, Leadscrew and Slider Pivot Assembly.

    b. Provide Commands: It defines the amount of movement expected in Joints

        i. Command 1 is given for Crankshaft rotation to allow it rotate in 360deg

ii. Command 2 is given for linear movement of Slider Pivot Assembly with respect to Leadscrew. It is specified from -100 to 100mm and 0 is the initial position

iii. Command 3 is given between Piston Pin and Primary connecting Rod to allow it for rotational displacement. 0deg position is maintained throughout the simulation

iv. Command 4 is given to Handle lever assembly which is connected to Leadscrew. It allows rotation of the Handle lever and Leadscrew with respect to the Engine Housing.

After defining the Joints and Commands if Degree of Freedom is 0 then only Mechanism can be simulated.

2. Edit Simulation

a. For Simulation 1 which is for Lower Compression Ratio, Command 1 is kept with value 0 which is initial position of Slider Pivot Assembly and then saved as Position 0 of Simulation. Then Command 1 value is modified to 360 and then it is saved as Position 1. Command 2, 3 and 4 is kept with value 0 throughout the simulation which specifies the Initial position of Slider Pivot Assembly, Vertical alignment of Primary Connecting Rod and Bottom position of Handle Lever respectively.

b. For Simulation 2 which is for showing the movement Slider Pivot Assembly using Leadscrew. Hence Command 2 is kept with value 0 and Command 4 is kept with value -360 for showing the initial position of Slider Pivot Assembly and initial position of Handle Lever assembly. This is saved as Position 0 of simulation. Then Command 2 is modified to value 100 and Command 4 is modified to value 360 and then saved as Position 1 of Simulation. Other Commands like 1 and 3 is kept with constant value of 0 for showing the Top Dead Center position of Piston and Vertical alignment of Primary Connecting Rod.

c. For Simulation 3 which is for Higher Compression Ratio, Command 2 is modified with value 100 to define the forward position of Slider Pivot Assembly and kept constant. Command 1 is kept with value 0 which is initial position of Slider Pivot Assembly and then saved as Position 0 of Simulation. Then Command 1 value is modified to 360 and then it is saved as Position 1. Command 3 and 4 is kept with value 0 throughout the simulation which specifies the Vertical alignment of Primary Connecting Rod and Bottom position of Handle Lever respectively.

After defining the initial and final step of the simulation it can be simulated to demonstrate expected movement of the components. For running the simulation Loop mode is kept on continuous mode for running it continuously and Interpolation step is defined as 0.01 to achieve slow and understandable results of simulation.

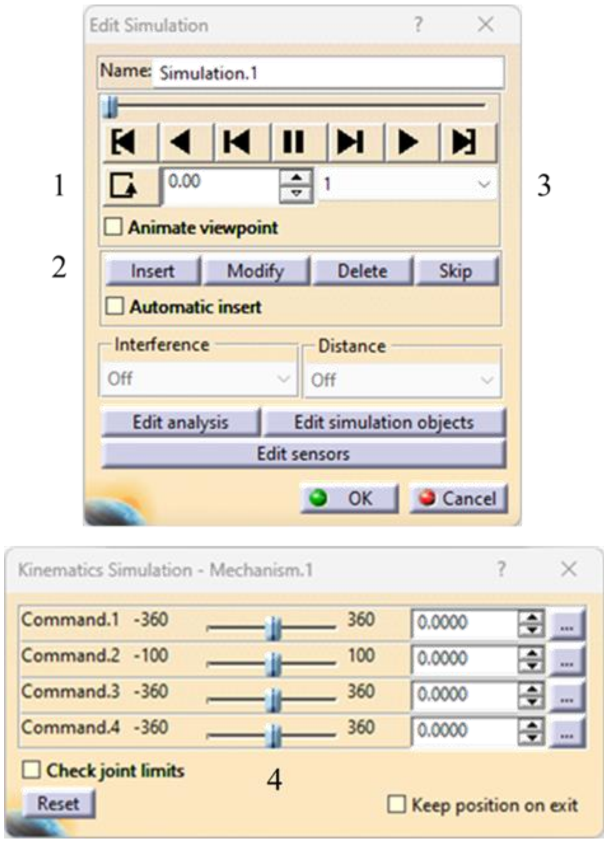

Fig -3: Commands and Edit Simulation Window

Table -3: Components in Fig 3

Sr.No.	Name of Command	Purpose	Value
1.	Loop Mode	For changing loop mode	Continuous
2.	Insert Button	For saving the step	NA
3.	Interpolation Step	For speed of Simulation	0.01
4.	Slider Cursor	For defining the step	As per Simulation

During Simulation 1 which is prepared for demonstrating lower compression ratio, Slider Pivot Assembly is at Initial position. Piston and Primary Connecting Rod moves up/down and provides rotary motion to Slider Arm with the help of Slider Joint 1. Slider Joint 2 receives the motion from the Slider Arm and pushes the Secondary Connecting Rod which in-turn rotates the Crankshaft. Slider Joint 3 guides on Vertical Guide to provide linear vertical motion to Secondary Connecting Rod.

Simulation 2 is prepared to show the movement of Slider Pivot Assembly inside the Engine Housing using Leadscrew and Handle lever assembly. In this Simulation Handle Lever Assembly and Leadscrew rotates with reference to the Engine Housing frame and moves the Slider Pivot Assembly forward from initial position using screw joint connection. This demonstrates the method to achieve the different pivot positions for Slider Arm so that it can provide different strokes to Secondary Connecting Rod while maintaining same top position of the Piston.

During Simulation 3 which is prepared for demonstrating higher compression ratio, Slider Pivot Assembly is at forward position than initial position. Piston and Primary Connecting Rod moves up/down and provides rotary motion to Slider Arm with the help of Slider Joint 1. Slider Joint 2 receives the motion from the Slider Arm and pushes the Secondary Connecting Rod which in-turn rotates the Crankshaft. Slider Joint 3 guides on Vertical Guide to provide linear vertical motion to Secondary Connecting Rod.

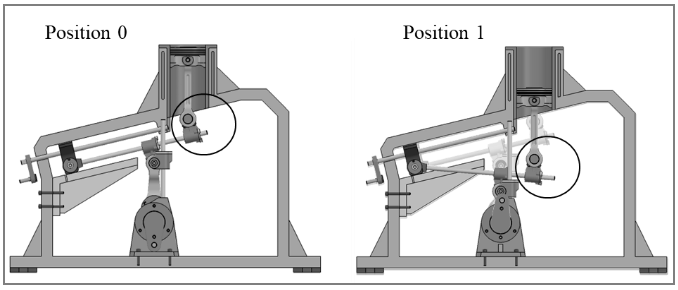

Fig -4: Representation of Simulation 1

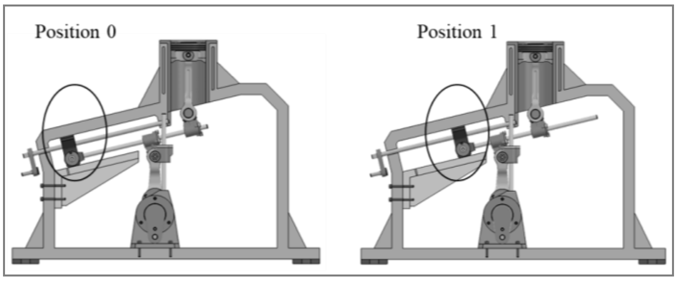

Fig -5: Representation of Simulation 2

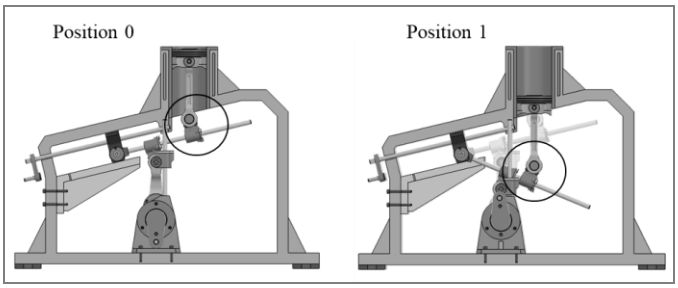

Fig -6: Representation of Simulation 3

2.4 Results

Following dimensions are used to Prepare CAD model

Piston Diameter = 77mm

Primary Connecting Rod Length = 130mm

Secondary Connecting Rod Length = 100mm

Crankshaft Throw = 30mm

Slider Pivot Assembly Stroke = 130mm

Clearance Volume height = 8.85mm

Following are the results from the Kinematic simulation

Piston Stroke for Lower Compression Ratio = 86.4mm

Piston Stroke for Higher Compression Ratio = 114.1mm

As per the formula to calculate Compression ratio, which is

Compression Ratio = Total Volume / Clearance Volume

Total Volume = Clearance Volume + Piston Stroke or Displaced Volume -- (1)

Let's Denote

Compression Ratio = CR

Total Volume = Vtl

Clearance Volume = Vcl

Displaced Volume = Vdl

Hence, CR = Vtl / Vcl -- (2)

Because, Vtl = (Vcl + Vdl) from equation (1)

Hence by putting value of Vtl in equation (2)

It gives, CR = (Vcl + Vdl) / Vcl ---------------------------------- (3)

As per the dimensions of the CAD model,

Clearance Volume = Vcl = 41490.54 mm3

Displaced Volume for Lower Compression = Vdls1 = 402332.46 mm3

Displaced Volume for Higher Compression = Vdls2 = 531320.99 mm3

Using the above formula in equation (3) and above values

Lower Compression Ratio = 10.7

Higher Compression Ratio = 13.8

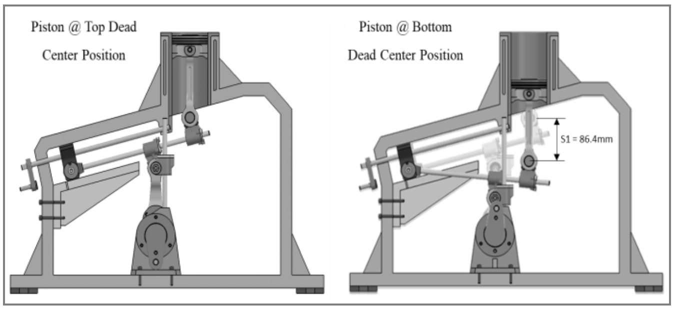

Fig -7: Results of the Kinematic Simulation 1

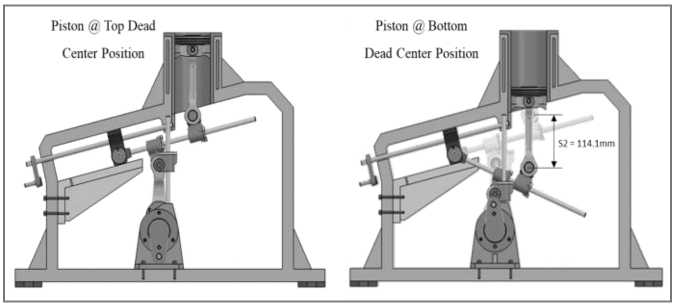

Fig -8: Results of the Kinematic Simulation 2

Table -4: Details of Existing Engine

Engine Parameters	Existing Engine			
	Tiago Petrol		Tiago CNG	
	Value	Unit	Value	Unit
Bore	77	mm	77	mm
Stroke	85.8	mm	85.8	mm
Displaced Volume	4.00E+05	mm3	4.00E+05	mm3
Clearance Volume Height	8.85	mm	8.85	mm
Clearance Volume	4.12E+04	mm3	4.12E+04	mm3
Compression Ratio	10.7		10.7	

Table -5: Details of Proposed Engine

Engine Parameters	Proposed VCR Engine				Formulae
	Lower Compression Ratio		Higher Compression Ratio		
	Value	Unit	Value	Unit	
Bore	77	mm	77	mm	D
Stroke	86.4	mm	114.1	mm	S
Displaced Volume	4.02E +05	mm3	5.31E +05	mm3	Vdls
Clearance Volume Height	8.91	mm	8.91	mm	hcl
Clearance Volume	4.15E +04	mm3	4.15E +04	mm3	Vcl
Compression Ratio	10.7		13.8		Vcl + Vdls / Vcl

3. CONCLUSIONS

According to the Results of the Kinematic Simulation lower and higher compression ratio can be achieved using the mentioned mechanism. Tata Motors vehicle Tiago's engine specifications are used for comparison.

- Minimum Compression ratio which can be achieved using proposed VCR mechanism is 10.7 which is equivalent to the Tata Tiago Petrol Engine

- Maximum Compression ratio which can be achieved using proposed VCR mechanism is 13.8 which is equivalent to the standard compression ratio for CNG as a fuel is between 13 to 14. This addresses the limitation of using same compression ratio of Petrol engine for CNG fuel.

- 7 new types of parts will need to be added in the mechanism between Piston and Crankshaft to achieve Variable Compression Ratio.

- Clearance Volume inside Engine Cylinder is possible to keep constant even after varying the compression ratio, which helps to consume the minimum amount of fuel compared to the other existing VCR mechanisms and can improve Volumetric fuel efficiency.

However, more study on the VCR mechanism is necessary while taking the following factors into account.

- Effects of new moving parts on the Speed and Torque requirements from Engine

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- Effects of change in RPM of Crankshaft due to the VCR mechanism arrangement
- Performance and Emissions of Engine using Petrol and CNG fuel with VCR mechanism
- Effect of Construction and Size on mounting and balancing arrangements of Engine with VCR mechanism

REFERENCES

[1] Mohammed Kadhim Allawi. (2016). The Effect of Compression Ratio upon the Performance and Emission of spark ignition engine. In International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869 (O) 2454-4698 (P), Volume-5, Issue-3, July 2016 .

[2] Aina T., Folayan C. O. and Pam G. Y. (2012). Influence of compression ratio on the performance characteristics of a spark ignition engine. In Pelagia Research Library Advances in Applied Science Research, ISSN: 0976-8610 CODEN (USA): AASRFC, 2012, 3 (4):1915-1922.

[3] Rinu Thomas, M. Sreesankaran, Jeevan Jaidi, Dileep M. Paul and P. Manjunath. (2016). Experimental evaluation of the effect of compression ratio on performance and emission of SI engine fuelled with gasoline and n-butanol blend at different loads. In Perspectives in Science (2016) 8, 743—746, http://dx.doi.org/10.1016/j.pisc.2016.06.076

[4] Pischinger S., Wittek K. and Tiemann C. (2009). Two-stage Variable Compression Ratio with Eccentric Piston Pin. In MTZ worldwide (Vol. 70, Issue 2, pp. 20–27). Springer Science and Business Media LLC. https://doi.org/10.1007/bf03227930

[5] Khan, I. R. (2017). Study of Variable Compression Ratio Engine (VCR) and Different Innovations to Achieve VCR. In International Journal for Research in Applied Science and Engineering Technology: Vol. V (Issue XI, pp. 1473–1478). International Journal for Research in Applied Science and Engineering Technology (IJRASET). https://doi.org/10.22214/ijraset.2017.11213

[6] Farha Tabassum Ansari, Abhishek Prakash Verma, Alok Chaube. (2013). Effect on Performance and Emissions of SI Engine Using Ethanol as Blend Fuel Under Varying Compression Ratio. In International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 12, ISSN: 2278-0181, December – 2013. DOI : 10.17577/IJERTV2IS120418

[7] Anand Ramachandran and Prof. A.V Waghmare. (2016). Experimental Investigation of the effect of Compression Ratio on the performance of a dedicated CNG engine. In International Engineering Research Journal (IERJ) Volume 2 Issue 5 Page 1925-1929, 2016, ISSN 2395-1621, October – 2016

[8] Krishna Prasad S and R Saravanan. (2020). The Study of Impact of Compression Ratio on the Performance and Emission Characteristics of DTSi Engine using Petrol and CNG as Fuel. In Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(9). ISSN 1567-214x, PJAEE, 17 (9) (2020)

[9] As per the figures mentioned on BP Indonesia Webpage, Specific Compression ratio is suitable for specific Octane number fuel. https://www.bp.com/en_id/indonesia/home/products-and-services/fuels-retail/news-article/type-of-fuel-that-is-suitable-for-your-vehicle.html

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