Journal of Techniques, ISSN: 2708-8383, Vol. 6, No. 4, 2024, Pages 73-80
DOI: https://doi.org/10.51173/jt.v6i4.2614

JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

RESEARCH ARTICLE - MECHANICAL ENGINEERING

A Comparative Design and Analysis of Conventional and Variable Connecting Rod of Engines

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Article Info.

Article history:

Received
19 August 2024

Accepted
17 December 2024

Publishing
31 December 2024

Abstract

Geometric compression is one of the primary design parameters for internal combustion engines. It is determined by the maximum volume ratio of the combustion chamber between the bottom dead center (BDC) and the minimum size of the combustion chamber in the position of the top dead center (TDC). In this study, a new motor was designed with a variable compression ratio (VCR) to enhance its performance. The comparison between the conventional engine and the turbo variable compression was analyzed using SolidWorks software. The results showed the advantages of VCR due to the change in performance according to changes in the required torque by varying the connecting rod stroke.

Publisher: Middle Technical University

Keywords: Connecting Rod; Variable Compression Ratio; Conventional S.I Engine; Design; Solid Works.

1. Introduction

The conventional internal combustion engine (SI) pressure ratio is a function of the volume compressed by the piston from the lower dead center (BDC) to the upper dead center (TDC) as shown in Fig. 1. Generally, the operating conditions of SI engines vary widely. This variety arises from driving the car in the city with crowded traffic or on high-speed highways. For that reason, a variable compression ratio is required to achieve optimum performance of the engine, the pressure ratio should not be constant. The rateof fuel consumption while driving in the city is high with lower heat efficiency inSI engines, due to low speeds or light loads with reduced acceleration [1].

Enhancing engine performance and efficiency while reducing the emission can be achieved through employing variable compression ratio (VCR). This method will increase the pressure and temperature in the cylinder during the first part of combustion with a fraction of gas residuals, as illustrated in Fig. 2. The results of a higher compression ratio, such as 19, will affect the flame velocity, especially during the third stroke [2]. Additionally, the ignition time should be reduced. In lower loading conditions, a higher compression rate can be achieved by reducing the combustion time. To optimize performance and decrease fuel consumption, a higher compression ratio is essential at partial loads. Consequently, a VCR can significantly enhance thermodynamic efficiency, the modification of this kind of connecting rod adopted by Nissan's INFINITI multi-link variable compression packages punching conventional engines [3].

There is a direct relationship between the compression ratio and combustion knocks. If the ratio increases beyond a certain extent, uneven burns in the engine (knocks) appear due to the high temperature of the air mixture, while the inlet airflow becomes at high speeds and the pressure ratio is high [4]. During acceleration, when the inlet airflow is high, the limit is low. Additionally, it becomes minimal for turbine engines utilizing compressed air [5]. In conventional SI engines, the movement of both the crankshaft and piston is directly related. The connecting rod converts the reciprocating movement of the piston to rotational movement, and here the compression ratio is constant [6]. Controllability of the compression ratio can be achieved by using a multi-link system as shown in Fig. 1 instead of a traditional connecting rod. In variable compression ratio SI engines, the compression ratio range changes between 8:1 (for high load) and 14:1 (for low load) [7]. This means that the driver, by depending on a multi-link system, can adjust to reach the optimum compression ratio during acceleration at different loads and speeds [8].

Nomenclature & Symbols			
SI	Spark-Ignition	T	Torque (N.mm)
BDC	Bottom Dead Center	F	Force (N)
TDC	Top Dead Center	A	Area (mm^2)
VCR	Variable Compression Ratio	L	Length (mm)
FOS	Factor of Safety		

1.1. Working mechanism

The engine operates in several ways. For example, the actuator motor strikes the actuator arm when a change in the compression ratio is needed. The actuator arm additionally rotates the management shaft, and this rotation strikes the lower-link (L-link), altering the multi-link mechanism angle [9]. Finally, the multi-link mechanism adjusts the vertical position of the piston stroke inside the cylinder, altering the compression ratio [10].

1.2. Optimization of the link layout

As the angular exchange of the top hyperlink (U-link) when the piston strikes up anddown is small [11, 12], the top hyperlink (U-link) stays extra vertical as it strikes down smoothly. This reduces friction with the cylinder walls and contributes to improved fuel economy. The reciprocating movement of the piston between TDC and BDC becomes symmetrical, helping to limit vibration [13, 14]. Friction is reduced because the angle of the upper link is almost vertical, and the thrust force on the cylinder bore can be reduced, as shown in Fig. 3.

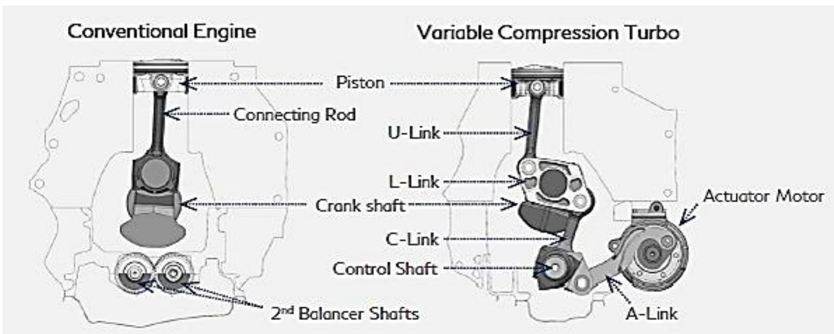

Fig. 1. Difference in piston height between compression ratios

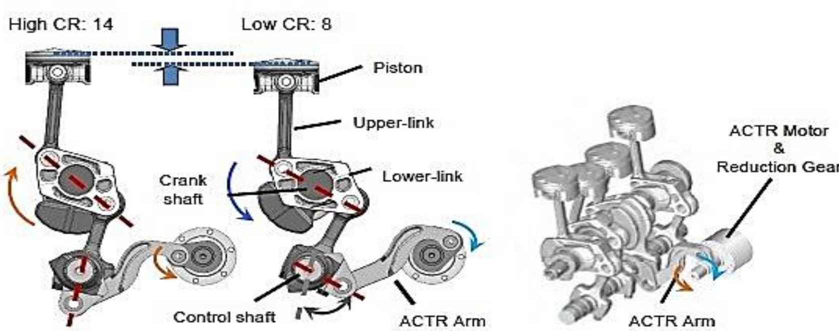

Fig. 2. Difference in piston height between compression ratios [11]

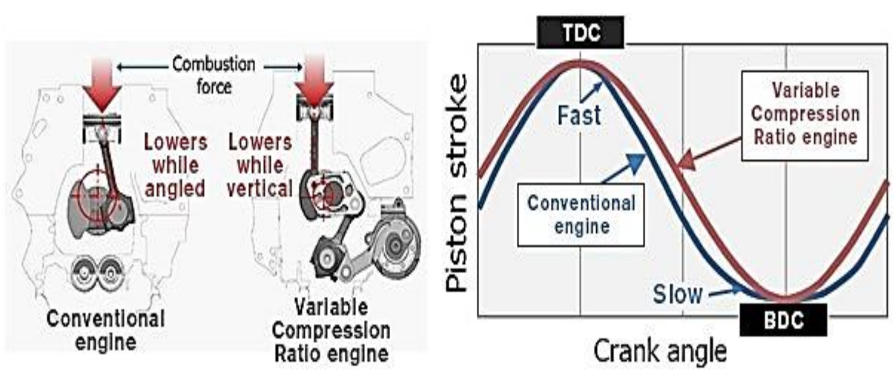

Fig. 3. An illustration of a distribution Thrust Force [11]

2. Design of S.I. Engine Piston

In this study, the specifications of the piston illustrated in Fig. 4 were utilized. The piston was designed in accordance with the procedures and specifications outlined in the machine design data for the Ford SI 1.8 DOHC 16V model, which contains four cylinders. Each cylinder operates at a speed of 1000 rpm, equating to a total of 4000 rpm, and produces a torque of 153 N.m, as detailed in Table 1. The variable parameters are presented in Table 2, while the mechanical properties for alloy steel are shown in Table 3.

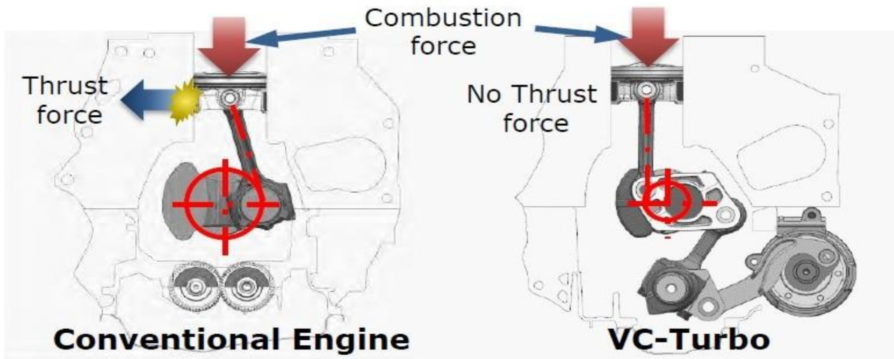

Fig. 4. An illustration of a distribution Thrust Force [11]

Table 1. Conventional Engine

No.	Name	Value	Unit
1	Cylinder bore, D	80	mm
2	Stroke, L	42	mm
3	Piston displacement for one cylinder	300	cc
4	Torque at 4000 rev/min	153	N.m
5	Torque for one cylinder	38.25	N.m
6	Speed	4000	rpm
7	Speed for one cylinder	1000	rpm

Table 2. Variable Compression Ratio VCR

No.	Name	Value	Unit
1	Cylinder bore, D	80	mm
2	Stroke, L	80	mm
3	Piston displacement for one cylinder	233.6	cc
4	Torque at 4000 rev/min	153	N.m
5	Torque for one cylinder	38.25	N.m
6	Speed	4000	rpm
7	Speed for one cylinder	1000	rpm

Table 3. Material S.I Engine Alloy Steel

No.	Name	Value	Unit
1	Elastic Modulus	210000	MPa
2	Poisson's Ratio	0.28	N/A
3	Tensile Strength	723.8256	MPa
4	Mass density	7700	kg/m^3
5	Yield Strength	620.422	MPa
6	Shear Modulus	79000	MPa

It is noteworthy that the rod bearing journals of both the VCR engine and the conventional engine share identical arm lengths. However, the mechanics of the twoengines differ based on their size.

One advantage of the VCR engine is the capability to alter the volume of its cylinder through the manipulation of a control shaft. By rotating the control shaft, the volume of the VCR engine cylinder can be increased or decreased according to the desired compression ratio. This feature provides a significant advantage to the VCR engine in terms of fuel efficiency and performance, as it allows for greater control over the engine's combustion process.

Variable Compression Ratio (VCR): The force on one cylinder was calculated in order to apply effective torque during analysis and equals 38.25 N·m.

$$T = \frac{P.A.L}{2} \tag{1}$$

Where: T = Torque, P = Pressure, F= Force, A= Area, L= Length

$$P = \frac{F}{A} \tag{2}$$

3. Methodology

The CAD model of Variable Compression Ratio (VCR) is designed using SolidWorks. The assembly of the piston, cylinder, crankshaft, and camshaft is shown in Fig. 5. Fig. 6 shows the side view of the multi-link system components.

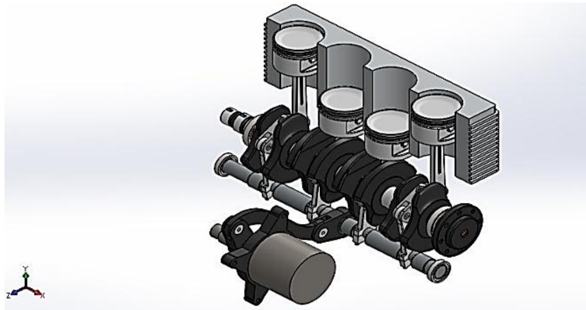

Fig. 5. Assembly view of Variable Compression Ratio VCR

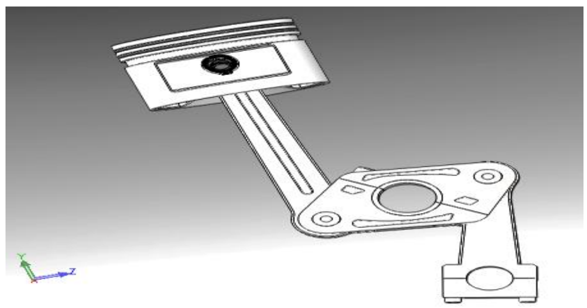

Fig. 6. CAD Design multilink Variable-Compression Engine Packs Punch

3.1. Engine dimensional design

The geometrical assembly design of the piston bearing components was generated by the SolidWorks version 2016 program as shown in Figs. 7, 8, and 9, where all the dimensions are in mm [15].

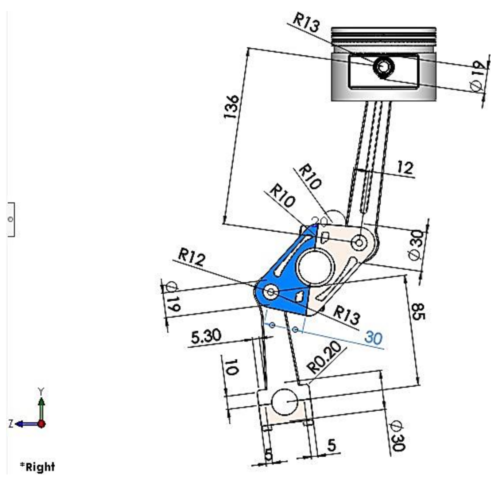

Fig. 7. Dimensions of VCR Engine

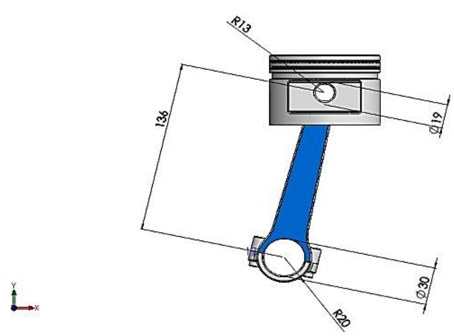

Fig. 8. Dimensions of Conventional Engine

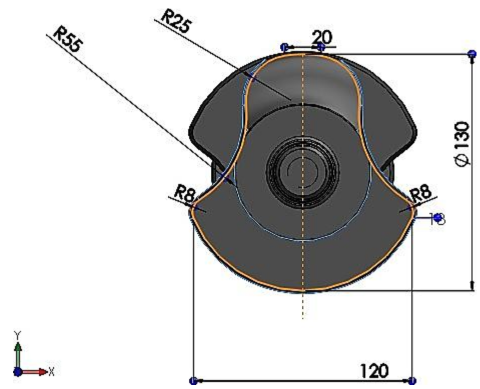

Fig. 9. Dimensions of Crankshaft

3.2. Design analysis between conventional and VCR engines

The SOLIDWORKS software is utilized to obtain the stress, deformation, and safety factor using the information in Table 4. Ford car engine specifications adopted during design [16], as shown in Table 4, In order to do the analysis, one cylinder divide the total torque of 153 N.m by 4 in order to obtain the torque of one cylinder and the force previously calculated for one cylinder for both engines VCR engine (F = 956 N) and Conventional Engine (F = 1851 N).

For both designs of the Conventional and VCR engines as shown in Figs. 10 and 11, the force in blue color represents the direction of the reaction force, while the force in red color represents the direction of the piston force, which appears duringational speed of 1000 rpm for one cylinder.

In this case, alloy steel [17, 18], mechanical properties improved by using heat treatment conducted with strict cooling process, this process improves hardenability, toughness, and wear resistance. This process is considered important for choosing the proper material for the connecting rod. One of the limitations of the VCR engine is that it requires strong alloy steel and an intricate design to withstand the stress exerted on it, although this analysis shows that the normal force of the VCR is less compared to the conventional engine, as seen in Fig. 12.

The speed used to analyze one-cylinder is 1000 rpm, and the crankshaft arm for both engines has the same value of 20 mm, as shown in Fig. 13. As seen in Table 5, the Von Mises stress, deformation, and factor of safety (FOS) values are better in the VCR engine compared to the conventional engine for the same material, as shown in Figs. 14 and 15.

As seen in Table 5, the Von Mises stress, deformation, and FOS values are better in the VCR engine compared to the conventional engine for the same material (in this case, alloy steel) [19, 20].

According to the working conditions shown in Table 6 for two types of analyzed connecting rods in the research, one of the limitations of the VCR engine is that it requires strong alloy steel and an intricate design to withstand the stress exerted on it, although this analysis shows that the normal force of the VCR is less compared to the conventional engine, as seen in Fig. 13. Additionally, the safety factor of the conventional and VCR engines, along with the Von Mises and deformation analysis, is obtained in Fig. 16.

Table 4. Engine Specifications

Make	Ford
Type	SI 1.8 DOHC 16 V
Emission code	83 US
Identification code	RDA
Finger order	1-3-4-2
Bore (mm)	80.6
Stroke (mm)	88.0
Cubic capacity (cc) 1796	
Compression ratio	10:1
Max. engine speed (rev/min)	5950
Power output (DIN-KW) at 5500 rev/min	77
Torque (Nm) at 4000 rev/min	153

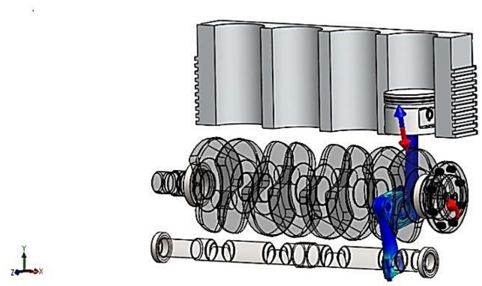

Fig. 10. Force application of VCR engine

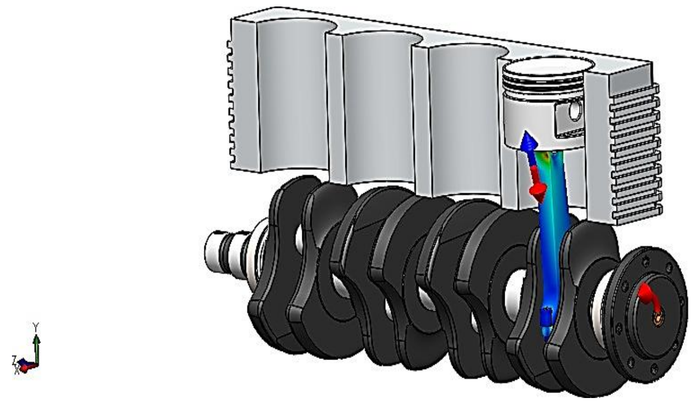

Fig. 11. Force application of Conventional engine

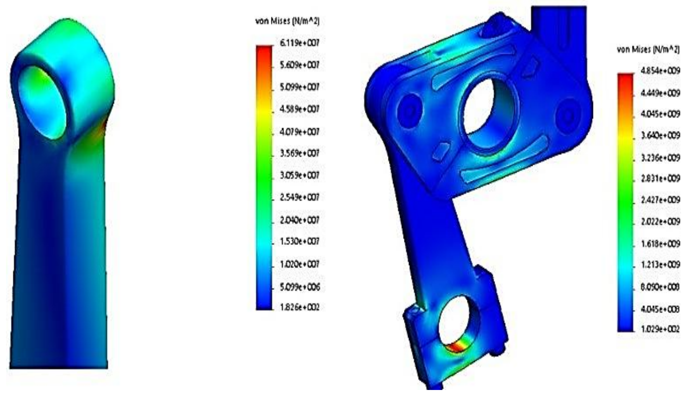

Fig. 12. Zoom image of Von Mises, on areas of weakness

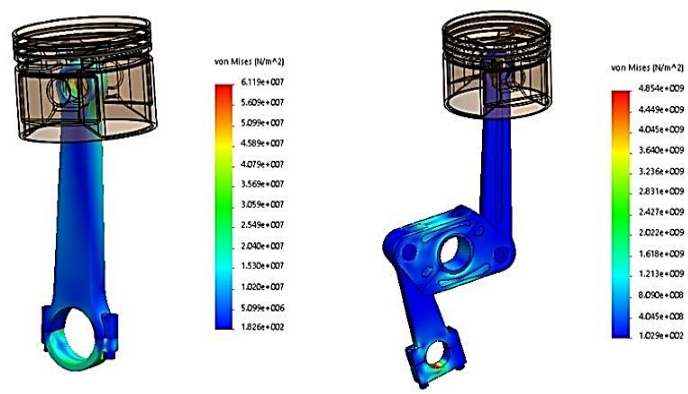

Fig. 13. Von Mises analysis results of VCR and Conventional Engine

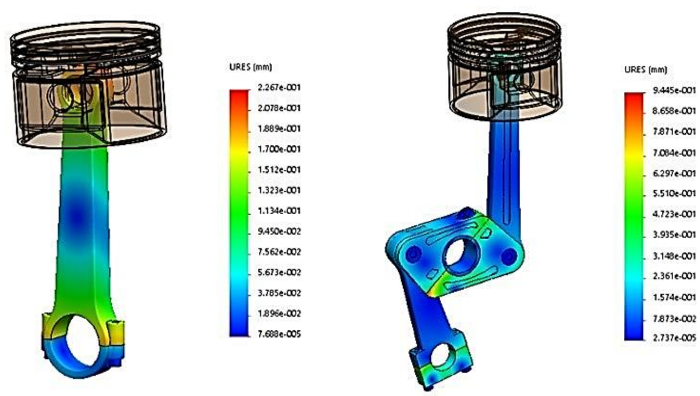

Fig. 14. Deformation analyses results of VCR and Conventional engine

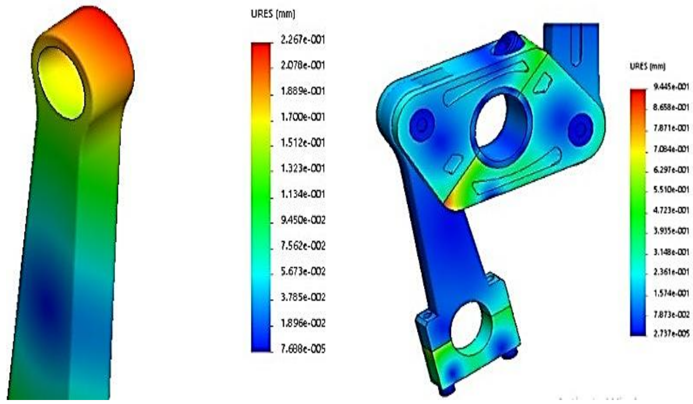

Fig. 15. Zoom image deformation analyses results, on areas of weakness

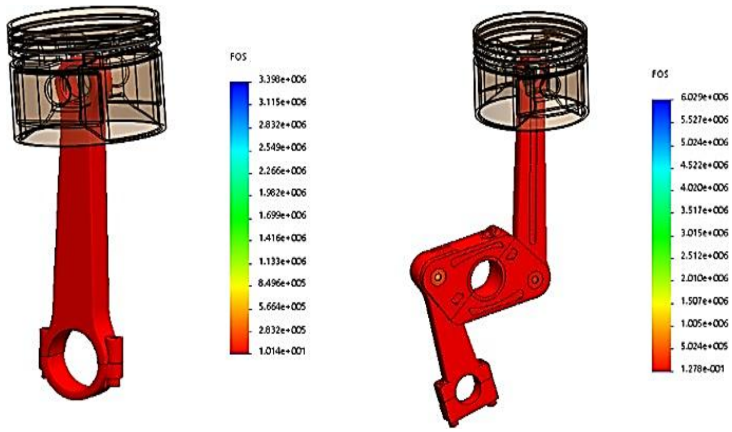

Fig. 16. Factor of safety (FOS) of VCR and conventional engine

Table 5. Results obtained by FEA motion analysis SOLID WORKS

Type	Material	Von mises stress Max	FOS min	Deformation Max (mm)	Yield Strength Max (N/m^2)
VCR engine	Alloy Steel	4.854e +009	1.278e-001 (0.13)	9.445e -001	620.422e +006
Conventional engine	Alloy Steel	6.119e +007	1.014e+0 1 (10)		

Table 6. Results of analysis SOLIDWORKS

type	Action Force N	Reaction Force N	Displacement mm	Velocity mm/sec	Torque N.mm
VCR engine	956	933	80	4302	4023
Conventional engine	1851	1794	42	1178	1364

4. Conclusion

The results were obtained from the analysis of the two engines using motion analysis in SOLIDWORKS. Through analysis, it was found that conventional engines are safe because the operation of the engine does not exceed the yield strength. In contrast, in the VCR engine, the yield strength reaches a critical point, especially in part (C link) and some areas of part (L link). To mitigate this failure, a metal with a higher yield strength must be used since these areas are subjected to great stress, as shown in Fig. 13. The conventional engine is safer and less expensive than the VCR engine, which is an advantage for FEA.

The advantage of the VCR engine is that it extracts more torque than a conventional engine, and its linear speed is higher, as shown in Table 6. A larger stroke is reached by controlling the stroke in a VCR engine, and this is the most important feature of this engine since the compression ratio is changeable, allowing for controlled fuel expenditure. On the other hand, the VCR engine has disadvantages due to higher manufacturing costs and maintenance complexity compared to conventional engines.

Acknowledgment

We want to thank the head of the Mechanical Department, College of Engineering, Kirkuk University, Kirkuk, Iraq, and all the department's teaching staff for their assistance.

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