KINEMATIC AND DYNAMIC ANALYSIS OF CONNECTING ROD FOR VARIABLE COMPRESSION RATIO DIESEL ENGINE

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Abstract
The main objective of this study has to investigate the stresses induced in connecting rod manufactured of of AISI E4340 forged steel and aluminum alloy. Connecting rod is one of the most important moving part with a complex geometry in internal combustion engine .when combustion takes place in the engine, there by high temperature and pressure will be developed inside the engine cylinder .due to high speed and at high loads ,the piston subjected to large structural stresses, which influences on the crank. An expermintation has carried out on a computerized variable compression ratio diesel engine test rig at compression ratio of 16.5, 17.5, 18.5 for obtaining the results. The results were tabulated for knowing pressure at various crank angles. The results were analyzed by drawing the pressure Vs crank angle variation diagram. The dynamic analysis is carried out by developing the equations of equilibrium from the free body diagrams of individuals of components of slider crank mechanisms. The forces induced at pin joints and inertia forces obtained from the dynamic analysis are maximum or minimum are also determined at some critical angle by dynamic analysis. Three dimensional model of diesel engine connecting rod is developed by using solid workbench software. Further analysis was carried out by anysis workbench. And dynamic analysis parameter is solving by MAT lab.

Index Terms: piston, Heat transfer coefficient, heat flux, Structural and thermal analysis.

1 INTRODUCTION:

Connecting rods in internal combustion engines are subjected to high cyclic loads comprised of dynamic tensile and compressive loads. They must be capable of transmitting axial tension and compression loads, as well as sustain bending stresses caused by the thrust and pull on the piston and by the centrifugal force of the rotating crankshaft. The invention of the crank-connecting rod system has enabled the invention of numerous machines. The most notable of which is the internal combustion engine. The various methods of manufacturing connecting rods includes: casting, wrought forged, and powder metallurgy, but more focus is laid on wrought forged and powder metallurgy. The modern manufacturing of connecting rod includes alloy elements including titanium, aluminum, magnesium, and polymeric connecting rods.The connecting rod as we know it today, operating inside the cylinder of an internal combustion engine, was first used in 1860, when the French inventor, Etienne Lenoir, built a small, single-cylinder, internal-combustion engine. Gas was injected first into one end of a horizontal cylinder, then into the other, and ignited. The tiny, confined, alternate explosions drive the piston inside the cylinder back and forth. A rod connected to the piston drove a crank which turned a fly wheel.

1.1. MATERIAL PROPERTIES :

It has been observed from the literature that oil quenched AISI E4340 forged steel is the most preferred material due to its enhanced properties. In the present analysis, the MOC is considered as 4340 forged steel. The physical properties of this material are mentioned in table 1.

Table .1 Properties of AISI E4340 Oil Quenched Forged Steel

S.No	Property	Value
1	Density	7820 kg/m^3
2	Poisson's ratio	0.3
3	Young's modules	206.8 GPa
4	Yield strength	1840 MPa
5	Ultimate strength	1985 MPa
6	Percent elongation	24 %

2. LITERATURE REVIEW:

The connecting rod is subjected to a complex state of loading. It undergoes high cyclic loads of the order of 108 to 109 cycles, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of this component is of critical importance. Due to these factors, the connecting rod has been the topic of research for different aspects such as production technology, materials, performance simulation, fatigue, etc. This brief literature survey reviews some of these aspects. To carry out kinematic and dynamic analysis of a connecting rod using the output of a test conducted on computerized VCR Kirloskar Diesel Engine equipment provided with pressure transducer .Further the results of Dynamic analysis are utilized for carrying out a Quasi-Dynamic Stress Analysis. Normally the stress analysis has to be carried at all angles of rotation. However, since this is time consuming and requires lots of computational time, the analysis is limited to specific positions of crank angle. Such an analysis is termed as Quasi-Dynamic analysis.

3. GEOMETRY

The model of the Connecting rod has been designed using Solid works software. The design of the model has been done in two different stages. 1. Part designing, In this stage, the connecting rod is designed with the required dimensions.**2.** Assembly ,The 3D model is created, by using various modeling operations like extrude, sweep, revolve, etc. Finite element model: The Solid model is converted into a FEM model and the results are obtained after applying the structural boundary conditions. The loads and the constraints are imposed on this FEM model. The element used for analysis is 4 noded tetrahedral element. The model is meshed with 15257 elements and 26804 nodes.

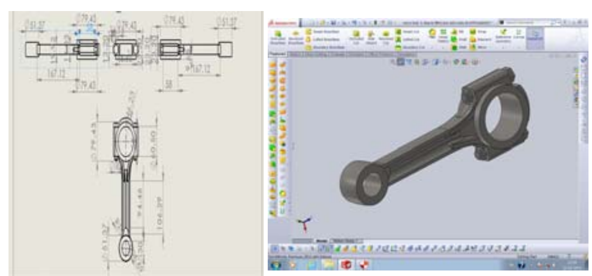


Fig 3.1: connecting rod (a) 2 D model (b) 3-D Model

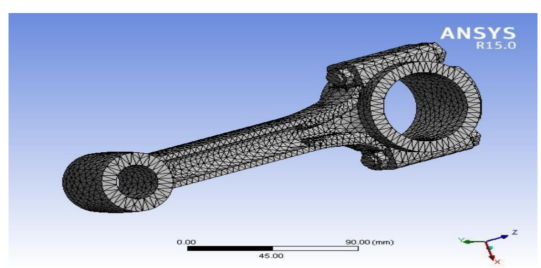


Fig :3. 2 connecting rod meshing Element

4. EXPERIMENTAL ANALYSIS AND CALCULATIONS

4.1: Computerized Variable Compression Ratio (VCR) Diesel engine specifications and Description: The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ & PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement.

Table .2 Engine specifications:-

Features	**Specifications**
Make	Kirloskar oil Engine
Type	Four stroke, Water cooled Diesel
No of cylinders	One
Combustion Principle	Compression ignition
Max speed	1500
Crank Radius	55mm
Connecting Rod length	300mm
Cylinder diameter	80mm
Compression ratio	variable
Stroke length	110mm

Table .3 The following reading were taken from experimentation:-

Features	**Specifications**
Maximum Load	23.86 N
Constant Speed	1500 rpm
Fuel rate	1.46-2.06 kg/hr
Air rate	16.20-17.08 m^3/hr
Water Flow	40.80 cc/sec
Cooling Water inlet Temp	26.70 ^{0}C
Cooling Water outlet Temp	30.80^{0}C

4. 2 Solution Methodology: Kinematic Analysis involves determination of linear displacement, velocity, acceleration of piston and angular displacement, angular velocity and acceleration of connecting rod. It is assumed that the crankshaft rotates at a constant angular velocity.

Displacement of piston

$(x_p) = r_1[(1 - \cos\theta) + (\sin^2\theta)/2n]$

By differentiating displacement (x_p) w.r.t time, we get velocity (v_p)

Velocity of piston $(v_p) = \omega_1 r_1[\sin\theta + (\sin 2\theta)/2n]$

By differentiating velocity (v_p) w.r.t time, we get acceleration (a_p)

Acceleration of piston (a_p)

$= \omega_1^2 r_1[\cos\theta + (\cos 2\theta)/n]$

Kinematics Of Connecting Rod:

Angular displacement (β) $= \sin^{-1}(-r_1 \sin\theta / l_2)$

By differentiating angular displacement (β) w.r.t time, we get angular velocity (ω_2)

Angular velocity of connecting rod (ω_2)

$= \omega_1 \cos\theta / \sqrt{(n^2 - \sin^2\theta)}$

Further differating

By differentiating angular velocity (ω_2) w.r.t time, we get angular acceleration (α_2)

Angular acceleration of connecting rod $(\alpha_2) =$

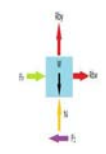
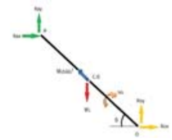
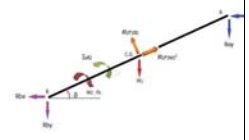
$\{-\omega_1^2 \sin\theta (n^2 - 1)\}/(n^2 - \sin^2\theta)^{3/2}$

Kinematics of Crank:

Angular velocity of Crank $(\omega_1) = 2\pi N/60$

Dynamic Analysis : Taking the Kinematic parameters and pressure force acting on piston into consideration, the Dynamic analysis of total mechanism is carried out. The first step in this direction is to draw the free body diagram of each of the members and identify all the forces which include the reactive forces of the constraints, inertia forces, weight of members and also external forces acting on them.

Dynamics of piston:

		
..Free body diagram of piston	Free body diagram of Crank	Fig.6. Free body diagram of Connecting Rod

The equations of equilibrium are

$$\sum F_x = 0$$

$R_{bx} + F_p - F_i = 0$

$R_{bx} = F_i - F_p$

…………………………………. (1)

$$\sum F_y = 0$$

$N + R_{by} - W = 0$

$N = W - R_{by}$ …………………………………. (2)

Dynamics of crank:

The equations of equilibrium are

$$\sum F_x = 0$$

$R_{ox} = m_1 \omega_1^2 r_c \cos\theta - R_{ax}$ ………………….. (3)

$$\sum F_y = 0$$

$R_{oy} = W_1 - m_1 \omega_1^2 r_c \sin\theta - R_{ay}$ ……………. ……. (4)

Dynamics of connecting rod:

The equations of equilibrium are

$$\sum F_x = 0$$

$R_{ax} = m_2 \alpha_1 r_1 \sin\theta + m_2 \omega_1^2 r_1 \cos\theta - R_{bx}$ .. …….. (5)

$$\sum F_y = 0$$

$R_{by} = -m_2 \omega_1^2 r_1 \sin\theta + m_2 \alpha_1 r_1 \cos\theta - W_2 - R_{ay}$ (6)

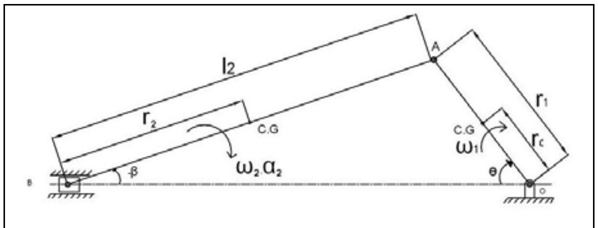


Fig 3 ..Slider-Crank Mechanism

∑M-Iα = 0

Considering moments about B cd necessary the terms

$R_{ay} = (m_2 \alpha_2 r_2^2 + I_2 \alpha_2 - W_2 \cos\beta r_2 - R_{ax} \sin\beta l_2)/ \cos\beta l_2$ ………………………….(7)

The above seven equations (1) to (7) are solved simultaneously in the obtain the

5. RESULTS AND DISCUSSION

Kinematic Analysis

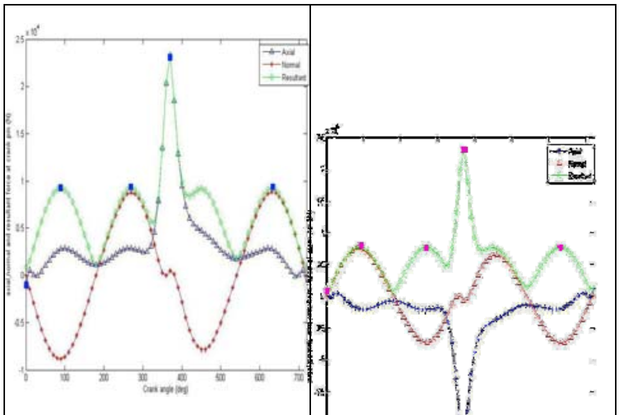
The results of kinematic analysis are summarized as follows: The Connecting rod has a plane motion which is a combination of translation and rotation. The variation of angular displacement of connecting rod is sinusoidal in nature. The variation of angular velocity of connecting rod shows a similar variation as that of piston. The maximum angular velocity occurs at the end of the piston stroke and the minimum angular velocity occurs at the middle of the stroke. The motion of connecting rod almost resembles a Simple Harmonic Motion.The angular acceleration reaches maximum value at the middle of the stroke, while it reaches minimum value at the end of the stroke

Dynamic Analysis

The results of Dynamic analysis are summarized follows:

Kinematic analysis is followed by dynamic analysis in which

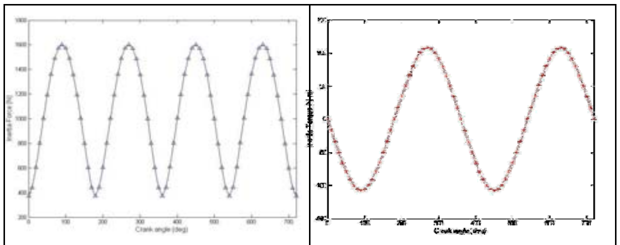
the equations of equlibrium are written for each of the links individually. the equations of equilibrium are further solved to obtain the forces at the joints and inertia torque.while writing the equations of equlibrium,the inertia force on the piston and connecting rod are also considered in addition to the pressure force which is obtained from experimental procedure. Since the present work is only limited to study of stresses in the connecting rod,the pin forces at crank pin joint and wrist pin joint are further resolved into axial and normal components as shown in in graphs 4.2 and 4.3.



At crank pin | At wrist pin

4.3 Variation of axial, normal and resultant forces at crank pin and wrist pin w.r.t crank angle

The variation of resultant inertia force on connecting rod is shown in fig 4.4 .The resultant inertia force is a vectorial summation of centrifugal and tangential forces. The resultant inertia shows a similar variation for every 180^o of crank rotation. The resultant inertia force and inertia torque along with the pin forces are considered for stress analysis.



inertia force | inertia torque

Fig 4.4Variation of inertia force ,inertia torque of connecting rod w.r.t crank angle

Calculations:

Based on these inputs following parameters for thermal analysis is calculated:

Total heat lost through water jacket = 20.59 watts

Average temperature of the piston =412 ^{0}C

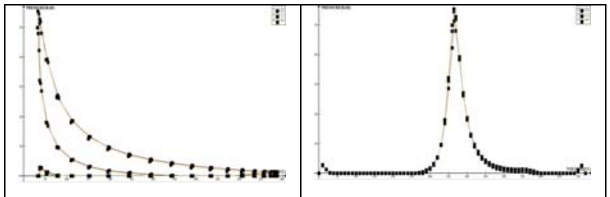
Heat transfer coefficient on top surface (h) = 174.125 w/m^{2}k

Heat transfer coefficient on bottom surface (h_b) = 8.6193 w/m^{2}k

Heat flux applied on lateral surface = 780 w/m^2

Diagrams of Pressure Vs Volume and Pressure Vs Crank Angle Rotation at Different Compression Ratio s Ratios 16.5, 17.5 and 18.5

At Compression Ratio 16.5, at a crank angle of 365^o, 635^0 piston is subjected to maximum axial compressive forces which are of high magnitude and hence it is subjected to maximum stresses of all the critical angles considered for analysis



P-V diagramfor CR **16.5, 17.5 and 18.5** | P- Ө diagram for CR **16.5, 17.5 and 18.5**

Fig :4.1 **P-V and P-Ө Diagram for Compression Ratios 16.5, 17.5 and 18.5**

The bending stresses are influenced by the normal forces whereas the buckling stresses are influenced by the axial compressive loads. The above results show that the bending stresses are more prominent than that of buckling stresses.

At a crank angle of 0^o, the connecting rod is subjected to maximum axial tensile forces which are of small magnitude and hence it is subjected to minimal stresses of all the critical angles considered for analysis. These stresses produce tension in the connecting rod. Similarly maximum axial compressive forces occur at 365^o crank angle at the start of expansion stroke. These forces produce buckling in the member and the stresses are in the order of 116 MPa.

At a crank angle of 90^o and 630^o, the connecting rod is being subjected to maximum normal forces in opposite directions. These forces induce bending in the connecting rod and the stresses alternate from compressive to tensile nature during a cycle of operation. The maximum stresses vary from 797.43 MPa to 748 MPa when the crank rotates from 90^o to 630^o.Though these alternating stresses are within allowable limits, they can cause fatigue failure. Hence it is further necessary to perform fatigue failure analysis of the connecting rod to determine the number of life cycles. The factor of safety considering the maximum stress is 2.3.Generally the factor of safety for machine members subjected to alternate loading is around 2-3.

6. CONCLUSION:

The Quasi dynamic stress analysis of the connecting rod was carried at a compression ratio of 16.5 with the experimental observations obtained from a computerized diesel engine test rig. The following inferences can be drawn from the study.

1. The results indicate the stresses in the connecting rod are well within limits and the factor of safety is 2.3.

2. It is also observed through this study that the connecting rod is being subjected to buckling loads and also bending loads which were both found to be critical. Hence, it was necessited to evaluate the stresses considering both the kinds of loads.

3. The analysis was performed by resolving the pin forces into axial and normal components so as to evaluate the effect of buckling loads, tensile loads and bending loads individually. It is further observed that the normal forces which cause bending are more critical.

4. The stress analysis was carried at five critical angles and it was determined that the connecting rod can withstand the loads at all the critical angles.

7. ACKNOWLEDGEMENT

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