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Optimum Design of Connecting Rod – A Review

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Abstract This study discusses a comprehensive review of the optimal design of the connecting rod used in internal combustion engines and compressors. The connecting rod is an important part and a major component that is produced in large quantities for automobile engines. Its purpose is to link the piston to the rotating crankshaft to create a mechanism for the movement reciprocating of the piston. Carbon steel is commonly used in the manufacture of connecting rods, but there is a growing trend towards utilizing aluminum alloys. Objective of this study is to optimize the shape of the connecting rod in an automobile engine. The optimization aims to minimize the stresses experienced by the connecting rod under both compressive loads from maximum engine output and bending loads caused by the inertia force during maximum engine power with a focused on reducing its weight. Various stresses and deformations need to be considered when designing the connecting rod, along with the comparison of different materials. Additionally, it is important to explore various software and Finite Element Method (FEM) packages that can be utilized for the modeling and analysis of the connecting rod.

Keywords: *connecting rod, optimization, design, material selection, FEM*

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1. Introduction

Connecting rod is a major link of the internal combustion engines and one of the most important components employed in automobiles, trucks, and buses. And principle working its connects the piston and the crankshaft and contributes to convert the reciprocating motion of the piston into rotatory motion of the crankshaft. Usually, it's applied to reciprocating internal combustion (I.C.) engines, like the ones found in automobiles. Spark ignition engines take a mixture of fuel & air, compress it, and ignition it was using a spark plug. The terms reciprocating' is given because of the motion that the crank mechanism through it. The connecting rod is subjected to highly-cycle of dynamic or fatigue loading. Therefore, consideration must be given to the effect of each gas forces and inertia forces. Many of research work have been carried out for optimization approach as a material selection or stress analysis [1,2,3,4,5]. Figure 1 shows the parts of connecting rod. The connecting rod is typically a durable and strong metal rod, usually made of steel or aluminum alloy, with a specific shape and design. It consists of two ends: the small end and the big end. The small end of the connecting rod is connected to the piston pin or wrist pin, while the big end is connected to the crankshaft journal. During the engine's operation, the connecting rod experiences high mechanical stresses and undergoes both tensile and compressive forces. It must be able to withstand these forces without deformation or failure. For this reason, connecting rods are engineered to be robust and lightweight to minimize inertia and maximize engine efficiency. Connecting rods are designed with careful consideration given to factors such as length, weight, strength, and balance. The length of the connecting rod and its ratio to the stroke length of the piston affects the engine's mechanical advantage and overall performance characteristics. The weight of the connecting rod is also critical as it impacts the engine's ability to reach higher RPMs and reduces the overall load on the crankshaft. In high-performance engines, connecting rods are often subjected to additional stress due to increased power output. To address this, performance connecting rods may be forged or made of stronger materials to provide enhanced strength and reliability. Its design and quality significantly impact engine performance, durability, and efficiency.

2. Literature Review

Table 1 represents a comprehensive review of previous studies of researchers, where it included design details represented by the calculation of stresses and deformations, as well as some focused on studying the behavior of buckling under the static and dynamic loading, in addition to experimental tests and comparing them with numerical analysis (using the Finite Element Analysis) as shown in the following table.

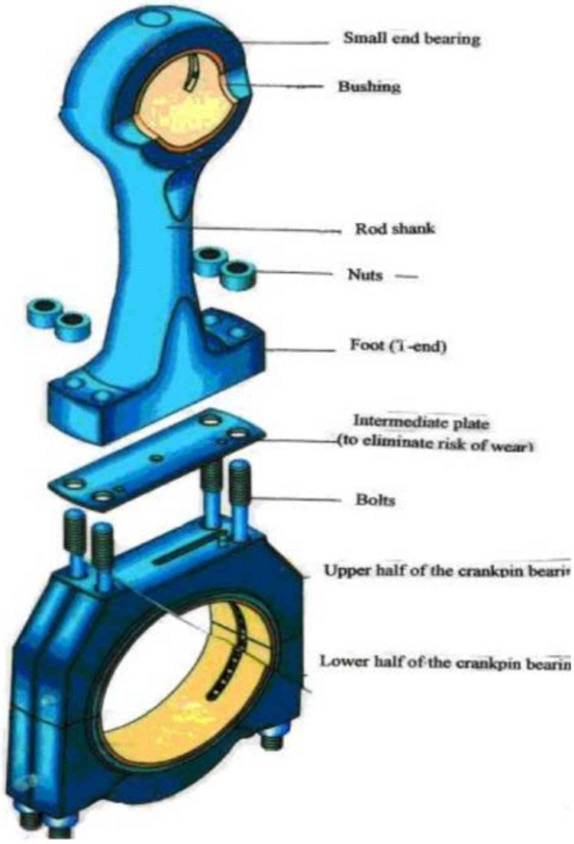

Figure 1. Parts of Connecting Rod

Table 1. Literature Review

Ref. No.	Pub. year	Study objectives	Software / Experiment / Theoretical	Conclusions
1	2010	Used topology optimization techniques to reduce the weight and predicted low maximum stress compare to the initial design.	SOLIDWORKS and MSC/NASTRAN	The optimized design is 11.7% lighter and has more strength than the initial design.
2	2012	Interested in weight minimization and structure simplified.	ANSYS	The optimal result shows the weight of connecting rod is lighter and long life, also can be used in the traditional design to replace partly numerical analysis.
3	2013	Studied stressed to develop under static loading with different loading conditions of tension and compression at the crank end and pin end of connecting rod. Also, designed by a machine design approach.	PRO-E wildfire 4.0 and ANSYS 11	The maximum value of equivalent stress has been found be to 197.41 MPa when the crank end of connecting rod is under tension loading for the analytical outcome compared with numerical results. In addition, stress is less than the yield strength of the material and gives a safety factor is 3.2 for static load conditions.
4	2013	Evaluated of stresses (big and small ends).	Experimental and Numerical by Pro/E Wildfire 4.0 and ANSYS WORKBENCH 11.0	Stresses in the small end of the connecting rod are greater than the stresses at the big end.
5	2013	Developed a new insight for composite material.	CATIA V5 & MSC. PATRAN	Used two composite materials (Conventional Steel and E-Glass/Epoxy) and same boundary conditions, and compared to obtain results.
6	2013	Re-optimize of design of connecting rod of universal tractor (U650) through change some of the design variables under same boundary and loading conditions.	CATIA 19, PRO-E and ANSYS workbench v12	Modelled and optimized for the reduced density, and improved life and manufacturability.
7	2013	Used of forged steel and compared with carbon steel material during examined of (Von misses Stress, strain, and Deformation) and reduced of density. Also, fatigue life analyzed.	CATIA V5 R19 & ANSYS 13.0	Forged steel offers a higher margin of safety, enabling weight reduction, enhanced stiffness and reduce the stress and stiffer.
8	2013	Focused to replace of materials.	ANSYS	The recently new material exhibits reduced weight and improved stiffness characteristics. This discovery led to a remarkable 43.48% reduction in weight and a substantial 75% decrease in displacement.
9	2013	Investigate possibilities for reducing weight.	PRO-E and ANSYS	The design and optimization of the connecting rod can encompass both extreme loads: a tensile load aligning with a 360 degree crank angle at maximum engine speed, and the pressure exerted on the crank.

				Additionally, the current connecting rod can be substituted with a novel one crafted from Genetic Steel.
10	2014	Examine opportunities for weight and cost reduction in the design and manufacturing of connecting rods and approached in two steps.	ANSYS	The results of the analysis can produce extremely good designs very quickly, and we can apply the best designs there. Additionally, it was thought that the methods used in this study would be very helpful to designers.
11	2014	Examination of the compressive stress on the connecting rod under various loading conditions. The numerical results will also be used to investigate the experimental results.	Experimental and Numerical by ANSYS	It was found that there is a greater similarity between the experimental results and the numerical results.
12	2014	Analysis of the various stresses under fatigue loading on the connecting rod, and optimization for both shape and weight.	SOLIDWORKS and ANSYS workbench 11	Shape-finding technology has been employed to reduce weight, and structural steel has a high density. Therefore, aluminum alloy was used instead of the original material, which results in a large weight reduction and improved outcomes for stresses. In the case of aluminum alloy, longevity is also increased. Due to the large buckling stress, when analyses of linear buckling were conducted, the maximum deformation was 1.0072 mm. Because of the significant multi-axially of the load, multiaxial fatigue analysis is required to calculate the fatigue strength.
13	2014	Reviewed about optimizing the connecting rod's design for use in car engines.	CATIA and ANSYS	It is possible to make connecting rods lighter, less expensive, and more durable. The connecting rod is stronger and lighter than it was in the original design, but only to a point.
14	2014	Static stress analysis has been carried out on a connecting rod composed of two distinct materials: E-glass/Epoxy and an Aluminum composite reinforced with Carbon nanotubes.	ANSYS 14.0	The connecting rod fabricated with Al-2 vol. % CNTs demonstrates a lower weight compared to the E-Glass/Epoxy counterpart. Upon analyzing the results for these two different materials, it was observed that the stress induced in the Al-2 vol. % CNTs composite is lower than that in the E-Glass/Epoxy variant.
15	2014	The main goal is to install an aluminum connecting rod in place of the LML Freedom's currently damaged forged steel connecting rod.	Pro/Engineer and ANSYS	When combined with a superior epoxy that can survive the heat within the chamber, composite materials like carbon fiber, which have good strength, can be used as connecting rods. A crank shaft made of aluminum would produce superior results and put less strain on the connecting rod, extending its lifespan.
16	2014	Investigated and compared of the connecting rods made of two materials (forged steel and powder metal), and analyzing the costs of both materials under fatigue behavior.	CATIA V5 and ALTAIR RADIOSS	Forged steel it have best properties of (tensile and compressive and fatigue) test. While the powder metal its cost effectiveness.
17	2015	Stress and deformation analysis and weight optimization	Pro/Engineer and ANSYS	Identify the areas or parts where there is a high risk of failure. The collected data may also be utilized to improve the performance and life cycle of the current designs.
18	2015	describes of real time problem used Cast Iron material and optimized with different materials	CATIA and ANSYS 14.0	Modified design is better than the existing design.
19	2015	Analysis the stress, strain, deformation used varying material with same solid geometry	Pro/Engineer and ANSYS	(Al 6061) is high strength compared with (Al 6060 + B4C)
20	2015	Investigation study of the strength behavior for the connecting rod through the engine operation under fatigue loads.	SolidWorks and ANSYS V14.0	The connecting rod experiences both compressive and tensile forces, with the compressive forces significantly outweighing the tensile forces. As a result, the design prioritizes the accommodation of compressive forces.
21	2016	General study of properties for the connecting rod and redesign optimization through weight reduction and dimensions.	Numerical (CAD Software)	Utilizing plastic material data for analysis would yield more satisfactory results. To enhance precision in calculating induced stresses, a finer and more detailed meshing of the connecting rod can be employed. Additionally, for future endeavors, we should consider factors such as bushings, crank bearings, and damping effects. Furthermore, incorporating bolts tightened to their rated torque to achieve the correct preload for analysis could yield results that closely align with the actual component.
22	2016	Reviewed about weight optimization with different materials.	CATIA and ANSYS 14.0	Numerical results were obtained through software utilized for modeling and analysis, facilitating the design of connecting rods for use in automobiles. This design process focuses on achieving weight reduction and cost optimization while simultaneously extending the lifespan of the connecting rod. To a certain extent, this approach yields lighter connecting rods with enhanced strength when compared to the original design.
23	2016	Examine the stresses generated on the connecting rod.	SolidWorks and ANSYS Workbench 16.2	The maximum compression stress was occur between the pin end and the rod. While the maximum shear stress was exist at the pin end. In addition, the connecting rod failure can occur at either end, but there is a higher probability of failure at the piston end as opposed to the crank end.

24	2016	Stress distribution analysis for two materials (Aluminum and steel) on application of the force.	CATIA and ANSYS (mechanical APDL 14.5)	The stress intensity in an Aluminum connecting rod is higher compared to a Steel connecting rod. Moreover, there is significant potential for enhancing the design. Consequently, Steel emerges as the superior choice for connecting rods.
25	2017	The objective is to redesign, analyze, and explore alternative materials for the connecting rod.	CATIA V5 R21 and ANSYS 18.1	The maximum stress examined by all materials is approximately equal. Furthermore, the deflection of the Aluminum 7075-T651 connecting rod is comparable to that of the existing carbon steel (42CrMo4) connecting rod. Notably, the Aluminum 7075-T651 connecting rod offers a significant weight advantage, weighing approximately 35% less than the current carbon steel connecting rod.
26	2017	Design a connecting rod with standard dimensions and redesign with different materials under fatigue loading.	CREO 3.0 and ANSYS	Special focus should be placed on the areas of the design that are most susceptible to buckling under stress in order to achieve a significantly more efficient outcome.
27	2017	A comprehensive review focused on reducing weight, stresses, strain, and deformations of the connecting rod without affecting its strength.	ANSYS	Improved the strength under the influence of the loads, and reduced of density. In addition, the I-section design was chosen.
28	2017	The investigation on the examination of appropriate materials and load factors, as well as the analysis of stress, strain, and deformation caused by these factors. Furthermore, a structural optimization model for the connecting rod was developed.	SolidWorks 2016 and ANSYS Work Bench14.5	From the results, it can be inferred that Al6061+B4C exhibits lower stress and deformation values in comparison to 42CrMo4. Consequently, materials with reduced stress levels are more desirable for the manufacturing of connecting rods.
29	2017	Optimization of the weight of a steel connecting rod while maintaining its original strength. To achieve weight reduction, titanium inserts will be incorporated without compromising the inherent strength of the rod.	UG NX7.0 and ANSYS R15.0	When comparing the weight reduction of a connecting rod made from forged steel and an Al-Ti composite, it is evident that the latter exhibits a significant decrease in weight. Conversely, the weight reduction for a connecting rod composed of steel and Steel-Ti composite is not as substantial. However, this combination does offer an increased load carrying capacity.
30	2017	Develop a robust model for optimizing the structure of connecting rods used different materials.	SolidWorks 2016 and ANSYS Work Bench14.5	Titanium is a considerably more expensive material compared to aluminum metal matrix composites, despite both materials having the same stress value. However, titanium exhibits less deformation than 42CrMo4. Furthermore, we conducted a deformation analysis under dynamic loading on three distinct modes, each corresponding to different frequencies.
31	2017	Discusses the process of designing and analyzing connecting rods subjected to fatigue loading using various materials.	CATIA V5 R20 and ANSYS 13.0	In regards to C70 Steel, Belgium, an optimal set of parameters can be determined to achieve superior performance. These parameters aim to simultaneously reduce weight, enhance stiffness, minimize stress, and surpass the rigidity of alternative materials.
32	2017	Reviewed of connecting rod design and analysis using a variety of materials	ANSYS	Aluminum and titanium alloys are more affordable replacements for steel. Using composite materials, weight may be optimized without changing the permissible stresses and boundary conditions.
33	2017	Design and assessment of a connecting rod used in Hero Honda Motor Cycle for fatigue life have been conducted and evaluated.	CATIA and FEMFAT Software	To enhance the fatigue life of the connecting rod, we implement minor modifications to its geometry. Specifically, for the increase the neck radius thickness from 20 mm to 22 mm at the crank end and from 12 mm to 15 mm at the pin end. Will achieve a significant improvement in the rod's durability, extending its lifespan.
34	2017	Identification of problems and weak points in the connecting rod structure, which provides the theoretical foundation for better structural design and optimization.	CATIA and ANSYS	Modal analysis and transient dynamic analysis were conducted to determine the resonant frequencies of the rod and to obtain the stress, displacement, and velocity of the connecting rod at different time intervals. These results are considered as a guide for researchers to lead them to optimal design.
35	2017	Comprehensive design review. In addition to focusing on the stresses generated during operation as well as paying attention to ways through which to reduce the density	ANSYS	Exploring alternative weight-loss materials that could be used in the manufacture of connecting rod
36	2018	Used Finite Element method (FEM) was employed to analyze and gain a comprehensive understanding of the structure of the connecting rod.	NX 6.0 and ANSYS14.5	Slight adjustment using optimization techniques without changing dimensions, thus achieving weight reduction and low stress level at the same time
37	2018	To achieve an optimal design for connecting rods that maximizes material efficiency, minimizes costs, and enhances overall quality.	CATIA	An innovative and effective design method that distinguished itself from the prototype by reducing weight and effectively predicting all expectations
38	2018	Stress analysis on the connecting rod, considering distinct compressive and tensile loads applied individually and operating at	Cero PTC software	A large part was determined to be removed in several areas of the connecting rod based on the results of the numerical analysis

		various speeds.		
39	2019	The weight optimization of the connection rod, was conducted using the Finite Element Method (FEM) through ANSYS Workbench.	SolidWorks and ANSYS 16.1	Through the digital results, it was found that the Ansys program is effective and suitable for use in engineering designs as well as conducting analysis and optimization processes.
40	2020	Reduce weight, adjust and replace materials for a lightweight connecting rod without compromising its performance	INVENTOR Software and ANSYS	The Al7075 material exhibits a lower weight compared to other materials under similar loading conditions, So it is an acceptable material in its manufacture. In addition, the Ti-6Al-4V material has a higher safety factor under the same operating conditions. Therefore, both Al alloy and Ti alloy are suitable choices for the production of connecting rods.
41	2020	Reviewed to comprehend the precise behavior of the connecting rod across various material properties.	CATIA and ANSYS	Improving the performance of the connecting rod depends on the properties of the composite material that can be remanufactured to achieve the required specifications and goals
42	2020	Focus on weight reduction using optimization techniques applied to the connecting rod used in diesel engines	SolidWorks and ANSYS	Production companies can used ANSYS software to effectively reduce material waste, enhance profitability, and simultaneously uphold product quality and reliability.
43	2021	Focused on design and analysis of the connecting rod and topology optimization.	Cero PTC and ANSYS	By reducing all stresses and weight, it gives a clear impression to reach the optimal design as a more efficient model
44	2021	The design has been thoroughly reviewed and improved, with enhancements made to both the material quality and design parameters.	CATIA v5 R21, NX NASTRAN , Pro-E software and ANSYS WORKBENCH	Improving performance and achieving properties requires modification in the composition of the materials used
45	2021	Elastic deformations of connecting rod components were ignored by greatly simplifying calculations. Additionally, it removes the requirement to compile the equations of dynamics using partial derivatives.	Theoretical	By comparing the calculation results with those obtained for a two-mass model, one can identify errors and select a design model that achieves the desired level of accuracy.
46	2021	The main emphasis lies in exploring avenues for reducing the mass of the two wheel connecting rod through the introduction of two alternative materials, in addition to the currently used material.	CREO and ANSYS	Among the three materials tested, namely Aluminum alloy 7475, Titanium alloy Ti-6Al-4V, and another material (not specified), the Aluminum alloy demonstrated superior performance. It exhibited the lowest mass and a remarkable strength-to-weight ratio, making it the optimal choice.
47	2021	To enhance the effectiveness of the MCI (Measurement and Comparison Parameters), geometric modifications are implemented to ensure both functional requirements and resistance limitations are met. This is achieved through the utilization of CAD/CAE systems, which facilitate the integration of advanced design and analysis tools.	SolidWorks and ANSYS 15.0	By reducing the mass of each connecting rod by 9.564%, the power of the MCI was successfully increased without compromising their resistance, rigidity, or the functional performance of the kinematic torque.
48	2021	To conduct analysis under static and dynamic loading. Also, study of weight reduction through material optimization.	SolidWorks and ANSYS	The results showed a significant improvement in efficiency and age
49	2021	To achieve a lightweight design that fulfills the demands for low energy consumption and reduced vibration, the original connecting rod's structural design is modified. The goal is to decrease its weight, enhance natural frequencies, minimize material usage, and boost the energy efficiency of internal combustion engines.	Numerical (CAD Software)	By employing finite element analysis and prioritizing lightweight design principles, significant improvements have been achieved. These include a reduction in maximum equivalent stress and an increase in low-order natural frequency.
50	2022	To investigate potential avenues for reducing weight and cost in the design and manufacturing of connecting rods.	ANSYS Work Bench	Upon examination, the findings indicated that both Ti-6Al4V and 17-4Ph stainless steel met the necessary property requirements. However, it was observed that 17-4Ph stainless steel demonstrated superior strength and also offered a more cost-effective alternative.
51	2022	To improve the design using a topology optimization algorithm with different factors and multiple objectives	SolidWorks and CAE	The results showed that there is a significant decrease in density with the quality of strength and stiffness requirements
52	2022	To investigate the fracture of connecting rods through the utilization of Finite Element Analysis. By employing specialized software, the stress and thermal factors impacting the connecting rod could be thoroughly analyzed. The main focus was to minimize the load exerted on the big end and main bearing, thereby enhancing their durability and performance.	CATIA 5 W/F and ANSYS 16.2	Observed that the crank end cap and piston end experienced the lowest levels of stress among all the loading conditions. Therefore, it is possible to reduce the amount of material used in these specific areas, resulting in a reduction in material costs. Moreover, through the process of optimization, it is feasible to replace the existing connecting rod with a new one that is lighter in weight by approximately 15%. Comparatively, aluminum alloy connecting rods exhibit greater weight and displacement when compared to magnesium and beryllium alloys.

				Consequently, aluminum connecting rods may demonstrate more vibration-induced behavior or instability.
53	2022	To obtain an accurate S-N curve for the connecting rod material, a fatigue test was performed. Additionally, the static strength of the connecting rod assembly was evaluated using an electrohydraulic servo universal testing machine. The test results served as the basis for validating the numerical modeling approach.	Experimental and Numerical by ANSYS	By optimizing the alignment between the large end fillet of the connecting rod and the long diameter of the rod section, not only was the mass reduced, but the safety factor was also enhanced. Following the structural optimization of the connecting rod, a reduction of 5.85% in mass, a decrease of 13.7% in maximum stress, and an increase of 16.0% in the safety factor were achieved. This optimization approach, along with the application of an empirical formula to calculate the maximum stress of the connecting rod, provides a novel analysis method for this model and similar types in conceptual and technological design stages. As a result, the efficiency of structural optimization and strength analysis for the connecting rod assembly has been significantly improved.

Table 2. Design parameters

No.	Nomenclature	Symbol
1	Maximum pressure of gas	p
2	Diameter of piston	D
3	Cross-section area of piston	A
4	Mass of reciprocating parts	m_R
5	Angular speed of crank	ω
6	Angle of inclination of the connecting rod with the line of stroke	ϕ
7	Angle of inclination of the crank from top dead centre	θ
8	Radius of crank	r
9	Length of connecting rod	L
10	Ratio of length of connecting rod to radius of crank = l / r	N

3. Mathematical Model

3.1. Forces Acting on the Connecting Rod

There are several types of forces acting on the connecting rod, which are as follows (the force acting on the piston as a result of gas pressure and inertia of the parts with reciprocating movement. As well as the forces resulting from the friction of the piston rings. In addition, the force resulting from the friction of the piston pin bearing and the crankpin bearing). Figure 2 an explained to forces on the connection rod and Inertia bending forces as the equations (1 to 5). While, the Table 2 explained the design parameters.

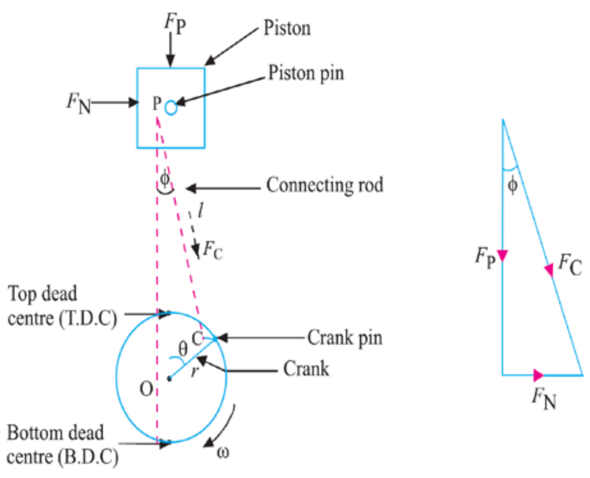

Figure 2. Forces on the Connecting Rod [54]

1- Force on the piston due to pressure of gas F_L = *Pressure* × *Area*

$$F_L = p\ .A = p \times \frac{\pi}{4} D^2 \tag{1}$$

2- Inertia force of reciprocating parts F_I = *Mass* × *Acceleration*

$$F_I = m_R.\omega^2.\,r\left(\cos\theta + \frac{\cos 2\theta}{n}\right) \tag{2}$$

3- Net force acting on the piston F_P = *Force due to gas pressure* ∓ *Inertia force*

$$F_P = F_L \mp F_I \tag{3}$$

Where the –ve and +ve are signs of TDC (top dead center) to BDC (bottom dead center) respectively, and weight of the reciprocating parts ($W_R = m_R\ .\ g$) then:

$$F_P = F_L \mp F_I \pm W_R \tag{4}$$

From figure (2) we see force of connecting rod (F_C) as in next equation:

$$F_C = \frac{F_P}{\cos\varphi} = \frac{F_P}{\sqrt{1 - \frac{\sin^2\theta}{n^2}}} \tag{5}$$

4- Force due to inertia of the connecting rod for the each point will be as follows:

$$InertiaforceatC = m.\omega^2.CO \tag{6}$$

$$InertiaforceatD = m.\omega^2.dO \tag{7}$$

$$InertiaforceatE = m.\omega^2.eO \tag{8}$$

Inertia force per unit length at the crankpin= $m_1 . \omega^2$, and inertia force per unit length at the piston pin = 0

Inertia force due to small element of divisions length dx at a distance x from the piston pin P,

$$dF_1 = m_1.\omega^2 r \,.\frac{x}{l}.\, dx \tag{9}$$

$$F_I = \int_0^l m_1.\omega^2 r \,.\frac{x}{l}.\, dx = \frac{m_1.\omega^2 r}{l}\left[\frac{x^2}{l}\right]_0^l \tag{10}$$

When Substituting ($m_1 . l = m$) we gets:

$$F_I = \frac{m}{2}.\omega^2 r \tag{11}$$

5- Force due to friction of piston rings and of the piston (F)

$$F = \pi\ D\ .t_R.n_R.p_R.\ \mu \tag{12}$$

3.2. Bending and Compressive Stresses

From figure (3) we see the bending moment is acting on the rod at section X – X at a distance x from P, where bending moment due to variable force from $\left(0tom_1\omega^2.\frac{x}{l}\right)$, and assuming the effect of the inertia force at two-thirds of the piston from point P. In addition, the concentration of mass is in one-third of the connecting rod from point P, which results in the reactions are as follows:

$$\left(R_P = \frac{1}{3}F_I\ ,andR_C = \frac{2}{3}F_I\right)$$

$$M_X = \left(R_P.\,x\right) - \left(m_1.\omega^2 r\ .\frac{x}{l}.\frac{x}{2}.\frac{x}{3}\right)$$

$$M_X = \frac{F_I.\,x}{3} - \frac{F_I\ .x^3}{3l}$$

$$\therefore M_X = \frac{F_I}{3}\left(x - \frac{x^3}{l^2}\right) \tag{13}$$

Now, differentiate M_X with respect to x axis to get maximum bending moment,

$$\frac{dM_X}{dx} = \frac{F_I}{3}\left(1 - \frac{3x^2}{l^2}\right) = 0$$

$$\therefore x = \frac{l}{\sqrt{3}}$$

$$\therefore M_{max} = \frac{F_I}{3}\left(\frac{l}{\sqrt{3}} - \frac{\left(\frac{1}{\sqrt{3}}\right)^2}{l^2}\right) = m\ .\omega^2 r\ .\frac{l}{9\sqrt{3}} \tag{14}$$

$$maximum\ Bending\ Stress\left(\sigma_{max}\right) = \frac{M_{max}}{Z} \tag{15}$$

Where: Z – Modulus section

Compressive Stress (σ_c)

$$\sigma_C = Direct\ copmressive\ stress + \sigma_{max} \tag{16}$$

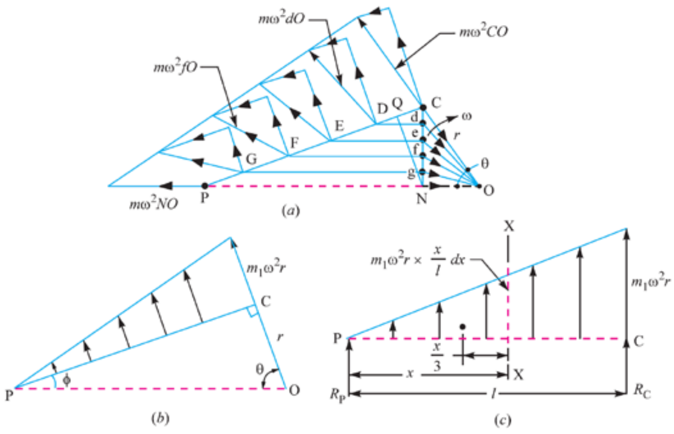

Figure 3. Inertia bending forces

4. Conclusion

Based on the aforementioned literature reviews, it has been determined that significant efforts have been made to enhance the material composition of connecting rods through basic studies and research. The performance of a connecting rod can be enhanced by altering the materials utilized, as different materials possess distinct properties. By alloying materials, the desired properties can be achieved. In their investigations, many researchers employed software such as CATIA, SolidWorks, NX NASTRAN, and Creo PTC for modeling purposes, while ANSYS software was used for analysis. Numerical analyses were conducted to determine the magnitude of loads (including stresses, deformation, and buckling) experienced by a connecting rod under applied loads. Furthermore, theoretical calculations and experimental studies were employed to identify errors and select a design model that achieves the desired level of accuracy.

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