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Design and Rigid Dynamic Analysis of Engine Cylinder with Integrated Mass Optimization of Connecting Link to Reduce the Weight for Maximum Stiffness Condition

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ABSTRACT: The connecting rod is the intermediate member between the piston and the Crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank. This paper describes designing and Analysis of connecting rod. Currently, existing connecting rod is manufactured by using Forged steel. In this, drawing is drafted from the calculations. A parametric model of Connecting rod is modelled using SOLIDWORKS software and to that dynamic motion analysis is performed and structural results generated from the motion condition to study the stress values. For the developed stress analysis at different RPM's have been calculated and mass optimization for maximum stiffness condition is performed to reduce the weight of the connecting rod for developed stress values. By performing the analysis, we have reduced the weight of the connecting rod.

Key words: Optimization, Link, Weight, stiffness, Connecting rod, Solidworks

I. INTRODUCTION

Connecting rod interconnects the piston and the crank shaft and transmits the gas forces from the piston to the crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin and thus convert the reciprocating motion of the piston into rotary motion of the crank. Generally connecting rods are manufactured using carbon steel and in recent days aluminium alloys are finding its application in connecting rod. In this work connecting rod is replaced by aluminium based composite material. And it also describes the fabricating and testing of connecting rod. It consists of a long shank a small end and big end. The small end of connecting rod is usually made in the form of an eye and is provided with a bush. It is connected to the piston by means of piston pin. The big end of connecting rod is connected to the crank by means of damping. Connecting rod has three main zones. The piston pin end, the centre shank and the big end. The piston pinned is the small end, the crank end is the big end and the centre shank is of I cross section. Connecting rod is a pin jointed strut in which more weight is concentrated towards the big end. Connecting rod is acted upon by gas loads and inertia loads during its operation. The forces include gas forces due to combustion and inertia forces due to its own weight. The automobile engine connecting rod is a high-volume production, critical component. Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine. Connecting rods for automotive applications are typically manufactured by forging from either wrought steel or powdered metal. They could also be cast. However, castings could have blow - holes which are detrimental from durability and fatigue points of view. The fact that forgings produce blow-hole-free and better rods gives them an advantage over cast rods. Between the forging processes, powder forged or drop forged, each process has its own pros and cons. Powder metal manufactured blanks have the advantage of being near net shape, reducing material waste. However, the cost of the blank is high due to the high material cost and sophisticated manufacturing techniques. With steel forging, the material is inexpensive and the rough part manufacturing process is cost effective. In this work connecting rod is replaced by aluminium based composite material and it also describes the design and analysis of connecting rod. Generally connecting rods are manufactured using carbon steel and in recent days aluminium alloys are used. Durability is one of the critical importance of this component, the critical importance of this component, this can be achieved by getting the knowledge about different aspects such as production technology, materials, performance simulation, and fatigue. When building a high-performance engine, great attention is paid to the connecting rods, eliminating stress risers by such techniques as grinding the edges of the rod to a smooth radius, shot peening to induce compressive surface stresses (to prevent crack initiation). Time and

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effort were necessary to create the best design for a connecting rod to allow it to handle high stresses while minimizing weight. The reduction of weight of connecting rods is important to ensure that the engine can operate safely in higher RPM's due to the decreased inertia held within the lighter rods. The goal has become to remove as much material from these rods while still maintaining their strength and integrity so as to safely perform under the conditions of each engine.

Fig 1.1 Connecting Rod

Fig 1.2 Connecting Rod Assembly

Different material used for connecting rod:

1. Forged steel connecting rods
2. Aluminium Connecting Rods
3. Steel Connecting Rods
4. Titanium Connecting Rods
5. Carbon Steel
6. Grey Cast Iron
7. Aluminium 5052 (H38)

Adnan Ali Haider, [1],

worked on a replacement of connecting rod with 14%weightsavings was designed by removing material from areas that showed high factor of safety Factor of safety with respect to fatigue strength was obtained by performing FEA with applied loads including bolt tightening load, piston pin interference load, compressive gas load and tensile inertia load. In this research, the engine was simulated in MSC/ADAMS/Engine software and forces acting on different parts of crank mechanism were extracted after that connecting rod was simulated in Solid Works software, meshed in ANSYS software and critical loads were exerted on it finally stress analysis was done. The kinematic and kinetic analyses of the crank mechanism, stress and fatigue analysis, and finally optimization of connecting rod were performed on Sam and engine. Forthis purpose, the slidercrank mechanism was simulated in MSC/ADAMS/Engine softwareand forces acting on different parts of crank mechanism were extracted after that connecting rod was simulated in ANSYS software, critical loads were exerted on it, stress and fatigue analysis was done. For stress analysis of connecting rod, it was modelled and meshed in ANSYS (Ver. 9) software. The von miss stress and total deformation of two different aluminium alloys were compared with the forged steel. Ramani et al focused on the two subjects, first, load and stress analysis of the connecting rod, and second, optimization for weight reduction. In the first part of the study, loads acting on the connecting rod and find out stress time history at some critical point. Magesh Kumar et.al., [2], connecting rods are being manufactured by conventional method of forging. Steel can be replaced by aluminium and titanium alloys on a cost of affordability. Weight optimization is possible using composite materials without varying the allowable stresses and boundary conditions. Akbar H Khan [3], research work investigated Static structural and experimental stress analysis of two-wheeler connecting rod using by theoretically, Finite element analysis and using Photo elasticity method. Connecting rod of two-wheeler 100 cc petrol engine is taken for the analysis, Finite element analysis includes the Design and modelling of connecting rod using Creo 2.0 and Ansys 15.0 for the Static Structural analysis. Photo elasticity analysis method includes the casting of Photo elastic sheet using Araldite AY 103 and Hardener HY 991 and then connecting rod model is prepared by laser cutting machine. In his research paper static structural analysis is carried out to find the von miss stresses and Stress analysis is carried out to find maximum principal stress and reason behind the failure of connecting rod. Conclusion drawn from his study, it is been observed that the maximum stresses are induces at the fillet section of both ends of the connecting rod and chances of the failure of the connecting rod is found at the fillet sections of both ends of connecting rod. Therefore, to avoid that stresses and failure material need to be added at the fillet sections of connecting rod. By observing the different fringes developed in the connecting rod specimen and by calculating the maximum principal stress at that section we can say that the stresses induced in the small end of the connecting rod are greater than the stresses induced at the big end. Form the Photo elasticity analysis it is found that the stress concentration effect exists at both small end and big end and it is negligible in the middle portion of the connecting rod. Therefore, the chances of failure of the connecting rod may be at fillet section of both ends. Nagaraj K L [4], in his thesis, a connecting rod is demonstrated utilizing Catia v5, discretization utilizing Hyper Mesh and analysis utilizing Nastran. The outcome predicts the most extreme buckling load and basic locale on the interfacing pole. It is imperative to find the basic

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territory of concentrated stress for fitting adjustments. He discovered the stresses created in interfacing pole under static loading with various stacking states of compression and tension at crank end and pin end of connecting rod. The displacement plot shows a very small value which does not affect the performance of the connectingrod. The linear static analysis of the connecting rod shows that the stress generated in the model is within the acceptable limits or maximum allowable stress. The buckling mode analysis gives the buckling factor greater than 1 and hence it can be concluded that the connecting rod can withstand the load applied. Sharma Manoj, Shashikant [5], taken connecting rod of a Mahindra Jeep CJ-340and change its material from Al360 to PEEK. The modelling of the connecting rod is done on Pro-E wildfire 4.0 and analysis work is done on ANSYS 11.0. The parameters like Von misses' stress, Von messes strain and displacement were obtained from ANSYS software which shows reduction in weight and improvement in strength. Kuldeep B [6], analysed the connecting rod by replacing Al360 material by aluminium based composite material reinforced with silicon carbide and fly ash. He also described the modelling and analysis of connecting rod. FEA analysis was carried out by considering 2 materials. The parameters like von misses' stress, von misses strain and displacements were obtained from ANSYS software. Compared to the former material the new material found to have less weight and better stiffness. It resulted in reduction of43.48% of weight, with 75% reduction in displacement. Mathanapalli Hari Priya, K. Manohar Reddy [7], a connecting rod for a 150ccengine has been model in 3D modelling software cero. The actual cross section connecting rod is I section, which have been changed to cross section H By changing the cross section, the weight of connecting rod is reduced by 10gms.The material used for connecting rod is carbon steel which is replaced with Aluminium alloy A360. By comparing the stress values for both materials, it is slightly less for Aluminium alloyA360 than carbon steel. Ram Bansal [8], conducted a Dynamic simulation was on a connecting rod made of Aluminium Alloy using finite element analysis. The connecting rod is one of the important parts of an engine. Connecting rod of the single cylinder four stroke diesel engine is used. After measurements were taken, connecting rods were modelled using CATIA software and saved in 'IGES' format. Then, the model of connecting rod (IGE format) imported into ANSYS software. In his analysis of connecting rod was performed under Dynamic load for Stress analysis, and optimization. The pressure-volume diagram was used to calculate the load boundary condition in dynamic simulation model, and other simulation inputs were taken from the engine Specification chart. The data obtained at engine run were plotted on graph by Engine-soft Software. The maximum deformation, maximum stress point and dangerous areas are found by the stress analysis of connecting rod. This analysis uses a different mesh to get more precise results. Relationship between the stress and the nodal displacement is explained by the modal analysisofconnecting rod. The results would provide a valuable theoretical foundation for the optimization and improvement of connecting rod. Dynamic load analysis was performed to determine the in-service loading of the connecting rod and FEA was conducted to find stresses at critical locations. The maximum deformation appears at the centre of big end& small end bearings inner fibre surface. The areas subjected to crushing due to crankshaft & gudgeon pin is shown through analysis after implementing boundary conditions The connecting rod deformation was mainly bending due to buckling under the criticalloading. And the maximum deformation was located due to crush & shear failure ofthe big & small end bearings. So these areas prone to appear the fatigue crack. Base on theresults, we can forecast the possibility of mutual interference between the connecting rodand other parts. The results provide a theoretical basis to optimize the design and fatigue life calculation.

II. DESIGNING OF CONNECTING ROD

5.1 Designing of connecting rod:

Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank. This Dissertation describes designing and analysis of connecting rod. Currently existing connecting rod is manufactured by using Carbon Steel. The following dimensions are required to be determined to design a connecting rod:

- Dimensions of cross-section of the connecting rod,
- Dimensions of the crankpin at the big end and the piston pin at the small end.

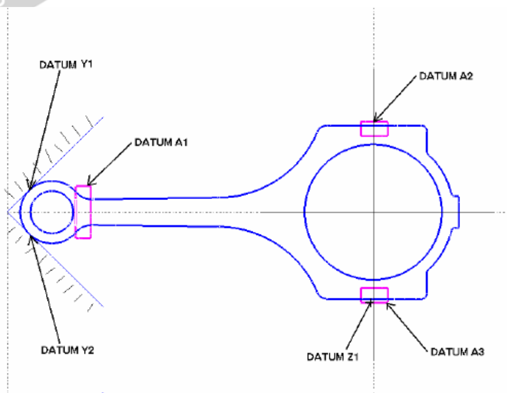

Fig 5.1: A typical connecting rod to be designed

5.2 MATERIALS USED FOR CONNECTING ROD:

5.2.1 Carbon Steel:

Steels containing carbon as the major alloying element are called carbon steels. They may also contain up to 1.2% manganese and 0.4% silicon. Residual elements

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such as copper, molybdenum, aluminium, chromium and nickel are also present in these steels. AISI 1065 carbon steel is a high-carbon steel, which has high tensile strength and heat treatable.

Also called **mild steel**, it's commonly used structurally in buildings and bridges, axles, gears, shafts, rails, pipelines and couplings, cars, fridges and washing machines. High **carbon steel** has a much better tensile strength, used to make cutting tools, blades, punches, dies, springs and high-strength wire.

5.2.2 Grey Cast iron:

It is the most common cast iron and the most widely used cast material based on weight. It is used for housings where the stiffness of the component is more important than its tensile strength, such as internal combustion engine cylinder blocks, pump housings, valve bodies, electrical boxes, and decorative castings. A typical chemical composition to obtain a graphitic microstructure is 2.5 to 4.0% carbon and 1 to 3% silicon by weight. Graphite may occupy 6 to 10% of the volume of grey iron. Silicon is important for making grey iron as opposed to white cast iron, because silicon is a *graphite stabilizing* element in cast iron, which means it helps the alloy produce graphite instead of iron carbides; at 3% silicon almost no carbon is held in chemical form as iron carbide.

5.2.3 Aluminium 5052 (H38):

Corrosion Resistance 5052 has the same high resistance to general corrosion as other non-heat treatable aluminium alloys. ...
The resistance of 5052 to corrosion in marine atmospheres is excellent, exceeding that of 5005, hence the frequent use of 5052 in marine applications.

5.3 Failure of connecting rod:

Failure of a connecting rod, usually called throwing arod, is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; which results from fatigue near a physical defect in the rod and/or lubrication failure. Connecting Rod fails for any of the above reasons. The rod is expanded and compressed at every stage. The rod breaks due to this pressure and other responsible factors. The deformed rod can completely block the engine, ruining the engine condition known as "throwing of rod"

5.3.1 Overloading the Rods:

Usually, the rods are strong enough to accommodate extreme performance modifications. They also can handle some of the racing types. However, they have the limits to which they can comfortably handle. With an increase in power levels and RPMs, the rods will get the point where they cannot support the job further and this can lead to the connecting rod failure which in return can get the engine destroyed within a second. Overloading associates with extreme racing where, the motor makes higher horsepower than needed. However, cases of rod failure about overloading are not common.

5.3.2 Less Lubrication and Heat:

When there is a reduced gap between the rod’s bearing and the crankshaft surface, it minimizes the amount of film oil space. As a result, there is an increase in friction which in return generates more heat. The heat makes the bearing to expand resulting into reduction of oil delivery. As the temperature increases to the peak, it results in annealing of the bearing towards journal race. And this tightens and freezes the bearings against crankshaft journal. The overheating, blue-black marks formed on the journals and the bearing results to rod’s failure.

5.3.3 Elongated Rod Bore:

In case the rod’s bore elongates more with high RPM, there it can distort clearances that exist between the bearings and the shaft. It can also happen in case the bolts do not get properly torqued. If the bolt torque doesn’t get proper fixing, it fails to keep the rod in place. The bolts can also be very weak at high RPMs. Such property will pull the cap away off the connecting rod. When the rod is not in its correct positioning, it results to rod’s failure which in return will destroy vehicle`s engine.

5.3.4 Bolt Stretch:

When we experience tight bearing, it can result in excessive bolt stretch. The final result is tearing and weakening of available threads in rod cap. When the rod bolts get exposed to such stresses, they weaken, and their tensile power gets reduced.

5.3.5 Fatigue:

Fatigue is the main cause of broken connecting rods mainly in older engines. The constant compression during the power stroke and stretching during the exhaust stroke, over thousands of times in a minute, eventually wears the metal out and it gets brittle and eventually stops the relative motion between the mating surfaces of connecting rod.

5.3.6 Pin Failure:

Piston pin or gudgeon pin connects the connecting rod to the piston. A lot of wear is acting on piston pin. Due to walkover of this pin the connecting rod disconnects to the any/both sides of connections. For some engines this results in catastrophic engine failure-the connecting rod goes through the engine block or the crankshaft is bent, but in some engines, it causes a heavy loss of power.

5.3.7 Over Revving:

Over revving is the primary reason of connecting rod failures

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in new and high-performance engines. If the tachometer hits the red--even briefly--the connecting rods are in peril of falling apart. This is because the forces acting on a connecting rod increase dramatically at high revolutions. It does not count if the tachometer is going into the red because the auto is traveling at a high fastness.

5.3.8 Hydro lock:

Hydrolock is a deformation of the connecting rod caused when water gets into the piston chamber. This usually happens after the car has been driven through deep water such as a flooded street. If only a little water gets into the cylinder the car makes a knocking or tapping sound and it can be repaired (have the water taken out and the gaskets replaced), but if enough water gets in the cylinder that it takes up all the space available at spark time, the connecting rod will bend or snap. Hydrolock is much more common in boats than in cars because boats are always operated around water.

5.3 Calculations:

Bore × Stroke =58×56 mm
Compression Ratio =9.5:1
Maximum Power =14.85 hp @9000 rpm
Maximum Torque =12.11hp @6500 rpm
Density of Petrol 737.22 kg/m3
Temperature of Petrol@ Room =288.855 K
Mass of Petrol =Density × Volume = 0.011 kg
Molecular Weight of Petrol =0.114228 kg /mole
Gas Equation:P.V = m×R×T
P =15.521 MPa
Standard Proportions of I-Section: -
Width of the section, B = 4t
Depth of the section, H =5t
Area of the section =11t2
Depth of the section near the big end = 1.1H to 1.25 H
Depth of the section near the small end = 0.75H to 0.9 H
Moment of inertia about X-Axis Ixx = 34.91 t4
Moment of inertia about y-Axis Iyy = 10.91 t4
Therefore, Ixx/Iyy = 3.2
Radius of gyration of the section about X-Axis = 1.78t
Length of crank pin = 1.25dc to 1.5dc
Length of piston pin = 1.5dp to 2dp

Dimensions of I-section of Connecting Rod:

The maximum force acting on the piston due to gas pressure,
Since the connecting rod is designed by taking the force on connecting rod (Fc) equal to the maximum force on the piston (FL) due to gas pressure, therefore
$Fc = \pi \times D\hat{}2 \times p / 4$ = 41007.714
Designed Force= Maximum Force × Factor of Safety
Fc = 102519.28 N
Since, factor of safety considered is 2.5
Radius of gyration of the section about X-Axis,

$$k_{xx} = \sqrt{\frac{Ixx}{A}} = \sqrt{\frac{34.91t^4}{11t^2}} = 1.78t$$

Radius of crank =56/2 = 28 mm

From Rankine's formula,

$$W_B = \left[\frac{\sigma_c . A}{1 + a\left[\left(\frac{L}{k_{xx}}\right)^2\right]}\right]$$

Where, σc= 250 MPa,

E = 2× 105MPa

$a = \sigma c / \pi 2\ E$ = 1/7895.68

t = 6.1 mm

Width of the section, B = 4t = 24.4 mm Height of the section = 5t =30.5 mm

For small end of rod, $FF_{pp} = I_p\ d_p\ p_b$

Where, Ip =Length of piston pin, d_p =Diameter of piston pin, Pb = Permissible bearing pressure, p_b is taken as 10 to 14 N/mm^2,

Ip =1.5; d =44.19 mm

For big end of rod, $Fp = lcdcpb$

Where, Lc=Length of crank pin, dc=Diameter of crank pin, Pb =Permissible bearing pressure, Pb is taken as 5 to 10 N/mm2

Maximum Tensile force:

Mass of the connecting rod, m = volume× length× density = 0.305 kg

Maximum force in the crank pin, Fmax =ρAω2 r = 80793 N

Resultant normal force on the connecting rod, Fn= 1/2 Fmax L = 3837.67 N

Maximum Bending moment, Maxx = 2Fn. L/9√3 = 46.77 N-m

Section Modulus, $Zx = Ixx / Y$max = 3.16×10−6mm3

Maximum bending stress due to inertia bending forces = Mmax/Zxx = 14.75×**111166** N/m2

This is safe

III. CAD MODELLING IN SOLIDWORKS:

SolidWorks is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) computer program published

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by Dassault Systems, that runs primarily on Microsoft Windows. While it is possible to run SolidWorks on an Intel-based Mac with Windows installed, the application's developer recommends against this.

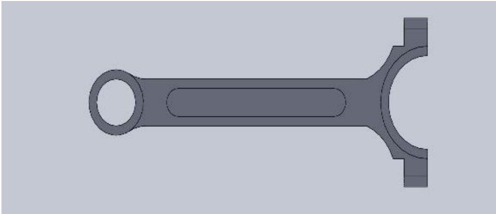


Fig 6.1.1 Front view of the connecting rod

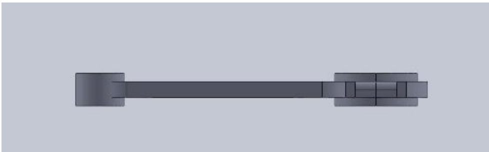


Fig 6.1.2 Top view of the Connecting Rod

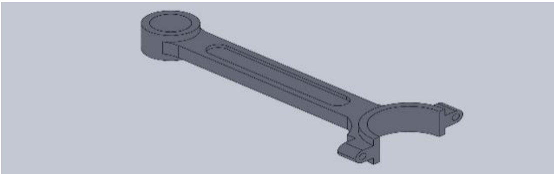


Fig 6.1.3 Isometric view of the connecting rod

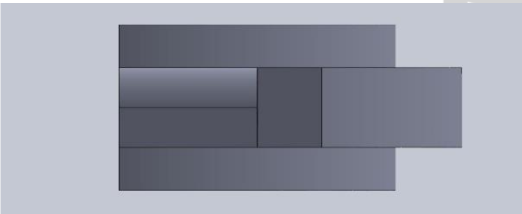


Fig 6.1.4 Front view of the Eccentric half end

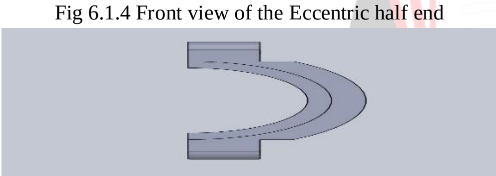


Fig 6.1.5 Top view of the eccentricity end

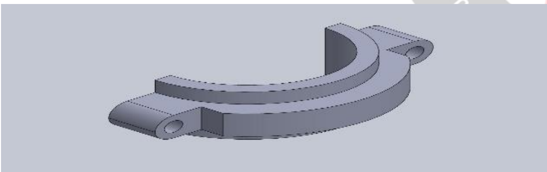


Fig 6.1.6 Isometric view of the Eccentricity one end

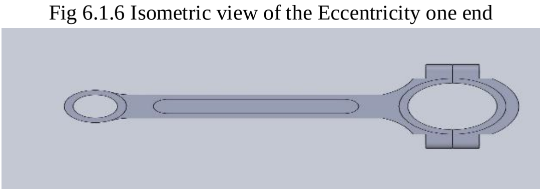


Fig 6.1.7 Front view of Assembled Connecting rod

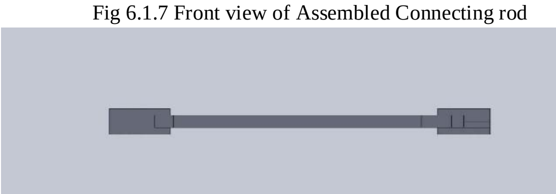


Fig 6.1.8: Top view of Assembled Connecting rod

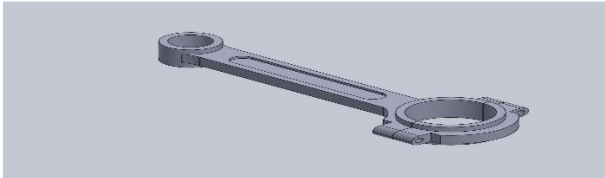
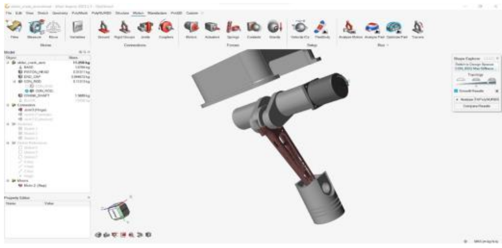


Fig 6.9 Isometric view of Assembled Connecting rod

8.6.1 BEFORE MASS OPTIMIZATION:

8.6.2 AFTER MASS OPTIMIZATION



Simulation results at 250 rpm

No	Parameters	Results before optimization(max)	Results after optimization(max)
1	Displacement	2.744e- 07 m	5.332e- 04 m
2	Factor of safety	4.03	6.68
3	Tension/compression stress	6.523e+ 05 pa	1.206e+ 60 pa
4	Shear stress	3.683e+ 05 pa	6.074e+ 01 pa
5	Von mises stress	6.523e+ 05 pa	1.206e+ 60 pa

Simulation results at 500 rpm

No	Parameters	Results before optimization(max)	Results after optimization(max)
1	Displacement	2.735e- 04 m	6.506e- 04 m
2	Factor of safety	4.17	6.61
3	Tension/compression stress	6.533e+ 05 pa	1.749e+ 60 pa
4	Shear stress	3.688e+ 05 pa	8.808e+ 01 pa
5	Von mises stress	6.533e+ 05 pa	1.749e+ 60 pa

Mass optimization of connecting rod at 500 rpm:

No	Mass of connecting rod before optimization	Mass of connecting rod after optimization
1	0.266 kg	0.113

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IV. CONCLUSION

This work investigated weight reduction and mass optimization for 500 rpm of crank shaft rotation. Dynamic analysis has been performed to check the displacements, factor of safety and stresses at different rpm of crank shaft. Load analysis was performed which comprised of the connecting rod, small and big ends of connecting rod using analytical techniques and computer-based mechanism simulation tools. FEA was then performed using the results from load analysis to gain insight on the structural behaviour of the connecting rod and to determine the design loads for optimization. The following conclusions can be drawn from this study.

- After performing the simulation, the factor of safety of the connecting rod is increasing, which means the life of connecting increased.
- At 250rpm and 500rpm before optimization the displacement is almost same. But after optimization the displacement developed at two rpms increasing but displacement is not too high.
- As the speed increasing the tension and compression in the connecting rod increasing but half cycle of the rotation is tension and half cycle compression. But the increased tension and compression are reasonable to optimise.

Further we need to perform the different material and different working conditions to further reduce the weight of engine cylinder and need to improve the efficiency of the engine cylinder.

We have performed the mass optimization of connecting rod at 500 rpm for maximum stiffness condition. Initially the weight of the connecting rod is 0.266 kg after mass optimization the weight of the connecting rod decreased to 0.113 kg.

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