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Design on Optimization of Connecting Rod

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Abstract. This project aims to reduce the weight of the connecting rod while at the same time improving the strength of the design and its reliability. Thus the mass of the connecting rod is minimized subject to the constraint of strength. The method adopted is called OPTIMISATION with mass as the objective function and the strength being the constraint within which the optimum value of mass and hence the design is evaluated. Optimization is an iterative process in which an objective function of single or many independent variables is evaluated over a domain of constraints to which these independent variables are subjected. The process starts at a convenient point and then proceeds towards a better approximation of the optimized design with each iteration and yields the final optimized design after many such iterations. It is a mathematical process involving a large number of computations and hence we use here HYPERMESH version 7.0 for this project to carry out the optimization process.

1. Introduction

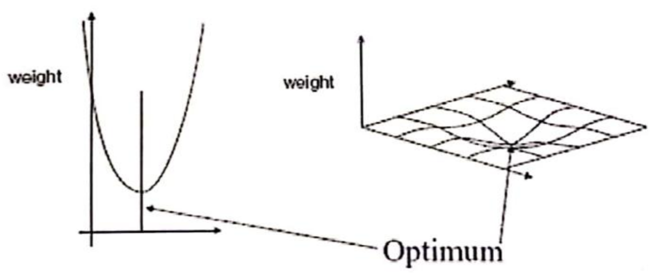
Due to the heavy parts, vibrations are higher in a diesel engine as compared to spark ignition engines since the parts are heavy, the engine speed and thus power produced were limited by inertial loads. But with the advancement in technology these problems were solved and the diesel engines available now can compete with spark ignition technology. Much of this was the result of advancement in material technology which led to the development of lighter and stronger materials and efficient cooling of the components. Also the advancement in design technology also was another significant factor. Many new CAD packages developed can simulate real world conditions better resulting in a more safe and efficient design. Attempts were made to reduce the vibrations and weight of the engine components and many of the inherent problems of the diesel engine were successfully reduced in magnitude if not completely eliminated. Thus as the diesel engine became better it became increasingly popular until the present when diesel engine technology has a significant advantage over spark ignition technology because of comparatively lesser fuel costs. The compression-ignition technology currently having a significant share in the automobile sector as compared to the past particularly when it comes to SUV, MUV and other heavy duty vehicles. Although the engine has changes a lot in functionality and in terms of materials used for construction, the basic structure of a reciprocating engine has remained unchanged throughout the process of change except for changes in their design techniques, geometry and construction of its components. Out of some 16000 components assembled together in an automobile engine, the four main components that are directly responsible for the conversion of the indicated power in the combustion chamber into the brake power that drives the automobile and which directly influence the engine efficiency are: Crankshaft, Connecting rod, Piston, Cylinder bore. Cylinder Bore: The cylinder bore provides the space for the combustion to take place and the piston fits into the bore with a small clearance which is sealed by piston rings. It is simply a cylinder bore made in an engine block and lined with a liner bush for smooth movement of the piston. Piston: The piston is the component responsible along with the cylinder bore and cylinder head to compress the air fuel mixture to a sufficiently high pressure and cause auto-ignition of the mixture. It is also responsible to transfer motive power to the crankshaft through the connecting rod when the hot gas on combustion expands pushing the piston. Also many pistons especially in diesel engines have provision to provide swirl to the air fuel mixture to help in proper mixing of air and fuel. The piston reciprocates within the cylinder bore. Connecting Rod: The piston's reciprocating action is converted into the crankshaft's rotating motion, which is then communicated to the wheels of the vehicle through the connecting rod, which sits between the piston and the crankshaft. It has two ends a big end and a small end. The big end bears on the crank pin while the gudgeon pin in the piston fits into the small end bearing. It has a combined rotary and linear motion. The connecting rod has a tendency to buckle and the load acting on it varies with time in a periodic manner. Also it is subjected to the high temperature in the engine. Crankshaft: The crankshaft consists of a series of eccentric pin at some distance from its axis of rotation at which it is connected with the connecting rods of each cylinder. Thus the connecting rod applies a torque on the crankshaft due to which it undergoes pure rotation. A flywheel is mounted on the crankshaft generally to control the speed fluctuations in the engines. The crankshaft is thus under torsion. Also multiple holes are drilled on the crankshaft as passages for lubrication of the big end bearing surface of the connecting rod. Thus the rotational form of the kinetic energy of the crankshaft which is easier to transmit, is transmitted to the gear box, propeller shaft, the differential, and hence the wheels thus propelling the vehicle. Many of the problems in the diesel engine can be traced back to its inherently huge weight. The lighter the parts and components the faster they can move as the inertial loads would reduce and would cause lesser stresses on the components. Also reduction in the weight of components would lead to reduce vibrations and thus would improve performance and increase engine life. Thus if it was possible to reduce the weight of the engine components, the efficiency, life and thereby the reliability of the engine would increase. Simultaneous with reduction in the weight of the components, the strength of the components must be increased for better performance. Thus the problem is of maximizing efficiency and performance of the engine by minimizing the weight of the component subject to the constraint of maintaining a predetermined and safe value of strength of the components. The connecting rod, is a critical component of an automobile engine. It is subjected to the huge loads arising from the pressure of the air-fuel mixture undergoing compression exerted on the piston. Also the load varies with time in a periodic manner which means fatigue strength becomes an important parameter in the design of connecting rod. Also the connecting rod acts in an environment of high temperature and the strength of the material at these high temperatures also needs to be considered. Thus strength is the primary concern while designing the connecting rod. On the other hand, reducing the weight of the connecting rod has some significant advantages: It reduces the inertial load on the crankshaft. The engine can attain higher speeds safely. The fuel consumption reduces. There are less problems of vibration. The engine life increases. The engine efficiency increases.

2. Specification of the Problem

Problem Definition: - Throughout its service life, a connecting rod is subjected to cyclical stresses. Longevity, fatigue performance, and reliability must all be taken into account throughout the design phase of this part. Certain a given loading condition, carbon steel (c45) is unsuitable because to its higher stresses and heavier weight, despite the fact that its lifespan can be extended. Objective the work: - Static and fatigue evaluations of a manufactured connecting rod are the focus of the current study. In order to see whether a carbon steel or aluminum connecting rod may be replaced with a newly designed composite connecting rod, researchers examined the stress distribution, deformation, and fatigue life of an aluminum alloy reinforced with boron carbide (B4C).

3. Introduction To Optimization

This project aims to reduce the weight of the connecting rod while at the same time improving the strength of the design and its reliability. Thus the mass of the connecting rod is minimized subject to the constraint of strength. The method adopted is called OPTIMISATION with mass as the objective function and the strength being the constraint within which the optimum value of mass and hence the design is evaluated. Optimization is an iterative process in which an objective function of single or many independent variables is evaluated over a domain of constraints to which these independent variables are subjected. The process starts at a convenient point and then proceeds towards a better approximation of the optimized design with each iteration and yields the final optimized design after many such iterations. It is a mathematical process involving a large number of computations and hence we use here HYPERMESH version 7.0 for this project to carry out the optimization process.



4. Conventional Versus Optimum Design Process

Engineers have a difficult problem in finding ways to save costs and improve performance without sacrificing reliability. The traditional design method is reliant on the designer's innate talents of intuition, experience, and expertise. The human factor has an outsized role, and this might cause harmful mistakes to be made during the synthesis of complex systems. Fig. depicts a self-explanatory flowchart for a standard design process that makes use of the designer's expertise and intuition in addition to data collected from one or more trial designs.

5. Conventional Design Process

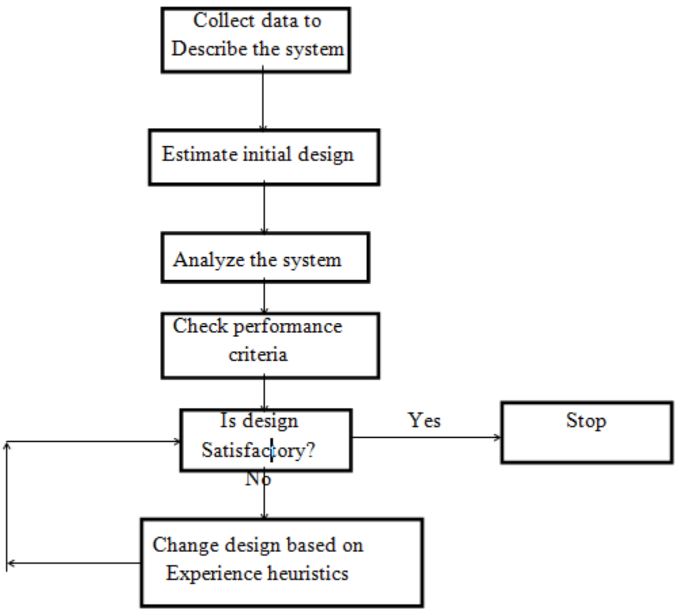


FIGURE 2. Conventional Design Process

Scarcity and need for efficiency in today's competitive world has forced engineers to evince greater interest in economical and better designs. With recent advances in computer technology affecting various disciplines of engineering, the design process can hardly remain untouched. Recently, the term computer aided design optimization (CAD) has been used for summarizing all computer aids in design. Next fig. shows the optimum design process.

6. Optimum Design Process

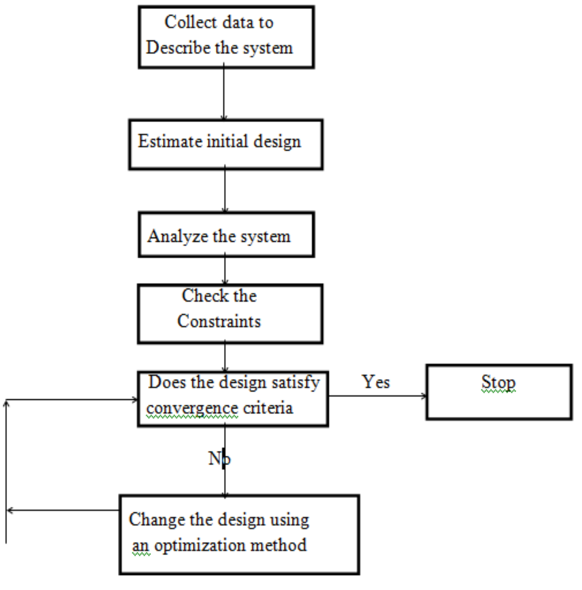
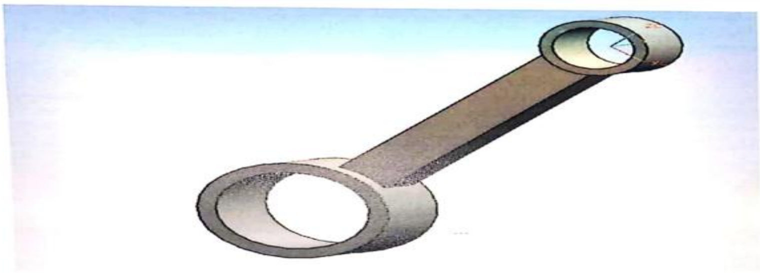


FIGURE 3. Optimum Design Process

7. Methodology

The basic steps adopted in optimization of the basic design are as follows: Creating a solid model, Topology optimization, Shape optimization. Creating The Solid Model: The first step towards optimization is creating the solid model of the connecting rod based on the basic design of the connecting rod. This model is made in UNIGRAPHICS. Since optimization is an iterative process, it starts with an approximation. In order to analyze the possibility of any other type of cross section for the connecting rod, we start with the initial approximation that the section is rectangular and the dimensions of the rectangle is obtained from the basic design of the connecting rod. Thus the solid model of the connecting rod has the big end and small end of the same dimensions as the basic design with the only change being the rectangular cross section.



UG MODEL

Topology optimization: Topology optimization is the process in which the software starts with an assumed cross section and for the given loading and constraint condition arrives at a suitable cross section iteratively by modifying the profile of the cross section without removing any mass. The basic steps in topology optimization are as follows: 1. Importing the solid model in a CAE software 2. Defining the collectors for material, loads and components in the software 3.Meshing the model 4. Specifying the loading and constraint conditions 5.Defining objective function and the design variables 6. Defining the type of responses 7.Running the topology optimization process 8.Post processing the results importing the solid model in cae software: After the solid model has been created, we import the solid model in CAE software, which is HYPERMESH in this case. Along with this, the OPTISTRUCT template is loaded for using OPTISTRUCT as the solver.

8. Defining The Collectors In The Software

The next step is the creation of the collectors for the materials, components and the loads. The collectors are defined in the collector's sub-panel of the HYPERMESH™ main menu. Material Collectors: First the material collector is created in which we define the material in this case being EN8 with the following properties:

Permissible value of stress = 380 MPa

Young's modulus 2.1 * 105

Poisson's ratio = 0.

Component Collectors: Next step is defining the component collectors. Here we create four component collectors, namely Designable, No designable, axial rigids, bending axial DESIGNABLE: It includes the 1 column of the connecting rod which is the domain of the optimization procedure. All the components in this domain are collected in the designable collector. NONDESIGNABLE: It includes the small end and the big end of the connecting rod which are out of the domain of optimization process and they are collected in the no designable collector. M The pins at the two ends of the connecting rod are assumed to be perfectly rigid and exert a force of reaction tending to constrain the connecting rod displacement in two directions - namely in axial direction and the horizontal direction when the connecting rod tends to bend. This is simulated using the two component collectorsaxial_rigids and bending axial respectively. LOAD COLLECTORS: The next step is the creation of load collectors in which the magnitude and other properties of the loads are collected. The two load collectors we create are, Constraint, Axial loading. CONSTRAINT: This collector simulates the loads exerted by the constraints on the connecting rod. AXIAL LOADING: This collector contains the axial load acting on the connecting rod due to the pressure of the gases which is exerted on the piston crown and also the inertial forces of the connecting rod. MESHING: HYPERMESH™ offers a variety of features for accurate and efficient meshing. Control can be exerted over the type of elements used, the number of nodes, the type of mapping, element size etc. The mesh can be modified interactively. There are a variety of parameters like Jacobian, war page etc which specify the mesh quality and a particular mesh generated can be tested for such quality criteria. The best possible mathematical modeling of the connecting rod can be done using a tetrahedral element. The meshing of the connecting rod is done in two steps. Creating a surface 2D mesh, creating the 3D mesh based on the surface mesh CREATING A SURFACE 2D MESH: The meshing starts by creating a 2D surface mesh on the connecting rod. Since we intend to mesh the connecting rod volume with tetrahedral elements, we use triangle elements for meshing the surface. This is basically done because if a 3D mesh is directly created, the surface does not get meshed. The meshing is done in the automesh sub panel in the 2D panel of the main page. Element size is chosen as 10.00. CREATING THE VOLUME 3D MESH: The initial 2D mesh is used as a starting point for the volume 3D mesh in which we use the triangle elements and the mesh proceeds inward. The element size used is 10.000. Element type is set to tetras.

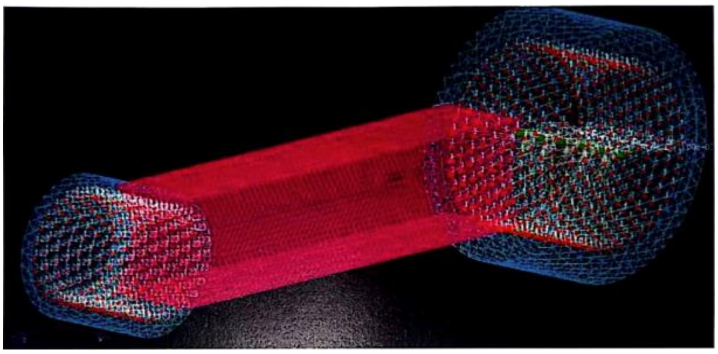


FIGURE 5. Mesh Model

9. E fining The Loads And Constraints

Constraints: After meshing the connecting rod, we define the loads and constraints acting on the connecting rod. The constrains are specified in the constraints sub panel in the BCS panel on the main page of the Hypermeshtm menu. The constraints specified are: All the nodes on the inner surface of the small end bearing are constrained in 3 translational motions. All the nodes on the inner surface of the bearing inner surface are constrained in translation along the X direction. LOADS: The loads acting on the connecting rod are of two types: Axial force, bending force In topology optimization, the nature of the loads is more important for determining the topology as compared to the magnitude. AXIAL FORCE: The axial force acting on the connecting rod arises due to the pressure exerted on the piston crown due to the combustion of the air-fuel mixture in the cylinder. The magnitude of the axial force acting is = 60830N BENDING FORCE: The bending force acting on the connecting rod is caused due to the side thrust of the piston tending to bend the connecting rod.

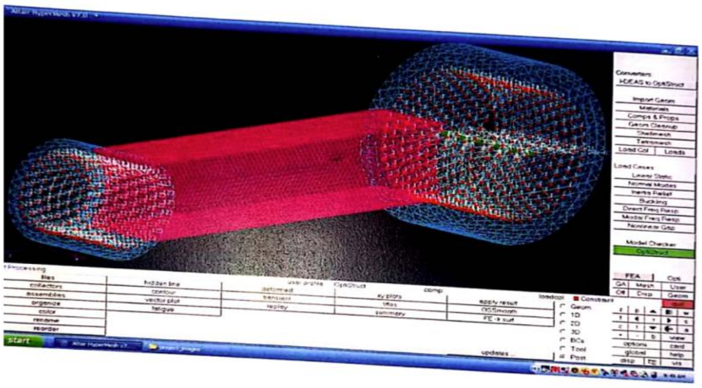


FIGURE 6. Loads and Constraints Image

Defining The Design Variables, Responses And Objective Function: Design Variable**:** The design variables are specified in the topology sub-panel in the optimization panel on the BC's page. The design variable used in the topology optimization process is dvtop_co, which in this case implies compliance. The design variable is assigned to the design space of the connecting rod. Responses: The two types of responses defined in topology optimization process are Volfr (Volume Fraction), Wcomp (Weighted Compliance), these two responses are defined in order to post process and analyse the value of compliance after the optimization procedure.

10. Objective Function

The next step in the optimization process is to define the objective function and the design variables. In topology optimization, we intend to minimize compliance. Since compliance is the inverse of stiffness, the stiffness of the design gets maximized in the process. This is done by staying within the constraint of volume the magnitude of the volume being that of the existing design. Thus we get an optimized high stiffness design as output which has a volume equal to the volume of the existent design. In other words we intend to get a cross section for the connecting rod which will be most resistant to deflection under the given loading and constraint conditions just by modifying the outer profile of the input design without removing any mass. The objective function here is compliance- wcomp, which is minimized here to get maximum stiffness. Thus as the stiffness gets maximized we attain our first objective which is to get the best possible design in the given load conditions which resists deflection. Constraint: The constraint is defined in the dconstraint sub-panel in the BC's page. The variable defined as the objective function cannot be used as a constraint variable. The constraint variable used here is volfr - which implies volume fraction and the upper bound of this is set to 0.4. Defining The Type of Responses the two types of responses defined in topology optimization process are Vol fr, Wcomp. These two responses are defined in order to post process and analyse the value of compliance after the optimization procedure. Running topology optimization process:

The completed design is submitted to the database. Then the design is checked for errors, if any. Once no errors are found, the optimization process is started by loading the optistruct template in the files panel on the Geom page. The optistruct button is then clicked to begin the optimization process. Post processing the results: First we import the result files from the directory where we had submitted the result files. To get the contour plot of the optimized design we follow the following steps select the contour panel on the Post page. Click simulation and select Design Iter18. Click data type and select Density. Click assign. The density of the model's components at the iteration of choice is represented graphically by their legend colours.

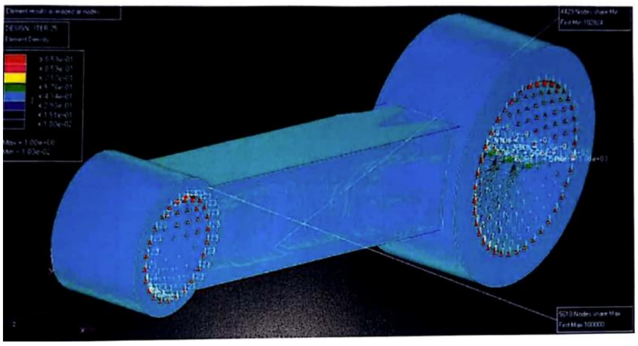


FIGURE 7. Final result model

11. Conclusion

Thus by the above process we aim to reduce weight of connecting rod as well as increasing its strength and thus achieve Reduce vibrations as the mass is reduced, Reduction in inertial loads, Increase in engine life, Increase in efficiency

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