OPTIMUM CONNECTING ROD DESIGN FOR DIESEL ENGINES

M.Sc. Kaya T. [1], Asist. Prof. Temiz V. PhD.[2], Asist. Prof. Parlar Z. PhD.[2]
Siemens Turkey[1]
Faculty of Mechanical Engineering – Istanbul Technical University, Turkey [2]

temizv@itu.edu.tr

Abstract: *One of the most critical components of an engine in particular, the connecting rod, has been analyzed. Being one of the most integral parts in an engine's design, the connecting rod must be able to withstand tremendous loads and transmit a great deal of power. This study includes general properties about the connecting rod, research about forces upon crank angle with corresponding to its working dependencies in a structural mentality, study on the stress analysis upon to this forces gained from calculations and optimization with the data that gained from the analysis. In conclusion, the connecting rod can be designed and optimized under a given load range comprising tensile load corresponding to 360^o crank angle at the maximum engine speed as one extreme load, and compressive load corresponding to the peak gas pressure as the other extreme load.*

Keywords: CONNECTING ROD, OPTIMIZATION, DIESEL ENGINE

1. Introduction

During the design of a connecting rod, optimized dimensions allowing the motion of rod during operation should be taken into account in the calculation of variable loads induced in the system and the resulting data should be tested experimentally. Therefore, a connecting rod design and manufacturing, production technologies, materials performance analysis is laborious and long lasting process involving many steps. Computer-aided design and analysis programs which are being used widely currently, are part of the design of a more flexible manner and to ensure a shorter time changes in design. By applying the finite element method, more reliable and more realistic results are obtained in practice. Thus, instead of using all designed models, only the most appropriate model optimized numerically can be used for performance testing, providing significant time and cost saving.

Connecting rod's loading state is quite complicated. It is exposed to high pressure loads due to the combustion in the chamber, is also repeatedly subjected to high tensile forces due to the inertia. Therefore, the reliability of this engine component is of critical importance. Due to the reasons mentioned above research topics such as connecting rod manufacturing technology, materials, performance simulation, fatigue are the subjects for both academic and industrial research. The connecting rod material and manufacturing technique have been demonstrated as the most important parameters for optimal design [1, 2]. Also, the stress distribution induced in the connecting rod depending on operating conditions, is examined in detail in related literature [3-5]. There are also remarkable researches involving the optimum design of the connecting rod which exposed to variable stress from the viewpoint of fatigue [6-9].

In the work presented here, a connecting rod is modeled numerically for a 4-cylinder, 4-stroke diesel engine. The most critical sections of connecting rod are determined based on mechanical strength. According to this, the optimum geometric parameters effecting connecting rod's mechanical parameters have been optimized.

2. Detailed information for available connecting rod

The modeled connecting rod is used for a commercial 4-cylinder, 4-stroke diesel engine. Operating parameters of engine is as follows: Maximum cylinder pressure is 190 bar and compressive load at 2000 rpm will be 100 kN when engine reaches its maximum speed of rotation (5100 rpm) tensile load will ve15 kN. Nominal power of engine is 150 kW, connecting rod length is 145 mm, diameter of crankshaft is 43,2 mm, stroke of cylinder is 88 mm, and diameter of cylinder is 85 mm.

A set of forces resulting from various effects such as pressure inside the cylinder, inertia and friction induce stresses on connecting rod. Force caused by pressure inside the cylinder reaches its maximum value around the top dead center. Inertia forces results from the acceleration of moving elements. Numerical values of these forces are dependent on the type, rated power and rotational speed of engine. Forces resulting from the pressure especially gain importance on diesel engines due to high combustion chamber pressures. Inertia force reaches remarkable values at high speeds. Inertia forces with respect to crank angle is given in Table 1.

Table 1: *Inertia forces for various crank angles.*

Crank angle (º)	Inertia Forces (kN)		Crank angle (º)	Inertia Forces (kN)		Crank angle (º)	Inertia Forces (kN)	
	Fpx	Fpy		Fpx	Fpy		Fpx	Fpy
0	-4.5	-2197.4	270	-149.1	492.7	450	153.6	499.8
30	-256.0	-1711.7	300	151.8	-586.7	480	280.5	1065.1
60	-152.8	-579.9	330	249.3	-1715.6	510	179.8	1202.3
90	153.6	499.8	360	-4.5	-2197.4	540	2.5	1204.8
120	280.5	1065.1	300	151.8	-586.7	570	-174.4	1200.1
150	179.8	1202.3	330	249.3	-1715.6	600	-274.4	1060.2
180	2.5	1204.8	360	-4.5	-2197.4	630	-149.1	492.7
210	-174.4	1200.1	390	-256.0	-1711.7	660	151.8	-586.7
240	-274.4	1060.2	420	-152.8	-579.9	690	249.3	-1715.6

Fpx: Inertia force at x-direction; Fpy: Inertia force at y-direction

In industrial applications, I and H formed cross-section for connecting rod design are used extensively regarding lightness and manufacturing advantages. In this study, H- type section is selected in order to achieve easy manufacturing from the viewpoint of lightweight design and to form more suitable transient region between the rod and big-end.

Connecting rods are generally manufactured by forging. Therefore, high strength malleable steels should be used as connecting rod material. Depending on the application, connecting rods are made of carbon steels or steel alloys. The research carried out on the powder forged in the 1970s and 1980s has led to the making of this method industrially applicable. In Table 2, the modeled connecting rod's mechanical properties are presented [10].

Table 2: *Mechanical properties of connecting rod material.*

	Powder forged rod	
	Powder Metal (C-70)	
	Specifications	Measured
Tensile Strength (MPa)	696 min	794
Yield Strength (MPa)	441 min	530
Elongation (%)	10 min	14
Specific gravity (g/cm^3)	7.65 min	7.71
Hardness (HB)	200 min	245

3. Modeling and Constitution of Finite Element Model for Connecting Rod

The literature review showed that there are three fundamental dimension to be take into account on a connecting rod design. These are;

- Small end inner diameter,
- Cross-section,
- Big end inner diameter.

These dimensions change with respect to type and properties of engine. For numerical analysis, a small end inner diameter, a big end inner diameter and a cross-section are defined based on given engine parameters. Some basic dimensions required for analysis is given Fig.1.According to this, the connecting rod is dimensioned by using empirical data recommended for basic parameters [11].

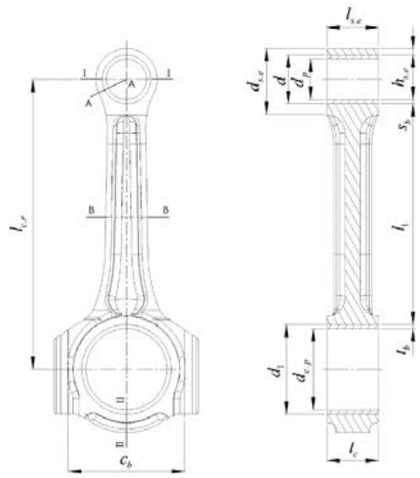


Fig.1 :*Some basic dimensions required for a connecting rod design.*

The most important part of the design is to form the transition regions from rod to small and big heads. Design and analysis studies were carried out simultaneously with many feedbacks and the analysis results were used to optimize the design. In the further stages of analysis, a parametric model has been constituted in CAD software in order to make some improvements on the critical sections without changing calculated parametric dimensions of the connecting rod. By using same software's linear elastic FEM module, numerical stress analysis has been carried out. As a results of analysis conducted on connecting rod, some improvements for manufacturing also have been carried out without creating any negatives effects in terms of strength. At the end of this stage, a final geometry is obtained. This model has been analyzed numerically with more sophisticated from the viewpoint of mechanical strength.

3.1 Finite Element Model

3D model and meshing of the designed connecting rod is shown in the Fig. 2. Meshing of model has been carried out by using tetra elements. The reason for using hexa elements instead of tetra elements is that connecting rod has a more detailed model surface relative to the crank journal and piston pin models. Discontinuities can be more easily handled in meshes with tetra elements.

Fig.2 : *Mesh in connecting rod.*

Both the piston pin connecting and the crank journal have been mountedto the connecting rod due to the necessity for placing loading point in the model as seen on Fig. 3. Tension and compression effects have been assigned to the piston pin with uniform distribution. Boundary condition has been selected in such a way that crank journal would be fixed with respect to axis of rotation. No bush was used in the model.

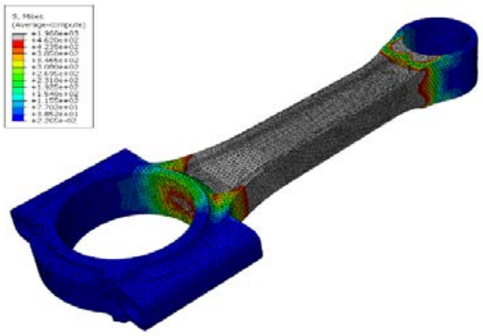
Fig.3 : *Model for analysis.*

3.2 Numerical Analysis

Numerical analysis is achieved in two stages. At the first stage, the compression effect resulting from the maximum gas pressure has been analyzed. At the second stage, the tensile effect occurring in the maximum speed due to inertia forces has been solved. The results of these analysis is shown in the Fig.4. As seen from the Fig. 4, under compressive stress, some sections of connecting rod seems overloaded. But, under the tensile stress, same element gives more promising result regarding the material's yield strength of 462 MPa.

According to the results of the analysis, some connecting rod sections have insufficient strength under compressive stress. Unnecessary accumulation of material especially in the shoulder region has been observed in analysis. Therefore, in first step the connecting rod section is strengthened, and at the other step, an optimization technique is implemented to regions having excessive material. In addition, the most import region in the design of a connecting rod excluding big head, small head and rod is transition zone to the heads. The highest stresses are induced in these zones.

As a solution, it is assumed that an increase in the l_c and b_{sh} dimensions would be satisfactory. Since, the available connecting rod design gave good results in tension analysis, an increase in the l_c and h_{sh} dimensions make the situation better.



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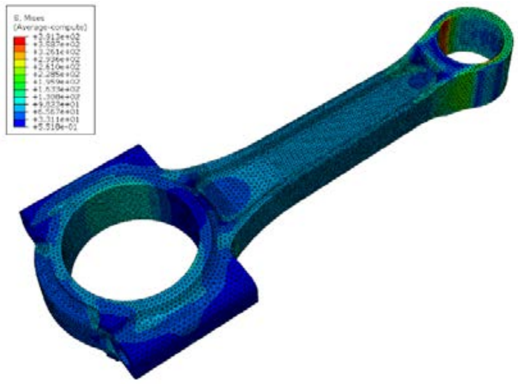


b)

Fig.4: *a) Compression analysis. b) Tension analysis*

4. Optimization of connecting rod

At this stage, a practical method is used to reach an optimal geometry by constituting a drawing model with an ability of varying parametric dimensions utilizing an analysis tool embedded in the software. Basic static models give satisfactory results for obtaining idealistic geometry at the optimization stage. Different models derived from parametric model by changing critical dimensions have been analyzed by using finite element software to reach an ideal form. By using optimal dimensions obtained from optimization process and by taking into consideration the appropriate manufacturing methods, a connecting rod is designed as shown in the Fig. 5 (named Model-4). The wall thickness was increased in this design in order to make improvement against compressive stresses.

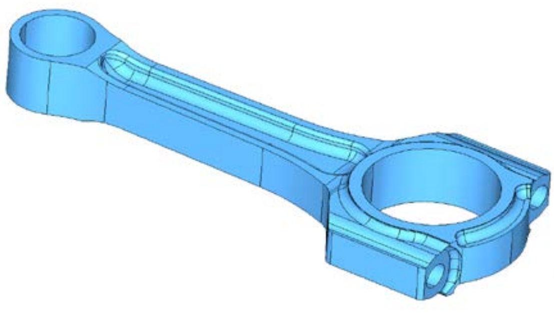
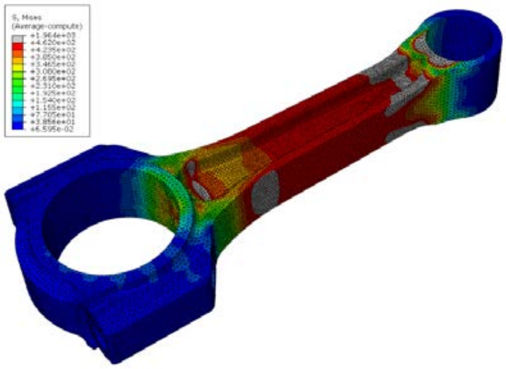


Fig.5 : *Model – 4*

The new geometry has been analyzed on the basis of both compression and tension. The results of analysis are shown in Fig. 6. Some improvements are observed with respect to other models.



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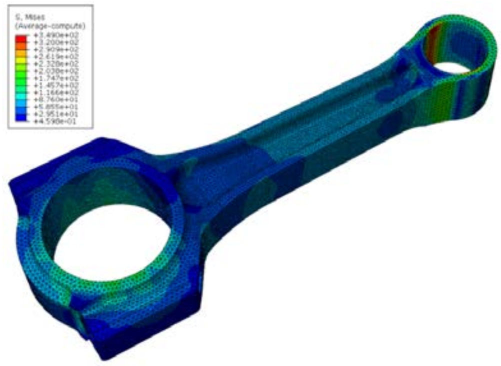

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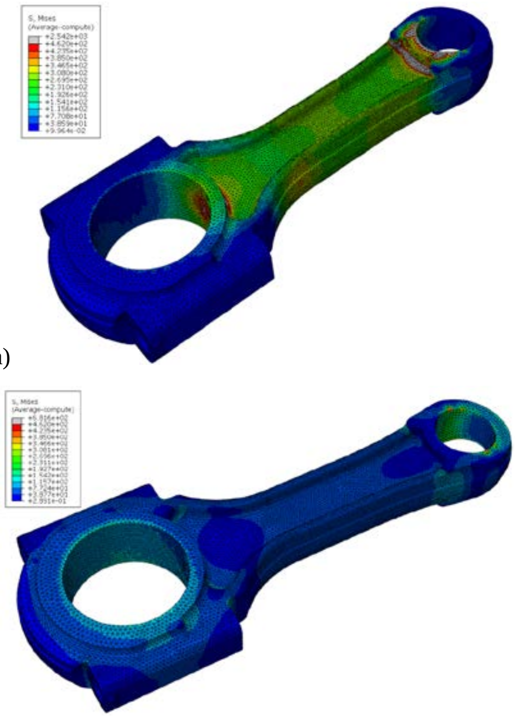
Fig.6: *Model-4 a) Compression analysis. b) Tension analysis*

Although new design modifications on connecting rod gave promising results, but the desired improvements have not been reached. It has been found that, increasing wall thickness is not sufficient enough to get better analysis results. Since further increase on wall thickness would be unfavorable, it has been considered that some fundamental variations on connecting rod form would be more realistic.

As seen from Fig. 7 that in the modified model named as Model-5, the material is gathered on the transition zones from rod to big and small heads. Some remarkable changes have been carried out especially on the transition zone between rod and big head. Unnecessary parts have been removed from the shoulder region. Force lines on the transition zone between rod and small head have been improved. Furthermore, h_{sh} dimension in Fig. 1 has been increased.

Fig.7: *Model – 5*

The analysis results for Model – 5 is shown in Fig.8. A satisfactory amount of improvement is observed for this model. Although there are some local points around the transition zone in which the yield strength of material is exceeded, this is mainly due to the neglecting damping effect and absence of bush on the on connecting rod.Analysis of connecting rod under tensile stress gives satisfactory results as expected. The overstressed point on the analysis results table take place as a result of a discontinuity on meshing process. This discontinuity has no effect on analysis process.



a)

b)

Fig.8: *Model -5 a) Compression analysis. b) Tension analysis*

4.1. Weight Reduction Studies

As a results of analysis conducted, satisfactory improvements are carried out for connecting rod. After this stage, some sections of connecting rod where the stress values are low can be redesigned from the viewpoint of weight reduction. Some remarkable amount of material was removed from cap section. Furthermore, material reduction was applied to the transition regions from the rod to big and small heads. Optimized connecting rod after weight reduction process is shown in Fig.9. Weight of connecting rod was reduced from 687.4 g to 663.7 g with this process.

Fig.9 : *Optimized connecting rod*

Analysis result of connecting rod under compression for the final optimized design is shown in Fig. 10.

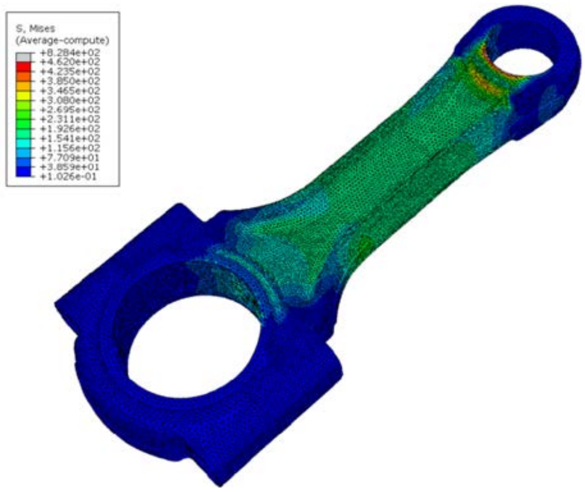


Fig.10 : *Analysis of final design connecting rod under compression.*

Transition from rod to big head is transferred to totally safe region according to the analysis for compressive stress. Even though the stresses on the transition section from rod to small head seems very close to yield strength, this is caused by not using a bush for modelling the system.

5. *Conclusion*

At end of this study, a new connecting rod design having optimized dimensions and sufficient strength has been suggested for given basic dimensions and operating conditions. At the first stage, the connecting rod formed from preliminary work was analyzed numerically and weak points of this design was determined. The optimum connecting rod geometry was reached by applying some design modifications to these points.

In this study, elastic properties for connecting rod material was used. Using plastic material data will be more satisfactory for analysis. Induced stresses can be more calculated more precisely by meshing the connecting rod finer and more detailed.

For preliminary work, linear static analysis will be sufficient in order to determine the basic geometry. But, for future work, bushing, crank bearings and damping effect can be taken into account. By introducing the bolts tightened with rated torque in order to obtain correct preload to analysis, it is possible to get results which have relatively good conformity with actual part.

Furthermore, these analyses can be compared to test data in order to increase reliability of design.

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