Study of Connecting Rod to the Shank Sectional Area Reduction of Variable Cross Section by using Finite Element Method
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Abstract—A connecting rod is an engine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a different cross section and the rankine formula is used. A connecting rod subjected to a cyclic as well as axial load \( W \) may buckle with \( x \)-axis as neutral axis in the plane of rotation of the connecting rod, or \( y \)-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about \( x \)-axis and one end is fixed and other end load is applied for buckling about \( y \)-axis. A connecting rod should be equally strong in buckling about either axis.

\textbf{Key words:} Connecting Rod, Buckling, Manufacturing of Connecting Rod

I. INTRODUCTION
In a reciprocating piston engine, the connecting rod connects the piston to the crank or crankshaft. In modern automotive internal combustion engines, the connecting rods are mostly made of structural steel for heavy engines, but can be made of aluminum for weight-light high strength, durability or titanium (for a combination of strength and durable at the expense of affordability) for high output performance engines, or of cast iron for applications like scooters mopeds etc. The small end attaches to the wrist pin, which is currently most often press fit into the connecting rod. The connecting rod is under huge amount of stress from the reciprocating load exerted by the piston, actually tearing and being compressed with every cyclic motion, and the load increases to the peak power with increasing engine acceleration. Failure of a connecting rod, usually called "throwing a rod" 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; it can result from fatigue near a physical defect in the rod, lubrication deficiency in a bearing due to low maintenance or from failure of the rod bolts from a defect, improper fastening, or used of less strength bolts where not recommended. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety.

II. TYPES CONNECTING RODS SECTION
The classification of connecting rod is made by the cross sectional area design i.e. I – section, H – section, Tabular section, Circular section. In low speed engines, the section of the rod is circular, with flatted sides. In high speed engines either an H – section or Tabular section is used because of their low weight. The rod usually tapers from the big end to the small end for density balance.

III. MATERIALS USED FOR CONNECTING RODS
Materials: The connecting rod materials are open hearth steel or sometimes even nickel steel or vanadium steel. For low to less capacity high speed engines, these are made of duraluminium or aluminum alloys. However, with the innovation of technology, the connecting rods now a day are also cast from malleable or spheroidal graphite cast iron. The different connecting rod steels materials are (40C8, 37Mn6, 35Mn6 MO3, 35Mn6 Mo4, 40Cr4, 40Cr4 Mo3, 40NiCr4MO2) etc. In general, forged connecting rods are durable and lightweight which is an advantage from inertia view point, whereas cast connecting rods are compared less cost, but due to less strength their use is less to small and medium size petrol engines.

A. Manufacturing of Connecting Rod:
1) Hot Forging:
Is a predominant technology to fabricate connecting rods. Due to a complex geometry, connecting rod cannot be manufactured in one blow and therefore dies with several design parameters have to be designed. Basically, connecting rod forging can be done in one at a time and two at a time version. One multi step one at a-time forging variable which is often applied in industry is shown in Figure. Before forging, billet is heated to defined temperature and then inserted to the die.
In some cases performing operations for connecting rod forging, which serve to distribute the material before actual forging, can be carried out also by reduced rolling and cross rolling operations. In order to improve forging productivity two-at-a-time forging version are also developed. Forging steps for two versions of such a technology are presented in Figure 4. As it is seen, in the first case cap parts have to be forged separately. Smaller size connecting rods are preferably forged in a two-at-a-time version while larger connecting rods in one-at-a-time version.

2) Casting:
Cast conrods are produced in green sand molds. Due to specific requirements of casting technology design of conrod has to be modified (I-beam cross section, radii). Material utilization in conrod casting reaches 90%. Mechanical properties of cast connecting rod are improved by sand blasting or shot peening.

3) Powder Metal (PM) Based Process:
In this process pre-blended powder material is filled up into the die, and then compacted at room temperature with the subsequent creation of preform by sintering at 1050-1300°C for 15 minutes. This preform is afterwards ejected from the die, heated in the furnace and finally hot forged to the final shape. In this way high density forging is produced.

In figure 3 these main steps of this alternative are given:
1) Powder filling
2) Compacting
3) Ejecting the preform
4) Sintering
5) Inserting the sintered rod into the forging die
6) Forged connecting rod
7) Ejecting final forging

After ejection, connecting rod is normalized in a protective atmosphere. Following operation is shot peening in order to remove forging pole and to increase durability of the connecting rod. First application of connecting rod powder forged was realized.

B. Types of Buckling:
1) Plastic Buckling:
Buckling will generally occur slightly before the calculated elastic buckling strength of a structure, due to non-linear behavior of the material. When the compressive load is near the buckling load, the structure will bow significantly and the material of the column will diverge from a linear stress-strain behavior. The stress-strain behavior of materials is not strictly linear even below yield, and the modulus of elasticity decreases as stress increases, and significantly so as the stresses approach the yield strength. This lower rigidity reduces the buckling strength of the structure and causes at a load less than that predicted by the assumption of linear elastic behavior. A more accurate approximation of the buckling load can be had by the use of the tangent modulus of elasticity, Et, in place of the elastic modulus of elasticity. The tangent modulus is a line drawn tangent to the stress-strain curve at a particular value of strain. Plots of the tangent modulus of elasticity for a variety of materials are available in standard references.

2) Buckling Prediction:
The representative buckling modes are the front-rear buckling and the side buckling as stated above. The critical buckling stress and the buckling mode are determined by factors such as the elastic modulus, effective length, cross-sectional area, area moment of inertia and boundary conditions. Further, the first and second buckling modes have mutually dissimilar slenderness ratios due to their different area moment of inertia. They also have dissimilar variations of slenderness ratio as the cross-sectional area reduces. For instance, when the thickness reduces, the slenderness ratio of front-rear buckling increases more than that of side buckling is. Therefore, designer should consider the first and second modes together in the light-weighting design. For two cases of front-rear and sides cutting, we examined the change rates of the safety factor, i.e. the sensitivity for yield, fatigue and buckling. The safety factor is determined as the specific value for each criterion (yield, fatigue, buckling) by the designers. It is usually used to evaluate the mechanical characteristics for trial products of connecting rods being developed. In addition to the safety factor, however, it is important to consider the sensitivity too in designing the connecting rod. High sensitivity of specific criterion means that its safety factor can exceed the critical value by slight variation of design parameter. Thus the sensitivity of each criterion would guide the designer in handling the design parameters.
Our study indicated that decreasing the thickness of shank part is inappropriate due to the higher sensitivity of buckling than those of yield and fatigue. Overall, the sensitivity of buckling is higher than or comparable to those of yield and fatigue. Consequently, buckling should be considered as an essential criterion when the weight reduction of connection rod shank is attempted.

1) Numerical and Experimental Investigation:
Some experimental and theoretical work on load analysis of connecting rod has been done in the last decades. Both the industrial and academic people have taken interest in this area. The following is a review of the research that has been completed especially on load analysis of connecting rod

2) Bai-yan He, Guang-da Shi, Ji-bing Sun, Si-zhuan Chen, Rui Nye [2013]
This paper presents the failure analysis of a connecting rod used in a diesel generator set on an offshore platform. Cracks occurred on the toothed mating surface of the connecting rod after approximately 6000–10,000th in service. To determine the failure mechanism, material characterization and numerical analyses are performed on the connecting rod. The macro and micro structures are analyzed by scanning electron microscope (SEM) and optical microscope. The chemical composition and metallographic structure investigation are conducted to study the characteristics of the material. Hardness and tensile tests are performed to verify the mechanical properties of the connecting rod. A nonlinear finite element (FE) analysis with the bolted assembly is performed to evaluate the local stress near the mating faces, and the results shows that the crack position is consistent with the high stress spots. As a result, lower yield strength of the material and high stress level or high stress concentration are concluded as the main reasons of failure of the connecting rod.

3) Tony George Thomas1, S. Srikari2, M. L. J Suman3 [2011].
The connecting rod forms an integral part of an internal combustion engine. The connecting rod is acted upon by different types of loads while undergoing its operation. One of the main reasons contributing to its failure is fatigue. The aim of this study is to re design the connecting rod by incorporating the manufacturing process effects into the analysis and obtain a better fatigue performance. The redesign is aimed at reducing the weight of the component. Heavy duty application’s connecting rod was selected for the study. The analytically calculated loads acting on the small end of connecting rod were used to carry out the static analysis using ANSYS. A stress concentration was observed near the transition between small end and shank. A piston-crank-connecting rod assembly was simulated for one complete cycle (0.02 seconds) using ADAMS to obtain the loads acting on small end of connecting rod. This force vs. time graph was converted into an equivalent stress vs. time graph. This stress vs. time graph was used as loading graph for fe-safe. The fatigue life calculated using fe-safe is 6.94x10^6 cycles and these results are validated with the help of Palmgren-Miner linear damage rule.

4) Ziya AKSOY*, Zafer ÖzDEMIR, Tekin ÖZDEMIR [2012].
Microalloyed high carbon steels (such as C70S6, SMA40 and FRACITIM) have been considered to be economic alternatives to powder metal and conventional steel, having been used as main crackable con-rod materials in recent years. Compared with powder metal and conventional steel, these microalloyed high carbon steels have remarkable advantages. One of the main advantages is that cost reduction can be achieved by changing the micro-structure of the con-rod. Sawing and machining processes of the rod and cap, in order to mate two faces can be eliminated, and is believed to reduce the production cost by 25%. Another advantage of this production method is that fracture-splitting connecting rods exhibit 30% higher fatigue strength and 13% less weight than conventional connecting rods, and can be splitted into two pieces (big body and cap) by fracturing with an instant impact load. Compared with powder metal and cast con-rods, it also has lower cost for the whole manufacturing process. Hence, it provides more advantageous production opportunities, and is preferred in manufacturing technology mostly. In this article, the metallographic and fracture surface analysis have been investigated using optical and SEM method. Hardness of C70 steel is also determined. In the article it has been made clear that, the microstructure of the fracture-split con-rod has a fine grain size with densely pearlite because of its high carbon content. Also it is shown that a high hardness value is determined approximately 280-300 HB. Almost no deformation exhibits after splitting into 2 pieces, which is what any connecting rod product or would like to expect when utilizing C70S6 crackable steel in production phase.

5) Prof. N.P.Doshi, Prof. N.K. Ingole [2013].
The connecting rod is a major link inside of a combustion engine. It connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft and sending it to the transmission. There are different types of materials and production methods used in the creation of connecting rods. The most common types of materials used for connecting rods are steel and aluminum. Connecting rods are widely used in variety of engines such as, in-line engines, V-engine, opposed cylinder engines, radial engines and oppose-piston engines. For the project work have selected connecting rod used in light commercial vehicle of tata motors had recently been launched in the market. We used PRO-E wildfire 4.0 software for modeling of connecting rod and ANSYS 11 software for analysis. ANSYS Workbench module had been used for analysis of connecting rod. We found out the stresses developed in connecting rod under static loading with different loading conditions of compression and tension at crank end and pin end of connecting rod. We have also designed the connecting rod by machine design approach. Design of connecting rod which is designed by machine design approach is compared with actual production drawing of connecting rod. We found that there is possibility of further reduction in mass of connecting rod.

The connecting rod is a structural component cyclic loaded during the Internal Combustion Engines (ICE) operation, it means that fatigue phenomena should be taken into account during the development, in order to guarantee the connecting rod required lifetime. Numerical tools have been
extremely used during the connecting rod development phase, therefore, the complete understanding of the mechanisms involved as well as the reliability of the numerical methodology are extremely important to take technological advantages, such as, to reduce project lead time and prototypes cost reduction. The present work shows the complete connecting rod Finite Element Analysis (FEA) methodology. It was also performed a fatigue study based on Stress Life (SxN) theory, considering the Modified Goodman diagram.

7) M.S. Shaari, M.M. Rahman, M.M. Noor, K. Kadirgama and A.K. Amiruddin [2010]. This paper presents the design connecting rod of internal combustion engine using the topology optimization. The objectives of this paper are to develop structural modeling, finite element analyze and the optimization of the connecting rod for robust design. The structure of connecting rod was modeled utilized SOLIDWORKS software. Finite element modeling and analysis were performed using MSC/PATRAN and MSC/NASTRAN software. Linear static analysis was carried out to obtain the stress/strain state results. The mesh convergence analysis was performed to select the best mesh for the analysis. The topology optimization technique is used to achieve the objectives of optimization which is to reduce the weight of the connecting rod. From the FEA analysis results, TET10 predicted higher maximum stress than TET4 and maximum principal stress captured the maximum stress. The crank end is suggested to be redesign based on the topology optimization results. The optimized connecting rod is 11.7% lighter and predicted low maximum stress compare to initial design. For future research, the optimization should cover on material optimization to increase the strength of the connecting rod.

8) B. Anusha, Dr. C. Vijaya Bhaskar Reddy [2013]. Connecting rod is a major link inside of a internal combustion engine. Its primary function is to transmit the push and pull from the piston pin to the crank pin thus converting the reciprocating motion of piston in to rotary motion of the crank. In the present investigation a 4-stroke petrol engine of a specified model, market available connecting rod is selected for the investigation. For present investigation the designed connecting rod is modeled using solid modeling software i.e. PRO/E. The modeled connecting rod imported to the analysis software i.e. ANSYS. Static analysis is done to determine von-misses stresses, strain, shear stress and total deformation for the given loading conditions using analysis software i.e. ANSYS. In this analysis two materials are selected and analyzed. The software results of two materials are compared and utilized for designing the connecting rod.

9) Marthanalapalli HariPriya, K. Manohar Reddy [2013]. Connecting rods for automotive applications are typically manufactured by forging from either wrought steel or powdered metal. They could also be cast. An optimization study was performed on a steel forged connecting rod with a consideration for improvement in weight and production cost. For this optimization problem, the weight of the connecting rod has little influence on the cost of the final component. Change in the material, resulting in a significant reduction in machining cost, was the key factor in cost reduction. This study has two aspects. The first aspect was to investigate and to compare fatigue strength of steel forged connecting rods with that of the powder forged connecting rods. The second aspect was to optimize the weight and manufacturing cost of the steel forged connecting rod. Constraints of fatigue strength, static strength, reducing inertia loads, reducing engine weight , improvised engine performance, fuel economy were also imposed. The fatigue strength was the most significant factor in the optimization of the connecting rod.

10) Deepak G. Gotiwal, Shaillesh D. Ambekar. This paper presents a study of redesigning of connecting rod for its weight reduction using c70s6 material. During its operation connecting rod undergoes various types of loads. Fatigue as well as static stresses are mainly responsible for failure of a connecting rod. Initially fatigue testing was carried out for studying failures during its life cycles. But after recognizing these failures during fatigue testing, fatigue life further enhanced by incorporating few changes and then analyzed with the help of FEA for highlighting critical points on connecting rod. These critical points are divide with respect to five different zones at connecting rod. Considering these five different zones and critical points, connecting rod was subjected to static FEA for tensile and compressive loading for both small and big end. In this process, first small end is restrained and simultaneously compressive and tensile load is applied at crank end. Similarly, crank end is restrained and simultaneously compressive and tensile load is applied at pin end. Stresses near these points are studied and the regions where stresses are less, are considered for material reduction areas from connecting rod. Then the connecting rod design is also supported by analytical calculations for its thickness. All these findings are incorporated in new digitized connecting rod. Therefore the aim of this paper is to study these causes or areas of failure with the help of FEA and redesigning the connecting rod by focusing on the scope of weight and cost reduction. Thus the component was redesigned with reduction in its weight.

11) Z. KALA, J. KALA [2005]. The effect of the initial geometric and material imperfections on the load-carrying capacity of bending stressed beams made of an IPE profile solved including the lateral buckling effect is studied by means of sensitivity analysis. Several variants of beams with different degrees of slenderness are solved. Members are on-met, assuming a thin walled effect. Imperfections are considered to be random quantities. The histograms of the main quantities (yield strength, e.g.) were determined experimentally. Random quantities which were not measured were taken over from specialized literature. For taking the variability of input quantities into consideration, the numerical simulation method (a method of the Monte Carlo type) has been used. The random load-carrying capacity is, in each simulation method run, solved by a geometrically and materially nonlinear FEM solution.

12) Ralf Peek and Mostafa Kheyrkhahan [1992]. Beginning with the work of Koiter in 1945, valuable insights into the post buckling behavior of structures have been gained by Lyapunov-Schmidt decomposition of the displacements followed by an asymptotic expansion about the bifurcation point. Here this methodology is generalized.
to include nonlinear pre buckling behavior, as well as multiple, not necessarily coincident buckling modes. The expansion of the reduced equilibrium equations is performed about a reference point (which need not coincide with any of the bifurcation points), and applies no matter whether the modes are coincident, closely spaced, or well separated. From a variety of possible decompositions of the admissible space of displacements, two are incorporated into a finite element program. Theoretical considerations, and numerical examples in which asymptotic results are compared to ‘exact’ results, indicate that one of the decompositions has some important advantages over the other. Examples include a shallow arch, and a beam on elastic foundation problem exhibiting symmetry-breaking modal interaction.

13) M. Ohsaki

The purpose of this review paper is to summarize the existing methods of design sensitivity analysis and optimization of elastic conservative finite dimensional systems with respect to nonlinear buckling behavior. Difficulties related to geometrical nonlinear singular behaviors are discussed in detail. Characteristics of optimized structures are demonstrated in reference to snap through behavior, hilltop branching, and degenerate critical points. A new optimization result of a flexible truss that fully utilizes the snap through behavior is also presented.

14) G. Naga Malleshwara Rao

The main Objective of this work is to explore weight reduction opportunities in the connecting rod of an I.C. engine by examining various materials such as Genetic Steel, Aluminum, Titanium and Cast Iron. This was entailed by performing a detailed load analysis. Therefore, this study has dealt with two subjects, first, static load and stress analysis of the connecting rod and second, Design Optimization for suitable material to minimize the deflection. In the first of the study the loads acting on the connecting rod as a function of time are obtained. The relations for obtaining the loads for the connecting rod at a given constant speed of crank shaft are also determined. It can be concluded from this study that the connecting rod can be designed and optimized under a comprising tensile load as one extreme load, and the crank pressure as the other extreme load. Furthermore, the existing connecting rod can be replaced with a new connecting rod made of Genetic Steel.

IV. CONCLUSION

There is considerable difference in the structural behavior of the connecting rod between axial fatigue loading and dynamic loading (service operating condition). There are also differences in the analytical results obtained from fatigue loading simulated by applying loads directly to the connecting rod and from fatigue loading with the pins. By using other facture crack able materials such as micro-alloyed steels having higher yield strength and endurance limit, the weight at the piston pin end and the crank end can be further reduced. Weight reduction in the shank region is, however, limited by manufacturing constraints.

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