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Stress Analysis of Connecting Rod for Weight Reduction- A Review

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Abstract- The main objective of this study is to explore weight and cost reduction opportunities in the design and production of a connecting rod. This can be achieved by performing a detailed load analysis. A study is performed on a steel connecting rod. Reduction in machining operations, achieved by change in material, is a significant factor in manufacturing cost reduction. This paper deals with the study of weight reduction performed under two cyclic loads comprising dynamic tensile and static compressive as the two extreme loads. The fatigue strength is the most significant factor in the process. The study analysis includes the determination of loads acting on the connecting rod as a function of time for finding out the minimum stress area to remove the material. The connecting rod can be designed and analysis under a load ranging from tensile load, corresponding to various degree 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. Furthermore, the existing connecting rod material can be replaced with a new composite material, the fracture crack ability feature, facilitates separation of cap from rod without additional machining of the mating surfaces. Also the same performance can be expected in terms of component durability.

Index Terms- Connecting rod, Weight reduction, Fatigue strength, Better machinability

I. INTRODUCTION

The connecting rod is the connection between the piston and the crankshaft. It joins the piston pin with the crankpin; small end of the connecting rod is connected to the piston and big end to the crank pin. The function of the connecting rod is to convert linear motion of the piston into rotary motion of the crankshaft.

The lighter connecting rod and the piston greater than resulting power and less the vibration because of the reciprocating weight is less. The connecting rod carries the power thrust from piston to the crank pin and hence it must be very strong, rigid and also as light as possible. There are two types of small end and big end bearings. Connecting rods are subjected to fatigue due to alternating loads.

In the case of four stroke engines, during compression and power strokes the connecting rod is subjected to compressive loads and during the last part of the exhaust and the beginning of the suction strokes, to tensile loads. In double acting steam engines, during the forward stroke the connecting rod is subjected to compressive load and during the return stroke, to tensile load. Connecting rod materials must have good fatigue and shock resistances.

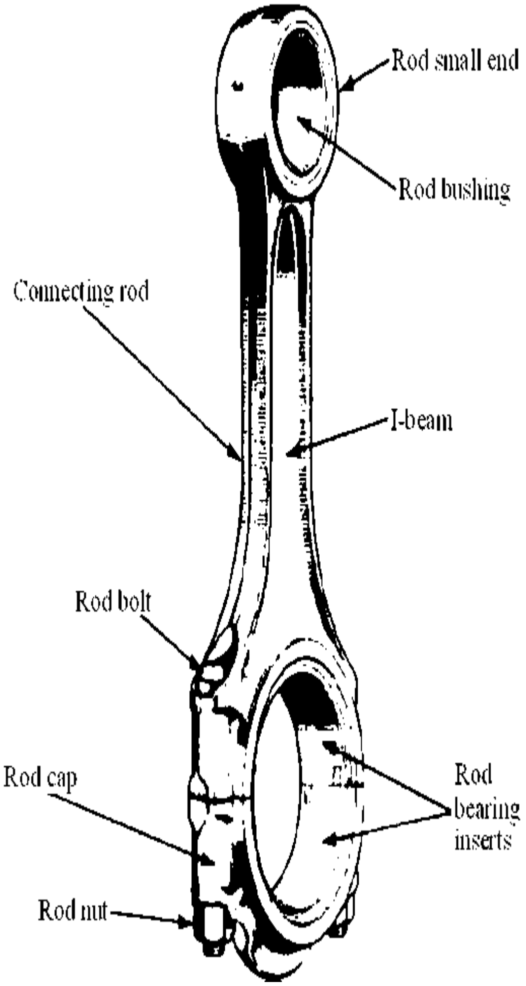


Fig.1 Connecting rod nomenclature

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. Bringing the part to final dimensions under the tight tolerance results in high expenditure for machining, as the blank usually contains more excess material.

Due to its large volume production, it is only logical that optimization of the connecting rod for its weight or volume will result in large-scale savings. It can also achieve the objective of reducing the weight of the engine component, thus reducing inertia loads, reducing engine weight and improving engine performance and fuel economy.

II. LITERATURE SURVEY

The connecting rod is subjected to a complex state of loading. It undergoes high cyclic loads, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of this component is of critical importance. Due to these factors, the connecting rod has been the topic of research on various aspects such as production technology, materials, performance simulation, fatigue, etc. For the current study, it is necessary to investigate finite element modelling techniques, optimization techniques, developments in production technology, new materials, fatigue modelling, and manufacturing cost analysis. This brief literature survey reviews some of these aspects.

For their optimization study, Serag et al. (1989) developed approximate mathematical formulae to define connecting rod weight and cost as objective functions and also the constraints. The optimization was achieved using a Geometric Programming technique. Constraints were imposed on the compression stress, the bearing pressure at the crank and the piston pin ends. Fatigue was not addressed. The cost function was expressed in some exponential form with the geometric parameters.

Webster et al. (1983) performed three dimensional finite element analysis of a high-speed diesel engine connecting rod. For this analysis they used the maximum compressive load which was measured experimentally, and the maximum tensile load which is essentially the inertia load of the piston assembly mass. The load distributions on the piston pin end and crank end were determined experimentally. They modelled the connecting rod cap separately, and also modelled the bolt pretension using beam elements and multi point constraint equations.

While investigating a connecting rod failure that led to a disastrous failure of an engine, Rabb (1996) performed a detailed FEA of the connecting rod. He modelled the threads of the connecting rod, the threads of connecting rod screws, the prestress in the screws, the diametric interference between the bearing sleeve and the crank end of the connecting rod, the diametric clearance between the crank and the crank bearing, the inertia load acting on the connecting rod, and the combustion pressure. The analysis clearly indicated the failure location at the thread root of the connecting rod, caused by improper screw thread profile. The connecting rod failed at the location indicated by the FEA. An axis symmetric model was initially used to obtain the stress concentration factors at the thread root. These were used to obtain nominal mean and alternating stresses in the screw. A detailed FEA including all the factors mentioned above performed, also including a plasticity model and strain hardening. Based on the comparison of the mean stress and stress amplitude at the threads obtained from this analysis with the endurance limits obtained from specimen fatigue tests, the adequacy of a new design was checked. Load cycling was also used in inelastic FEA to obtain steady state situation.

Hippoliti (1993) reported design methodology in use at Piaggio for connecting rod design, which incorporates an optimization session. However, neither the details of optimization nor the load under which optimization was performed were discussed. Two parametric FE procedures using 2D plane stress and 3D approach developed by the author were compared with experimental results and shown to have good agreements. The optimization procedure they developed was based on the 2D approach.

Park et al. (2003) investigated micro structural behavior at various forging conditions and recommend fast cooling for finer grain size and lower network ferrite content. From their research they concluded that laser notching exhibited best fracture splitting results, when compared with broached and wire cut notches. They optimized the fracture splitting parameters such as, applied hydraulic pressure, jig set up and geometry of cracking cylinder based on delay time, difference in cracking forces and roundness. They compared fracture splitting high carbon micro-alloyed steel (0.7% C) with carbon steel (0.48% C) using rotary bending fatigue test and concluded that the former has the same or better fatigue strength than the later. From a comparison of the fracture splitting high carbon micro-alloyed steel and powder metal, based on tension-compression fatigue test they noticed that fatigue strength of the former was 18% higher than the later.

Sarihan and Song (1990), for the optimization of the wrist pin end, used a fatigue load cycle consisting of compressive gas load corresponding to maximum torque and tensile load corresponding to maximum inertia load. Evidently, they used the maximum loads in the whole operating range of the engine. To design for fatigue, modified Goodman equation with alternating octahedral shear stress and mean octahedral shear stress was used. For optimization, they generated an approximate design surface, and performed optimization of this design surface. The objective and constraint functions were updated to obtain precise values. This process was repeated till convergence was achieved. They also included constraints to avoid fretting fatigue. The mean and the alternating components of the stress were calculated using maximum and minimum values of octahedral shear stress. Their exercise reduced the connecting rod weight by nearly 27%.

Athavale and Sajanpawar (1991) modeled the inertia load in their finite element model. An interface software was developed to apply the acceleration load to elements on the connecting rod depending upon their location, since acceleration varies in magnitude and direction with location on the connecting rod. They fixed the ends of the connecting rod, to determine the deflection and stresses. This, however, may not be representative of the pin joints that exist in the connecting rod. The results of the detailed analysis were not discussed, rather, only the modeling technique was discussed. The connecting rod was separately analyzed for the tensile load due to the piston assembly mass (piston inertia), and for the compressive load due to the gas pressure. The effect of inertia load due to the connecting rod, mentioned above, was analyzed separately.

Pai (1996) presented an approach to optimize shape of connecting rod subjected to a load cycle, consisting of the inertia load deducted from gas load as one extreme and peak inertia load exerted by the piston assembly mass as the other extreme, with fatigue life constraint. Fatigue life defined as the sum of the crack initiation and crack growth lives, was obtained using fracture mechanics principles. The approach used finite element routine to first calculate the displacements and stresses in the rod; these were then used in a separate routine to calculate the total life. The stresses and the life were used in an optimization routine to evaluate the objective function and constraints. The new search direction was determined using finite difference approximation with design sensitivity analysis. The author was able to reduce the weight by 28%, when compared with the original component.

Yoo et al. (1984) used variational equations of elasticity, material derivative idea of continuum mechanics and an adjoint variable technique to calculate shape design sensitivities of stress. The results were used in an iterative optimization algorithm, steepest descent algorithm, to numerically solve an optimal design problem. The focus was on shape design sensitivity analysis with application to the example of a connecting rod. The stress constraints were imposed on principal stresses of inertia and firing loads. But fatigue strength was not addressed. The other constraint was the one on thickness to bound it away from zero. They could obtain 20% weight reduction in the neck region of the connecting rod.

In a published SAE case study (1997), a replacement connecting rod with 14% weight savings 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. The study lays down certain guidelines regarding the use of the fatigue limit of the material and its reduction by a certain factor to account for the as-forged surface. The study also indicates that buckling and bending stiffness are important design factors that must be taken into account during the design process. On the basis of the stress and strain measurements performed on the connecting rod, close agreement was found with loads predicted by inertia theory. The study also concludes that stresses due to bending loads are substantial and should always be taken into account during any design exercise.

III. METHOD AND DISCUSSIONS

As today's engines, required to have higher speed and power, their connecting rods have higher strength and stiffness, but must be lighter in weight and size. In developing power output engine, importance is placed on the weight of the reciprocating and oscillating parts such as piston, connecting rod, valve trains etc. The overall performance of the internal combustion engine is affected by higher inertia forces, generated by the moving parts of the engine. Therefore, it should always be investigated to avoid any failure of the engine in the long run.

As the speed increases, the maximum tensile load (at 360° of crank revolution) increases where as the maximum compressive load decreases at the crank end. Quasi-dynamic finite element analysis rather than static finite element analysis is used in this process, which can capture the actual structural behaviour of a connecting rod. During quasi-dynamic finite element analysis process, external calculated loads were also taken into interest to perform the elemental calculations. The inertia and dynamic loads were calculated and applied internally based on these inputs.

Of the 15 locations as shown in the Fig., at point 9, the maximum stress occurs at 360° crank angle, but the maximum stress (i.e. Due to influence of bending stress) occurs at 348° crank angle at location 13 respectively.

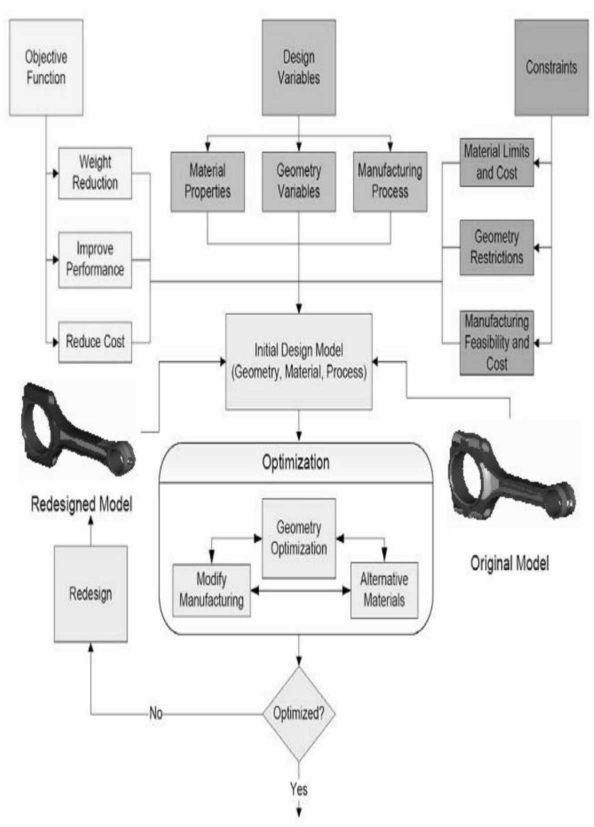
A. Model of Connecting Rod

Solid modelling tool is available to develop the concepts and initial design of any mechanical components and systems that can be analysed by using Finite Element Technique is discussed in literatures. Occurring of unnoticed mistakes can be avoided till the phase of prototype stage by the use of above citied technique.

Since the connecting rod involves several merging radii and surfaces, a classical study into this complicated problem has limitations and hence a finite element analysis is more appropriate to study the effect of combined loads due to gas pressure and inertia of reciprocating and oscillating parts of an engine.

B. Finite Element Model of the Connecting Rod - Meshed View

C. Optimization Procedure



IV. CONCLUSIONS

A connecting rod forms a basic element of an internal combustion (IC) engine, which performs the function of converting the reciprocating motion of the piston into angular effort of the crank. The objective of this study is to optimize connecting rod for its weight and manufacturing costs, taking into account the recent developments.

An optimized solution is the minimum or the maximum value that an objective function can take under a given set of constraints. The optimization carried out here is not true in mathematical sense, since while reducing the mass, manufacturing feasibility and cost reduction forms an integral part of markets.

The load cycle that is used here consists of compressive gas load corresponding to maximum torque and dynamic tensile load corresponding to maximum inertia load. A finite element routine is first used to calculate the displacements and the stresses in the connecting rod, which is further used in another routine to calculate the total life. For this optimization problem, high priority is given to the weight of the connecting rod. Change in the material, there by resulting in significant reduction in the machining cost is the key factor in the optimization process. During optimization, weight and cost are dealt separately.

APPENDIX

SAE - Society of Automotive Engineers
FEA - Finite Element Analysis

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REFERENCES

[1] Adila Afzal and Ali Fatemi, 2003, “A Comparative Study of Fatigue Behavior and Life Predictions of Forged Steel and PM Connecting Rods”, SAE International.

[2] Adila Afzal and Pravardhan Shenoy, 2003, “Dynamic Load Analysis and Fatigue Behavior of Forged Steel v_s Powder Metal Connecting Rods”, American Iron and Steel Institute, October Edition.

[3] Athavale, S. and Sajanpawar, P. R., 1991, “Studies on Some Modelling Aspects in the Finite Element Analysis of Small Gasoline Engine Components,” Small Engine Technology Conference Proceedings, Society of Automotive Engineers of Japan, Tokyo, PP. 379-389.

[4] Augugliaro G. and Biancolini M.E., “Optimisation of Fatigue Performance of a Titanium Connecting Rod”, ISPESL, Italy.

[5] Farzin H. Montazersadgh and Ali Fatemi, 2008, “Optimization of a Forged Steel Crankshaft Subject to Dynamic Loading”, SAE International.

[6] Farzin h. Montazersadgh and Ali Fatemi, 2007, “Dynamic Load and Stress Analysis of a Crankshaft”, SAE International.

[7] Giuseppe Sala, 2002, “Tecnology-Driven Design of MMC Squeeze Cast Connecting Rods”, Science and Technology of Advanced Materials, No. 3, PP. 45-57.

[8] Hippoliti, R., 1993, “FEM Method For Design and Optimization of Connecting Rods for Small Two-Stroke Engines,” Small Engine Technology Conference, PP. 217-231.

[9] James R. Dale, 2005, “Connecting Rod Evaluation”, Metal Powder Industries Federation, January Edition.

[10] Pai, C. L., 1996, “The Shape Optimization of a Connecting Rod with Fatigue Life Constraint”, Int. J. of Materials and Product Technology, Vol. 11, No. 5-6, PP. 357-370.

[11] Park, H., Ko, Y. S., Jung, S. C., Song, B. T., Jun, Y. H., Lee, B. C., and Lim, J. D., 2003, “Development of Fracture Split Steel Connecting Rods,” SAE Technical Paper Series, Paper No. 2003-01-1309.

[12] R.J. Yang, D.L. Dewhirst, J.E. Allison and A. Lee, 1992, “Shape optimization of connecting rod pin end using a generic model”, Finite Elements in Analysis and Design, No. 11, PP. 257-264.

[13] Rabb, R., 1996, “Fatigue Failure of a Connecting Rod”, Engineering Failure Analysis, Vol. 3, No. 1, PP. 13-28.

[14] Repgen, B., 1998, “Optimized Connecting Rods to Enable Higher Engine Performance and Cost Reduction”, SAE Technical Paper Series, Paper No. 980882.

[15] Rice, R. C., ed., 1997, “SAE Fatigue Design Handbook”, Society of Automotive Engineers, Warrendale, 3rd Edition.

[16] Sarihan, V. and Song, J., 1990, “Optimization of the Wrist Pin End of an Automobile Engine Connecting Rod With an Interference Fit”, Journal of Mechanical Design, Transactions of the ASME, Vol. 112, PP. 406-412.

[17] Serag, S., Sevien, L., Sheha, G., and El-Beshtawi, I., 1989, “Optimal Design of the Connecting Rod”, Modelling, Simulation and Control, B, AMSE Press, Vol. 24, No. 3, PP. 49-63.

[18] Teruie Takemasu, Victor Vazquez, Brett Painter and Taylan Altan, 1996 “Investigation of Metal Flow and Perform Optimization in Flash Less Forging of a Connecting Rod”, Journal of Materials Processing Technology, No. 59, 95-105.

[19] Webster, W. D., Coffell R., and Alfaro D., 1983, “A Three Dimensional Finite Element Analysis of a High Speed Diesel Engine Connecting Rod,” SAE Technical Paper Series, Paper No. 831322.

[20] Yoo, Y. M., Haug, E. J., and Choi, K. K., 1984, “Shape Optimal Design of an Engine Connecting Rod,” Journal of Mechanisms, Transmissions, and Automation in Design, Transactions of ASME, Vol. 106, PP. 415-419.

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