Abstract- The automobile engine connecting rod is a high volume production, critical component. It connects reciprocating piston to rotating crankshaft, transmitting the thrust of the piston to the crankshaft. In order to carry out successfully the function, it is needed to grasp the rotating crankshaft and also to keep the good stiffness of the big-end of the connecting rod in acceptable ranges during engine operation. When the stiffness of the Connecting rod is needed to be reinforced, in general, some geometric dimensions are simply increased without consideration of their complex effects on deformation. Sometimes the reinforced geometry causes negative effects on the stiffness.

This paper mainly focuses on the effect of geometric parameters on stiffness in the big-end structure of connection rod. It is found that the side flange is the most influencing parameters. The FEA simulated results are compared with experiments.

Keywords- Stiffness, Finite element analysis, Big End of Connecting rod

1. Introduction

It has been forced for engine power and performance to be dramatically increased in recent years and it brings a higher ignition pressure and rated rpm. As the power and rated rpm increase, the inertia force to the connecting rod at rated rpm also increases. Since the main role of the connecting rod in the engine is to deliver the firing load to crankshaft and to rotate the crankshaft smoothly, the much severe forces to the connecting rod require a more reliable design in the fields of not only the fatigue strength but also the stiffness of the big-end structure.
The most important thing in view of the stiffness of big end is the smooth rotation of crankshaft without failure during engine operation. When a connecting rod cannot hold properly a crankshaft, it causes a failure of connecting rod or a fretting problem between the bearing and crankshaft and sometimes the failure of the bearing is happened due to the severe contacts of them. To solve these problems, most researchers have been focused on the lubrication and the fretting between bearing and crankshaft such as oil film thickness and oil pressure.

However, in order to prevent the fretting problem, authors believe that the stiffness of the big-end structure should be concerned before the lubrication of the bearing. As far as authors know, a parametric study to see the geometric effects on stiffness of connecting rod has never treated before. This paper studied the individual effect of each geometric parameters of the big-end structure on the stiffness performance. The results obtained here can be used as a design guide to increase the stiffness performance of the connecting rod.

2. Control Parameters

There are many geometric parameters to affect the stiffness of big-end and it is hard to figure out the individual effect of the parameters. In order to know the quantitative effect of parameters. In this study, we chose 7 geometric parameters as control factors: (A) a section coefficient of the shank, (B) a thickness of the cap, (C) a shape of the cross section of cap, (D) use of a side flange, (E), use of the jig spot, (F) a thickness at the outside of bearing housing, and (G) a diameter of the connecting rod bolt (see Fig. 1). The levels of the factors are listed in Table I.

The L8 orthogonal array shown in Table 2 is selected in this study. Since we do not plan to look into the effect of factor A, it is treated as a dummy which level is not changed. The eight models having different geometric combinations given by L8 array are modeled for the simulations. Their shapes are presented in Fig. 2. The actual values of geometric dimensions for the models are selected as reasonable data within acceptable ranges in usual connecting rod design.
<table>
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<th>Level 2</th>
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<td>A</td>
<td>Section Coefficient of Shank</td>
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<tr>
<td>E</td>
<td>Jig Spot</td>
<td>No Use</td>
<td>Use</td>
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<tr>
<td>F</td>
<td>Bearing Housing Thickness at outside</td>
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<tr>
<td>G</td>
<td>Bolt Diameter</td>
<td>Smaller</td>
<td>Thicker</td>
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Table 1. Levels of the control factors

Fig 2. Eight Models due to L8 Orthogonal Array (The smaller bolt in diameter is painted in blue and the bigger is in yellow.)
Table 2. L8 Orthogonal Array Showing Combinations of Levels of Factors (Factor A is omitted, since the effect of dummy is meaningless)

The analysis of the S/N (Signal/Noise) ratio is useful to check the robustness of the control factors. Noises are unwanted or uncontrollable factors given from the surroundings of the system. S/N ratio is defined as the ratio of the work by designed inputs to the work by noises. Therefore a system with a bigger S/N ratio losses smaller energy by the noises and, in other words, the bigger S/N ratio gives a better performance. As you know the value of the clearance between bearing and crankshaft is controlled as a spec in manufacturing process, therefore, the clearance is going to be in a certain range. In this study, the maximum and minimum clearances are treated as noise levels.

3. Simulations

The deformations of the big-end structure are simulated by FEA (Finite Element Analysis). The commercial programs HYPERMESH and ABAQUS respectively are used for modeling and solving. The one of the FEA meshes is shown in Fig. 3. The half model with tetra parabolic elements is used due to the geometric symmetry of the connecting rod. The clearance between bearing and crankshaft and the tight-fit between piston pin and connecting rod are treated with the gap option of ABAQUS. The longitudinal displacement at the centerline of the crankshaft is fixed to resist the inertia force applied at the piston pin. The firing load compressing the connecting rod should be included in the durability analysis. However the stiffness problem such as bearing failure usually occurred at the split areas of cap and rod because of the fretting due to the severe contact between bearing and crankshaft. The main reason for contact is due to the inertia force not the firing load. Hence only the maximum inertia force is considered in the stiffness analysis. The force is calculated with the rotating and oscillating masses of the connecting rod system (connecting rod and piston assembly) under the rated rpm (6000rpm) of the engine. It is assumed that the tightening force of connecting rod bolt is enough so that the split between the cap and the rod does not occur during engine operation. The analyses are performed with maximum and minimum clearance respectively for each model to see S/N ratio.

The deformation and the distribution of the maximum principal stresses for model (1) under the maximum inertia force are shown in Fig. 4. The rounded area of rod and split area inside bearing have higher stresses. The area shows the maximum compressive deformation with respect to the original inner shape of the bearing as it deforms towards crankshaft. It may cause a bearing failure when a contact is severe.
4. Analysis results

We calculated the sensitivities and S/N ratio of the control factors by analyzing the obtained deformation results. They are plotted in Fig. 5 and 6. The first and second dots in the column represent the result of level 1 and 2 of the factors written in the top respectively. Since the smaller tensile deformation is better for the big-end stiffness, it is expected that the smaller value of sensitivity will show a good performance. And it is the same to the compressive deformation.

Fig 3. FEA Meshes for Simulation to Model (1)

Fig 4. Deformation and Distribution of Maximum Principal Stresses for Model (1) with Maximum Clearance in Bearing and Crankshaft under Maximum Inertia Force

Fig 5. Sensitivity (a) and S/N ratio (b) of control factors to Maximum Tensile Deformation
Fig 6. Sensitivity (a) and S/N ratio (b) of control factors to Maximum Compressive Deformation.

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Table 3. Prior Level of control factors in Sensitivity and S/N to Maximum Tensile (a) and Compressive (b) Deformation (The meanings of level are explained in Table 4.)

When looking into the results of factor B (the first column of Fig.6), it is found that the level 1 of factor B (B1) is a good choice in sensitivity and S/N ratio to get a better tensile deformation performance. It concludes that the cap having a thicker thickness may reduce the tensile deformation and is much insensitive to the clearance than the thinner. Meanwhile in the view of tensile deformation, B2 is better for the sensitivity, however B1 is better for S/N ratio.

The effects of each control factors to the deformations are printed in Table 3. From Fig. 5, Fig. 6 and Table 3, it is easily found that factors B and F have a big influence on tensile deformation, and factor D is the most influencing parameter on compressive deformation. The factor E, F, and G do not have large effects on compressive deformation, hence the selection of E1 (level 1 of factor E), F2, and G1 may reduce tensile deformation without loss of compressive deformation performance. The factor D has definitely to be selected as D2 (use of the flange). The side flange has an advantage in both performances of tensile and compressive deformation.

The tendencies of the some results are not coherent. For example, if we increase the thickness of the cap, it may reduce a tensile deformation but enhance a compressive deformation. It has counter effects. Here we should
choose the thicker or thinner cap thickness with considering which performance of deformation needs to be improved in current design.

5. Conclusion

In this paper, the geometric effects on the stiffness of big-end structure of connecting rod are studied. As the results, we summarize the effects of geometric parameters as followings;

- Factor B (thickness of cap); The thicker is better to prevent the tensile deformation but is not good to reduce the compressive deformation. The factor B has a big effect to tensile deformation than compressive deformation.

- Factor C (shape of the cross section of cap); When I type of cross section is used rather than T type, the better deformation performance is expected.

- Factor D (use of a side flange); Use of a side flange is strongly recommended to have good quality of tensile and compressive deformations. When applying this factor, the consideration about a production is needed, because this face is usually used as a datum in splitting process.

- Factor E (use of the jig spot); A connecting rod with a jig spot has a benefit in split-fracture process, since the split area changes a little in direction of fracture. However, no-use of the jig spot show good performance in tensile deformation and the jig spot has a little effect on compressive deformation.

- Factor F (thickness at the outside of the bearing housing); It has a big effect only on the tensile deformation. The increase of the thickness at the outside of the bearing housing may greatly reduce the tensile deformation without affecting the compressive deformation performance

- Factor G (diameter of the connecting rod bolt); The diameter of the bolt is not important parameter in the deformation when the tightening force is enough not to make a split between cap and rod. If there is lack of the force, it may lead the failure of the connecting rod and it is beyond the scope of this paper.

The deformation performance of big-end structure is greatly related with the geometry of the structure as well as the inertia force at rated rpm. Even if all the good geometric parameters for the deformation performance are included in the design, the final deformation results could not be improved or be worse. It could be happened if the inertia force is increased too much because of a great weight rise due to the geometric reinforcements. Designer should carefully select the combination of the geometric parameters and determine the proper values. Even the dimensions of the geometry may be decreased to get good quality of rigidity. For example, the factor B (cap thickness) has a counter effect to the tensile and compressive deformation. If there is a margin to the guideline of tensile deformation, it is possible to decrease the thickness of the cap in order to reduce the inertia force and its weight. It is worth mentioning again that the results presented here would be valid when the dimensional data of connecting rod are within reasonable ranges.

We expect the results obtained here can be used as a design guide to increase the stiffness performance of the connecting rod.
6. References


