R&D Efforts Regarding Lightweight, High-Rigidity Hub Units

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In recent years, the demand worldwide for weight reduction in automotive parts in order to improve fuel efficiency has increased. Despite this, automakers are requiring that wheel bearing performance in the areas of rigidity, strength and life be maintained or improved. This report explains JTEKT's development of a generation Ⅲ hub unit featuring both lightweight and high rigidity, achieved by means of a parameter study regarding bearing specifications and the outer ring and shaft shape along with utilization of advanced CAE analysis technology. JTEKT will continue utilizing this study method and these results to create products with the optimal performance to meet the needs of customers in regard to multiple design requirements including strength, rigidity, life, and mass.

Key Words: *hub unit, light weight, moment rigidity, CAE, optimization*

1. Introduction

In order to intensify measures against global warming, the regulation to limit the CO_2 emission of new cars to 120 g/km by the year 2012 is being validated in Europe. Meanwhile, in the United States, the CAFE regulation is being strengthened step by step every year towards the year 2020. Consequently, fuel efficiency improvement has become increasingly necessary for the automotive industry all over the world[1)].

Weight reduction of vehicles is one of the important factors for improving fuel efficiency. On the other hand, rigidity, life, and fatigue strength of 3rd generation hub unit bearings for passenger cars (hereinafter referred to as hub unit) are critical performance parameters that influence vehicle maneuverability performance, braking performance, and strength reliability. Accordingly, it is important to maintain and improve these contradictory performances as well as weight reduction. Recent R&D efforts for weight reduction applying CAE analysis have also been reported in the previous journals[2), 3)].

This report explains our study result on the development of lightweight, high-rigidity hub units, utilizing the parameter study and the sophisticated CAE analysis.

2. Target Performance

In this report, taking the hub unit for the non-driven wheel as shown in **Fig. 1** as the initial design (hereinafter referred to as the current product), we targeted to realize a design with the highest rigidity under the condition where the bearing weight is reduced, while maintaining or improving the bearing life, fatigue strength, etc. required for strength reliability, compared to the current product.

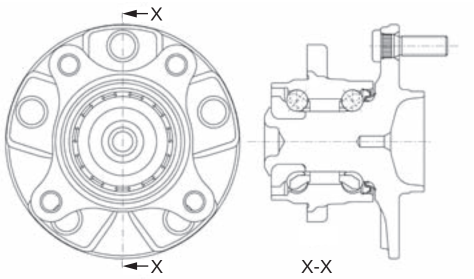


Fig. 1 Current product

3. Outline of Optimal Design

The outline of the optimization design study in developing the lightweight, high-rigidity hub unit is introduced hereunder.

3. 1 Parameter Study on Bearing Specifications, Outer Ring Shape, and Shaft Shape

As the bearing life is calculated based on vehicle specifications and bearing specifications, it is important to determine the bearing specifications including the proper number of balls, the ball pitch circle diameter (hereinafter referred to as ball P.C.D.), and the distance between ball centers at the initial stage of designing. **Figure 2** shows the result of the parameter study on the number of balls and the distance between ball centers in case the vehicle specifications are the same. **Figure 2** also shows that as the number of balls in the current product increases, the ball P.C.D. becomes larger, causing the increase in mass. The specifications for which bearing life is the same or longer than the current product, the increase in mass is minimal, and rigidity is maximum, have been selected from the above specifications.

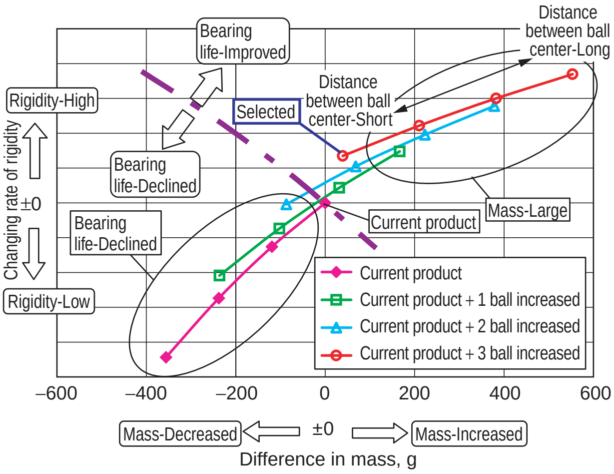


Fig. 2 Relationship between bearing specifications, mass, and rigidity

Figure 3 shows the results of the parameter study on the shaft shape and each position. It becomes possible to significantly improve the shaft rigidity without increasing the mass when deflection is reduced by adopting a thicker shaft diameter and a shorter shaft length. In addition, a thicker shaft diameter would make it possible to hollow out the bore section of the shaft spigot joint to a large extent and to further reduce weight.

Figure 4 shows the result of the parameter study on the outer ring shape and each position. Considering the fact that the symmetry angle of the bolt hole of the flange and the pitch circle diameter of the bolt hole (hereinafter referred to as bolt hole P.C.D.) are instrumental in higher rigidity, it has become possible to improve the rigidity of the hub unit without increasing the mass, by narrowing the distance between the bolt in vertical direction where the moment is loaded and by decreasing the bolt hole P.C.D.

Based on the study mentioned above, a base model with light weight and high rigidity for an assembly (hereinafter referred to as ASSY) has been determined, taking into account the multipurpose use of components such as retainers and seals, as well as the installation dimensions to the vehicle body. **Figure 5** shows the main differences between the base model and the current product.

3. 2 Shape Optimization Analysis

3. 2. 1 Outline of Optimization Model

On the basis of the base model as described in the previous section, further improvement in performance has been studied utilizing shape optimization analysis. In this study, a mesh morphing shape optimization method using a finite element model is adopted. The condition of this optimization is to maximize rigidity under limited volume. The objective function for optimization (physical quantity to be minimized) is the mean compliance (work by external force) when the moment is loaded. In other words, the purpose of this analysis is to determine the shape with minimum displacement at loading point (or high rigidity) under the limitation of constant volume.

Figure 6 shows the finite element model for shape optimization analysis. In the model, two areas have been determined: the design area where dimensional change is possible as far as the bearing performance is not affected and the non-design area where dimensional change is not considered. With the emphasis on the ease of forging and machining, the design areas of hub shaft, inner ring, and outer ring have been divided into several sub-areas,

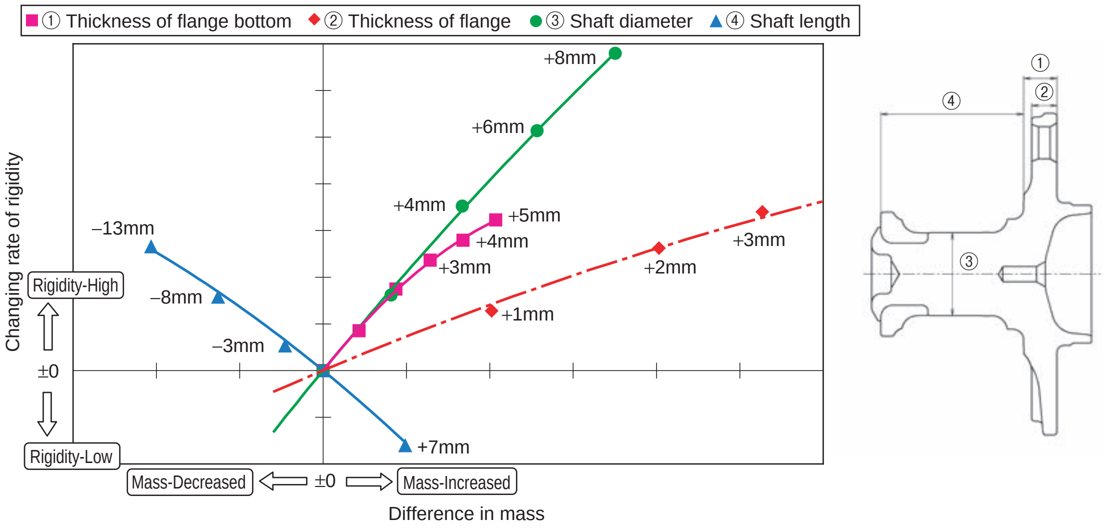


Fig. 3 Relationship between shaft shape, mass, and rigidity

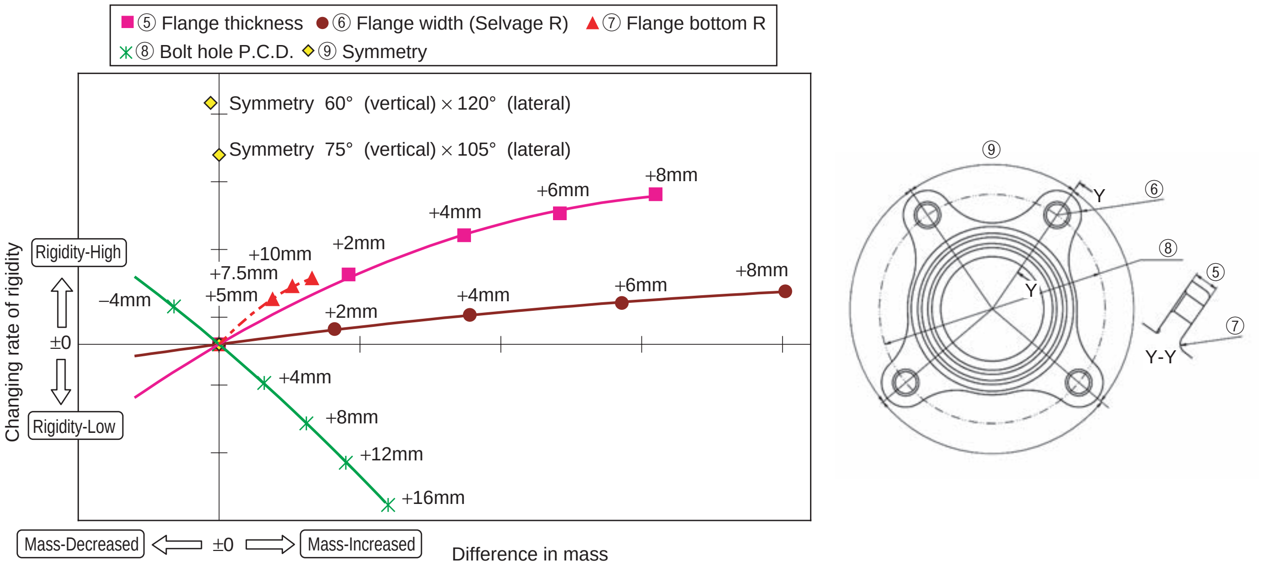


Fig. 4 Relationship between outer ring shape, mass and rigidity

<Main differences from current product>
- Shortened distance between ball center and shaft length
- Increased 3 balls per row and enlarged ball P.C.D.
- Enlarged shaft diameter and thinned shaft spigot joint bore section
- Decreased outer ring bolt hole P.C.D.
- Changed symmetry angle of outer ring flange, etc.

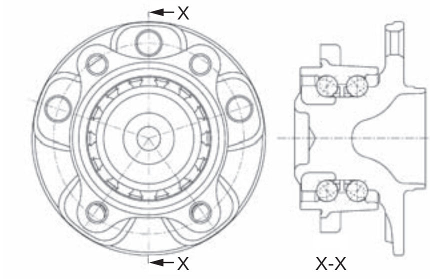


Fig. 5 Base model

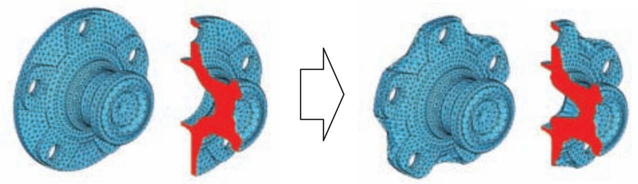
in each of which different limitations on shape alteration (such as limitation on freedom of alteration, assignment of draft direction of forging) are provided.

3. 2. 2 Result of Shape Optimization

The result of shape optimization analysis is shown in **Figs. 7** and **8**. Also two graphs shown in **Fig. 9** are the history of model volume and mean compliance against the number of repeated calculations. All of hub shaft, inner ring, and outer ring have a shape in which the volume of such sections with low rigidity contribution degree as the volume between fixed bolts of the flange is decreased, and the volume of such sections needed are reinforced. Finally, the mean compliance of each model is reduced by 9 to 10% against the initial shape. In other words, it can be seen that a convergence shape with increased rigidity has been obtained with the initial volume maintained.

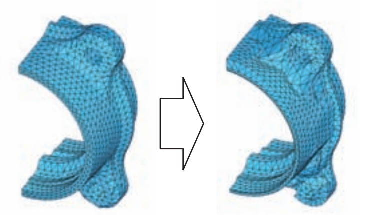
(a) Inner shaft/inner ring (full model) (b) Outer ring (half model)

Fig. 6 Finite-element model for shape optimization analysis



(a) Base model (b) Optimization model

Fig. 7 Result of shape optimization (hub shaft & inner ring)



(a) Base model (b) Optimization model

Fig. 8 Result of shape optimization (outer ring)

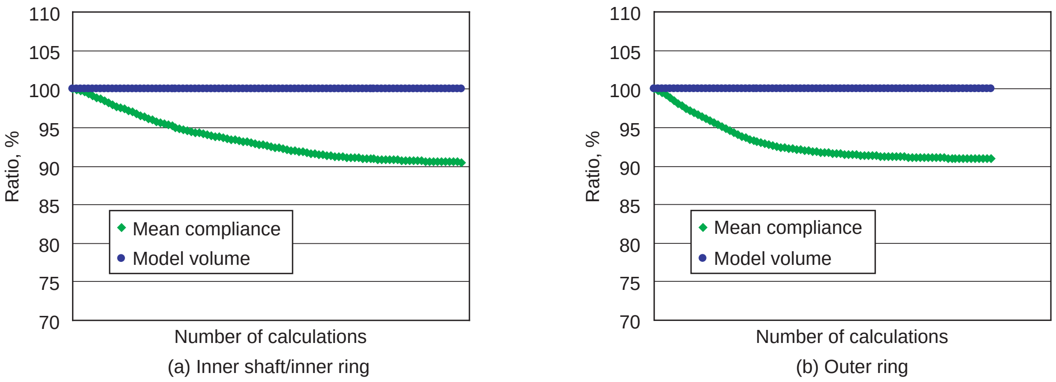


Fig. 9 History of model volume and mean compliance

3. 2. 3 CAD Modeling of Optimization Shape

CAD modeling of the final shape has been performed on the basis of the optimization shape obtained in the previous section, with due consideration of manufacturing requirements such as turning or forging. **Figure 10** shows the final model. Using the shape optimization analysis allows the shape of rib to be effectively arranged, an idea that cannot be obtained with the two-dimensional system. Hence, for a bearing ASSY, the mass of this model has been reduced by 125 g compared to the current model.

Fig. 10 Final model

3. 3 Bearing ASSY Analysis

In order to verify the performance of the final model shape hub-unit on the computer, a rigidity analysis by way of the bearing ASSY model was conducted. The analysis model is shown in **Fig. 11**. For the purpose of simulating to the actual bearing rigidity evaluation test, this ASSY model is composed of hub unit ASSY including a inner shaft, inner ring, outer ring, balls, and fixed bolts, and also rigidity body backup similar to the test jig. Moment was applied to the analysis model and the relative value of misalignment between the inner shaft and the outer ring flange was confirmed.

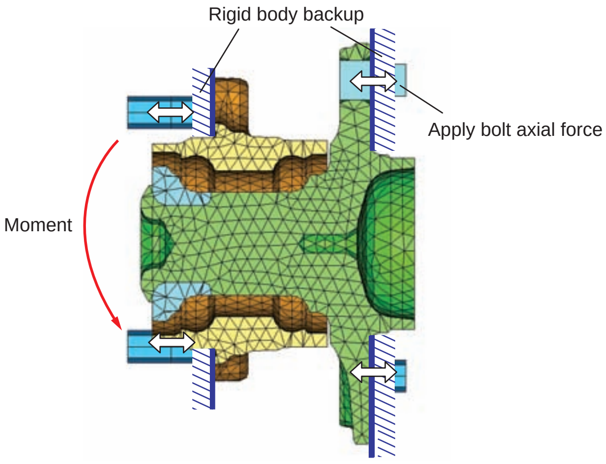
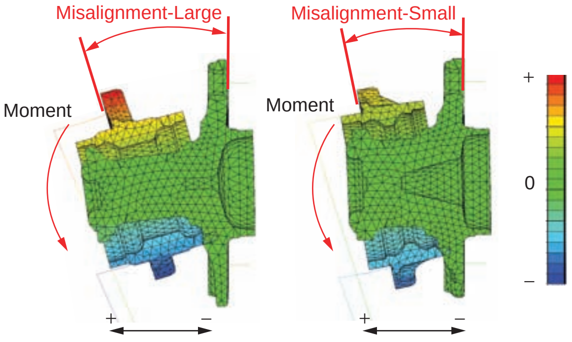


Fig. 11 Bearing assembly analysis model

Figure 12 shows the bearing ASSY analysis result (two contour maps of axial displacement) and **Table 1** shows the bearing rigidity evaluation result. The final model showed an improvement of more than 50% in moment rigidity (the moment force needed to misalign the bearing by 1 deg.) compared to the current model. In addition, it was also confirmed that the fatigue strength and the calculated bearing life of the final model were more than that of the current product, resulting in superiority in performance.



(a) Current product (b) Final model

Fig. 12 Contour map of Bearing assembly axial displacement (X50)

Table 1 Result of rigidity evaluation

Shape	Current product	Final model
Misalignment, deg.	0.339	0.224
Moment rigidity ratio	1.00	1.51

4. Verification Using Actual Product

In order to verify the moment rigidity of the actual bearing product, evaluation test samples of the final model (hereinafter referred to as the developed product) were prepared, and the moment rigidity of both the current product and the developed product was measured. **Figure 13** shows the appearance of the developed product and **Fig. 14** shows the result of moment rigidity measurement. Compared to the current product, the developed product showed remarkable improvement in weight reduction of about 125 g and rigidity increase of 56% as expected in the CAE analysis. On top of that, the CAE analysis result is well matched to the actual measurement result. This fact shows that the bearing ASSY analysis is very effective for the future study of rigidity.

Fig. 13 Developed product

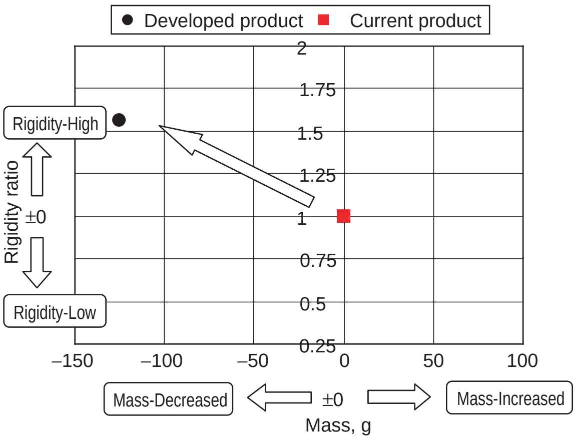


Fig. 14 Result of moment rigidity measurement

5. Conclusion

As described above, the optimization of lightweight, high-rigidity hub unit was examined in perspective of how much both weight reduction and rigidity improvement can be attained at the same time. As a result, a weight reduction of 125 g and a rigidity improvement of more than 1.5 times could be attained compared to the initial shape product. The shape optimization analysis made it possible to acquire the optimal shape which could not have been examined in a conventional parameter study. Also, high conformity between the bearing ASSY analysis result and the rigidity evaluation test result on the actual products was observed, resulting in an improvement of design accuracy by desk investigations.

6. Closing Remarks

This report introduced the development efforts on lightweight, high-rigidity hub units. By applying this study method, the optimization design in pursuit of the utmost weight reduction is made possible while maintaining bearing life, strength, and rigidity. It is our keen desire to develop optimized performance products that can meet customer needs in a short time by widely applying the technique and knowledge obtained during this study to future hub unit design.

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