

Optimization Method for Reduction of Transmission Housing Weight

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ABSTRACT

An optimization method has been developed as a tool to contribute to the design of lightweight and high-rigidity automotive transmission housings. The method is divided into topology optimization and shape optimization and can be applied at any of three different stages depending on the maturity of the design. The application of topology optimization from the framework conception stage in the design of an actual automotive transmission enabled rigidity targets to be met with a reduction in weight of 10%. Study of the generation of stress in the optimized shapes predicted by the method indicated that the placement of ribs along the paths of transmission of bearing load to increase rigidity was highly efficient.

1. Introduction

Due to recent heightened concerns toward protection of the global environment and conservation of resources, demands are mounting to reduce weight and size in the development of automotive transmissions.

The transmission housing accounts for a high proportion of the overall transmission weight, and as such is a part with great need of weight reduction.

The housing rigidity and strength could be predicted in the design stage using conventional analysis technology⁽¹⁾, but the input load transmission routes are complex and there are many design parameters that must be taken into account, so the calculation model size increased and prediction calculations took time. Therefore, numerous designs had to be investigated separately during the short development period, which made it difficult to obtain a shape that satisfied the weight reduction targets.

The topology optimization functions of commercially available finite element analysis applications are nearing the practical level that would enable application to obtaining lightweight product shapes. However, while there have been reports of topology optimization theory⁽²⁾⁻⁽⁵⁾ and application

to simple shapes such as beam shapes⁽⁶⁾ and pressed parts^{(7),(8)}, there are no cases yet of application to complex shapes such as transmission housings.

Therefore, this research applied both topology optimization and shape optimization methods to transmission housing design, and realized a reduction in weight while still taking into account rigidity. These details are reported below.

2. Method of Setting Conditions for Application of Topology Optimization to Transmission Housings

When applying topology optimization, it is necessary to set the load conditions, limiting conditions (design parameter tolerance range), and the optimization subject space.

Methods of setting the conditions for applying topology optimization to transmission housings were investigated for these three items.

2.1. Load Setting Method

The engine torque is transmitted as a load (hereafter, bearing load) through the gears and shaft to the bearings that support these parts and then to the housing.

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In the topology optimization calculations, it is extremely difficult to calculate the bearing load in a practical time by modeling all parts that transmit the engine torque and creating a calculation model that also takes into account torque transmission due to gear teeth contact.

Therefore, the newly developed method created two-dimensional elastic elements in the direction of the bearing load, and set the load at the bearing center-point which is the terminus of these two-dimensional elastic elements. (Fig. 1)

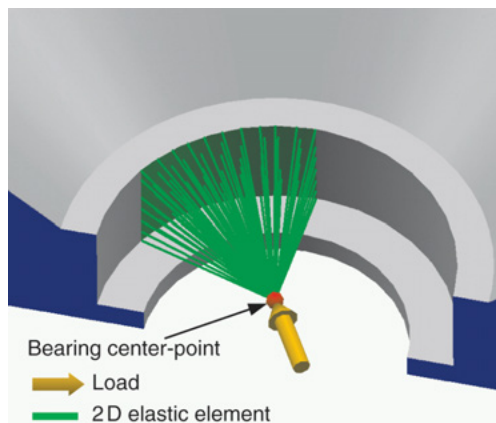


Fig. 1 Definition of load

2.2. Limiting Condition Setting Method

When evaluating the housing rigidity, it is important to determine the degree of bearing center-point displacement caused by the bearing load from the no-load condition⁽¹⁾.

Therefore, keeping bearing center-point displacement within a certain target value was set as a limiting condition. (Fig. 2)

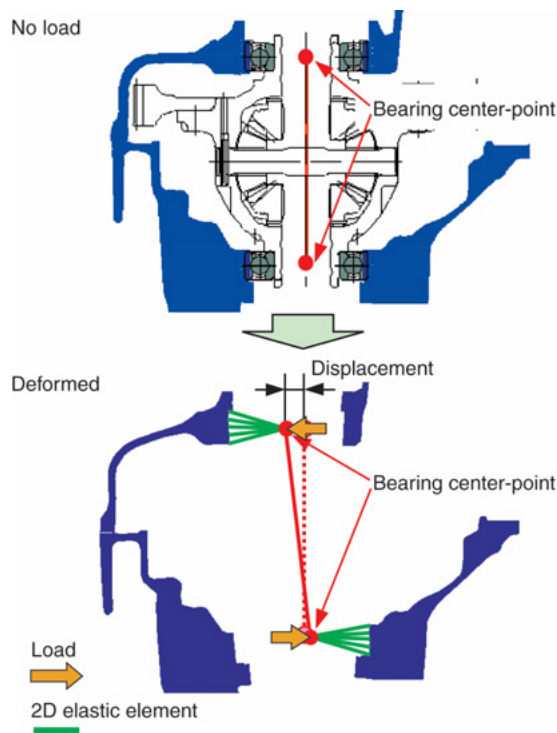


Fig. 2 Displacement of bearing center-point as limiting condition for design responses

2.3. Optimization Subject Space Setting Method

If the design space that is the subject of optimization has a large spatial volume to be set, the number of meshes increases. These calculations may not be possible due to the limitations of current computer resources, so the space to be set must be narrowed down to some extent.

The stress produced on the transmission housing by the bearing load is not uniform, and has local concentrations. Therefore, static analysis was performed and the design space was set (Fig. 5) with the focus on portions where high stress is produced (Fig. 3) and portions with high displacement (Fig. 4).

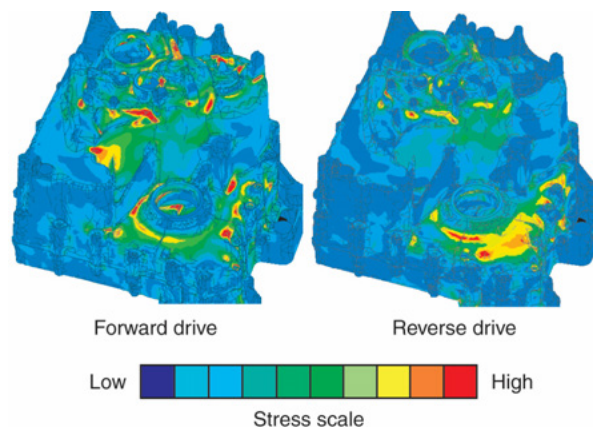


Fig. 3 Example of static analysis : stress

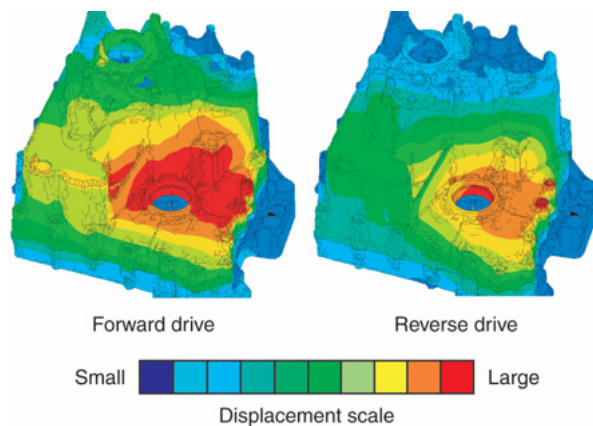


Fig. 4 Example of static analysis : displacement

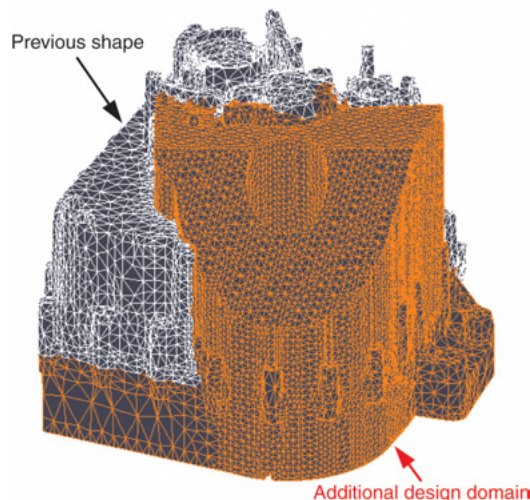


Fig. 5 Defining design domain

3. Method of Applying Optimization to Transmission Housings

3.1. Housing Design Process Using Optimization

In the early design stages there is generally a high degree of usable space freedom, and this degree of space freedom then decreases thereafter as the specifications mature. This means that the weight reduction effects of optimization are higher in the early design stages and lower in later design stages.

Therefore, a design process is needed to determine the most appropriate optimization method according to the maturity of the design. Design stages were classified into the following three stages, and optimization methods were investigated for each stage.

- (1) The framework concept stage with a high degree of freedom during early development
- (2) The stage where investigating the housing external rib shapes
- (3) The stage where only minor modifications are made to the rib thickness and height, etc.

3.1.1. Topology optimization in the framework concept stage

This is the shaft placement, main section and housing joint surface layout stage. In this stage the stiffeners needed to withstand the bearing load (Fig. 7) could be predicted by setting the maximum usable space as the design domain that is the subject of optimization (Fig. 6), and applying topology optimization.

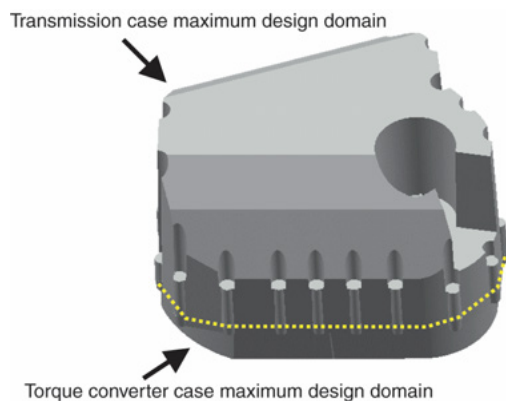


Fig. 6 Maximum design domain in early design stage

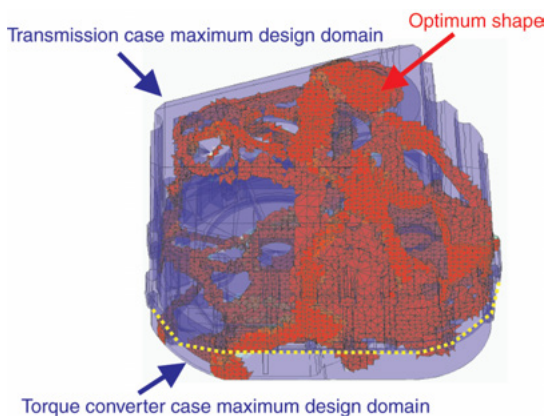


Fig. 7 Result of topology optimization using maximum design domain

In the framework concept stage, the gears, shaft, oil pressure control unit and other internal parts are designed in parallel with the housing layout work, so the housing internal layout is matured to allow effective use of the stiffeners predicted by topology optimization.

3.1.2. Topology optimization for investigating the housing external rib shapes

In the stage where the internal parts layout has been for the most part established, the main design work is to investigate the housing external rib shapes.

In this stage, as mentioned in section 2, attention was focused on the stress and displacement conditions, and the space that avoids interference between the frame and mounting brackets inside the engine room and other items outside the housing was set as the design domain for applying topology optimization. At this time modeling was performed with the housing internal wall shape as a non-design domain that was not subject to optimization in order to consider the stiffness of the walls (the fixed thickness portion that covers the entire housing to seal in the lubricating oil). (Fig. 8) In addition, transmission housings are manufactured using the die casting process, so the draw direction was also specified.

This made it possible to predict the rib shapes that can be applied to the 3D drawing (three-dimensional model used to create the official drawings). (Fig. 9)

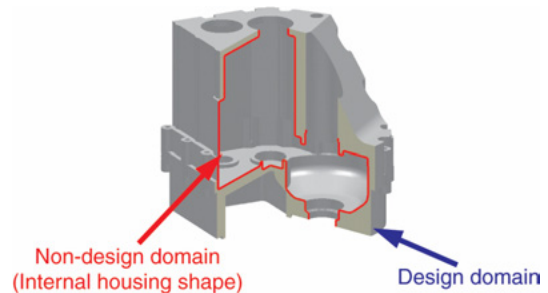


Fig. 8 Defining domain in external housing rib shape optimization phase

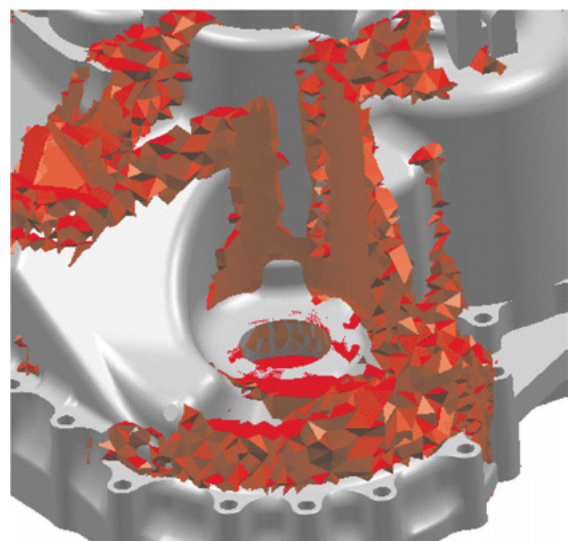


Fig. 9 3D drawing with optimum shape

3.1.3. Shape optimization when making minor modifications to the rib thickness and height, etc.

The shape predicted by topology optimization is displayed using meshes as the minimum unit. Given the limitations of current computer resources, it is necessary to create mesh of a certain size or larger. This means that topology optimization cannot predict a smooth shape (Fig. 9), which makes it difficult to accurately reflect the shape to the 3D drawing.

When performing weight reduction in stages with a high design maturity, the main design work consists of making minor modifications to the rib thickness and height, etc. For this reason, the shape predicted by optimization must have high dimensional accuracy. Therefore, shape optimization was applied to predict the optimum shape by morphing the mesh. The obtained results are expressed as the amount of change in the dimension values, which made it possible to accurately reflect the shape to the 3D drawing. (Fig. 10)

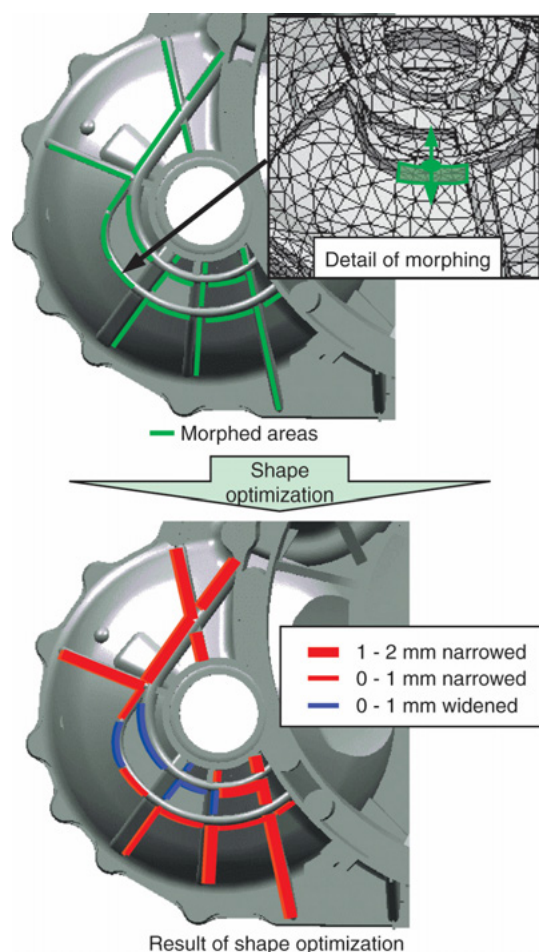


Fig. 10 Morphing and result of shape optimization

4. Application Effects

4.1. Confirmation of Weight Reduction Effects and Verification of Rigidity

The newly developed method was applied to a horizontal automatic transmission in order to reduce the weight.

Topology optimization was applied from the housing framework concept stage, and resulted in a 10% reduction in weight when the most efficient stiffener layout space could

be obtained.

In addition, the weight reduction effects were also confirmed to decrease in later development stages with a low degree of design freedom when optimization was applied from the housing external rib shape definition stage to the rib thickness and height modification stage. (Fig. 11)

In addition, the displacement amount of the bearing center-point was calculated for four different types of transmission housings using analysis technology that takes into account housing joint surface contact and friction⁽¹⁾ in order to verify the stiffness of the shape predicted by optimization. These results are shown in Fig. 12, and confirm that the stiffness is the same as the shapes before applying optimization.

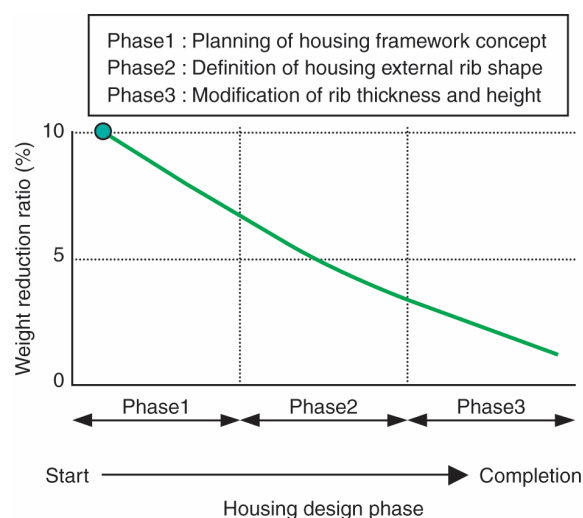


Fig. 11 Reduction of housing weight by optimization

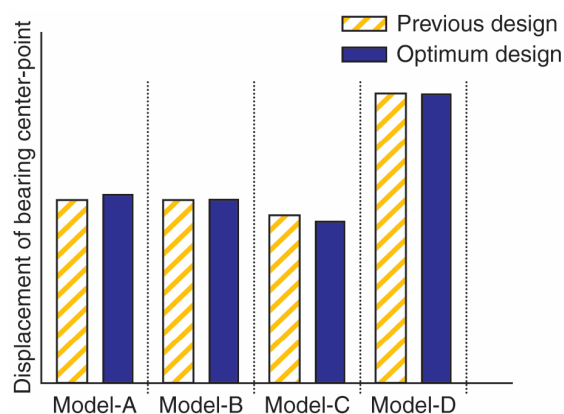


Fig. 12 Example of stiffness calculation

4.2. Study of Optimized Shapes

Static analysis was performed on the shapes before and after optimization and the stress distributions were calculated to confirm whether the shapes predicted by optimization were efficient with regards to the bearing load transmission routes.

The differential bearing load is dominant for overall transmission deformation⁽¹⁾, so the shape of the housing part that supports the differential bearing was studied.

Figure 13 shows that stress generation along the ribs is not uniform for the transmission case shape before optimization, indicating that this is not an efficient shape.

In contrast to this, stress is generated evenly along the ribs for the optimized shape, thus confirming that the stiffeners have been efficiently designed along the bearing load transmission routes.

In addition, Fig. 14 shows that stress generation is also not uniform for the torque-converter case shape before optimization, and that there are some portions that are not functioning as stiffeners.

In contrast to this, stress is generated along the ribs and there is low stress on the walls for the optimized shape, thus confirming that this is an efficient shape.

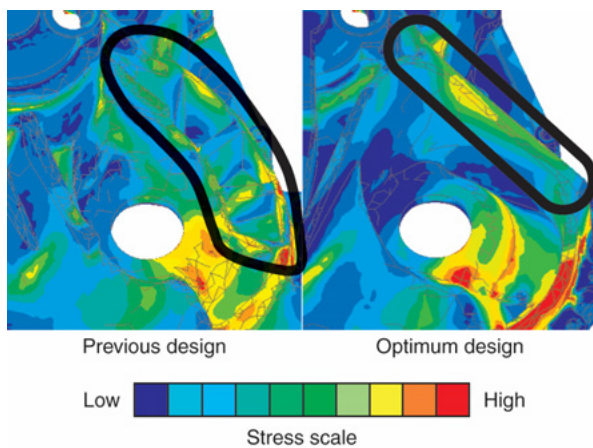


Fig. 13 Example of static analysis of transmission case

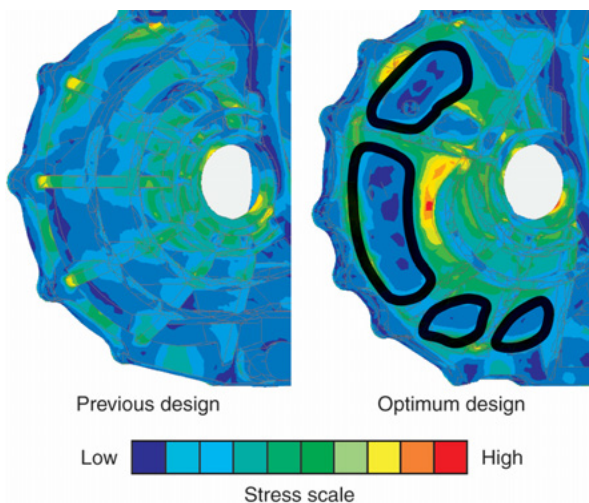


Fig. 14 Example of static analysis of torque converter case

5. Conclusion

Topology optimization and shape optimization methods were applied to transmission housing design, and the following results were obtained.

- (1) The stages for applying optimization were classified into three stages according to the maturity of the design, and a design method that makes selective use of topology optimization and shape optimization methods as appropriate was established in order to design lightweight

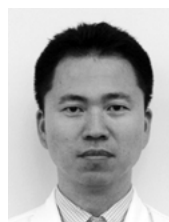
and high-rigidity automotive transmission housings.

- (2) Applying topology optimization from the housing framework concept stage resulted in a 10% reduction in weight while still meeting the target rigidity values.
- (3) Shapes predicted by optimization were studied from the viewpoint of the stress generation conditions, and it was confirmed that the ribs placed as stiffeners along the bearing load transmission routes were efficiently designed.

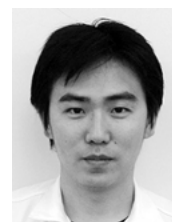
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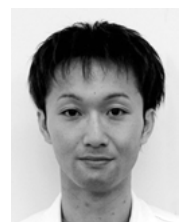
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