Strength Verification of the Planetary Gear System

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Abstract—Planetary gear systems are used in the driving system of excavators as a reduction gear and they are widely used in industrial areas such as transmission in automobile, machine tools, semiconductor equipment, and so on. Planetary gear systems have the advantages of high power density, large reduction in a small volume, multiple kinematic combinations, and axial direction of power path. Gears in planetary gear systems sometimes get short life due to wear and breakage by repetitive load during operation time.

In this paper, a strength design evaluation for the planetary gear system was performed to ensure the gears’ stability and durability during operation time.

Keywords—Strength design verification, Planetary gear system, Reduction gear, Stability, Durability

I. INTRODUCTION

PLANETARY gear systems normally consist of a centrally pivoted sun gear, a ring gear, and several planet gears found between the sun gear and ring gear. Compared to traditional gear boxes, the planetary gear systems have some advantages. Planetary gear systems possess larger efficiency in small volumes because of the compact combination of gears in the planetary gear system. They also have an outstanding efficiency of just 3% for power transmission tantamount to the power loss that occurs on each of the shift stages. Through this aspect, we can figure out that the rate of transmissible input energy in the planetary gear system is smaller than the mechanical loss which comes from a gear box. Based on the advantages mentioned above, the planetary gear system has been designed. [1]-[6]

The driving system of excavators consists of two parts which are a planetary gear system and a hydraulic motor as shown in Figure 1.

There are numerous researches to verify strength of gears in planetary gear systems. [7]-[9] Therefore, in this paper, strength design verification for a planetary gear system that is used in the driving system of excavators has been performed.

II. MODELING OF PLANETARY GEAR SYSTEM FOR ANALYSIS

Optimum modeling for analysis is needed to carry out a more precise analysis result. Therefore, the modeling for strength and durability analysis is focused on gear train part. [10]

In order to perform the research for comparing gears with two kind of different materials for each, the same modeling is used. In order to perform the research for comparing two shapes of gears, the width of the planetary gears is extended to 1mm as shown in Figure 2. We have assumed that the contact face between the sun gear and the planetary gears can be wider than in the previous model of planetary gears by extending the widths of the gears. The occurring stress can be smaller than the previous model as well. Therefore, the modified model of the planetary gears has been also used for the research.

III. STRENGTH ANALYSIS OF PLANETARY GEAR SYSTEM

A. Boundary Conditions and Load Conditions

In this research, SCM420H and SCM822H are applied to the planetary gear system as its materials. SCM420H and
SCM822H are applied to perform the research for two kind of different materials, and SCM420H is also applied to perform the research for two shapes of gears.

SCM420H is widely used as a component material of industrial reduction gear, and SCM822H is widely known as a typical alloy steel for machine structural use. SCM822H has many advantages such as excellent mechanical attributes, increase of corrosion-resistance and wear-resisting quality, protection from decline in mechanical attributes if subject to high temperature, improvement of quenching efficiency, and so on. The material properties are shown in Table 1. [11]

Power to drive the planetary gear system is generated from the hydraulic motor of the driving system. The maximum output of hydraulic motor is 210.5 Nm and 1,294.5 rpm. Analysis for stability and durability of the planetary gear system design should be performed under extreme load conditions. Thus, outputs in maximum torque are applied as input conditions for analysis. The average temperature in the planetary gear system is established at 60°C, and the lubricant is established SAE 80W grade which is generally used for planetary gear systems as well. [12]-[13]

In addition, according to evaluation standards for the lifetime of RS B 0095, the standard of track drive units for small excavators [14], input conditions are established to verify durability for driving over 1,000 hours. The input conditions are arranged in Table 2 and applied to the three researches.

B. The Results of Strength Analysis for Gears

Strength analysis is performed to evaluate the durability and stability of gears in the planetary gear system. Boundary conditions, load conditions, and material properties are established to perform this research.

The results of the strength analysis for the two materials and the modified model are shown in Figure 3 to Figure 8. The stress on planetary gears occurs in two parts. The two parts are internal contact part which contacts the sun gear, and external contact part which contacts the ring gear. Further, the substances for the divided stress form two parts and are shown in Figures 4, 6, and 8.

According to the analysis results, the first maximum bending stress occurs on the sun gear, and the second maximum bending stress occurs on the planetary gear by power transmission route.

In the case of applying on SCM420H, the measurement of first stress is 204.5 MPa, and the measurement of second stress is 182.6 MPa. The maximum contact stress on the sun gear and planetary gear occurs at the same measurement of 1733.2 MPa.

In the case of applying on SCM822H, the maximum bending stress occurs at 240.5 MPa on sun gear and occurs at 182.6 MPa on planetary gear. The maximum contact stress occurs at the same measurement of 1703.6 MPa on sun gear and planetary gear.

In the case of the modified model with SCM420H, the maximum bending stress occurs at 212.8 MPa on sun gear and occurs at 161.5 MPa on planetary gear. The maximum contact stress occurs at the same measurement of 1630.3 MPa on sun gear and planetary gear.

By comparing the analysis results for SCM420H with the analysis results for SCM822H, the bending stress for two materials occurs with similar measurements. However, we could find that the measurement for SCM822H is larger than SCM420H at about 30 MPa in the case of the contact stress.
Above all things, the analysis results for the modified model are definitely remarkable. Although the maximum bending stress that occurs on sun gear is larger than the maximum bending stress of SCM420H, the other results of stress except the above case are small by at least over 20 MPa.

The results of the strength analysis for three cases are shown in Table 3.

Table 3 The results of gear strength analysis

<table>
<thead>
<tr>
<th></th>
<th>Bending stress (MPa)</th>
<th>Contact stress (MPa)</th>
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<tbody>
<tr>
<td></td>
<td>SCM 420H</td>
<td>SCM 822H</td>
</tr>
<tr>
<td>Sun gear</td>
<td>240.5</td>
<td>240.5</td>
</tr>
</tbody>
</table>

(a) Fig. 3 Stress of the sun gear for SCM420H
(b) contact stress : 1733.2 MPa
(b) bending stress : 240.5 MPa

(a) Fig. 4 Stress of the planetary gear for SCM420H
(b) contact stress : 1733.2 MPa
(b) bending stress : 182.6 MPa

(a) Fig. 5 Stress of the sun gear for SCM822H
(b) contact stress : 1703.6 MPa
(b) bending stress : 240.5 MPa

(a) Fig. 6 Stress of the planetary gear for SCM822H
(b) contact stress : 1703.6 MPa
(b) bending stress : 182.6 MPa
C. Safety Factor of Gears

Safety factor is the result applied at JIS 4 grade, the result of safety factors for SCM420H and SCM822H, with the modified model arranged in Table 4.

According to the result of the strength analysis, in the case of applying SCM420H properties, safety factor for contact stress at the planetary gear is more than 1.0; however, the safety factor at the sun gear is less than 1.0 as in Table 4. In the cases of applying SCM822H and the modified model, the safety factors for contact stress at the sun and planetary gear are more than 1.0. Therefore, it is possible to design gears which have high strength in cases of applying SCM822H and the modified model.

IV. DURABILITY ANALYSIS OF PLANETARY GEAR SYSTEM

A. Durability Evaluation of Gears

Durability analysis for driving over 1,000 hours is performed by the standard of RS B 0095. The results are arranged in Table 5.

As a result of the durability analysis, all cases are satisfied with the evaluation standard for a life of RS B 0095 except in the case of the sun gear where SCM420H is applied.

V. CONCLUSION

In this research, strength and durability analysis for SCM420H, SCM822H, and the modified model have been performed to analyze the durability and stability of a planetary gear system which is used in the driving system of excavators, the result of the analysis obtained by dimensional analysis. The analysis results for the three cases are compared and analyzed. The case where SCM420H is applied as material of the gears lacks stability and durability because the safety factor for contact stress is less than 1.0.

On the other hand, if SCM822H is applied as material of gears, any problems for stability and durability will not occur because the safety factor for contact and bending stress is over 1.0. The case using the modified model is also stable and durable. Therefore, the application of SCM822H as material of the planetary gear system is appropriate to use.

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REFERENCES