An innovative gear tooth analysis and evaluation technique

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Abstract: When gears engage, high stress occurs on gear teeth surface if edge contact occurs on the tooth surface. To minimize this stress, it is crucial for gear designers to consider crowning on gear teeth. To determine the most advantageous crowning, it is very important to accurately evaluate surface stress for all phases of engagement. An innovative method with employing Abaqus user subroutine to allow trace history was developed for this application.

In this paper, an analytical example of this innovative technique will be presented on one of Nabtesco Corporation ("Nabtesco" hereinafter)'s products.

Keywords: Gear Engagement, Crowning, Experimental Verification.

1. Introduction

When gears engage, high stress occurs on gear teeth surface if edge contact occurs on the tooth surface and this phenomenon may cause damage on gear tooth surfaces (Komori, 2003). To prevent the damage, maximum stress has to be decreased. Generally, to decrease maximum stress, it is necessary to increase contact area when gears engage. But even if the contact area is large, high stress can occur if edge contact occurs on the tooth surface. So the most suitable tooth shape should not be decided only by contact area. It is very important to consider not only contact area but also maximum stress when determining tooth surface shape. FEM can analyze both of these aspects.

2. Analytical object

2.1 Drives for wind turbines

Nabtesco produces yaw and pitch drives for wind turbines (Figure 1). Each of these drives has a pinion to transmit the power to the nacelle or the blade and these pinion tooth surfaces are often subject to damage due to severe conditions. To prevent the damage, contact area must be increased and maximum stress decreased when the pinion is engaged. The tooth shape must be optimized to minimize damage to the pinion.

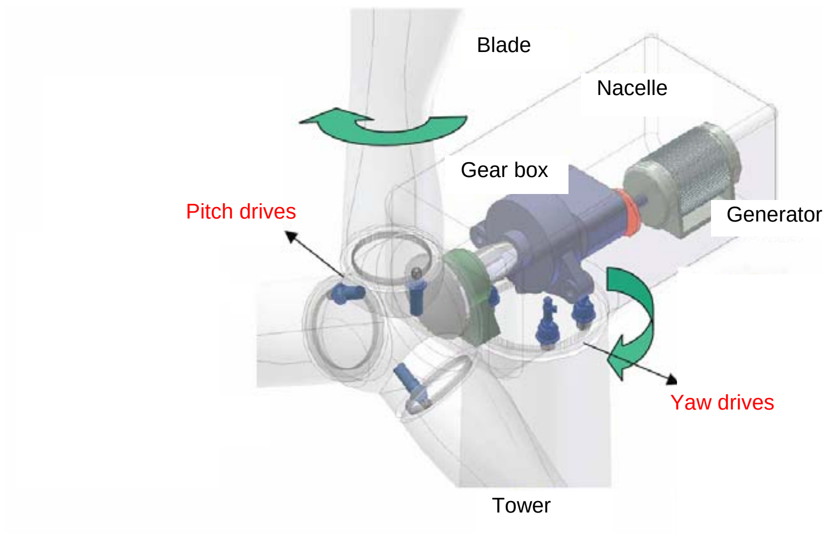

Figure 1. Wind turbine structure.

2.2 Crowning

On the pinion tooth surface, there is crowning to prevent contact on the edge (Figure 2). As crowning has a great effect on both contact area and maximum stress, it must be carefully designed.

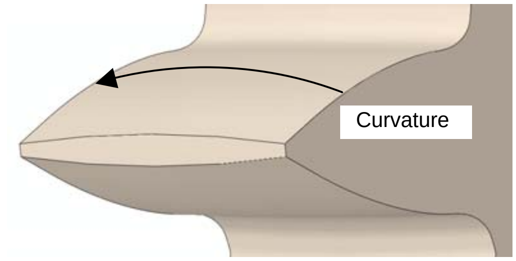

Figure 2. Crowning.

2.3 Test method and results

To measure contact area when the teeth engage, the pinion is tested using “Komyotan”, a Japanese paint containing lead oxide. The test apparatus and results are shown in Figure 3. When the teeth coated with “Komyotan” engage, the “Komyotan” on the contact area is worn off and the contact area can be measured. But using this method, a lot of pinions have to be manufactured to consider the most suitable shape, and maximum stress cannot be calculated.

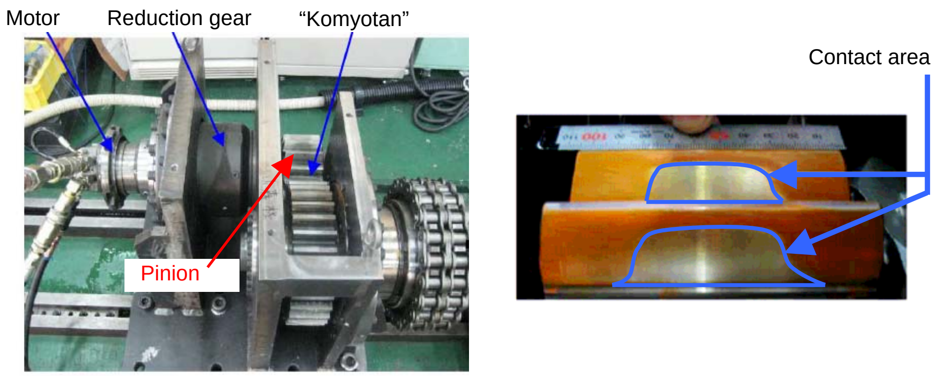

Figure 3. Test apparatus and result.

3. Analytical method

3.1 Models

The goal of the analytical model was to simultaneously analyze tooth contact area and maximum stress on the teeth using FEM. Analytical model is shown in Figure 4.

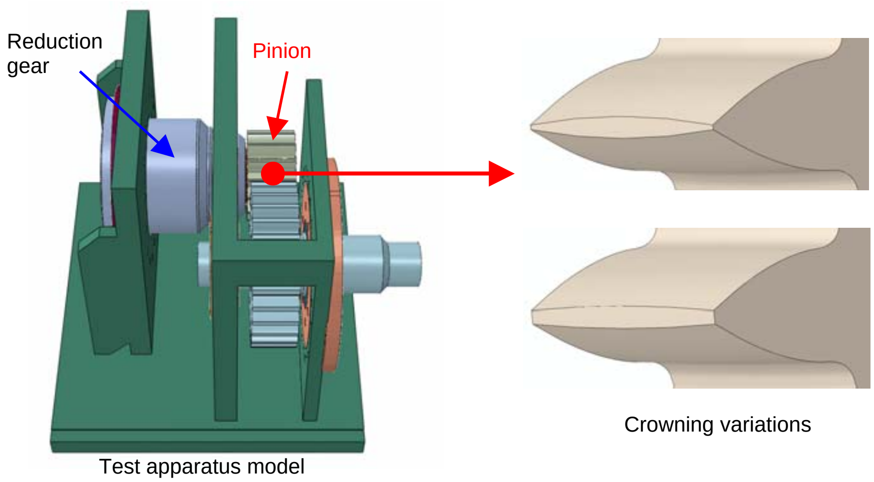

Figure 4. Analysis model.

3.2 Conditions

In this analysis, the bottom surface of the test apparatus model was fixed, resistance was applied to the reduction gear shaft and the pinion was rotated in prescribed angle (Figure 5).

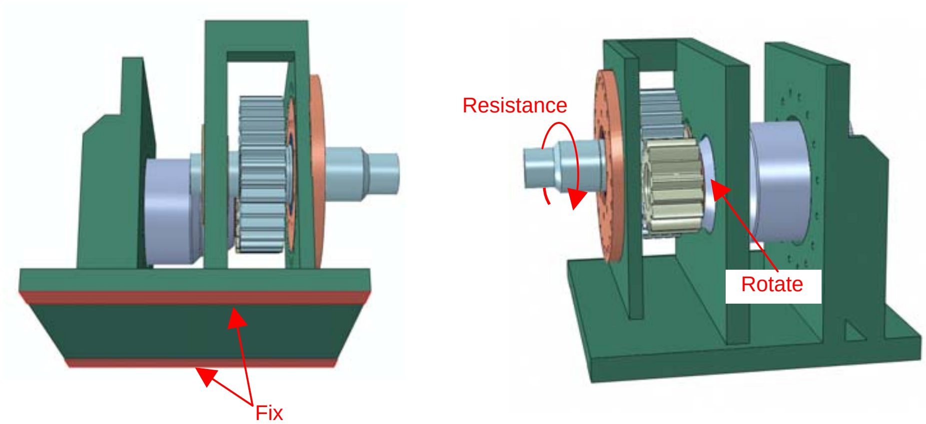

Figure 5. Analytical conditions.

3.3 Software and procedures

Abaqus version 6.10, with improved Dynamic, Implicit function (Abaqus Analysis User's manual), was used as the solver and Abaqus/CAE version 6.10 was used in both pre- and post-processing. To calculate maximum stress on the gear tooth surface accurately, the mesh had to be very fine, which increases the number of elements and therefore increases calculation time. To avoid this problem, Submodeling analysis was used (Figure 6).

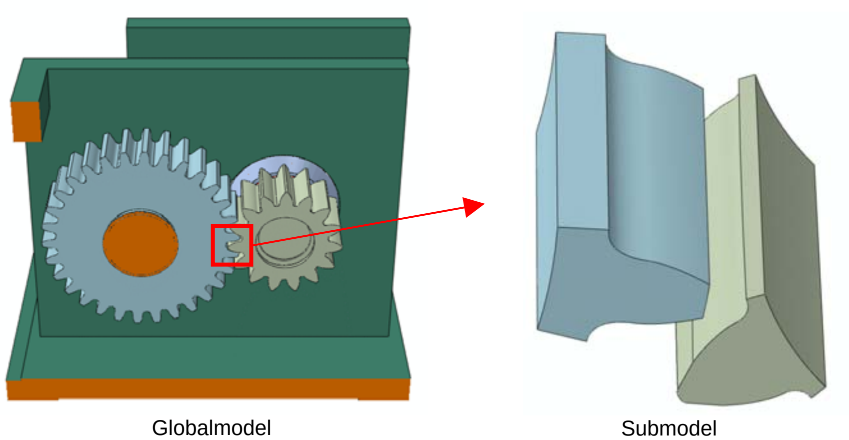

Figure 6. Submodeling analysis.

3.4 Evaluation method

In this analysis, stress on the pinion tooth at each phase of engagement can be calculated accurately but total contact area cannot be analyzed. So a new post processing technique that can show the history of stress was developed using an Abaqus user subroutine (Figure 7).

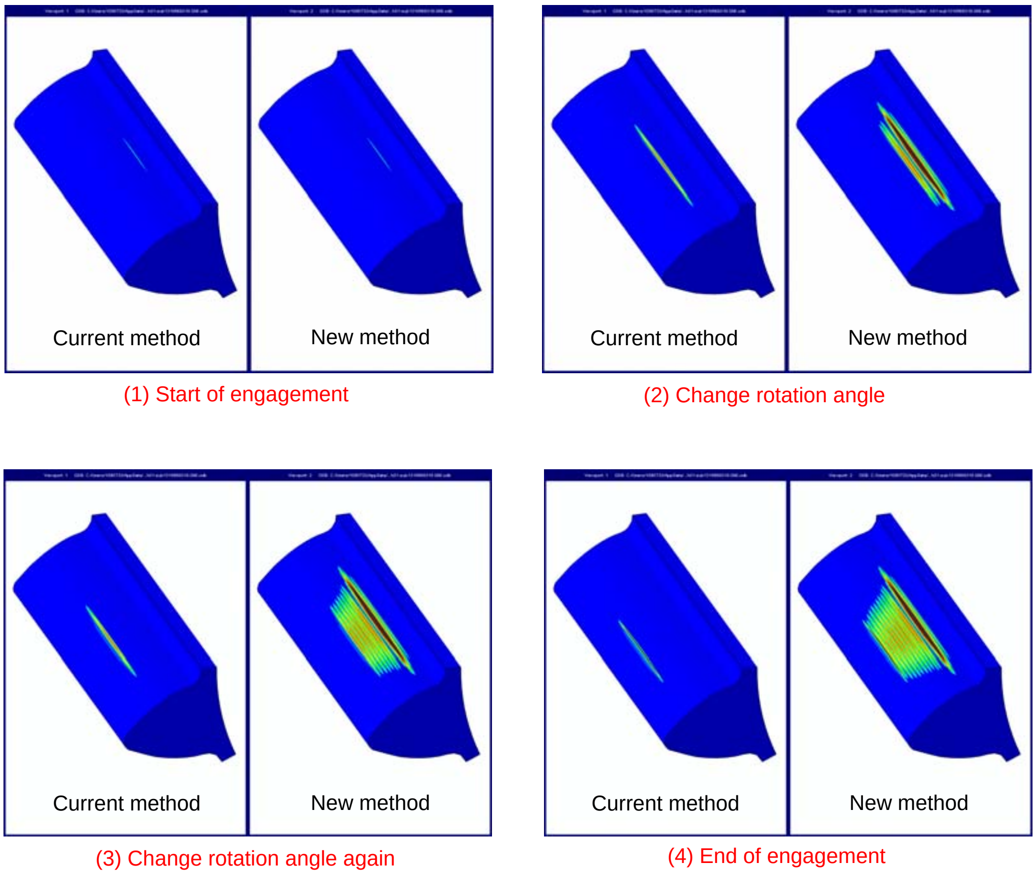

Figure 7. Analysis results of new method.

4. Results

The analysis results are in good agreement with the test results (Figure 8). Stress distribution during all phases of engagement is shown in Figure 9. Maximum stress during all phases occurs at the end of engagement.

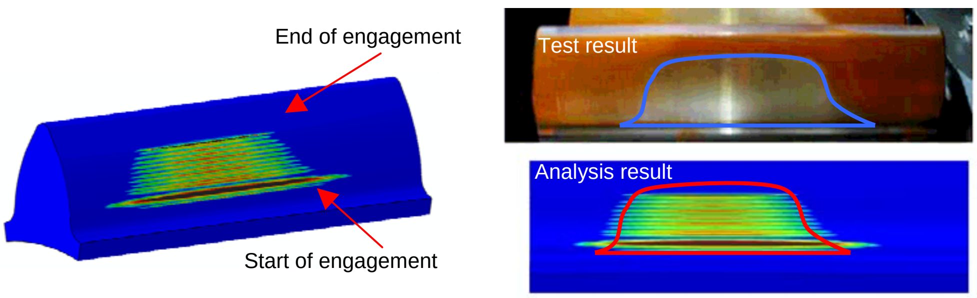

Figure 8. Analysis results and comparison with test results.

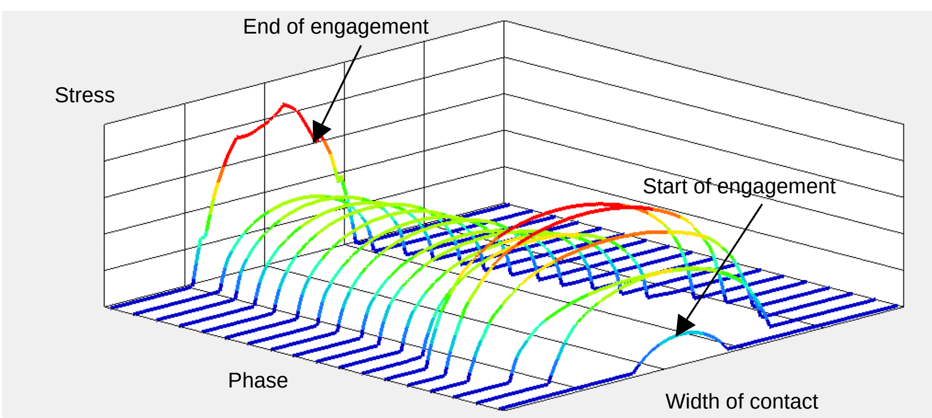

Figure 9. Stress distribution.

5. Discussions

This analysis method makes it possible to analyze contact area and maximum stress at the same time. Using this method, it is possible to determine the optimal tooth shape. The analysis results of the optimized shape are shown in Figure 10.

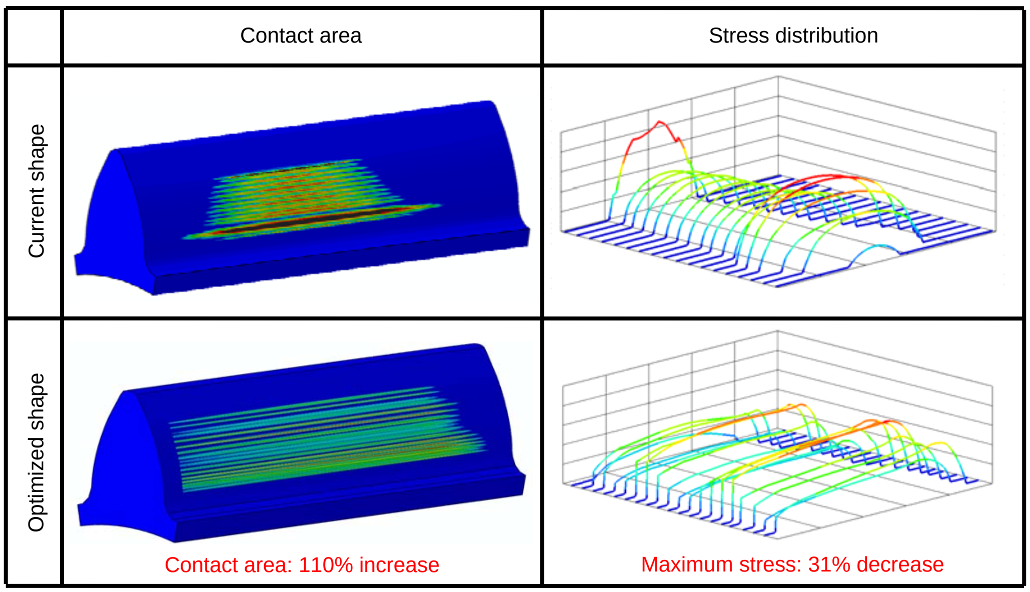

Figure 10. Improved shape results.

6. Conclusion

An innovative analysis and evaluation technique for gear engagement analysis was developed, allowing analysis of contact area and maximum stress over the entire history of engagement.

7. References

1. Komori, M., Kubo, A., Takahashi, T., Tanaka, T., Ichihara, Y. and Komiyama, M., “Failures of Involute Gears Due to Contact of Side Edge and Crest of Tooth : 1st Report, Chipping of Side Edge of Tooth and Progress to Tooth Breakage” The Journal of the Japan Society of Mechanical Engineers (in Japanese), vol. 69, no. 685, 2003.
2. Abaqus Analysis User’s manual, 6.3.2 Implicit dynamic analysis using direct integration.

8. Acknowledgements

This paper has been organized based on the contents of a paper presented at the 2011 Simulia Customer Conference Japan held on November 28-29. The authors would like to take this opportunity to thank the support members of SIMULIA Japan, DASSAULT SYSTEMES K.K. for their assistance.