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2023 年 8 月 22 日 Email: shutingnpu@yahoo.co.jp

Numerical Analysis for Contact Strength of Three-Dimensional, Thin-Walled Spur Gears Considering the Effect of Centrifugal Force

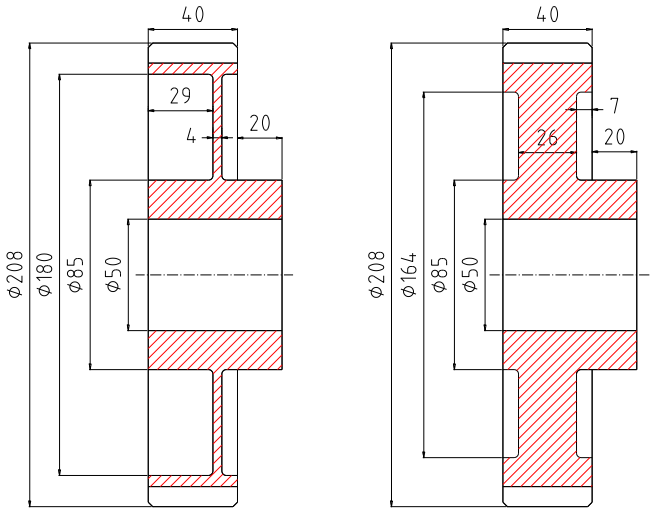
By Prof. Shuting Li

1． Abstract

Gears used in aircraft and helicopters are characterized by high rotational speeds and thin-walled rim and web structures designed to reduce weight. Consequently, significant centrifugal forces act on these thin-walled gears, causing substantial structural deformation; therefore, when calculating gear strength, it is necessary to account for the effect of centrifugal forces on gear strength. However, because strength calculations for thin-walled gears are an extremely difficult challenge, very little research had been conducted on strength calculations for thin-walled gears that account for the effects of centrifugal force. To resolve this unresolved issue, the authors [1–2] developed specialized three-dimensional, finite element method software and used it to clarify the effects of centrifugal force on the strength of high-speed rotating thin-walled gears. Here, we briefly present the results.

2． Three-Dimensional Thin-Walled Spur Gears Under Study

As shown in Figure 1, this study focuses on a pair of spur gears with identical specifications. The number of teeth is Z = 50, the module is m = 4, and the shifting coefficient is x = 0. Figure 1(a) shows a thin-walled spur gear with a three-dimensional structure, while Figure 1(b) shows a solid gear used as the mating gear.



(a)　Thin-walled spur gear　　(b)　Solid gear

Figure 1: A pair of spur gears under study

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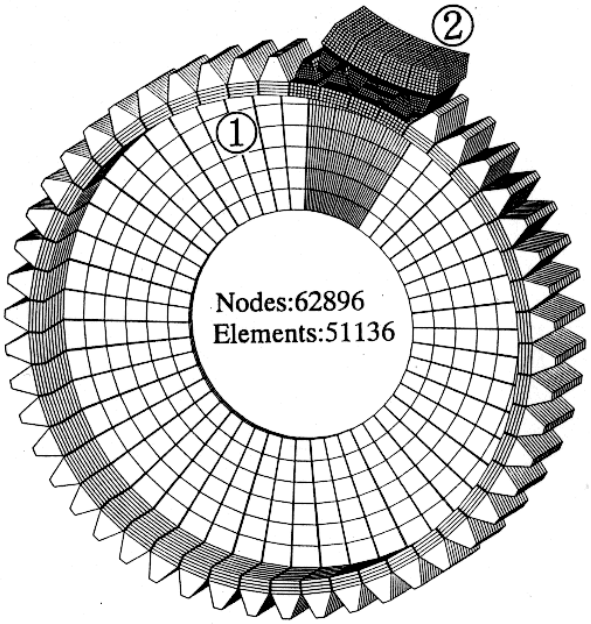
3． Contact Analysis of Thin-Walled Gears

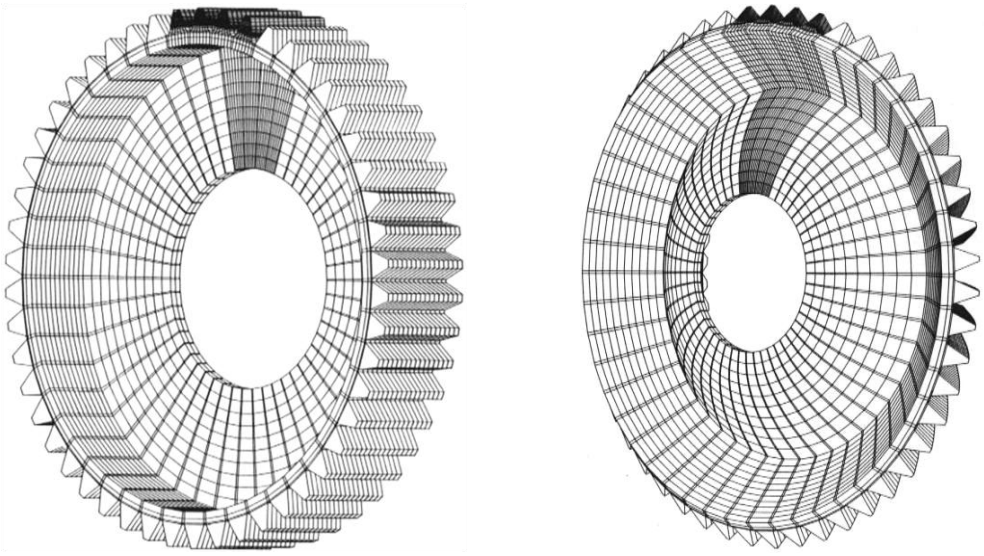
Figure 2 shows a three-dimensional FEM mesh model of thin-walled and solid gears meshing. Using this model, we investigated the effect of centrifugal force on gear strength during high-speed rotation. Here, we briefly present only the analysis results; for details of the study, please refer to References [1–2].

Figure 3 shows a thin-walled spur gear before and after centrifugal deformation.



① Thin-walled gear； ② Solid gear

Figure 2: FEM model for contact analysis of thin-walled gears



(a) Before centrifugal deformation (b) After centrifugal deformation

Figure 3: Appearance of a thin-walled spur gear before and after centrifugal deformation

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Figure 4 is used to define the contact area on the tooth surface. As shown in Figure 4, the area hatched with red diagonal lines is the region used in the analysis of tooth contact problems and is referred to as the contact area. The X-axis represents the tooth lead direction, and the Y-axis represents the tooth profile direction. Figure 5 shows a contour plot of the surface pressure (contact stress) distribution in the contact area on the tooth surface of a thin-walled spur gear when the effect of centrifugal force is ignored, while Figure 6 shows a contour plot of the surface pressure distribution in the contact area of a thin-walled spur gear when the effect of centrifugal force is taken into account. The rotational speed in this case is 40,000 rpm. Comparing Figure 6 with Figure 5, it can be seen that the surface pressure distribution pattern on the tooth face has changed significantly. Therefore, it has been determined that the effect of centrifugal force on gear strength cannot be ignored when thin-walled gears rotate at high speeds.

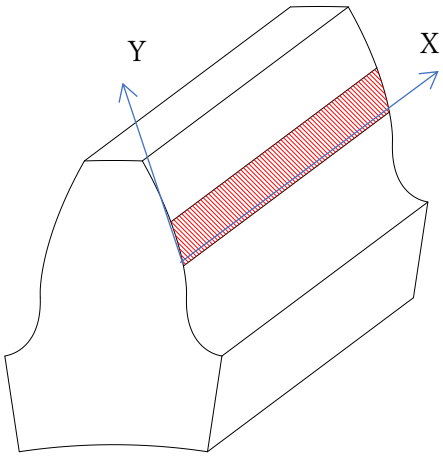

Figure 4: Definition of the contact area on the tooth surface (X-axis = tooth lead; Y-axis = tooth profile)

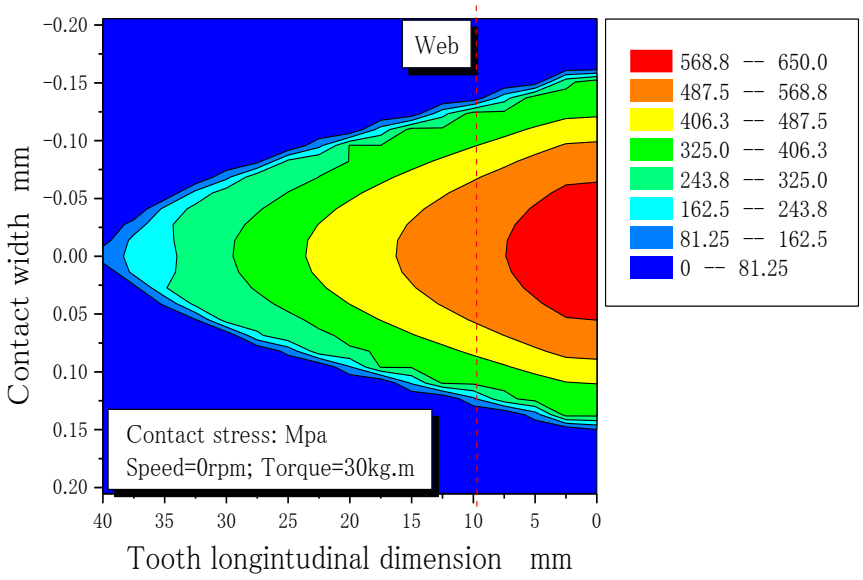

Figure 5: Contour plot of tooth surface contact stress distribution for a thin-walled gear neglecting the effect of centrifugal force (rotational speed = 0 rpm)

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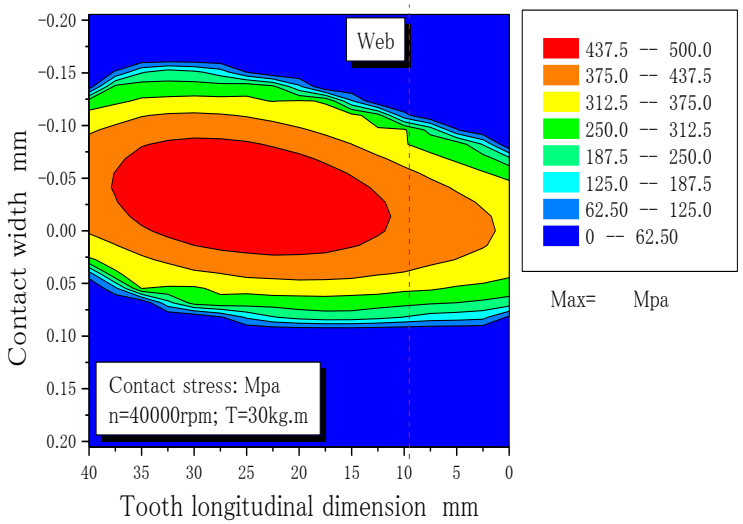

Figure 6: Contour plot of tooth surface contact stress distribution for a thin-walled gear considering the effect of centrifugal force (rotational speed = 40,000 rpm)

References：

(1) Shuting Li, “Centrifugal load and its effects on bending strength and contact strength design of a high speed thin-walled gear with offset web”, Mechanism and Machine Theory, Vol. 43, Issue 2, pp.217-239, 2008.

(2) Shuting Li, “Effects of centrifugal load on tooth contact stresses and bending stresses of thin-rimmed spur gears with inclined webs”, Mechanism and Machine Theory, Vol. 59, Issue 1, pp. 34-47, 2013.