Study on Welded Structure Gears* (8th Report, Analyses of Web and Rib Stresses)

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This paper presents a study on the root fillet, web and rib stresses and tooth deflections of thin-rimmed spur gears with different web thicknesses and arrangements by the three-dimensional finite element method (FEM).

The effects of web thickness and rib on web and rib stresses of single web gears with ribs were investigated by carrying out web and rib stress analyses by FEM and a static bending test. The effects of web thickness, rib and maldistribution of loads along face width on root stress distributions and tooth deflections were clarified.

Furthermore the effects of web distance and maldistribution of loads along face width on root stress distributions of double web gears were investigated.

Key Words : Gear, Welded Structure, FEM, Root Stress, Deflection, Web Stress, Rib Stress, Web Arrangement, Web Thickness

1. Introduction

In the previous papers^{(1)~(3)}, the method of changing the rim thickness of a thin-rimmed gear model in the FEM-analysis was examined. The effects of rim thickness on the root stress distributions and root and rim stresses of thin-rimmed spur gears with different web arrangements were investigated.

In the present paper, the root fillet, web and rib stresses and tooth deflections of thin-rimmed spur gears with different web thicknesses and arrangements were analysed by the three-dimensional finite element method (FEM).

The effects of web thickness and rib on web and rib stresses of single web gears with ribs were computed and measured by carrying out web and rib stress analyses by FEM and a static bending test. The effects of web thickness, rib and maldistribution of loads along face width on root stress distributions and tooth deflections were clarified. Furthermore the effects of web distance and maldistribution of loads along face width on root stress distributions of double web gears were investigated. Thus useful design data for thin-rimmed welded gears with and

without ribs were obtained.

2. Computation of Stresses and Tooth Deflections by 3-dimensional Finite Element Method

2.1 Computer program system for 3-dimensional analysis

The computer program used in this computation is SANAS-F⁽¹⁾, which is applicable to the static and dynamic analyses of structures.

Fig.1 Web arrangement of G.U

Table 1 Dimensions of gears

Gear sign	G.U	G.V	G.W
Module m	7		
Pressure angle α	20°		
Number of teeth z	69		
Face width b	100 mm		
Rim thickness t_r	2m* mm		
Web thickness b_w	12 mm	10 mm x 2	
Gear structures	Symmetric (Ribbed)	Asymmetric (Ribbed)	Double web

* m : Module

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were computed for the loading conditions of cases 0, 1, 2.

3. Experimental Method and Apparatus

3.1 Test gear

Test gear used in this experiment is

an asymmetric type of single web gear G.V. Dimensions of G.V are shown in Table 1 and the web arrangement is shown in ref.(2). Test gear is made of STPT49 (web, rib : SS41) with teeth surfaces ground after induction hardening, to an accuracy of 1st class in JIS. Hardness of tooth surface is about $H_{RC}41$.

3.2 Measurements of root, web and rib stresses

The root stresses on compressive side of G.V were measured for a normal tooth load $P = 5.8$ kN which is applied to 11 points along the tip (2 mm toward the root) of the tooth one after another. The measured positions of root stresses are the same as in the case of ref.(2). Strain gages were pasted at the computed positions of maximum web and rib stresses and the web and rib stresses were measured for a normal tooth load $P = 5.8$ kN. The testing method is described in ref.(2) in detail.

4. Computed and Experimental Results and Discussions

4.1 Computed and measured results of root, rib and web stresses

Figure 4 shows the computed and measured root stresses of an asymmetric type of single web gear G.V for a concentrated normal tip load $P = 10$ kN on the tooth just above rib. The measured root stresses are corrected considering the differences in the loading point and load value between the computation and the measurement⁽¹⁾. It is seen from this figure that the computed root stresses are in a fairly good agreement with the measured ones and this method of finite element analysis is considered valid.

Figures 5, 6 show the computed web stresses near the rim and boss of G.U due to the distributed load on the teeth just above and between ribs respectively. The

(a) $b_w = 6$ mm

(b) $b_w = 12$ mm

(c) $b_w = 18$ mm

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf
Fig.5 Computed web stresses (G.U, distributed load, above rib)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf
Fig.6 Computed web stresses (G.U, $b_w = 12$ mm, distributed load, between ribs)

web stress due to the distributed load shows the maximum value near the boss regardless of web arrangement. It is seen from Fig.5 that the web stress decreases with an increasing web thickness. The maximum web stress due to the distributed load on the tooth just above rib is larger compared with the case of load on the tooth between ribs. Figure 7 shows the maximum web stress for each gear due to the distributed load. The maximum web stresses of G.V, G.U, G.W become smaller in the order mentioned. Even the maximum web stress of G.V is much smaller than the

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.7 Effect of web arrangement on maximum web stresses (distributed load)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.8 Computed rib stresses (G.U, side B, distributed load P = 110 kN, above rib)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.9 Relation between maximum web stresses and web thickness (distributed load)

root stress (mean root stress 445 MPa⁽²⁾). Figure 8 shows the computed rib stresses on B side (Fig.3) of the rib just below the loaded tooth of G.U under the distributed load. In this figure, the values of rib stresses are represented by the length of straight lines normal to the rib surface. The maximum rib stress occurs near the rim and is much smaller than the maximum root stress. The maximum rib stresses in the case of Fig.8 are the largest of those for any position of loaded tooth. The computed and measured web, rib stresses for the concentrated load P = 5.8 kN are 10~20 MPa and much smaller than the maximum root stress.

4.2 Effects of web thickness and rib on stress distributions and tooth deflection

Figure 9 shows the computed maximum web stress of G.U and G.U₀ of various web thicknesses under the distributed load on the teeth just above and between ribs. It is seen from this figure that the maximum web stress decreases with an increasing web thickness as is the case with the results of Fig.5. Since in Fig.9 the maximum web stress of G.U₀ is almost equal to that of G.U, the effect of rib on web stresses is considered fairly small. Figure 10 shows the computed maximum rib stresses on A and B sides (Fig.3) of rib just below the loaded tooth of G.U of various web thicknesses under the distributed load. It is seen from this figure that the maximum rib stress is almost constant regardless of web thickness.

Figure 11(a), (b) show the deflections in the direction of line of action of a gear tooth computed for G.U₀ and G.U (between ribs) of various web thicknesses for a concentrated normal tip load P = 10 kN. Arrows in this figure indicate the positions of load applications. It is seen from this figure that the maximum

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.10 Relation between maximum rib stresses and web thickness (G.U, distributed load)

tooth deflection increases with a decreasing web thickness. The tooth deflections of $G.U_0$ and $G.U$ are almost equal for the load application at the middle of face width, but for the load application at one end of face width the maximum tooth deflection of $G.U_0$ is larger than that of $G.U$ and this phenomenon becomes more remarkable with a decreasing web thickness. Thus the rib is considered useful to reduce the tooth deflection.

Figure 12(a), (b) show the root stress distributions of $G.U_0$ and $G.U$ (between ribs) of various web thicknesses computed for the maldistributions of loads as given in sec.2.4. It is seen from this figure that the root stress distributions of $G.U_0$ and $G.U$ are almost equal regardless of web thickness for the normal contact (case 0) but fairly different under the maldistribution of loads (case 1, 2). It is seen that the rate of increase in maximum root stress of $G.U$ due to maldistribution of loads is larger compared with the case of $G.U_0$. The maximum root stress of $G.U_0$ decreases with a decreasing web thickness, but that of $G.U$ increases. It may be inferred from this fact that the increase in maximum root stress due to maldistribution of loads can be reduced by adopting a thinner web without ribs.

(a) $G.U_0$ (b) $G.U$ (between ribs)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.11 Effect of web thickness on tooth deflection (concentrated load)

4.3 Effect of web position on root stress distribution of double web gear

Figure 13 shows the computed load and root stress distributions⁽²⁾ of double web gears $G.W$ with $c/b = 0.4, 0.6, 0.8$ (c : web distance, b : face width) for normal contact. The load distributions are almost equal regardless of web distance. The root stress distribution of double web gear with smaller c/b is similar to that of symmetric type of single web gear. In the case of double web gear with larger c/b , the root stress shows the highest value at the ends of face width (just above the webs).

Figure 14 shows the computed root stress distributions of double web gears with $c/b = 0.4, 0.6, 0.8$ under the maldistributions of loads as given in sec. 2.4. In this figure the root stresses are given as the ratios to the mean stress. The root stress distributions in cases 0 and 1 are almost equal regardless of web distance. In case 2, the effect of

(a) $G.U_0$ (b) $G.U$ (between ribs)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.12 Effects of web thickness and maldistribution of loads along face width on root stress distribution (distributed load)

1 MPa = 0.102 kgf/mm², 1 kN = 102 kgf

Fig.13 Effects of web distance on load and root stress distributions (G.W)

△, ▲, ▲: Web positions

1 kN = 102 kgf

Fig.14 Effect of maldistribution of loads along face width on root stress distribution (G.W)

maldistribution of loads on root stress distributions becomes larger with an increasing web distance. It might be recommendable to take the web distance of double web gear as $c/b = 0.6$ and $c/b < 0.6$ for smaller and larger degrees of maldistribution of loads respectively.

5. Conclusions

The main results obtained from this

investigation are summarized as follows.

(1) Both the web and rib stresses are much smaller than the root stress.

(2) The maximum web stresses occur near the boss regardless of web arrangement and those of asymmetric type of single web, symmetric type of single web and double web gears become smaller in the order mentioned. The maximum rib stress occurs near the rim at the rib just below the loaded tooth.

(3) The web stress decreases with an increasing web thickness and the rib stress is almost equal regardless of web thickness.

(4) The rib is considered useful to reduce the tooth deflection.

(5) The effects of web thickness and ribs on the root stress distribution in a symmetric type of single web gear are small under normal contact but very large under maldistribution of loads. A symmetric type of single web gear with thinner web without rib is more effective to compensate for the maldistribution of loads.

(6) The root stress distribution in double web gear with smaller web distance is similar to that in symmetric type of single web gear. In the case of double web gear with larger web distance, the root stress shows the highest value at the ends of face width (just above the webs). The maximum root stress of double web gear increases with an increasing web distance under maldistribution of loads.

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