Tooth contact analysis of spur gears. Part 2- Analysis of modified gears

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Abstract. The misalignment between gears axes or direction deviations of teeth leads accentuate the edge effect, Modified spur gears which localize the initial bearing contact by proper modifications of the lead profile are used to avoid the development of the edge effect. A semi-analytical method was involved to find the contact area, pressures distribution and depth stresses states for the standard gears and gears with modified lead profile. The lead modifications concerned the crowning of the flank surface and the end relieving of the tooth flanks, both being applied to the pinion teeth only.

1 Introduction

The spur and helical involute gears are running in line contact at every instant and therefore they are very sensitive to the misalignment of their axes, elastic deformations or various deviations of parts involved in the power transmission process, which determines transmission errors and pressures concentration at the ends of the contacting lines [1, 2].

Fig. 1. Flank with longitudinal crowned profile.

Fig. 2. Flank with end relief profile.

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The concentrated contacts in gears meshing are no longer of Hertz type [3], and semi-analytical methods (SAMs) have been developed to find the contact area, pressures distribution and depth stresses state [4-7]. For spur and helical gears some techniques as flank crowning Figure 1, or flank end relief Figure 2, are frequently used to modify the initial line contact to a localized bearing contact [1, 2, 8-10].

2 Pinion modification by longitudinal crowning of flank profile

All simulations have considered the same nominal loading and the contact point C in the meshing pole, $\alpha_{c1} = \alpha_{c2} = \alpha_w = 20^\circ$ resulting the Hertzian stress $\sigma_H = 564 \text{ MPa}$, and half-width of Hertzian contact area $b_H = 0.113 \text{ mm}$. Different values for both, the misalignment angle ψ between gears axes and the crowned parameter C_β , have been taken into account.

2.1 Modified spur gears with longitudinal crowned flank profile, case $\psi = 0$

For $C_\beta > 0$ and $\psi = 0$ the contact between the mating teeth is transformed into a point contact type, located evenly along the flank. The contact area is an elongated ellipse with the greater half-axis along the flank. The pressure distribution is a quasi-ellipsoid and no edge effect develops if the value C_β was correlated with the normal load, Figure 3. A higher value for C_β reduces the contact area and considerably increases the maximum pressure.

2.2 Modified spur gears with longitudinal crowned flank profile, case $\psi > 0$

2.2.1 Pressures distribution

When the operating conditions included a misalignment $\psi = 0.5 \text{ min}$, the usage of a rather small value for the lead parameter $C_\beta = 5 \text{ }\mu\text{m}$, led to a skewed pressures distribution with an emerging edge effect and a smaller contact area, Figure 4. The detrimental effect of misalignment is revealed by stress analysis.

Fig. 3. Distributions of pressures and von Mises depth stresses, ($\psi = 0$, and $C_\beta = 5 \text{ }\mu\text{m}$).

Fig. 4. Distributions of pressures and von Mises depth stresses, ($\psi = 0.5 \text{ min.}$, and $C_\beta = 5 \mu\text{m}$).

The maximum value of pressure increased, from $p_{max} = 697 \text{ MPa}$ in middle of the quasi-ellipsoid of pressures, Figure 3, to $p_{max} = 853 \text{ MPa}$ at the edge, Figure 4.

The maximum value of the von Mises stress increased from 389 MPa , Figure 3, to 521 MPa , Figure 4. However, a good correlation of the value for crowning parameter C_β with operating values of misalignment and radial load, assures more favorable distributions for both the contact pressures and von Mises depth stresses.

For a large misalignment, as $\psi = 4 \text{ min.}$, a crowned flank with the parameter $C_\beta = 30 \mu\text{m}$ changed the location for pressures and von Mises stresses distributions Figure 6, but preserved the shape and values provided by the case $C_\beta = 30 \mu\text{m}$ and $\psi = 0 \text{ min.}$

Fig. 5. Distributions of pressures and von Mises depth stresses, ($\psi = 4.0 \text{ min.}$, and $C_\beta = 30 \mu\text{m}$).

3 Flank modification by end relief

The end relief is defined by parameters $b_{I(II)}$ and c , Figure 2, representing the length of the modified flank and end relief of profile, respectively [2]. In this numerical study, the parameter $b_{I(II)}$ was maintained constant, $b_{I(II)} = 0.1 * B$ and the parameter c was variable.

3.1 Modified spur gears by end relief of flank profile, case $\psi = 0$

The contact area is a rectangle with little wider ends, (*dog bone* shape). The pressures distribution is close to an elliptic cylinder distribution and no edge effect develops when the value of parameter c was accurate correlated with the normal load, Figure 6.

Fig. 6. Distributions of pressures and von Mises depth stresses, ($\psi = 0$ min., and $c = 5 \mu\text{m}$).

For operating condition without misalignment between gears axes the longitudinal modification of tooth flank profile by end relief provides smaller values for the maximum pressure in comparison with the values provided by the longitudinal crowning of the tooth flank profile.

3.2 Modified spur gears with end relief of flank profile, case $\psi > 0$

3.2.1 Distribution of pressures

When the operating conditions included a misalignment $\psi = 0.5$ min., the pressures shown a skewed distribution with a slight edge effect, Figure 7.

The harmful effect of misalignment is revealed by stress analysis. When for parameter c the value $c = 5 \mu\text{m}$ was used, the maximum value of pressures increased, from $p_{max} = 633$ MPa, Figure 6, to $p_{max} = 854$ MPa, Figure 7.

Fig. 7. Distributions of pressures and von Mises depth stresses, ($\psi = 0.5 \text{ min.}$, and $c = 5 \text{ }\mu\text{m}$).

The skewed distribution of pressures generates a lop-sided depth distribution of von Mises stresses, with the maximum value in the vicinity of maximum pressure, below the contact surface, Figure 7 and Figure 8.

Fig. 8. Distributions of pressures and von Mises depth stresses, ($\psi = 2 \text{ min.}$, and $c = 15 \text{ }\mu\text{m}$).

3.2.2 Contact areas

When gears operate with a small misalignment, $\psi = 0.5 \text{ min.}$, the contact area is changed from quasi-rectangular shape to a trapezoidal shape, Figure 9a. For greater values of misalignment, the contact area has a triangle shape, the contact length representing only a portion of the flank width, even less than half-width, Figure 9b.

Fig. 9. Contact areas: a - small misalignment, $\psi = 0.5$ min. and small end relief $c = 5 \mu\text{m}$;
b - large misalignment, $\psi = 2$ min. and average value for the end relief $c = 15 \mu\text{m}$.

4 Conclusions

Modified spur gears able to localize the initial bearing contact have been analyzed using the semi-analytical method Non-Hertz presented in part I of the paper.

Spur gears with pinion teeth having a longitudinal crowned flank profile make an ellipsoidal distribution of pressures on an elliptical contact area. These gears have indicated a good capacity to avoid the end edge effect when the operating conditions included the misalignment between gears axes.

For operating conditions without misalignment, the spur gears modified by end relief of flank longitudinal profile generate a pressures distribution close to an elliptic-cylinder and a quasi-rectangular contact area. The presence of misalignment creates a skewed pressures distribution with severe pressures concentrations at one end of the tooth flank.

For given operating conditions, a tooth contact analysis (TCA) is needed to find the optimum values for parameters that define the modified spur gears.

References

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