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Study on Effect of Toothed Rim on Stress in Flexspline

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Abstract The Effect Coefficient of Gear Tooth(ECGT) is an important parameter while the flexspline's fatigue strength is studied. In this paper, the model for researching ECGT is established firstly under several assumptions, then effects of mesh and geometrical parameters on ECGT are analyzed after it is deduced more correctly.

Key words: Harmonic drive, Flexspline strength, Effect coefficient of gear tooth

1 Introduction

Compared to the conventional gear, harmonic drive has the advantages of not only high drive ratio in single stage, high transmission accuracy, compact structure, high torque to weight ratio and low noise, but also the economy, so it has been widely applied in many fields such as the precision engineering, robotic industry, aerospace, etc.

Because the flexspline is the elastic thin shell component which stands for cyclic loading, the life span of harmonic drive is mainly limited by flexspline's fatigue strength. On account of the structure's nonlinear., we have no way to get the precise solutions of the stress and the strain in flexspline. The general process to study the flexspline's fatigue strength is just narrated as the following: Firstly, given the teeth have no effect on the shell, deduce the solutions of stress and strain by applying the bending moments theory of cylindrical shell. Secondly, considering the effect of the teeth on flexspline in solutions, for example, the effect coefficient of tooth and effective stress concentration coefficient, et., generally there are several other parameters that must be included. In this paper, the effect coefficient of tooth is studied.

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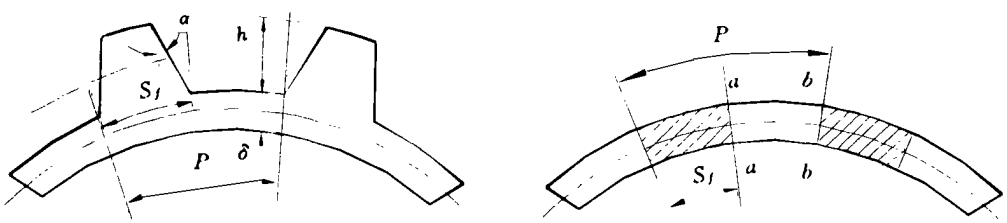
2 Formula of ECGT

The gear teeth influence the stress state of flexspline through the following three route: Tooth root leads to the stress concentration, incontinuous stiffness results in the growth of stress in flexspline, and the addition bending moments will exist on toothed rim if the harmonic drive device suffers a load. The structure of flexspline can be described as an elastic thin shell covered by hundreds of small teeth., as is shown in figure 1(a), h is the tooth height, δ is the rim thickness, α is the pressure angle on pitch circle, and p is the picth, this is a pure nonlinear problem in elastic mechanics, since the difficulty in theory, the precise solution of stress and strain in this type of structure can not be obtained. If the practical formula in engineering may be derived, we must adopt a simplified method with adequate accuracy. in this paper, besides the three Kirchihoff- Love basic hypotheses[1], the following assumptions are also harnessed: The tooth profile is simplified as a trapezium which has the same tooth thickness at pitch circle, as is also shown in figure 1, the bending stiffness of one tooth is uniform distribution within the length of its tooth root thickness S_f, and the thin shell with incontinuous stiffness shown in figure 1(b) is in the pure bending state while a loading is applied.



(a) flexspline with tooth profile simplified (b) scheme of incontinuous stiffness

Fig. 1 Illustration of the flexspline model

Because the bending stiffness of flexspline is incontinuous, the most dangerous points on it exist on the section a-a or section b-b. Applying the conditions mentioned above in linear elastic mechanics theory, the effect coefficient of tooth on the flexspline can be deduced and written as

$$K_t = [1 - k_s(1 - \frac{1}{\sum_I + \sum_{II}}]^{-1} \quad (1)$$

where

$$\sum_I = \zeta^3 + \eta(1 + \zeta + \zeta^2 - 3\zeta^3)$$

$$\sum_{II} = 3(1 - 4\eta)(1 - \zeta^2\zeta^3 + (3\eta + 6\xi)(1 - \zeta^3\zeta^3 \quad (2)$$

$$\eta = \frac{h\tan\alpha}{2k_s p}; \quad \xi = \frac{\delta\tan\alpha}{2k_s p}; \quad \zeta = \frac{\delta}{h + \delta}; \quad k_s = \frac{S_f}{p}$$

As we know, the inertia moment of simplified flexspline tooth must be converted to the neutral circle of flexspline, however, it is converted to flexspline reference circle in literature[2,3], this method led to only $\sum_I$ is contained in formula (1) and twenty percent error in value approximately.

3 Effects of mesh and geometrical parameters on ECGT

In above equations, k_s is the tooth root thickness to pitch ratio, $\sum_I$ and $\sum_{II}$ are the functions of the ratio of tooth height and rim thickness(RTHRT), teeth numbers(TN), and modification coefficient of flexspline(MCF), thus, the effect coefficient of gear tooth (ECGT) relies on the three parameters mentioned above. By numerical method, the dependence of K_t on tooth height to rim thickness ratio and on modification coefficient is shown in figure 2 and figure 3 respectively.

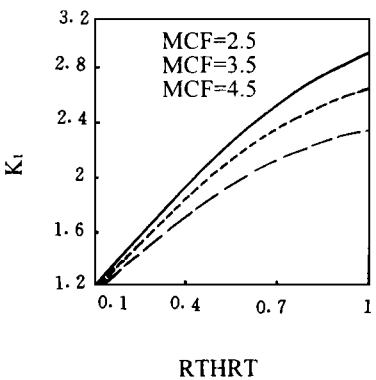


Fig. 2 Kt-RTHRT curves

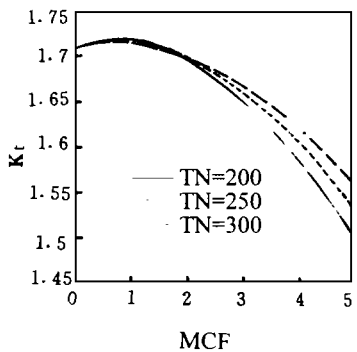


Fig. 3 Kt-modification coefficient curves

As can be seen in figure 2 and figure 3, the increase of RTHRT and TN will result in the increase of stress in flexspline, but the increase of MCF will decrease the stress in flexspline, the numerical results show that the RTHRT is the most effective parameter leading to the growth of stress, RTHRT doubled will lead to a growth of 25% in stress at least, but the greatest growth of stress, to which is led by the variance of TN from 100 to 500 will less than 5%, and MCF's increase from 1 to 4 has the result of decrease in stress, which is not more than 10%.

4 Conclusion

In this paper, the more correct equation of effect coefficient of gear tooth(ECGT) is obtained under several assumptions, the research results show that the most important factor which leads to the stress growth is the ratio of tooth height and rim thickness. The variance of tooth numbers has a little contribution to ECGT, and this kind of stress growth can easily be compensated by adopting an suitable modification coefficient of flexspline between one and four. If we assume that two set of harmonic drive devices have same drive ratio, same rim thickness, same wave numbers of wave generator, and same reference circle diameter, owing to the difference of gear tooth size, that is, the RTHRT in one device is approximately twice times of it in the other one, the impact of gear tooth on the flexspline in former device is reduced and accordingly, the fatigue strength of this flexspline is improved and the life span of the transmission device is lengthened.

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柔轮齿圈对其应力影响的研究

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摘要 轮齿影响系数(ECGT)是研究柔轮疲劳寿命时一个非常重要的参数。本文首先在几个假设的基础上建立了研究轮齿影响系数的数学模型,较为准确地推导出计算轮齿影响系数的数学公式,详细分析了啮合参数和几何参数对该系数的影响。

关键词 谐波传动 柔轮强度 轮齿影响系数

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