Parametric Design and Finite Element Analysis of Involute Helical Gears

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Abstract. The establishing for involute helical cylindrical gear and involute helical bevel gear were completed based on Pro/E. The simulation for assembly and operation was also accomplished for them.The modal analysis, static analysis and the dynamic contact transient analysis for the involute helical gears were finished by using ANSYS. The statics analysis results showed that on the premise of the same load the equivalent stress of involute spiral bevel gear and other principal stress were larger than involute helical cylindrical gear. The dynamic contact analysis showed that the involute helical gear tooth surface contact stress in the meshing process gradually became larger and then gradually became smaller. The contact stress distribution was mainly concentrated in the ends of the gear, so we should pay attention in the design and use.

Introduction

Involute helical gear helical gear transmission is stable. Its impact and vibration are small. It is suitable for high speed, heavy load transmission, widely used in production and life [1-2]. However, with the development of mechanical discipline, gear has the development of heavy load and high speed, low noise, high reliability. Modern gear design of the gear transmission system's static and dynamic characteristics put forward to higher requirements, some scholars of home and abroad do some research on modeling and grinding of involute helical gears forming [3-5]. In order to study the involute helical gear better, using a method of parametric design of involute helical gear based on Pro/E [6], the rapid establishment of involute helical cylindrical gears and the involute spiral bevel gear model. Then the ANSYS software is used to analyze the mechanical characteristics of the two kinds of gear models, and provide a reference for the design and application of the involute helical gears.

Parameter equation of involute helical gears

Parameter equation of involute

In Pro/E, the parameter equation of involute in Descartes coordinate system is:

$R_0 = \frac{db}{2}$ / * Circle radius of involute helical gear * / (1)

$theta = t \cdot 45$/* Cylindrical coordinate angle */ (2)

$X = \frac{R_0 \cdot \cos(theta) + R_0 \cdot \sin(theta) \cdot theta \cdot pi}{180}$ /* X coordinate value of Descartes coordinate system */ (3)

$Y = \frac{R_0 \cdot \sin(theta) - R_0 \cdot \cos(theta) \cdot theta \cdot pi}{180}$ /* Y coordinate value of Descartes coordinate system */ (4)

$Z = 0$ /* Z coordinate value of Descartes coordinate system */ (5)

The parameter equation of involute in cylindrical coordinate system:

$$R_0 = \frac{db}{2} \tag{6}$$

$$afa = 60 \cdot t \quad \text{/* Parameter variation range */} \tag{7}$$

$$r = \sqrt{(R_0^{\,2} + (pi \cdot R_0 \cdot afa \div 180)^2)} \tag{8}$$

$$theta = afa - a\tan\left(\frac{pi \cdot R_0 \cdot afa}{R_0 \cdot 180}\right) \tag{9}$$

Involute spiral surface tooth surface equation

In Pro/E, the spiral surface equation is:

$$x_1 = R_b \cos(\beta + \alpha + q) + R_b\alpha \sin(\beta + \alpha + q) \quad \text{/β/* Helix angle */} \tag{10}$$

$$y_1 = R_b \sin(\beta + \alpha + q) - R_b\alpha \cos(\beta + \alpha + q) \tag{11}$$

$$z_1 = P \cdot q \tag{12}$$

The normal equation of helix is:

$$n_x = PR_b\alpha \sin(\beta + \alpha + q) \quad \text{/Rb/* Circle radius of involute helical gear */P/* Helical parameters *} \tag{13}$$

$$n_y = -PR_b a \cos(\beta + \alpha + q) \tag{14}$$

$$n_z = R_b^{\,2} a \tag{15}$$

Helix parameter equation

In Pro/E, the Descartes coordinate spiral line parameter equation is:

$$R_0 = \frac{m \cdot t \cdot z}{2} \quad \text{/z/* Gear tooth number */} \tag{16}$$

$$C_0 = \frac{B \cdot \tan(bt)}{R_0 \cdot 180 \cdot pi} \tag{17}$$

$$X = R_0 \cdot \cos(t \cdot C_0) \tag{18}$$

$$Y = R_0 \cdot \sin(t \cdot C_0) \tag{19}$$

$$Z = \frac{R_0 \cdot t \cdot C_0 \cdot pi}{180 \cdot \tan(bt)} \tag{20}$$

Parametric modeling of involute helical gears

Because of the difference of the shape of between involute helical cylindrical gear and involute spiral bevel gear, a few parameters are modified in the modeling process. This model has little effect on the results of finite element analysis.

Based on the data in Table1, the 3D model of involute helical cylindrical gear and involute spiral bevel gear are obtained by modeling in Pro/E.

Table 1 Basic parameters of involute helical gears

Basic parameters of involute helical cylindrical gears			Basic parameters of involute spiral bevel gears		
Name	Value	Explanation	Name	Value	Explanation
m	3	modulus	m	3	modulus
z	20	teeth	z	11	Pinion
PA	20	Pressure angle	Z_ASM	30	Big gear
HAX	1	Addendum coefficient	ALPHA	20	Pressure angle
CX	0.25	Top gap coefficient	B	20	Tooth width
x	0	Coefficient of variation	HAX	1	Addendum coefficient
BT	25	Helix angle	CX	0.25	Top gap coefficient
B	30	Tooth width	x	0	Coefficient of variation
		BETA		40	Helix angle

The helix equation is modified to：

$$R_0 = \frac{db}{2} \tag{21}$$

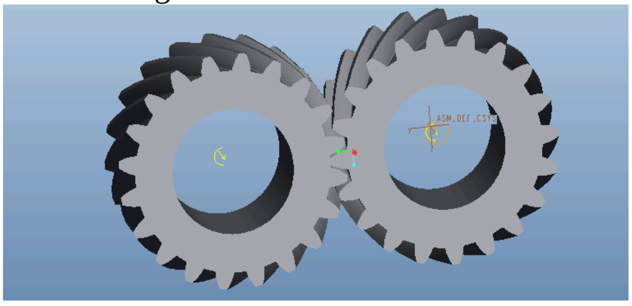
$$C_0 = \frac{B \cdot \tan(bt)}{R_0 \cdot 180 \cdot pi} \tag{22}$$

$$X = R_0 \cdot \cos(t \cdot C_0) \tag{23}$$

$$Y = R_0 \cdot \sin(t \cdot C_0) \tag{24}$$

$$Z = \frac{-R_0 \cdot t \cdot C_0 \cdot pi}{180 \cdot \tan(bt)} \tag{25}$$

In the Pro/E model, another involute helical cylindrical gear is obtained, and then the alignment constraints are added to assemble and run the simulation. Similarly, the simulation model of involute spiral bevel gear assembly is established. The simulation models of two pairs of gear assembly are shown in Fig.1.



（a）involute helical cylindrical gears

（b）involute spiral bevel gears

Fig.1 Meshing simulation of involute helical gears

Finite element analysis of involute helical gears

Modal analysis of involute helical gears

Modal analysis is a modern method to study the structures dynamic characteristics, and the application of system identification method in the field of Engineering Vibration.

Modal analysis of involute helical cylindrical gear and involute spiral bevel gear in ANSYS is carried out. Elastic modulus E=2 * 10^{11}N/m2, Poisson's ratio μ=0.3 and Density ρ=7850kg/m3 are defined and imported model. After the meshing of the involute helical gear, a cylindrical constraint is added. Let the gear run at 75 rad/s, and 6 order modal number are defined. Then the natural frequency of gear within different modes are obtained , as shown in Table2.

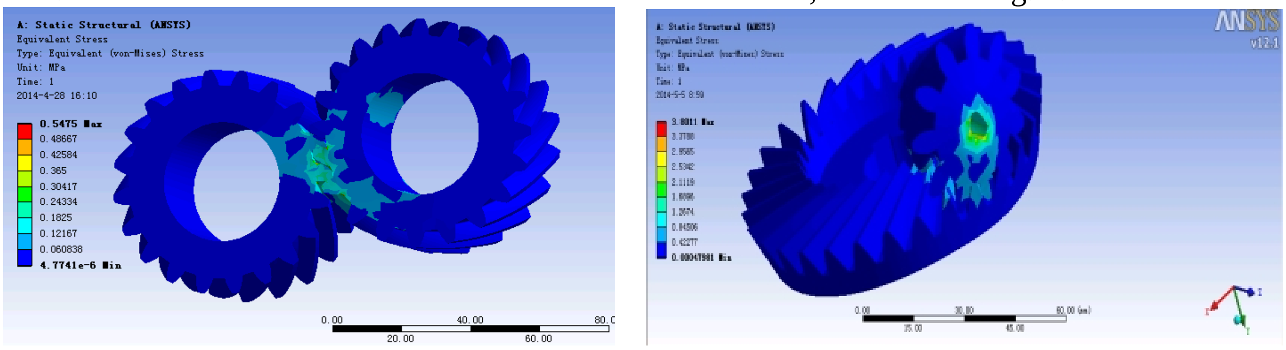
Table 2 Natural frequencies of gears under different modes of involute helical gears

Involute helical cylindrical gear		Involute spiral bevel gear	
Modality	frequency（Hz）	Modality	frequency (Hz)
1	7.85092	1	11.906
2	26120.7	2	22620
3	26121.3	3	29949
4	41506.0	4	33152
5	41520.6	5	36447
6	44513.8	6	38949

Statics analysis of involute helical gears

It is very necessary and important to study the gear static characteristics and optimize its design, which can save materials, reduce cost, shorten development cycle, improve the gear performance life and work efficiency[7-8].

Elastic modulus E=2 * 10^{11}N/m2, Poisson's ratio μ=0.3, and density ρ=7850kg/m3 defined in the static analysis module of ANSYS, are imported into two assembled gears. the two-gear tooth and alveolar contact with surface-to-surface. When we add constraint, one gear is fixed, another gear is added a cylindrical constraint, and then a 1000N·mm torque is exerted on the gear rotating around the axis. The stress distributions of the static contact are calculated, as shown in Fig. 2.



（a）involute helical cylindrical gears （b）involute spiral bevel gears

Fig. 2 Distribution of equivalent stress of involute helical gears

According to the involute helical cylindrical gear and involute spiral bevel gear static comparative analysis, we can see that under the same load the equivalent stress of involute spiral bevel gear and other principal stress are higher than the involute helical cylindrical gear.

Dynamic contact transient analysis of involute helical cylindrical gears

Gear dynamic contact analysis reflects better actual-work conditions, because involute spiral bevel gears and the involute helical cylindrical gear belong to the same class of involute helical gear, and their dynamic contact movement are roughly the same. Based on the above reasons, we only analyze the involute helical cylindrical gear dynamic contact transient .

After importing the gears into ANSYS software, when a constraint is applied, a rotation speed is applied to a gear to rotate around the center axis of the gear, and it uniformly increase with the size of 15 rad/s. And another gear is exerted a load torque whose size is 1 * 105N·mm, direction is opposite to the above gear rotation direction. The distribution figure of the stress in the dynamic contact engineering can be obtained by solving the gear stress distribution. In order to observe intuitively the gear stress change, the maximum stress distribution of the gear meshing cycle can be obtained, as shown in Fig. 3. At the beginning of meshing, the maximum contact stress is 242.38Mpa, and the maximum contact stress is concentrated on inside of alveolar medial. After turning an angle at the time of 0.05s, the contact point has been moved, and the gear begins the formal meshing.Then the maximum stress is 188.86Mpa. At the time of 0.065s, when a tooth of the gear completely gets out of meshing and the next tooth just begins contact, at this moment the gear contact stress reaches the maximum value of 355Mpa during whole meshing cycle. At the time of 0.1s, the gear begins begin to enter into the next meshing, and the maximum contact stress is 178.92Mpa.

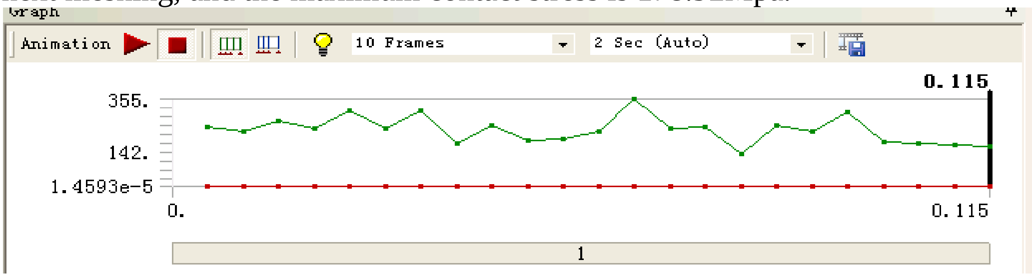


Fig.3 The maximum stress distribution of gear meshing period

In Fig. 4, we can see that the distribution of contact stress is mainly concentrated on both ends of two gears, which suggests that these areas are easy to be worn and broken, so that there are certain requirement limitations on materials .

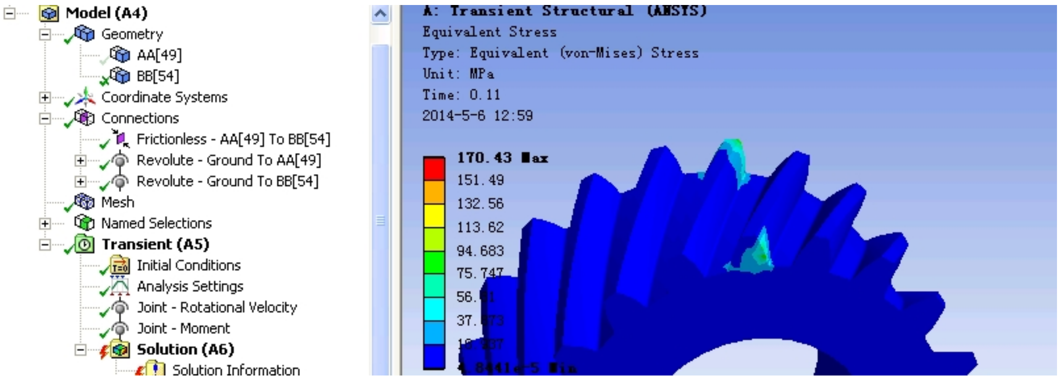


Fig.4 Stress concentration distribution of involute helical gear

Calculation of contact stress of gears based on Hertz formula [9]

$$\sigma_H=\sqrt{\frac{1}{\pi(\frac{1\mu_1^2}{E_1}+\frac{1\mu_2^2}{E_2})}}\sqrt{\frac{2}{\cos^2\alpha\tan\alpha}}Z_E\times\sqrt{\frac{2KT_1}{bd_1^2}\times\frac{u+1}{u}}=328Mpa \quad (26)$$

The maximum gears stress calculated in ANSYS is close to σ_H, and the difference between them is not more than 5%, so the error range is within the allowable range. It can be seen from Fig. 4 that The results of finite element analysis are closer to the actual situation.

Conclusions

（1）The 3D parametric models of involute helical cylindrical gear and involute spiral bevel gear are constructed Based on the Pro/E platform,. Through the modal analysis of the model, the natural frequency of the gear under different models is obtained, which provides the parameter basis for the use of the involute helical gear in different working conditions.

（2）The static analysis of involute helical cylindrical gear and involute spiral bevel gear is carried out. The results show that the equivalent stress and other principal stress of involute spiral bevel gear are greater than involute helical gear under the same load.

（3）Through the dynamic contact analysis of involute helical gear and involute helical gear stress concentration distribution, on the one hand, it can be found that the maximum involute helical cylindrical gear contact stress in meshing process gradually became larger and then gradually became smaller, which reflects the distribution of stress distribution in addition to the maximum contact stress. On the other hand, the distribution of contact stress is mainly concentrated on both ends of the gear, and these areas are easy to be worn and broken, so there must be certain requirement limitations on materials.

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