Elliptical Gear Dynamic Analysis Based on ANSYS Workbench

Jian Zhang[1], Peng Rao[1], Bin Zheng[1] and Xuemei Qi[1]
1School of Transportation and Automobile Engineering, Panzhihua University, China

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Abstract: Aiming at the problem of 3D parametric modeling and dynamic analysis of elliptical gears, an elliptical gear was taken as the object of study, and the three - dimensional parametric modeling of elliptical gear was realized by combining MATLAB parametric design and Pro/E entity. Through the modal, harmonic response and transient dynamics analysis of the elliptical gear by using ANSYS, the first six natural frequencies of the elliptical gears and the distribution modes of the main modes and corresponding displacement response curves, strain cloud maps and stress response curves were obtained. The results of dynamic analysis show that the elliptical gear stress and deformation are more serious suffered in the direction of long diameter, keyway direction and keyway, so it should be considered in the design and optimization of elliptical gear.

1 INTRODUCTION

Elliptic-gear pitch curve is irregular, therefore it is quite difficult to determine each-tooth direction and position, which greatly increases the difficulty of modeling 3D and reduces the efficiency and precision [1]. Study on kinematics characteristics of mechanical movement parts gets vibration characteristic through modal analysis to provide fundamental analysis data for harmonic response, transient dynamics, which judges the rationality of gear pair design and weak position, provides reference for optimal design, for example, elliptical gears pair[2-3]. With unique non-linear dynamic characteristics, elliptical-gears dynamic analysis is more complex compared to circular gears [4-8].

In order to improve the modeling accuracy and efficiency of elliptical gears, parameterized hybrid modeling of MATLAB and Pro/E was used. Modal, harmonic response and transient dynamics analysis were analyzed by using ANSYS Workbench. Then the dynamics parameters distribution regularities were obtained, and found out the elliptic gear stress concentration and easily damaged parts to provide reference for elliptical gear and other non-circular gear design and optimization.

2 ELLIPTIC GEAR MODELING

Table 1: The elliptic gear basic parameters.

Gear parameters	Value
Order n_1	2
Eccentricity e_1	0.6
Number of teeth Z_2	45
Breadth tooth b(mm)	14
Addendum coefficient	1
Root clearance coefficient c	0.25
Modulus m(mm)	3
Angle of pressure α(°)	20

Elliptic gear design flow chart is shown in Fig 1.

According to the Fig1, 2 order elliptical solid model is established by using MATLAB and Pro/E, as shown in Fig 2, and its basic parameters are shown in Table 1.

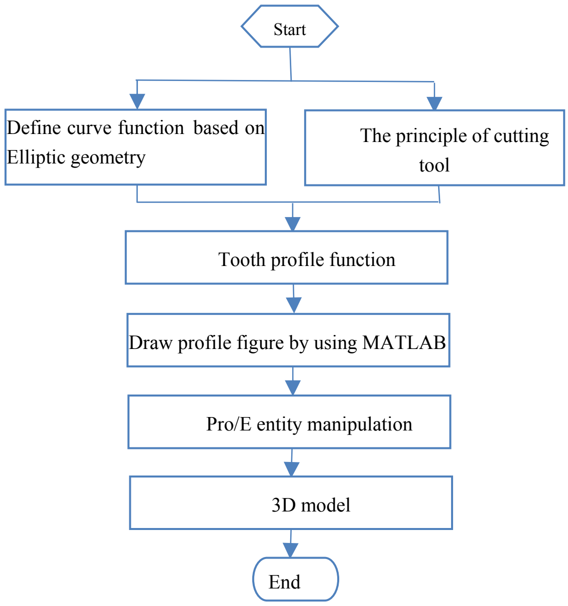


Figure 1: Elliptic gear design flow chart.

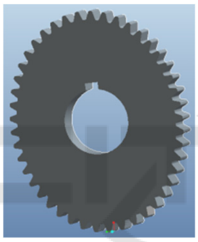


Figure 2: Elliptic gear model

3 MODAL ANALYSIS

3.1 Modal Analysis Theory

Modal analysis, that is, free vibration analysis and a modern method for studying the structures dynamic characteristics, which can be used to determine natural frequencies, vibration mode and vibration mode participation coefficient, which is how much extents some vibration mode participates in vibrating in a certain direction.

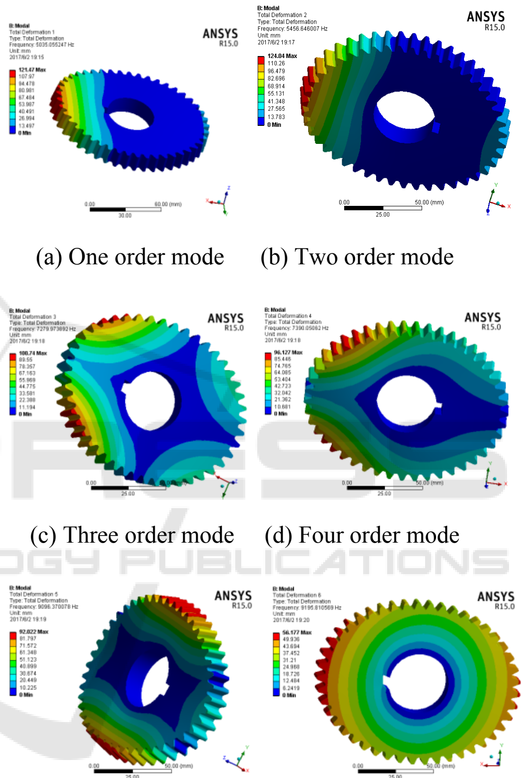
For modal analysis, the analytical formula is:

$$([K] - \omega_i^2[M])\{\phi_i\} = 0 \tag{1}$$

In formula (1), φi is modal; ωi is vibration frequency; K is stiffness matrices; M is mass matrix.

Elliptical-gear natural frequency and each order vibration mode are infinite, while each natural frequency and corresponding main vibration modes represent the free vibration modal of a single freedom system. This modal is non-circular gear basic vibration characteristics which plays a decisive role in low order mode. Therefore, it is only necessary to analyze the modal vibration of elliptical gears under low order natural frequencies when we perform modal analysis.

3.2 Modal Result Analysis and Evaluation



(a) One order mode (b) Two order mode

(c) Three order mode (d) Four order mode

(e) Five order mode (f) Six order mode

Figure 3: Modal vibration modes

The material of the two order elliptical gear is 45 steel, the mesh cell size is 10mm, torque is 105 N•m, the phase angle is 0. Through modal analysis for inner hole constrain conditions, six vibration modes and their natural frequencies are shown as Fig 3.

Below the graphics window of “Mechanical”, natural frequencies of the models can be obtained, as shown in Table2.

Table 2: Elliptical-gear natural frequency.

Mode	Frequency [Hz]
1	5035.1
2	5456.6
3	7280
4	7390.1
5	9096.4
6	9195.8

According to Figure 3 and Table II, elliptical-gear one order frequency is 5035.1Hz. The main deformation is that X-axis positive direction teeth tension and bend along the Z axis. The two order frequency is 5456.6 Hz, the main deformation and one order deformation are axisymmetric about the Z axis. The three order frequency is 7280Hz, the main deformation is left and right teeth X-axis positive direction stretch and bending along respectively Z-axis positive and negative direction； The four frequency is 7390.1 Hz，the main deformation is that left and right teeth of X-axis negative direction stretch and bending respectively along Z-axis positive and negative direction; The five frequency is 9096.4Hz， the main deformation is Y-axis direction teeth symmetrically stretched and bending along Z axis；The six frequency is 9195.8 Hz， the main deformation is that the teeth in the long half axle stretch along the angle between the X axis and the Y axis. The reason is that the vibration frequency generated by external excitation is close to elliptical-gear natural frequency, initiating resonance. Therefore， we should manage to avoid this frequency range during design to improve gear life span.

4 HARMONIC RESPONSE ANALYSIS

4.1 Harmonic Response Analysis Theory

Harmonic response analysis is a technique used to determine the steady-state response of linear structures bearing load varying with time in accordance with the sinusoidal (harmonic) rule. The purpose of the analysis is to calculate response of structure at several frequencies and obtain some response values (usually displacements) corresponding frequency curves.

The equation of motion of harmonic response is：

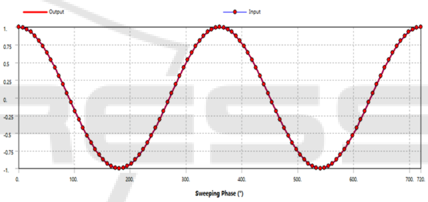
$$\left(-\omega^2[M]+i\omega[C]+[K]\right)\left(\{\phi_1\}+i\{\phi_2\}\right)=\left(\{F_1\}+i\{F_2\}\right) \quad (2)$$

Setting up the stiffness matrices[K] and mass matrix [M] are constant values, and the material is linear, using small displacement theory (not including non-linearity), damping is[C], and harmonic loading is[F].

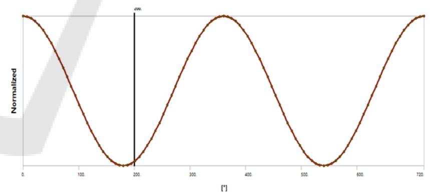
Harmonic response analysis aims to calculating the response at the excitation frequency and obtaining the frequency response curves. Gear "peak" response can be found through the curve.

4.2 Harmonic Response Analysis and Evaluation

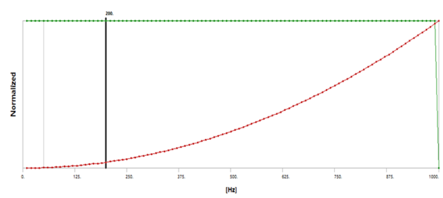
The material of the two order elliptical gear is 45 steel, the mesh cell size is 10mm, torque is 105 N•m, the phase angle is 0. The harmonic-response analysis for gear inner hole conditions, we get the gear unit of each order response angle and deformation，gear unit each order frequency and phase angle，the gear node change curve with frequency and displacement response cloud map are shown as Fig 4.



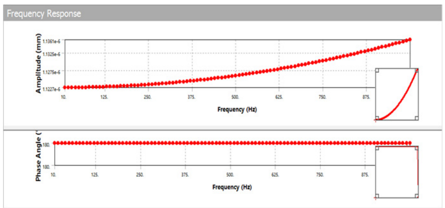
(a) Each order response angle of gear unit



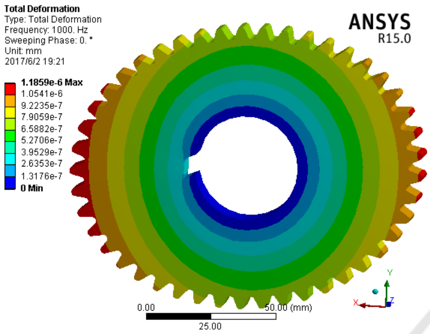
（b）Each order deformation curve gear unit



（c）Response frequency curve of gear unit



（d）Gear node change curves with frequency



（e）Displacement response cloud chart

Figure 4: Harmonic response analysis result

According to （a）， （b）, the elliptical gear unit each order response angles and deformations follow harmonic response equation, whose period, input and output are same. According to（c）, with the increase of input frequency, each order response frequency also increase, the phase angle remains 180°, but it changes suddenly and sharply reduced to zero near to the final value. According to （d）， gear node response frequency curve and phase angle change with frequency, and unit each order response frequency and phase angle change with frequency are the same. According to （e）, gear long axis direction displacement is larger, especially the keyway direction. We can infer that, in actual movement, elliptical-gear stress mainly concentrates on keyway direction and the part where the radius of curvature is longer. Thus, this part is more vulnerable to damage. This part should strengthen when processing.

5 TRANSIENT DYNAMIC ANALYSIS

5.1 Transient Dynamic Analysis Theory

Transient dynamic analysis (also called time history analysis) can be used to determine the dynamic response while structures are subjected to arbitrarily varying loads. Non-circular gears transient dynamics can determine gear's displacement, strain, stress and force vary with time under the random combination action of steady state load, transient load and harmonic load.

The basic motion equation of transient dynamics is：

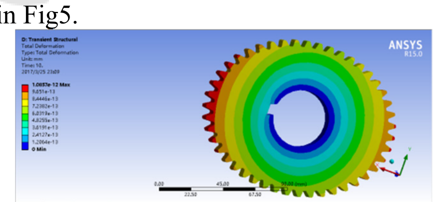
$$M\ddot{u} + C\dot{u} + Ku = F(t) \qquad (2)$$

In formula (3)， M is mass matrix； C is damping matrix； K is stiffness matrices； $\ddot{u}$ is Nodal acceleration vector； $\dot{u}$ is Nodal velocity vector； u is Node displacement vector.

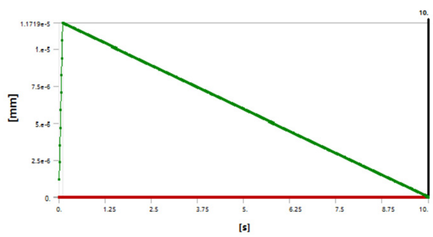
In order to analyze whether two order elliptical gear can bear low speed impact, some questions such as vibration response caused by gear over convex point need to do transient dynamics analysis.

5.2 Analysis and Evaluation of Transient Dynamics Results

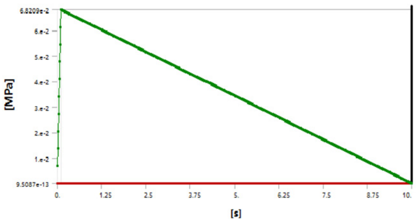
The material of the two order elliptical gear is 45 steel, and the mesh cell size is 10mm, torque is 105 N •m, the phase angle is 0. The harmonic-response analysis for gear inner hole condition， we get elliptical gear displacement and stress changes are shown in Fig5.



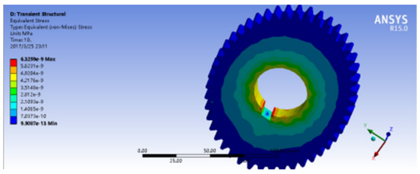
（a）Deformation analysis cloud map



（b）Displacement response curve



（c） Stress response curve



（d） Stress cloud map

Figure 5: Transient dynamic analysis result

According to （a）， the gear long axis deformation is bigger, especially the keyway direction. We can infer that, in actual movement, elliptical gear longer-pitch-diameter parts and keyway direction are much more vulnerable to damage. According to 5（b）and（c）, elliptical gear displacement and stress change synchronously with time, the mutation at the starting point increases sharply, and decreases with the passage of time. According to（d）, in actual movement, gear bore diameter and shaft outer diameter interference fit through. Bore diameter bear torque delivered by shaft and produce stress. Because of the stress concentration produced by the keyway, there is more vulnerable to damage.

6 CONCLUSIONS

First, through modal analysis the first six nature frequencies and principal vibration mode are obtained by using ANSYS Workbench. The vibration frequency produced by external excitation is close to the nature frequency, which is vulnerable to cause resonance. So, we manage to avoid this frequency range during then design. Second, through harmonic response analysis, pitch response frequency curve and displacement response cloud maps are obtained whose results show that stress is mainly concentrates on the long diameter and keyway direction. Therefore, this part is vulnerable to damage. Finally, through transient dynamics analysis, deformation and strain cloud maps and displacement and stress response curves are obtained. Elliptical gear stress and deformation are more serious suffered in the direction of long diameter, keyway direction and keyway, so it should be considered in the design and optimization of elliptical gear.

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