Elliptical Gear Dynamic Analysis Based on ANSYS Workbench

Jian Zhang¹, Peng Rao¹, Bin Zheng¹ and Xuemei Qi¹

¹School of Transportation and Automobile Engineering, Panzhihua University, China

Keywords: Elliptical gear; parametric modelling; dynamics; Pro/E; ANSYS.

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].

Elliptical 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.

2 ELLIPTIC GEAR MODELING

Table 1: The elliptic gear basic parameters.

<table>
<thead>
<tr>
<th>Gear parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order n</td>
<td>2</td>
</tr>
<tr>
<td>Eccentricity e₁</td>
<td>0.6</td>
</tr>
<tr>
<td>Number of teeth Z₂</td>
<td>45</td>
</tr>
<tr>
<td>Breadth tooth b(mm)</td>
<td>14</td>
</tr>
<tr>
<td>Addendum coefficient</td>
<td>1</td>
</tr>
<tr>
<td>Root clearance coefficient c</td>
<td>0.25</td>
</tr>
<tr>
<td>Modulus m(mm)</td>
<td>3</td>
</tr>
<tr>
<td>Angle of pressure α(°)</td>
<td>20</td>
</tr>
</tbody>
</table>

Elliptical 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.
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:

\[
[K] - \omega^2 [M] \phi_i = 0
\]  

In formula (1), \(\phi_i\) is modal; \(\omega_i\) 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

![Modal vibration modes](image)

The material of the two order elliptical gear is 45 steel, the mesh cell size is 10mm, torque is 105 N\(\cdot\)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.
### 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:

\[ (-\omega^2 [u] + i\omega [c] + [K][\phi] + i\omega[C]) = ([f_c] + i[f_i]) \]  \hspace{1cm} (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 node change curve with frequency and displacement response cloud map are shown as Fig 4.
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:

\[
M \ddot{u} + C \dot{u} + K u = F(t)
\]  

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
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.

ACKNOWLEDGMENT

This work was financially supported by the Education Department of Sichuan province in 2016 scientific research program of natural science project (16ZB0482) and the national innovation training program for college students (201411360016).

REFERENCES