EFFECT OF CONTACT LOAD ON THE BENDING DEFLECTION OF GLOBOIDAL CAM PROFILE WITH ROLLER FOLLOWER MECHANISM
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Abstract:
A globoidal cam and roller follower mechanism were discussed and analyzed for dynamic response of the follower and bending deflection of the cam profile. The theory of circular plate was applied to derive the analytic solution of the bending deflection. The dynamic response of the follower had been determined by using SolidWorks software based on the contact parameters. The experimental setup was done through an infrared camera device. Finite element analysis was used to calculate the bending deflection of the cam profile numerically. Finite element analysis was carried out by using ANSYS Ver. 19.2.
Motivation and Application:
Bending deflection and contact load problems are in many engineering applications:

Figure (1)
Challenges:

- Measuring the bending deflection at the point of contact experimentally based on the tension and compression in cam profile.
- Finding a suitable Hertzian contact theory is important.
- Measuring the maximum contact load at the point of contact experimentally at high speeds.
- Material selection. Most of the materials deform plastically. More advanced contact model are needed.

Contact Models:

- In numerical simulation, the globoidal cam and roller follower were assumed to be a parallel cylinders. The area of contact was assumed to be a semi-ellipsoid with a rectangular contact zone of a half width (b) and length (L).
- In analytic solution, the contact was assume to be a volume of a small elliptical region (Contact between two curved surfaces).
- Smoothness contact was assumed in which the surface roughness was enough to be disregarded and the contact was fully flooded.
- The cam was partially immersed in oil to get rid of the temperature effect.
Analytic Study:
Nonlinear Dynamics Response of the Follower:

\[ x_C(t) = e^{-\beta t} \left[ \frac{\Omega X_{st} \left( \frac{\omega^2}{\omega^2 - \beta^2} + \frac{2\beta^2}{\omega^2} - 1 \right)}{H \sqrt{\omega^2 - \beta^2}} \sin(\sqrt{\omega^2 - \beta^2}t) + \frac{2X_{st} \beta \Omega}{H\omega^2} \cos(\sqrt{\omega^2 - \beta^2}t) \right] + \frac{X_{st}}{H} \left[ 1 - \left( \frac{\Omega^2}{\omega^2} \right) \right] \sin(\Omega t) - \frac{X_{st}}{H} \frac{2\beta \Omega}{\omega^2} \cos(\Omega t) \]

Where:

\[ X_{st} = \frac{F}{\omega^2}, \quad H = \left[ 1 - \left( \frac{\Omega^2}{\omega^2} \right) \right]^2 + \frac{4\beta^2 \Omega^2}{\omega^2}, \quad \frac{C_g}{w} = 2\beta, \quad \frac{k_g}{w} = \omega^2, \quad F = \frac{P}{g} \]

\[ P = k_1(\Delta + x(t)) - kx(t) - c\dot{x}(t) - \frac{w}{g} \dot{x}(t) \]

Contact Load:

\[ P_0 = \frac{3P}{2\pi a_1 b_1} \]

Where:

\[ a_1 = a_1 \left( \frac{3P}{4A_1} \right)^{1/3} \], \[ b_1 = b_1 \left( \frac{3P}{4A_1} \right)^{1/3} \]

\[ A_1 = 0.5 \left[ \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_2} + \frac{1}{K_3} \right] \]

\[ B_1 = 0.5 \left[ (\frac{1}{K_1} - \frac{1}{K_1})^2 + (\frac{1}{K_2} - \frac{1}{K_2})^2 + 2(\frac{1}{K_1} - \frac{1}{K_1})(\frac{1}{K_2} - \frac{1}{K_2}) \right] \cos(2\psi) \]

\[ \Delta_1 = \frac{1}{K_1} (1 - \psi^2) + \frac{1}{K_2} (1 - \psi^2) \]

\[ \psi = \tan^{-1} \left( \frac{x(t)}{x(t) + \sqrt{K_1}} \right) \]
General equation of circular plate:

\[
\frac{\partial^4 w}{\partial r^4} + \frac{2}{r} \frac{\partial^3 w}{\partial r^3} - \frac{1}{r^2} \frac{\partial^2 w}{\partial r^2} + \frac{1}{r^3} \frac{\partial w}{\partial r} + \frac{2}{r^2} \frac{\partial^4 w}{\partial r^2 \partial \theta^2} - \frac{2}{r^3} \frac{\partial^3 w}{\partial r \partial \theta^2} + \frac{4}{r^4} \frac{\partial^2 w}{\partial \theta^2} + \frac{1}{r^4} \frac{\partial^4 w}{\partial \theta^4} + \frac{\rho}{D} \frac{\partial^2 w}{\partial t^2} = \frac{P_o}{D}
\]

\[w(r, \theta, t)_H = [A \sin(r\theta) + B \cos(r\theta)] \sin(\omega_n t)\]

\[w(r, \theta, t)_P = C r \theta \sin(\Omega t), \quad t_1 = \frac{\theta_P}{\Omega}\]

\[At(r = r_1), (\theta = \theta_P), t = t_1, w(r, \theta, t) = 0\]

\[At(r = r_1), (\theta = \theta_P), t = t_1, \frac{\partial w(r, \theta, t)}{\partial r} = 0\]

\[w(r, \theta, t) = \left(-\frac{P_o R_P^3}{\theta_P D} + \frac{\rho \Omega^2 R_P^3}{\theta_P D}\right) \sin(\Omega t_1) \sin(\omega_n t_1)\]

\[+ \left(-r_1 \theta_P \sin(r_1 \theta_P) \sin(r \theta) - \cos(r_1 \theta_P) \sin(r \theta) + \sin(r_1 \theta_P) \cos(r \theta) - \theta_P \cos(r_1 \theta_P) \cos(r \theta)\right)\]

\[\sin(\omega_n t_1) + \left[\frac{P_o R_P^3}{\theta_P D} + \frac{\rho \Omega^2 R_P^3}{\theta_P D}\right] r \theta \sin(\Omega t)\]
Experimental Study:

Setup:
The setup must have the followings;

• Manufacturing of globoidal cam, roller follower and the two guides by using 3D printing filament technique.
• Brush-less motor to control the cam motion.
• Optical sensor or marker to track the follower motion.
• OPTOTRAK / 3020 with three lenses to transfer the follower signal through a hardware-software control unit.
• Follower positions was saved as an excel sheet.
• An elastic spring with known design specifications to keep the two mechanical part in permanent contact.

Figure (4)
Figure (5)
Numerical Study:

- ANSYS Package is used to calculate the bending deflection of cam profile.
- SolidWorks Software is used to simulate the basic kinematic relations of dynamic response of the follower (Displacement, Velocity and Acceleration).
- Element (PLANE 42) to create the mesh generation of finite element analysis.
- In contact analysis, element (TARGE 170) and element (CONTA 174) were used to create the contact between the globoidal cam and the roller follower.
- Cam represents the source while the follower was the target.
- Mesh convergence test is used to determine the size of elements in finite element analysis.
- Two types of analysis, including modal and harmonic analysis were performed to find the natural frequency and bending deflection respectively.

![Figure (6)](image6)
![Figure (7)](image7)
![Figure (8)](image8)
In this study, the profile of globoidal cam was divided into three tracks at the point of contact.
Path no.(1): nose(1), flank(1), and nose(2)
Path no.(2): flank(2), and nose(1)
Path no.(3): nose(2) and flank(3)

Comparison:

Figure (9)

Figure (10)

Figure (11)
Conclusion:

Spring-damper system had been added at the end of follower stem to reduce the bending deflection at the point of contact. Nonlinear dynamic response of the follower were checked and verified analytically, numerically, and experimentally. Two types of analysis, including modal and harmonic were performed to determine the natural frequency and bending deflection.

The reduction rate for bending deflection was (73.42%) for path no.(1), (85.92 %) for path no.(2), and (61.46 %) for path no.(3). The reduction rate for contact load was (27.68 %) for path no.(1), (34.61%) for path no.(2), and (38.08 %) for path no.(3).
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