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Dynamics analysis of a crowned gear transmission system with impact damping: Based on experimental transmission error

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ABSTRACT

The impact characteristics of a crowned gear transmission system are investigated with experimental static transmission error (TE) and backlash. The effects of load, input speed and impact force exponent coefficient n on the dynamic characteristic of system are investigated. The numerical simulations show that the static TE can be combined with a backlash parameter. Under low speed conditions, the dynamic load is mainly connected with the high frequency component of TE, which can be effectively suppressed with the increase of tooth surface accuracy and the improvement of tooth profile error and roughness. Under high speed conditions, the shaft frequency component of TE has a dominate influence on dynamic load in the resonance area. Parameter n is decreasing and the dynamic load coefficient is increasing especially in the resonance area. When n is 1.0, a loss contact impact area exists in the system and the amplitudes of shaft frequency component in dynamic TE are almost equal, which indicates that dynamic characteristics are little affected by load and parameter n when there is no loss contact. It proves that the nonlinear impact model is sufficient to study the rattling process of gear pairs.

1. Introduction

Nonlinear dynamic behaviors, with respect to noise and vibration, have been the subject of numerous investigations in recent decades. There is a large amount of literature on gear dynamic models [1,2]. When backlash is considered, the gear pair system is a strong nonlinear system and it can be modeled as a piecewise smooth system. Generally, this type of system can be classified as a vibro-impact system. In recent years, many researchers have been devoted to this issue such as Ibrahim [1], di Bernardo et al. [2] and Stronge [3]. As for the vibro-impact induced by gear backlash, Pfeiffer [4–8], Luo [9–11], Singh and Kahraman [12–14] and Natsiavas et al. [15–17] have conducted relevant studies.

As noted in literature [18–20] that "the mechanism of impact damping in impact system should be investigated precisely to analyze the effect of impact damping". To understand the effect of impact damping on the characteristics of system vibration, the dynamic characteristics of damping system should be exhibited quantitatively and comprehensively. The investigation of impact damping in gear tooth system is preliminary and the issue of energy loss during impact was adduced by Azar and Crossley [21], Herbert and McWhannell [22], Smith [23]. On the basis of the issue, Yang and Lin [24,25] adopted a gear impact damping model with stationary stiffness, and the load variation on the effect of system response was addressed.

Subsequently, in 2003 Kim et al. [26] imported an impact model as

$$f(\delta,\dot{\delta}) = \delta(1+\beta\dot{\delta}) \tag{1}$$

to study the effect of impact damping on resonance, harmonic frequency and super-harmonic frequency. However, the investigation of impact damping on the gear tooth was inadequate, mainly for the neglect of geometric factors of gear tooth face.

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Nomenclature

B	half of gear backlash
D	impact damping coefficient
e	the coefficient of restitution
$e_s(t)$	static transmission error
f, F_K, F_D	impact force, elastic force and damping force of impact system
$f(x)$	nonlinear backlash function
F_d	fluctuation of load
F_v	viscous damping force
f_m	meshing frequency
f_{rev}	shaft rotation frequency
h_i (i = 1,2,…,6)	coefficient of ith harmonic components of static transmission error
I_1, I_2	moment of inertia of pinion and gear
K	the mesh stiffness of gear transmission system
$k(t)$, k_{tp}, k_r, k_0	meshing stiffness function, single tooth stiffness, rth coefficients of stiffness and averaged nonlinear meshing stiffness
K_v	gear dynamic load
m	modulus of gear
m_e	equivalent gear mass
n	impact force exponent coefficient
N_1, N_2	line of action
R_{b1}, R_{b2}	basic radii of the pinion and gear
S	difference of pinion and gear in line of action
T_1 ($T_1(t)$), T_2 ($T_2(t)$)	input and output torque of gear transmission system
$v_{\max}$	maximum velocity
z_1	number of gear tooth
σ	coefficient of load fluctuation
ω_n	approximate natural frequency of gear pair
ξ	non-dimension viscous damping coefficient
φ_r	phase of rth stiffness
ϕ_i (i = 1, 2,…,6)	phase of ith harmonic components of static transmission error
β	impact damping coefficient
$\delta, \dot{\delta}, \dot{\delta}^{(-)}$	the local relative penetration, velocity and initial velocity of impact
θ_1, θ_2	angle displacement of pinion and gear
ICR	gear contact ratio
DF	dynamic load coefficient
DMF	dynamic mesh force
DTE	dynamic transmission error
DTE_{ppv}	peak-to-peak values of dynamic transmission error
DTE_{rms}	root-mean-square of dynamic transmission error
SMF	static mesh force
TE	transmission error

Moreover, impact damping coefficient β was location constant and the relationship between impact damping and impact velocity —as well as geometric parameters was neglected. In this paper, on the basis of an impact dynamic model, the effects of impact damping parameters, etc. on the system dynamic are considered for the perspective of nonlinear dynamics.

In this paper, the impact characteristics in gear system with impact damping are investigated, and the experimental static transmission error and backlash are adopted in the theoretical analyses. The crown modification is performed in the pinion teeth surface. The nonlinear impact damping model is adopted. And that the nonlinear exponent n is non-integer indicates the point contact relative to crown modified gear. The following sections of this paper are organized as follows: in the second section, the impact force model, gear transmission model and consideration of static transmission error and backlash are interpreted. Subsequently, systematic consideration is remarked for a direct comparison between numerical results and experimental dynamic transmission error. The effects of load, input shaft velocity, parameter n on the dynamic characteristics of gear transmission system in terms of frequency response and dynamic load are investigated. Finally, a short remark is exhibited in the last section.