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Experimental and simulation investigation of nonlinear dynamic behavior of a polydyne cam and roller follower mechanism

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ABSTRACT

In this study a polydyne cam and a roller follower with different cam rotational speeds are analyzed. The chaos has been investigated based on positive Lyapunov exponent value. The effect of follower guide's clearance on chaos is considered. The contact between cam and follower is simulated by using Solidworks program. The power spectrum of Fast Fourier Transform and phase plane have been examined the follower non-periodicity during follower motion in the y-direction. Rosenstein program is used to calculate largest Lyapunov exponent. The experimental setup has been implemented by using OPTOTRAK/3020 through a 3-D infrared markers to track follower motion. The signal of follower motion in the y-direction has been processed depend upon data acquisition technique. The system with follower guide's clearance C = 2 mm is more chaotic than the others at cam rotational speed N = 800 rpm and N = 1200 rpm. The simulation and experimental results are compared and verified for largest Lyapunov exponent.

1. Introduction

A cam is a mechanical device which is used to transmit motion to the follower. Many attempts have been conducted to study the chaos phenomenon in cam-follower mechanism to keep the cam and follower in permanent contact. The polydyne cam with translated roller follower is proposed in this paper. The considered mechanism is used in automobile valve-gear linkages and textile machine mechanisms. Alzate et al. presented a design of a radial cam and a flat-faced follower taking into account bifurcations and chaos. They observed that the follower detached from the cam depend on the variation of cam rotational speeds, [1,2]. The normal form of bifurcation was derived analytically by means of a discontinuous acceleration of cam profile. Osorio et al. explained the abrupt conversion from periodic attractor to chaos at high rotational speed, [3]. Demeulenaere and Schutter solved a second-order, nonlinear, ordinary differential equation through the solution of finite Fourier series and nonlinear least-square method, [4]. They reduced the fluctuation of drive speed by using the input torque balancing method in cam-follower mechanism, [5]. A Fourier Series with Laplace Transform was used by Bagci and Kurnool to determine the response of follower system. They evaluate the critic cam speed and follower bounce status. One and two degrees of freedom have been considered to describe the disc cam and roller follower mechanism, [6]. Mahyuddin and Midha used Floquet theory of phase-plane diagram to determine the periodic response of cam-follower system as a single-degree-of-freedom. They presented a linear, second-order, ordinary differential equation to define the parametric stability of a cam and the follower, [7,8]. Zhou et al. proposed an exhaustive technique to design a displacement function

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Nomenclature

Δt	discrete time strides, s
λ	Lyapunov exponent
ω_n	natural frequency, rad/s
ψ	cam rotational speed, rpm
$\rho(\theta)$	radius of curvature at the point of contact, mm
θ	angle of contact between cam and the follower, Degree
ζ	damping ratio
$d(t)$	mean euclidean distance or mean divergence between neighboring trajectories in state space at time t
d_0	average displacement between trajectories at t = 0, mm
d_E	embedding dimension
$d_j(i)$	distance between the jth pair at i nearest neighbors, mm
$s(\psi)$	follower displacement at the point of contact, mm
x_c	horizontal coordinate of the point of contact, mm
y_c	vertical coordinate of the point of contact, mm
a	beginning angle of rotation of dwell cam, degree
$x, \dot{x}, \ddot{x}$	follower displacement, velocity, and acceleration, mm, mm/s, mm/s^2
$y, \dot{y}, \ddot{y}$	cam displacement, velocity, and acceleration, mm, mm/s, mm/s^2
z, z_c, z_p	general, complementary, and particular solutions, mm
c	damping coefficient, N/mm/s
k	spring rate or spring constant, N/mm
m	mass or any external force, kg
y(i)	curve fitting of follower linear displacement.

of a disc cam and roller follower by using Fourier series method, [9]. Taborda et al. applied a Fixed-Point Inducting Control technique on a radial cam and flat-faced follower to suppress the chaotic phenomenon. They varied the input speed of a cam-follower system to maintain the motion of periodic-impact and chaos. Stroboscopic and impact maps had been used to select a suitable criterion of a single-impact periodic motion of the follower, [10]. On the other hand Calvo and Osorio built the chaos and bifurcation histogram under the diversity of cam angular speeds,[11]. They used the discontinuity map and Poincare section to identify the nonlinear dynamic. The numerical simulation had been done for multi-impact trajectories by using the rule of Newton's coefficient of restitution, [12]. Moreover Yousuf et al. analyzed the dynamic simulation of a polydyne cam with flat-faced follower. The effect of follower guides' clearances for different cam rotational speeds was investigated, [13]. The largest Lyapunov exponents for the simulated and experimental data were analyzed and selected over a range of cam rotational speeds, [14]. The purpose of the this paper is to quantify the largest Lyapunov exponent based on different follower guides' clearances over a range of speeds. The chaos phenomenon has been studied to keep the cam and the follower in permanent contact. The non-periodicity of roller follower is increased with the increasing of cam rotational speeds and follower guides' clearances. To the best of our knowledge, the influence of follower guide's clearance on chaotic phenomenon of polydyne cam and roller follower has not been studied.

2. Equations of motion for dynamic response

In many applications, the change of θ with respect to time t represents the constant angular velocity ω: ($\frac{d\theta}{dt} = \omega$), [15]. The follower structure has been considered as a single degree-of-freedom system (spring-mass-dashpot system) with mass m, spring constant k, and damping coefficient c, as shown in Fig. 1, [15]. Newton's second law of dynamic motion is used with single-degree-of-freedom showing in Fig. 1, [16], to obtain:

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0 \tag{1}$$

The vibration form of Eq. (1) is:

$$m(\ddot{x} - \ddot{y}) + c(\dot{x} - \dot{y}) + k(x - y) = -m\ddot{y} \tag{2}$$

By substituting $z = x - y$ yields,

$$m\ddot{z} + c\dot{z} + kz = -m\ddot{y} \tag{3}$$

The general solution of Eq. (3) accommodates the complementary and particular solutions. The complementary solution indicate to homogeneous solution as below, [16]:

$$m\ddot{z} + c\dot{z} + kz = 0 \tag{4}$$