Comparison of Nonlinear Dynamic Simulation of Lyapunov Exponent for a Cam and Different Translated Followers with Clearance

By Louay S. Yousuf

Abstract- In this paper, a cam with translated at-faced and roller followers are analyzed. There is a clearance between the follower and the guide. The dynamic simulation is investigated taking into account the nonlinear dynamic of Lyapunov exponent parameter. The simulation has been done by using Solid works program. The effect of follower guides' clearances on follower non-periodicity is considered based on Lyapunov exponent technique. Nonlinear dynamic package is used to calculate largest Lyapunov exponent for different angular velocities of the cam. The power spectrum analysis of Fast Fourier Transform and phase plane contour are examined at-faced and roller followers non-periodicity. The at-faced follower with follower guide's clearance C=2 mm and cam rotational speed N =1200 rpm has more non-periodic motion than roller follower. The values of largest Lyapunov exponent for at-faced follower are bigger than the values of largest Lyapunov exponent for roller follower based on(C=2 mm and N=1200 rpm).

Keywords: nonlinear dynamic comparison, cam-roller follower, lyapunov exponent.

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Abstract - In this paper, a cam with translated at-faced and roller followers are analyzed. There is a clearance between the follower and the guide. The dynamic simulation is investigated taking into account the nonlinear dynamic of Lyapunov exponent parameter. The simulation has been done by using Solid works program. The effect of follower guides’ clearances on follower non-periodicity is considered based on Lyapunov exponent technique. Nonlinear dynamic package is used to calculate largest Lyapunov exponent for different angular velocities of the cam. The power spectrum analysis of Fast Fourier Transform and phase plane contour are examined at-faced and roller followers non-periodicity. The at-faced follower with follower guide’s clearance C=2 mm and cam rotational speed N =1200 rpm has more non-periodic motion than roller follower. The values of largest Lyapunov exponent for at-faced follower are bigger than the values of largest Lyapunov exponent for roller follower based on (C=2 mm and N=1200 rpm).

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I. INTRODUCTION

The cam and follower mechanism is a complex impacting system. The pro-poused cam can be used on motor car camshafts to operate the engine valves. Many researches has been done based on Fast Fourier Transform (FFT) of non-linear 5 dynamic. Bagci and Kurnool [1] presented a Fourier series Laplace transform to end the follower response at any time and at any cycle. They measured the angular speed of the cam speeds and the discontinuities of the follower. Also, Demeenlenaere and Schutter [2] used a finite Fourier series to design an inverted cam mechanism by considering the cam rotational speed. Yousuf et 10 al. analyzed the dynamic simulation of a polydyne cam with at-faced follower. The effect of follower guides’ clearances for different cam rotational speeds was investigated, [3]. The largest Lyapunov exponents for the simulation and experimental data were analyzed and selected over a range of cam rotational speeds,[4].

The power spectrum of Fast Fourier Transform and phase plane have been examined the follower non-periodicity during follower motion in the y-direction.

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He used Rosenstein program to calculate largest Lyapunov exponent, [5, 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 of a disc cam and roller follower by using Fourier series method, [9]. In this paper, the comparison of nonlinear dynamic of Lyapunov exponent is investigated for a cam with different translated follower to maintain the contact between cam and follower. 25 To the best of our knowledge, the comparison of nonlinear dynamic based on different shapes of followers with clearance has not been studied yet.

II. SIMULATION PROCEDURE

The simulation process has been done by using Solid works program, [10]. Solid works program is used to draw polydyne cam, atffaced follower, roller 30 follower, and followers’ guides. The general dimensions of cam-follower mechanism have been shown in Fig. 1 and Fig. 2. The dynamic analysis presents follower displacement driven by a cam rotating at a uniform angular velocity. There is a clearance between the follower and the guides. In simulation process, the follower with three degrees of freedom is considered in which it has 35 translation in x, y directions and rotation about z axis. Four different follower guides’ clearances such as C = 0.5, 1, 1.5, 2 mm have been used to simulate the non-periodic analysis. The follower non-periodicity is occurred because of the follower guide’s clearance and the three degrees of freedom. It can be compared the follower non-periodicity by using the conception of largest Lyapunov exponent. The point with the coordinates (x = 0, y = 140.13 mm, z = 0) has been selected on the follower to present follower motion.

III. NONLINEAR DYNAMICS

The nonlinear dynamic tool of computer algorithm is used to determine the time delay and the embedding dimension dE. The first minimum of the Average 45 Mutual Information (AMI) has been chosen to calculate the time delay. The embedding dimension
has been found from a Global False Nearest Neighbors (GFNN) analysis, [6,11]. The global dimensions have been selected when the total percentage of neighboring trajectories reaches zero. Figures (3) and (4) indicate the (AMI) and (GFNN) algorithms for roller and at-faced follower 50 respectively.

IV. NON-PERIODICITY OF CAM-FOLLOWER MECHANISM

The non-periodicity of translated follower stem has been occurred because of the clearance. The non-periodicity in this system is increased with the increasing of follower guide's clearance value from C = 0.5 mm to 2 mm. The 55 nonperiodicity phenomena follows the divergence between trajectories during the follower motion with clearance and different degrees of freedom. In this paper, the main cause of follower non-periodicity is the three degrees of freedom.

V. LYAPUNOV EXPONENT

Lyapunov exponent is a quantity that represents the amount of separation 60 of neighboring trajectories in state space domain, [12]. The method of Lyapunov characteristic exponents serves as a useful tool to quantify follower nonperiodicity. Specifically, Lyapunov exponent measures the rates of convergence or divergence of nearby trajectories, [13]. Positive values of Lyapunov exponents imply nonperiodicity in follower system while negative values react periodic 65 motion. In this paper, the largest lyapunov exponent has been selected because it determines a notion of predictability for a dynamical system. The maximum Lyapunov exponent $\lambda$ can be characterized by using Eqn. (1) below, [11, 14].

$$d(t) = De^{\lambda t}$$  

(1)

The $\lambda$ is estimated from best-fit linear slopes of average logarithmic divergence over the time between four and ten strides as indicated in Eqn. (2), [11, 6, 14]:

$$y(i) = \frac{1}{\Delta t} \langle \ln|d_j(i)| \rangle$$  

(2)

Figures (5) shows the average logarithmic divergence of largest Lyapunov exponent for a clearance $C=1$ and 2 mm at cam rotational speed $N = 400$ rpm.

VI. FREQUENCY POWER SPECTRUM

The power spectrum describes the distribution of power into frequency components composing that signal,[15]. The fast Fourier transform (FFT) tool of 75 computer algorithm is used to convert the signal from its original domain to a representation in the frequency domain and vice versa. The frequency spectrum is examined follower non-periodicity of the dynamic response.

VII. RESULTS AND DISCUSSIONS

Figures (6) and (7) show the phase plane diagram of follower linear displacement-80 ment and velocity for translated at-faced and roller followers. The follower non-periodicity varies like a spiral. The follower non-periodicity increase with the increasing of cam rotational speed and follower guide's clearance. The follower non-periodicity for at faced follower is more chaotic than roller follower for the same cam rotational speeds and follower guide's clearance.

Figures (8) and (9) show the amplitude comparison of nonlinear dynamic simulation of Fast Fourier Transform based on power spectrum for at-faced and roller followers. The fundamental frequency due to the nonlinear dynamic of roller follower is clear and obvious because of the quasi periodic motion of the follower. The fundamental frequency of the at-faced follower is not clear 90 enough because due to the increasing in cam rotational speeds the system completely converted to non-periodic motion of the follower.

Figures (10) and (11) show the comparison of largest Lyapunov exponent varying with cam rotational speeds for at-faced and roller followers. The largest Lyapunov exponent increase with the increasing of cam rotational speeds and 95 follower guide's clearance. The values of largest Lyapunov exponent for at faced follower are bigger than the values of largest Lyapunov exponent for roller follower due to the increasing in time delay and embedding dimensions values.

VIII. CONCLUSIONS

This study analyze and discuss the comparison of largest Lyapunov expo-100 tent of cam and different translated follower mechanism. The simulation has been done by using solid works program. The whole values of largest Lyapunov exponent are positive because of the non-periodicity motion of the follower. The at-faced follower with follower guide's clearance $C=2$ mm and cam rotational speed $N=1200$ rpm has more nonperiodic motion than roller follower. The 105 values of largest Lyapunov exponent for at faced follower are bigger than the values of largest Lyapunov exponent for roller follower based on ($C= 2$ mm and $N =1200$ rpm).

REFERENCES RÉFÉRENCES REFERENCIAS


Figure 2: General Dimensions of Polydyne Cam and Flat-Faced Follower Mechanism

Figure 3: (AMI) and (GFNN) for Translated Roller Follower
Figure 4: (AMI) and (GFNN) for Translated Flat-Faced Follower

Figure 5: Average Logarithmic Divergence Comparison of roller and Flat-Faced Followers at N = 400 rpm
Figure 6: Phase-Plane Diagram Comparison of Roller and Flat-Faced Followers at C = 0.5 mm and N = 600 rpm

Figure 7: Phase-Plane Diagram Comparison of Roller and Flat-Faced Follower at C = 2 mm and N = 1200 rpm
Figure 8: Amplitude Comparison of Roller and Flat-Faced Followers at Frequency at $C = 0.5 \text{ mm}$ and $N = 600 \text{ rpm}$

Figure 9: Amplitude Comparison of Roller and Flat-Faced Followers at Frequency at $C = 2 \text{ mm}$ and $N = 1200 \text{ rpm}$
Figure 10: Largest Lyapunov Exponent Versus Cam Rotational Speeds for Roller and Flat-Faced Followers at $C = 0.5$ mm and $C = 1$ mm.

Figure 11: Largest Lyapunov Exponent Versus Cam Rotational Speeds for Roller and Flat-Faced Followers at $C = 1.5$ mm and $C = 2$ mm.