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Research Article

Dynamic Analysis of High Speed Cam Follower System using MATLAB

Ketan Tamboli†, Taranjeetsingh Singh‡, Saurin Sheth† and Tejas Patel†*

†Mechatronics Department, G H Patel College of Engg & Tech, Vallabh Vidyanagar, Gujarat, India
‡Technical University of Hamburg-Hamburg, Germany

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Abstract

The motion machined into the cam surface is not always faithfully reproduced by the follower because of the speed and elasticity or flexibility of the members of the follower train. Thus, vibration theory is applicable in order to determine the manner in which the follower responds to the motion prescribed by cam. Especially, the high speed cams used for various applications such as engines, turbines, entertaining rides, automated machines etc. need to be analysed for response of the follower. Moreover, when a cam is designed to impart a particular motion to the follower, for high speed cams the problems such as large velocities, accelerations and jerks over a cycle are quite pronounced. In such cases the analysis of cam is desirable. In the present work, the dynamic analysis of high speed cam and follower systems is carried out in two parts. The first part deals with the combined static and inertial analysis of the systems in following manner: Cam angle vs. Displacement, Velocity, Acceleration, Inertia force, spring force, Resultant force, Shaft torque. In the second part of the work, the cam follower system is analysed for the jump speed using well known Johnson Method for determining the follower response. It has an advantage that it can also be used for design purposes. The calculations are performed using MATLAB and the outputs are presented for D-R-D cam with i) cycloidal motion ii) parabolic motion iii) uniform motion iv) constant acceleration and retardation. The results are presented in form of follower response and follower command vs. Cam angle for the jump.

Keywords: *Dynamic Analysis, High Speed Cam, Jump, MATLAB*

1. Introduction

The cam and follower constitute one of the most widely used versatile mechanism found in modern machines today. The change in cam curve results in characteristics of follower motion. The design of cam curve is crucial from point of view of velocity, and jerk effects resulting in high stresses and vibrations in associated components. Unless the designer selects appropriate cam curve based on number of parameters such as displacement, velocity, acceleration and shaft torque etc. either wear or fatigue will result in short life of parts. Moreover the high speed cams need to be analyzed for jump speed and related aspects also. Hence, cams are considered here are plate cam with roller follower with cycloidal, SHM, uniform and parabolic motion.

Chan *et al.* have developed a computer based method to optimize the cam mechanism on the basis of radius of cam base circle, width of cam, follower radius, offset, etc. It was shown that volume of material reduces by 35%. A methodology to design cam for motor engine valve trains to maximize the time integral of the valve area opened in gas flow (A. Cardona, 2002). The minimum & maximum levels of acceleration were made limited to avoid excessive forces in the mechanism chain. A flexible cam mechanism has been analyzed for dynamic stability (Tounsi, 2009). A shaft cam-follower mechanism was modeled by a single degree of freedom system. The instability regions and dynamic response were identified. A mathematical model was presented and solved using few methods for flexible cam mechanisms (Balkwill, 1999). The performance can be predicted. Analytical solution in Excel have presented for kinematics and dynamic analysis of cam follower system (Desai, 2010). Cam is one of the essential element for mechanical automation Various special purpose machine(Sheth,2014) use such kind of mechanical automation, but the limitation of jump phenomenon occurring in high speed cam compels the use of hydraulic and pneumatic systems in automation (Patel, 2015).

2. Problem Definitions and Results

The kinematic and dynamic analysis of various cam curves with follower motions are presented in first part of the work while in the second part the response is analyzed based on jump phenomenon. In Part-I, A

*Corresponding author: **Tejas Patel, Taranjeetsingh Singh** is a PG Scholar

plate cam driving a roller follower with cycloidal motion with 1200 rpm having the rise and return strokes each of 1200 with two equal dwells is considered. The follower is retained against cam by compression spring having scale of 26250 N/m. The spring is compressed 6.35 mm (1/4 in) in assembly to provide an initial load. For rise of 25.4 mm and a follower mass of 8 N. The results are generated as shown in Fig. 1 to Fig. 6. The related Eq. (1,2,3) for displacement, velocity, acceleration are given below for cycloidal motion (H.D. Desai *et al*, 2010; Gajjar *et al* 2014; J. S. Shigley *et al*, 1998). The Eq. (4, 5, 6) are for inertia force, spring force and total force respectively.

$$y = d\{\theta/\beta - 1/2\pi\,(\sin 2\pi\theta/\beta)\} \quad (1)$$

$$y' = d\omega/\beta(1 - \cos 2\pi\theta/\beta) \quad (2)$$

$$y'' = 2d\pi(\omega/\beta)^2 \sin 2\pi\theta/\beta \quad (3)$$

$$\text{Inertia Force} = -m_4\, y'' \quad (4)$$

$$\text{Spring Force} = Fs = k(y_0 + y) \quad (5)$$

$$F_{32}^{y} = F_s - m_4 y'' \quad (6)$$

Where, y=displacement (m), y`=velocity(m/s), y``=Acceleration(m/s²), β=cam angle for rise(radian), θ=cam angle (degree), d=follower rise(m), ω= angular velocity of cam(rad/s), rm4 = Follower Mass and Load, k = Spring Stiffness, y0 = Initial Spring Compression, y = Displacement, y'= Velocity, y'' = Acceleration, F32y = Total Radial Force and T2 = Shaft Torque, d = 25.4 mm, β = 1200, ω = 125.7 rad/sec, k = 26250 N/m.

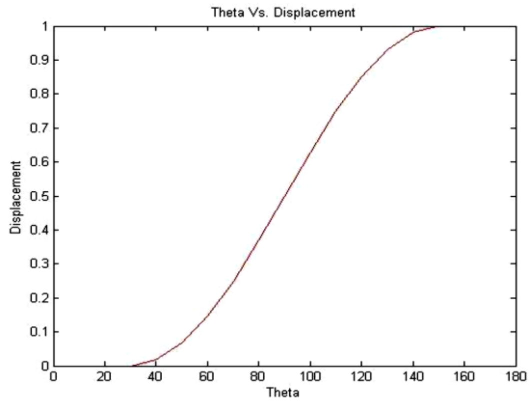

Fig.1 Cam angle vs. Displacement for cycloidal

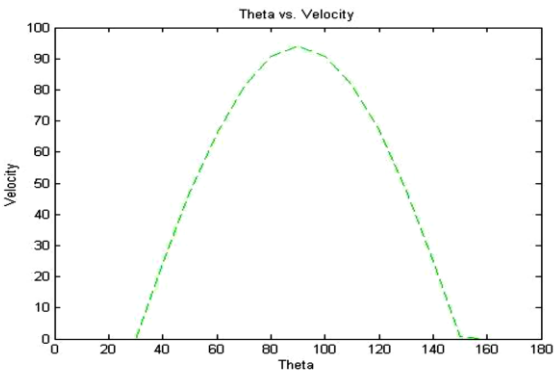

Fig.2 Cam angle vs. Velocity for cycloidal

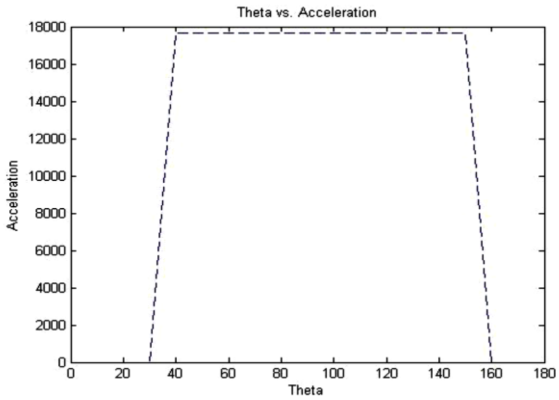

Fig.3 Cam angle vs. Acceleration for cycloidal

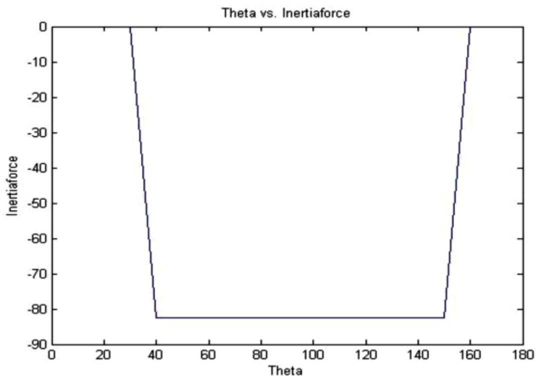

Fig.4 Cam angle vs. Inertia force for cycloidal

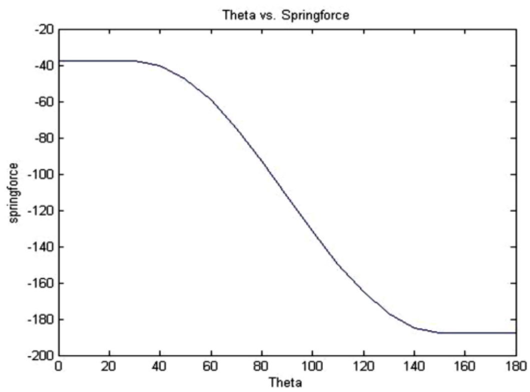

Fig.5 Cam angle vs. spring force for cycloidal

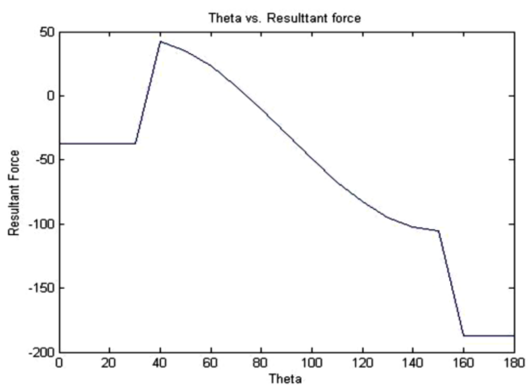

Fig.6 Cam angle vs. resultant force for cycloidal

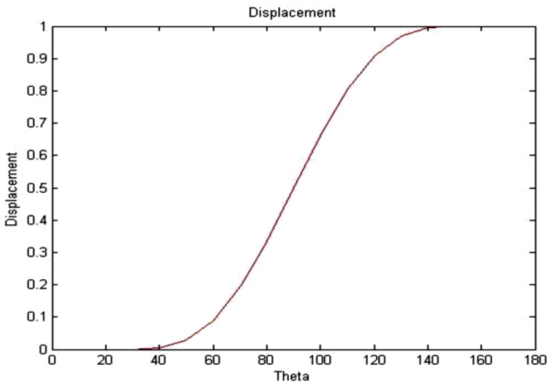

Fig.7 Cam angle vs. Displacement for SHM

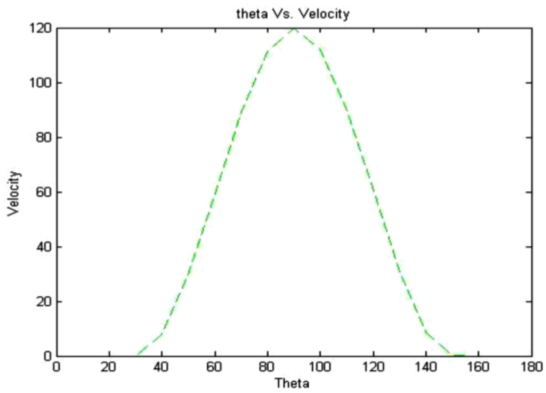

Fig.8 Cam angle vs. Velocity for SHM

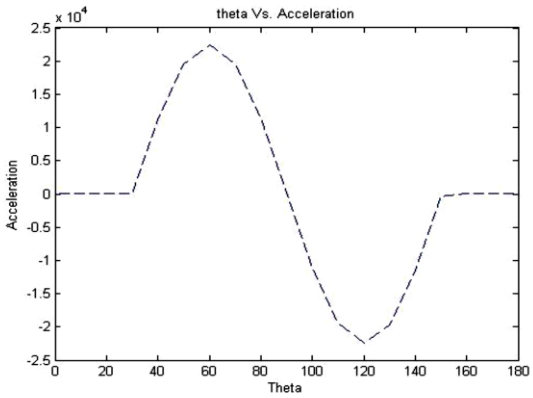

Fig.9 Cam angle vs. Acceleration for SHM

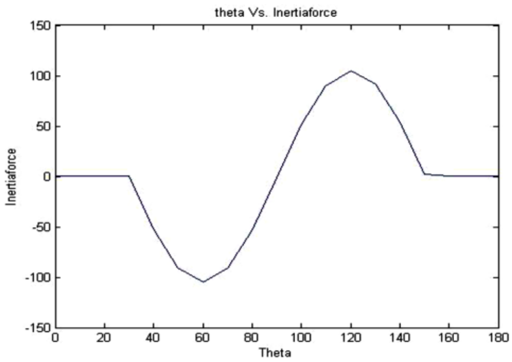

Fig.10 Cam angle vs. Inertia force for SHM

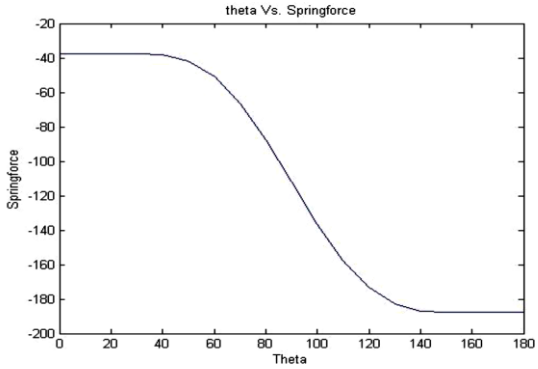

Fig.11 Cam angle vs. spring force for SHM

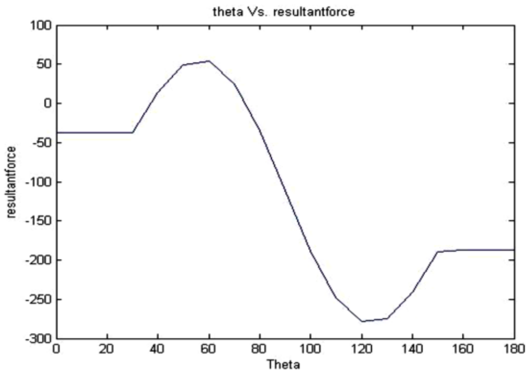

Fig.12 Cam angle vs. resultant force for SHM

The related Eq. (7, 8, 9) for displacement, velocity, acceleration are given below for SHM motion. Fig. 7 to Fig. 12 shows the generated results for plate cam with roller follower producing SHM motion.

$$y = d/2\,\{1 - \cos \pi\theta/\beta\} \quad (7)$$
$$y' = (\pi d\omega/2\beta)\,\sin \pi\theta/\beta \quad (8)$$
$$y'' = d/2\,(\pi\omega/\beta)^2 \cos \pi\theta/\beta \quad (9)$$

The related Eq. (10, 11, 12) for displacement, velocity, acceleration are given below for uniform motion. Fig. 13 to Fig. 18 shows the generated results for plate cam with roller follower producing uniform motion.

$$y = \theta\, d/\beta \quad (10)$$
$$y' = \omega\, d/\beta \quad (11)$$
$$y'' = 0 \quad (12)$$

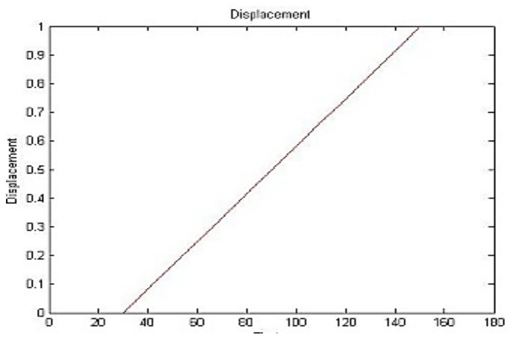

Fig.13 Cam angle vs. Displacement for uniform motion

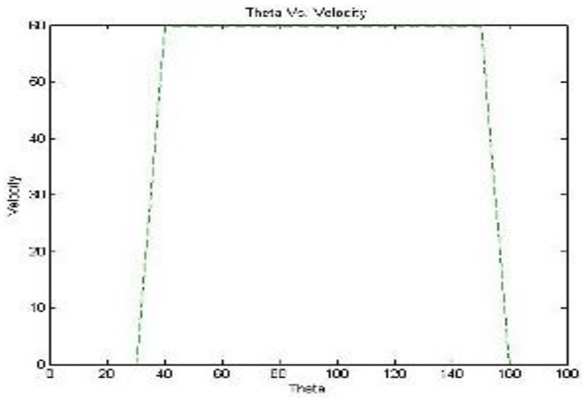

Fig.14 Cam angle vs. Velocity for uniform motion

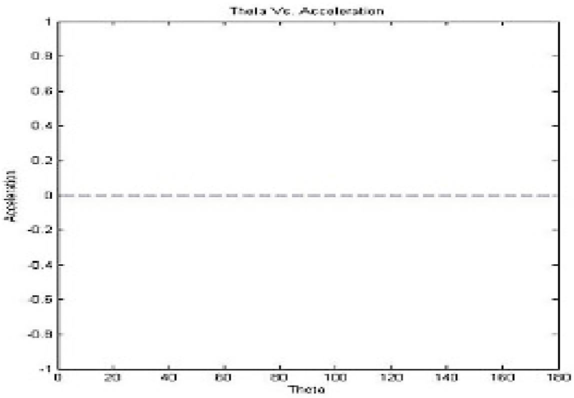

Fig.15 Cam angle vs. Acceleration for uniform motion

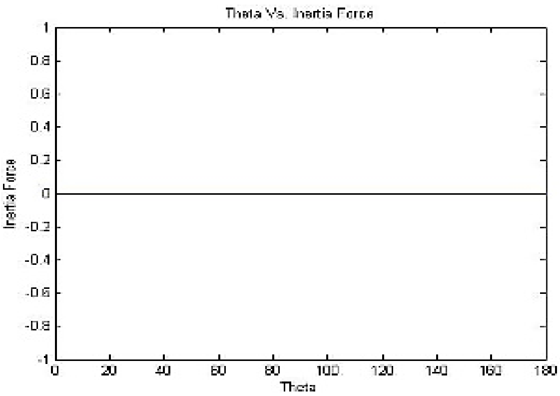

Fig.16 Cam angle vs. Inertia force for uniform motion

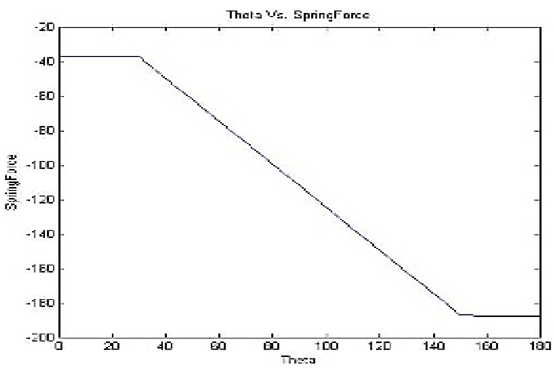

Fig.17 Cam angle vs. Spring force for uniform motion

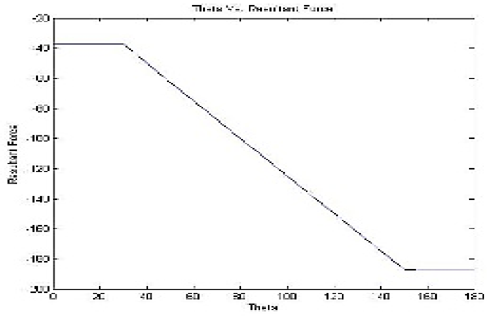

Fig.18 Cam angle vs. Resultant force for uniform motion

The related Eq. (13, 14, 15) for displacement, velocity, acceleration are given below for parabolic motion. Fig. 19 to Fig. 24 shows the generated results for plate cam with roller follower producing parabolic motion.

$$y = 2d(\theta/\beta)^2 \quad (13)$$

$$y' = 4\omega\, d\theta/\beta^2 \quad (14)$$

$$y'' = 4\omega^2\, d\theta/\beta^2 \quad (15)$$

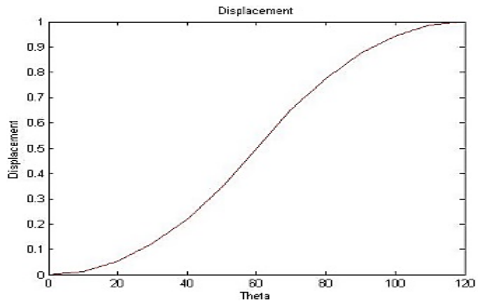

Fig.19 Cam angle vs. Displacement for parabolic motion

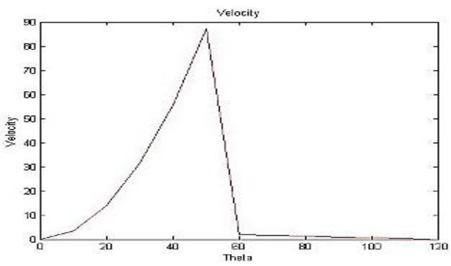

Fig.20 Cam angle vs. Velocity for parabolic motion

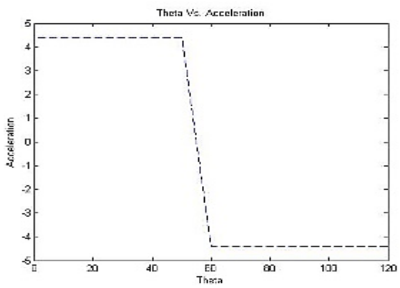

Fig.21 Cam angle vs. Acceleration for parabolic motion

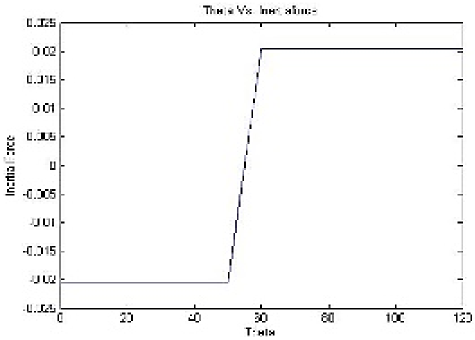

Fig.22 Cam angle vs. Inertia force for parabolic motion

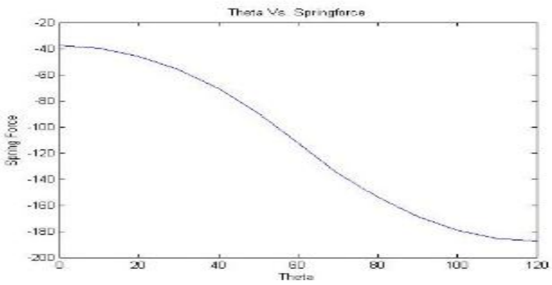

Fig.23 Cam angle vs. Spring force for parabolic motion

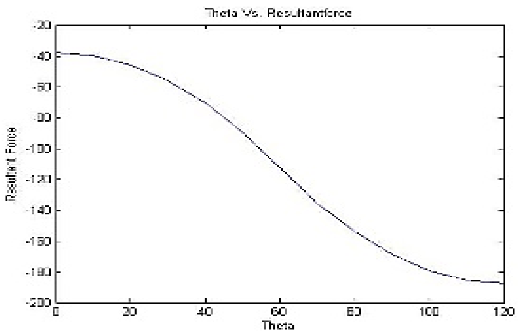

Fig.24 Cam angle vs. Resultant force for parabolic motion

3. Analysis of jump

In Part-II the jump phenomenon (J. S. Shigley *et al,* 1998; Patel; T *et al*, 2015) is applied to a D-R-D cam with cycloidal, SHM, uniform motion and constant acceleration and retardation using well known Johnsons Numerical Analysis. The numerical analysis is used to determine the follower response. The method has an advantage that it can be used for design purposes. A dwell-rise-dwell cam having 26.82 mm rise with cycloidal motion in 1360 of cam rotation with 3500 rpm is considered. The follower is assembled with 3500 N/mm, retaining spring is used with no preload. The follower train has equivalent mass of 2.67 N and an equivalent spring constant of 63000 N/mm.

Fig. (25) shows the results of follower command, response and jump criteria for the cycloidal motion. The related Eq. (16) is for follower command. Fig. (26, 27, 28) show the result for SHM, Uniform Motion and Constant acceleration and retardation respectively.

$$y_1 = \frac{k_2 y}{k_1 + k_2} \qquad (16)$$

where, y1 = follower command, k1 = retaining spring constant, k2= equivalent spring constant.

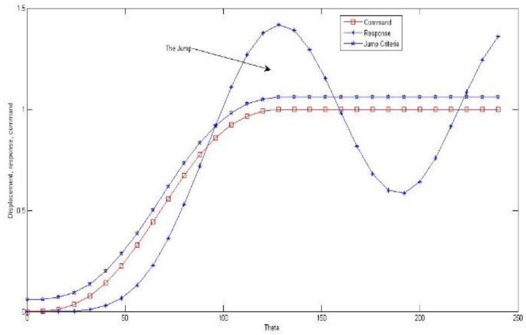

Fig.25 Result generated for cycloid motion and its rise

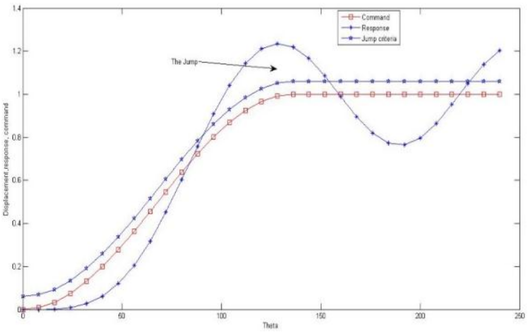

Fig.26 Result generated for SHM motion and its rise

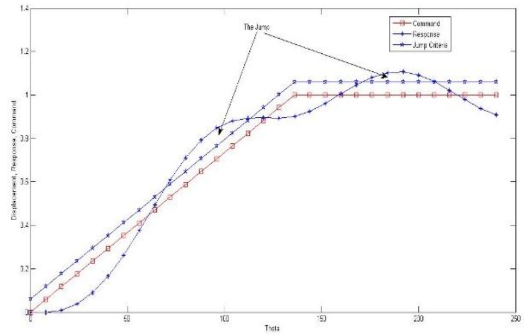

Fig.27 Result generated for uniform motion and its rise

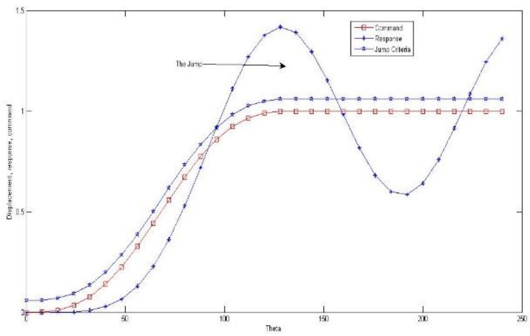

Fig.28 Result generated for constant acceleration and retardation and its rise

Conclusion

In present work the analysis of high speed cam is presented. The kinematic analysis is useful for designer as ready reckoner to investigate the angles at which the maximum velocity and acceleration occur. Also the inertia and spring force variations can be known accordingly. The inertia force is balanced by spring force and other external forces as can be seen from graphs for all different types of follower motions. This confirms the jump prevention of follower. Hence the dynamic equilibrium is observed. While the analysis of jump phenomenon yields to the follower response, command and jump. From Table 1 it is seen that for cycloidal and CAR motions of follower the jump is high and hence the cam curves need to be improved. While the SHM and uniform motion gives almost true description of the cam curve. The methodology followed here is simple, quick and easy to employ for cam follower designers.

Table 1 Comparison of jump magnitude for different follower motions

Sr. No.	Follower Motion	Jump Starts (degree)	Jump Ends (degree)	Magnitude of Jump
1	Cycloidal	90	160	High
2	SHM	80	160	Moderate
3	Uniform Motion	70 170	110 210	Moderate
4	Constant Acceleration & Retardation (CAR)	90	160	High

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