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KINEMATIC ANALYSIS OF CYCLOIDAL CAM PROFILE GENERATED USING SIX-POINTS BÈZIER CURVES

Sharad Singh Thakur	Sunil Kumar Srivastava
M.Tech Student, MED, M. M. M. University of Technology, Gorakhpur	Professor, MED, M. M. M. University of Technology, Gorakhpur

ABSTRACT

Cam follower mechanisms are frequently used for generating the complex motion at the follower end. The key input in mechanism is the cam profile curve which decides the competency of cam for acquiring the desired kinematic behaviour of follower. In this work, the cam profiles are simulated using different Bèzier curves, generated parametrically through a set of known control points, and their effects on the kinematic quantities of roller follower is studied. The kinematic behaviour of roller follower is simulated for cam profiles generated using Bèzier curves and cycloidal curve. The follower velocities, accelerations and jerks are analysed and comparated with the same obtained for the cycloidal cam profile. Thus, synthetic curve such as Bèzier curve is an alternative solution for generating the complex cam profile over the conventional analytical curve.

Keywords: *Cycloidal Cam, Roller Follower, Six-Points Bèzier Curves, Simulation, Kinemtic Parameters.*

INTRODUCTION

Cam is a type of mechanical element of direct contact type that provides desired motion to the follower. Cam helps to program output motions which may be difficult to obtain and often complicated [1]. The edge of follower tracks the shape of cam in the form of movement pattern by travelling along the cam's profile. The principle is simple and versatile in nature; thus, can be applied to variety of jobs [2]. The cam and follower mechanisms are simple in design but can be used for generating distinct motion curves. Although the small size cams are designed for internal combustion engines, but large size are also used in presses. The cam and follower are in direct contact giving rise to direct stresses resulting in fast and easy wear-out. In addition to quick wear-out, the dynamic effect become significant under the heavy loads and high speeds; therefore, the use of cam must be discarded while designing a machine transmitting high torques operating at high speeds [3].

The selection of different cam profiles such as trigonometric cam profile, polynomial cam profile or cam profile based on synthetic curves depends upon the specific requirement. The trigonometric cam profile and polynomial cam profile are exhaustively used while applications of synthetic curves are limited due to large computations involved in the generation of cam profiles. The synthetic curves-based cam profiles may become dominant due to the advancement in computational technology [4].

The synthetic curves in parametric form are mathematically tractable and suitable for defining complex curves and surfaces. The designer has full control on the shape of curve. The applications of synthetic curve can be seen in automobile designing, ship hulls, aerospace wings, propeller blades, etc. In parametric form, differentiation and integration of polynomials is typical which paces up the computation and hence makes it computationally convenient. The shape of the curve is controlled by defining the vertices of the polygon determined by the boundary conditions imposed, specific blending functions and characterizing matrix [5].

U. Chavan et.al [6] studied the effects of acceleration and interface force on jump between cam and follower. Knot locations (four polynomial pieces of spline curves tied together at end) were considered as design variables and acceleration profile was not predefined whereas it was initiated with displacement profile. Mathematical relation between interface force and knot locations was presented as wear and jump models. It was concluded that kinematic and dynamic parameters can be controlled without changing the system's physical parameters. S. Cardona et.al [7] generated the parallel flat-faced double translating follower and parallel flat-faced double oscillating follower based on the non-parametric Bézier curves. The design procedure guaranteed the global continuity of law of displacement. M. H. Martinez et.al [8] investigated the application of Bézier curves for designing cam paired with negative radius follower by optimising the Bézier ordinate of cam profile using numerical method. The follower lift was maximised by discarding the undercutting problem for low pressure angle. Cam systems with negative radius follower were synthesised using optimization. A. B. Shahriman et.al [9] mathematically modelled B-Spline curve-based cam profile mechanism using MATLAB. A higher cam performance increased the engine performance corresponding to highest displacement factor. Mall et.al [10] studied the follower's kinematic behaviour obtained for cam profiles based on the synthetic curves. The kinematic parameters such as displacement, velocity, acceleration and jerk were analysed and compared for the cycloidal cam profile. The Bézier curve facilitated follower's continuous jerk giving increased versatility for high speed and complex applications unlike cycloidal profile. The synthetic curves enhanced the control over kinematic parameters due to the flexibility of better profile shape control.

The traditional and polynomial cam profile possess less flexibility over the shape control. Synthetic curves are generated parametrically with a set of known data points with desired number of curve segments, which makes it more flexible and

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suitable for the CAD/CAM applications. In the present work, the kinematic analysis of roller follower for the cycloidal cam profile generated using six-points Bèzier curve has been carried out. The present work aims at the study of implementation of Bézier curves for cycloidal cam profile and investigating the effects of curve parameters on the kinematic behaviour of roller follower.

CAM PROFILE SIMULATION USING BÉZIER CURVES

Bézier curve interpolates the endpoints and approximates the additional points outside the curve. The positions of the control points strongly affect the shape of Bézier curve. The magnitudes and angles of tangent vectors are not directly defined; rather, they are defined indirectly, by defining two additional control points outside the curve. The polynomial coeffcients for Bèzier curve are alternatively defined by the Bernstein polynomial as [5]

$$B_{n,i}(t) = \begin{cases} {}^{n}C_{i}.t^{i}(1-t)^{n-1}, & when\ n \geq i \\ 0, & when\ n < i \end{cases} \quad (1)$$

Where Bernstein polynomial $B_{n,i}(t)$ is known as $i^{th} - n^{th}$ order Bernstein basis function.

And, $${}^{n}C_{i} = \frac{n!}{i!(n-i)!} \qquad (2)$$

Where,

n = Degree of the defining Bernstein basis function

(n+1) = Numbers of control points (vertices)

i= control point (vertex) in the order (sequence)

Degree of defining Bernstein basis function, n, is also degree of polynomial of curve's parameter, one less than the number of control points, in the defining Bézier characteristics polygon. For (*n* + 1) control points, the parametric Bézier curve of degree *n* is defined as

$$P(t) = \sum_{i=0}^{n} P_i\, B_{n,i}(t) \quad (3)$$

The following parameters are assumed for simulation of cam profile using Bézier curves:

Follower displacement = 15 mm

Angle of cam rotation during ascent = 120^0

SIX-POINTS BÉZIER CURVES

The control points P0, P1, P4 & P5 remain fixed and points P2 & P3 are varied to get different Bézier curves.

Curve B1 represents 1st Bézier curve with intermediate points P2(50,2) & P3(70,13).

Curve B2 represents 2nd Bézier curve with intermediate points P2(45,2) & P3(75,13).

Curve B3 represents 3rd Bézier curve with intermediate points P2(40,2) & P3(80,13).

Table 1 shows the set of control points for generating different six-points Bézier curves.

The cycloidal cam profile curve is simulated using Bézier curve equations (eq. 3) in MATLAB. Fig. 1 shows the simulated follower displacement of cam profile using six-points Bézier curves and follower displacement based on the cycloidal cam profileSimulation of Kinematic Parameters of Roller Follower

Firstly, all the input data are provided in the MATLABprogram. The program is executed for the generation of threeBèzier curves & other necessary data (Blending functions and curve inputs). The Simulink model considered the synthetic curves as input and simulatesthe velocity, acceleration & jerk of thefollower as output. These data are plotted in Fig. 2, 3 & 4, respectively. These figures include the kinematic analysis of roller follower based on cycloidal cam profile for the comparison. The best profileis selected based on the acceleration and jerk produced in the roller follower. The lowest acceleration and jerk produced during operation will be suitable for the cam design.

RESULTS AND DISCUSSION

Figure 2 shows the velocity profiles of roller follower based on three different Bézier curves and cycloidal cam profile. In Bézier curves, curve B3 shows lowest peak velocity (0.26 mm/sec) as compared to the other curves B1 (0.29 mm/sec) and B2 (0.27 mm/sec), respectively, whereas cycloidal curve shows lowest peak velocity (0.25 mm/sec) among all the curves. The peak velocities of curves B1 & B2 with respect to curve B3 are 14.3% and 6.6% higher, respectively. Therefore, curve B3 is most suitable for cam design among Bézier curves. It should be noted that the peak velocity of curve B3 is only 2.5% higher than the cycloidal cam profile

Figure 3 shows the acceleration profiles of roller follower for three different Bézier curves and cycloidal cam profile. The curve B3 shows lowest peak acceleration (7.36 µm/sec^2) as compared to the other curves B1 (8.42 µm/sec^2) and B2 (7.70 µm/sec^2), respectively whereas cycloidal curve shows lowest peak acceleration (6.55 µm/sec^2) among all the curves. The peak accelerations of curves B1 & B2 with respect to curve B3 are 14.3% and 4.5% higher, respectively. Therefore, curve B3 is most suitable for cam design as regards to the acceleration of follower among Bézier curves while curve B3 is showing peak acceleration 12.6% higher than cycloidal curve.

Figure 4 shows the jerk profiles of roller follower for three different Béziercurvesand cycloidal cam profile. The curve B3 shows lowest peak jerk (0.34 µm/sec^3) as compared to the other curve B1 (0.75 µm/sec^3) and curve B2 (0.50 µm/sec^3), respectively, whereas cycloidal curve shows lowest peak jerk of 0.30 µm/sec^3 among all the synthetic curves. The peak jerks of curves B1 & B2 with respect to curve B3 are 123.1% and 47.8% higher, respectively. Therefore, curve B3 is most suitable for cam design among Bézier curves as it posseses lowest peak as regards to the jerk.

It is further observed from Fig. 4 that the curve B3 depicts double peaks with negligible variation of jerks for the wide range of cam rotations (45^0 – 75^0), thereby indicating minimum jounce (rate of change of jerk); therefore, makes the curve B3 most suitable as compared to the other Bèzier curves and cycloidal curve.

CONCLUSIONS

The results show that Bèzier curves provide skewed acceleration profile which facilitates continuous smooth jerk of follower over the wide range of cam rottaions in comparison with cycloidal cam profile; consequently, leading to minimum jounce for most of the cam rotations. Therefore, Bèzier curves provided additional versatility to suit more complex cam profiles for the high-speed applications.

It is concluded that the Bèzier curves provide a better control on the kinematic behaviour of roller follower cam mechanism. This is possible only with synthetic curves because of the shape control by adjusting the positions of control points as per the design requirements.

REFERENCES

[1] Moon CH. Cam Design, Commercial Cam Division, Emerson Electric Company, **1961**.

[2] Norton RL. Cam Design and Manufacturing Handbook, Industrial Press, Inc., New York, **2002**.

[3] Rattan SS. Theory of Machines, Tata McGraw-Hill Publishing Company Ltd., New Delhi, **2004**.

[4] Rothbart HA. Cam Design Handbook McGraw Hill, New York, **2004**.

[5] Srivastava SK. Computer Aided Design – A Basic and Mathematical Approach, I. K. International Publishing House Pvt. Ltd., New Delhi, **2012**.

[6] Chavan U and Joshi S. Synthesis of cam profile using classical splines and the effect of knot locations on the acceleration, jump, and interface force of cam follower system, Proc. I MechE Part C: J. Mechanical Engineering Science 225, **2011**.

[7] Cardona S, Zayas EE, Jordi L, Català P. Synthesis of displacement functions byBézier curves in constant-breadth cams with parallel flat-faced double translating and oscillating followers, Mechanism and Machine Theory 62 51–62, **2013**.

[8] Martínez MH, Sanmiguel-Rojas E, Burgosb MA. Design of cams with negative radius follower using Bézier curves, Mechanism and Machine Theory 82 87–96, **2014**.

[9] Shahriman AB, Syafiq AKM, Hashim MSM, Hazry D, Razlan ZM, Wan K, Daud R, Cheng EM, Zaaba SK and Azizan A. Improvement of cam performance curve using B-Spline curve, Journal of Physics: Conf. Series 908 012043, **2017**.

[10] Mall SP and Srivastava SK. Cam profile analysis and simulation using synthetic curves, International Conference on Advances in Mechanical, Industrial, Automation and Management Systems (AMIAMS), Allahabad, **2017**.

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***Table 1**: Control points for generating different six-points Bézier curves*

			Control Points					
			P_0	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**
Co-ordinates	**Curve - B1**	**x**	0	40	50	70	80	120
		y	0	0	2	13	15	15
	Curve - B2	**x**	0	40	45	75	80	120
		y	0	0	2	13	15	15
	Curve - B3	**x**	0	40	40	80	80	120
		y	0	0	2	13	15	15

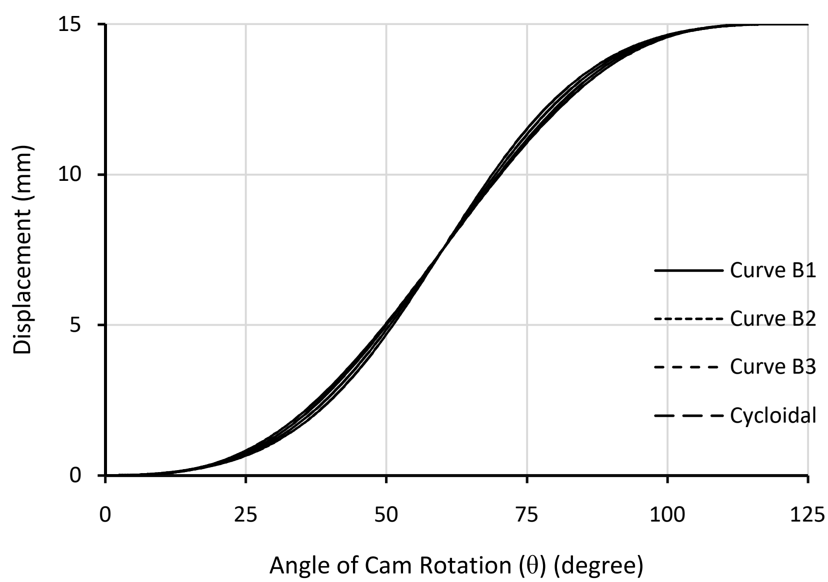

***Figure 1:** Simulated Follower Displacement of Cam Profileusing Six-Points Bézier curves*

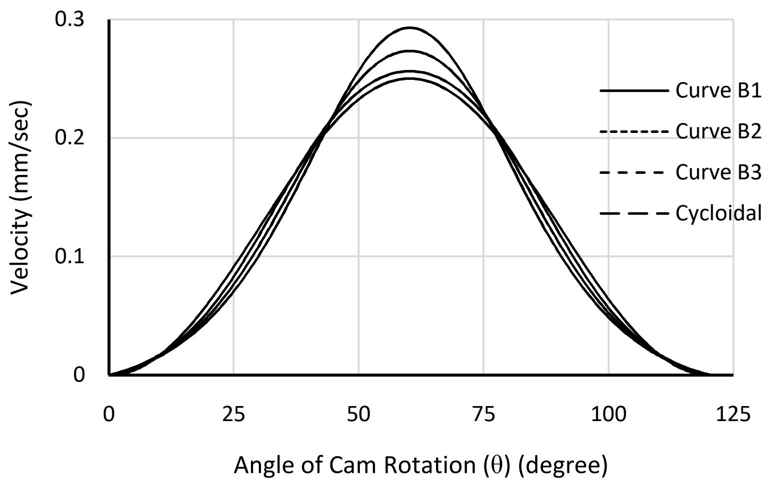

Figure 2*: Velocity Profiles of Roller Follower for Six-Points Bézier Curves*

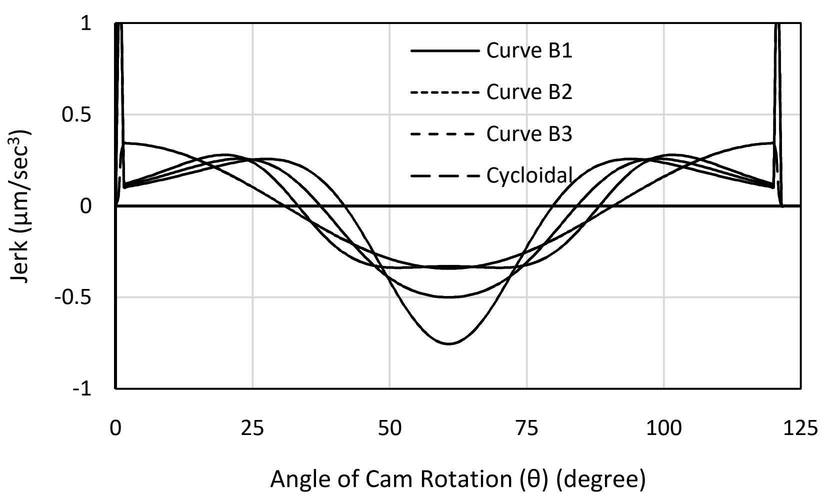

Figure 4*: Jerk Profiles of Roller Follower for Six-Points Bézier Curves*

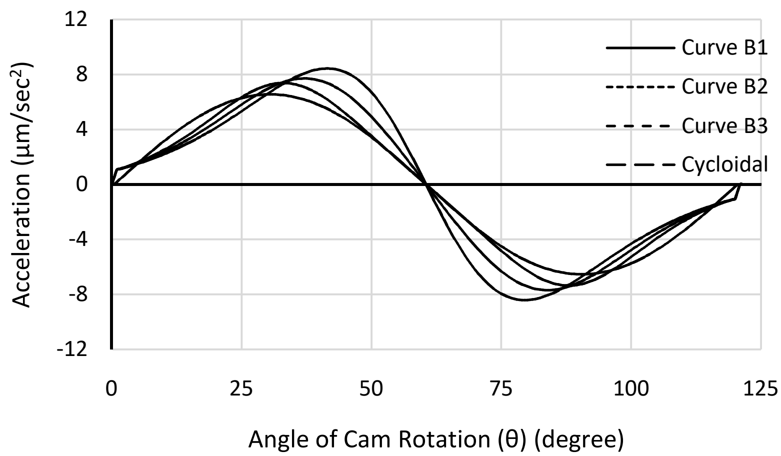

***Figure 3**: Acceleration Profiles of Roller Follower for Six-Points Bézier Curves*