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Design of Cam and Follower system using Basic and Synthetic curves: A Review

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Abstract

The requirement of high performance machinery demands efficient methods for design and manufacturing of Cams. Many authors used different techniques for improving design, machining and performance of Cams. Design of Cam still needs to be improved for better performance of mechanical systems. This paper reviews the past and present research work in the field of kinematic and dynamic aspect of design and optimization of Cam profiles. The basic curves and splines used to design the Cam profile by various researchers in past two decades have been discussed in this paper.

Keywords: Cam profile; Analytical curve; Polynomial curve; Synthetic curve.

1. Introduction

A review paper cannot merely be a catalogue of all the articles published on a subject, and can't include contributions of all the authors in a single paper. Therefore this survey paper concentrates only on those contributions that are considered to be mile stone in the area of Cam Design (CD). Basic motion curve and freeform curves have been widely used in various engineering applications. One of the applications using these curves is CD which plays important role to automate the machines and design jerk less / vibration free motion of the machine (Roth Bart, 1956, Makino, 1976). The traditional Cam design process includes the specification of motion curves for the follower and the subsequent calculation of the Cam profile (Chen, 1982). Once the profile is generated, the radius of curvature, pressure angles, and other properties of the profile are checked for feasibility, and the process is repeated until a feasible design is generated (Mortenson, 1985). Motion curves are used to specify the input-output motion relation for the Cam design (Jenson, 1987). During the process of designing Cam-follower mechanisms, the designers must select or synthesize the motion curve for the desired output positions of the follower and the dynamic responses of the system, and then design the Cam profiles (Mabie and Reinholtz, 1987). Accordingly the design quality of motion curves influences the transmission performance of the mechanisms. Earlier researchers used many forms of curves which include basic motion curves, polynomial curves and trigonometric series curves to synthesize the Cam (Angeles and Lopez, 1991, Norton, 2001). In the family of trigonometric motion curves, there are several industrial standard curves including Modified Sine (MS), Modified Trapezoidal (MT), and Modified Constant Velocity (MCV). These curves are symmetric dwell-rise-dwell types and belong to the so-called universal curve developed originally by Universal Match Corp (Reeve, 1995). In recent years, spline curves completely replaced the use of these basic and polynomial curves because of their flexibility and versatile properties. Researcher uses many forms of spline curves like Bezier, B-spline and NURBS in Cam motion synthesis.

This paper is organized as following the introduction; basic motion curve used by many authors for CD is discussed in second section. The synthetic curves used for CD by various authors have been discussed in the third section. Finally conclusion on the basis of a comprehensive discussion by various researchers is mentioned in fourth section.

2 Basic motion curves

Traditionally, many basic forms of motion curves have been developed or applied to Cam follower mechanisms, including simple polynomial curves and trigonometric curves. Trigonometric form curves are simple harmonic motion (SHM), which has a cosine acceleration curve, cycloidal which has sine acceleration curve, double harmonic and elliptical and their modified forms. The derivation of a numerical procedure of Cam curve for an arbitrary shape of acceleration curve to satisfy the motion values at certain points is described and the numerical integration of displacement curve is obtained by using a trapezoidal rule (Zigo, 1967). An approximate method of calculating the Cam contour has been developed for a prescribed acceleration characteristic of a Cam follower (Chen, 1969). He has derived an algorithm based on simple mathematical induction using the reversion of finite differences. On one hand, he has extended his previous work to refine the prescribed acceleration data so that it improved the numerical accuracy for the use of finite-difference equation (Chen, 1972). On the other hand, he applied the finite integration method to synthesize the displacement curve for the same given conditions (Chen, 1973). All research community agrees with finite difference method shown in fig. 1.

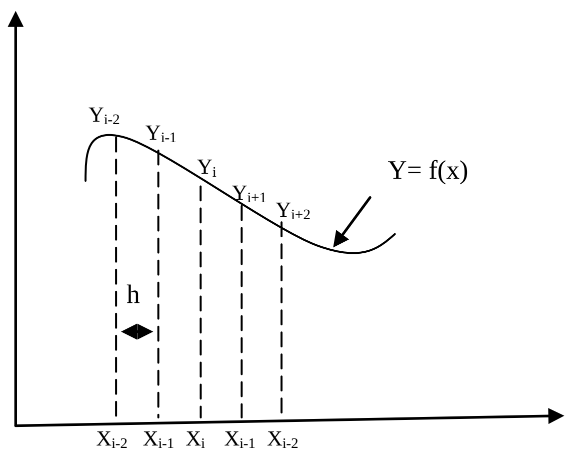

Fig. 1 Central Difference approximation of a function

Trigonometric series curves are introduced for dynamic synthesis of Cam and follower system (Wiederrich and Roth, 1975). A unified approach for the analytical design of three-dimensional Cam follower systems has been presented by Dhande et *al*. (1975). They have presented generalized expressions for equations of the conjugate profile, the pressure angle and the locations of the cutter. Effectiveness of the proposed method is illustrated by applying it to Camoids, three-dimensional cylindrical Cams with translating and oscillating followers, Globoidal Cams with oscillating followers and two-dimensional disk Cams with translating and oscillating roller followers. A finite trigonometric series is used to represent the displacement curve to cover the entire cycle of Cam follower motion by Lakshminarayana and Kumar (1987). They found that the theoretically exact dwells were not required for the motion synthesis. A methodology based on combined curve fitting is developed by Lin et *al*. (1988). Through this methodology Cam drawings and Numerical Control (NC) codes can be automatically created after specifying the Cam motion function. They have calculated the Cam profile co-ordinates to obtain an accurate Cam profile by establishing equations for the velocity and acceleration at the curve junction. To optimize the Cam design an exploratory search method called the Monte Carlo method is developed by Chan and Sim (1998). A CAD system which is an integration of the design calculations and an optimization algorithm provides an optimized solution, a graphical diagram, and a simulation of Cam movement for different type of follower motion but does not provide the data for Cam machining. Generally type of follower motion includes dwell rise dwell return (DRDR), Dwell rise return (DRR) and rise return (RR) illustrated in Figure 2.

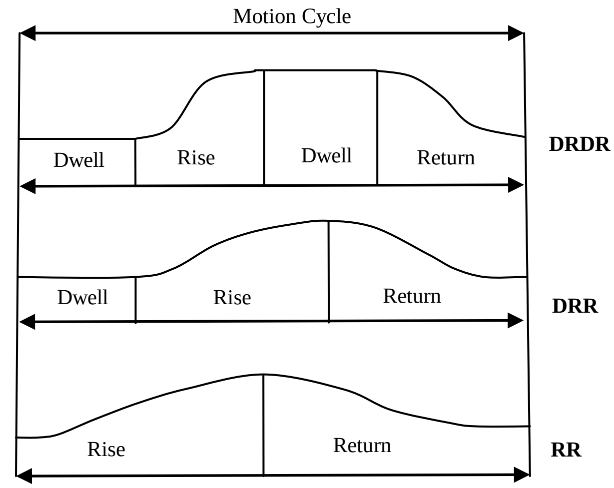

Fig. 2 Different types of motion events

A new approach using universal motion curve is synthesized in a generalized model (Chang, 2002). These curves are designed using sine curves and constants on an acceleration basis. This approach establishes generalized design equations based on a generalized model of the motion curves shown in Fig. 3.

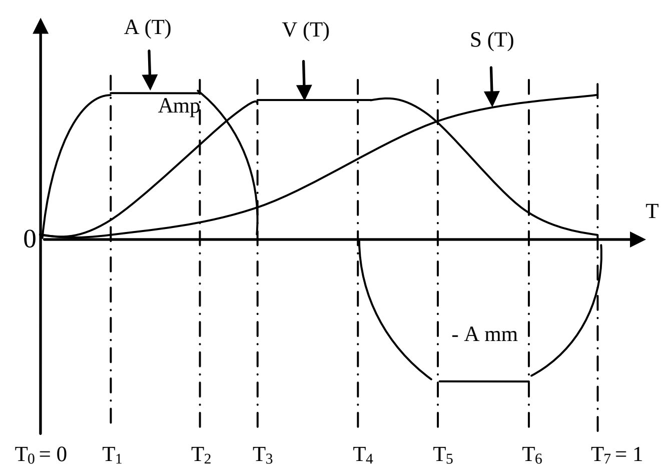

Fig. 3 Universal motion curves

The curve shape on each varying-acceleration interval may be represented by trigonometric, polynomial, exponential or other functions and the motion curve may be symmetric or asymmetric. Modified trapezoidal Cam profile with an adjustable forward and backward acceleration profile is suitable for single-dwell Cam (DRR) and follower applications and gives an easy way to adjust the maximum forward or backward acceleration to prevent vibration problems (Flocker, 2009).

2.1 Polynomial Curves

The polynomial curves plays important role to design Cam profile. Many researchers used polynomial curves to design the efficient Cam profile. Polynomial curves are firstly used in well known Polydyne Method (PM) for the purpose of improving the design of Cam. The *PM* is a smooth Cam profile method which uses a simple valve train dynamic model to determine the lobe shape that will produce a specified dynamic profile. "Polydyne" word is basically derived by combining and contracting the words polynomial and dynamics. Automobile valve-gear linkages and textile machine members are prime examples of good Polydyne applications. The Polydyne method was originally presented by Dudley (1948) and elaborated by Thoren et *al*. (1952). This is the first method ever proposed that designs the Cam shape to give the desired follower action. Stoddart (1953) improved this method and proposed that vibration of the follower of Polydyne Cam will be close to zero as long as there is sufficient spring force to keep it in contact. Cam profile is improved such that the follower lift curve matches a desired polynomial equation at the desired design speed given the Cam-follower system dynamic characteristics. This method was apparently tried by many of the car companies, but was not adopted by any one because this method uses an incomplete polynomial to specify the profile. Kwakernaak and Smit (1968) formulated the problem of finding Cam profiles with limited follower velocity, acceleration and jerk and minimal residual vibrations over a prescribed range of Cam speeds as a mathematical optimization problem. They have formulated these problems as a quadratic problem formulation and a linear programming formulation by using a digital computer. Examples of profiles are presented and compared with the well-known cycloidal profile. Kanzaki and Itao (1972) developed Cam design method for type head positioning in high-speed tele printers and determined the polynomial equations for the Cam followers by considering certain boundary conditions and the characteristics of the residual vibrations over a wide range of rise times. Tesar and Mathew (1976) have used an analytical function for dynamic synthesis of Cam profiles, to validate a number of fundamental design rules of thumb pertaining to classification, motion specification, motion distortion due to off-speed operation, and reduction of system potential for growth of wear. Proper use of these elementary design rules makes complex analysis procedures unnecessary. They have developed design charts for linear, damped, one & two degrees of freedom (DOF) models and have derived motion equations of the follower using polynomial functions by considering the case of variable speed Cams. Specified motion (y) is expressed in the mathematical form in terms of polynomial equation as:

$$y = \sum_{k=p}^{t} C_k \theta^k \qquad (1)$$

Where, y = Specified motion.

C_k = Constants.

θ^k = Cam rotation angle.

Berzak and Freudenstein (1979) stated optimization criteria of Polydyne Cam design which dealt with the design tradeoff between kinematic and dynamic characteristics of Cam-follower system. Berzak (1982) developed a general method for obtaining the optimum design of a Cam-follower system using polynomial output motions which satisfy both the kinematic and dynamic properties of the system. Phan et *al*. (1989) investigated an indirect repetitive control theory for linear discrete multivariable systems using the polynomial functions. A suitable family of polynomial output motions are selected to obtain optimum design using a linear sum of the weighted performance coefficients. Proposed theory is described by numerical examples for third degree polynomial output motions. Sadek and Daadbin (1990) proposed a method of smoothing the specified profile curve in which Polynomial curve fitting was used to replace the profile curve and found that the Cam can cause less vibration with polynomial curve fitting and it has fewer tendencies to bounce. However, their work does not deal with the development of diagrams, simulation and the manufacture of Cams. A Computer Aided Design (CAD) system has been developed for cylindrical Cams with a translating conical follower (Tsay and Wei, 1993). Cams can be designed and graphics can be displayed once the follower motion program has been given. By using previously developed smoothening method, a contact line of the follower can be obtained at any angle of rotation to find analytical profile expressions. All these procedures were carried out without the assistance of a CAD/CAM system. Chew et *al*. (1993) applied an optimal control theory to the Cam design to synthesize the high speed Cam-follower system. Fabien et *al.* (1994) used linear quadratic optimal control theory to design high-speed DRD Cams. They designed such Cams at a fixed operating speed as well as over a range of speeds. Also they have used trajectory sensitivity minimization to design a Cam which is insensitive to speed variations. All the problems are solved by using an efficient numerical procedure. Their designed Cams have significantly lower peak contact stress, contact force and energy loss when compared to a

Polydyne Cam design. Furthermore, the trajectory sensitivity minimization approach is shown to yield Cams that have lower residual vibration, over a range of speeds. Chew and Phan (1994) used Learning control theory in reducing residual vibrations in electromechanical high-speed Cam follower systems. Learning control is an off-line process and is a sub-category of repetitive control, which is a continuous process. Chew and Chuang (1995) used a direct procedure based on the generalized Lagrange multiplier method to design high-speed Cam-follower systems over a range of Cam speeds. They minimized residual vibrations at the end of the rise of a DRD Cam motion for any specified range of rise times by specifying a minimum of boundary conditions to reduce unnecessary constraints on the Cam displacement function. Chang (1996) developed a repetitive control system for high speed Cam follower system. They used third degree polynomial curve for Cam lift trajectory and five degree polynomials as desired output trajectory. These polynomials are expressed in the mathematical form as

$$Y_c/H_c = a_0 + a_1\theta_c + a_2\,\theta_c^{\,2} + a_3\theta_c^{\,3} \qquad (2)$$

$$Y_c/H_c = a_0 + a_1\theta_c + a_2\,\theta_c^{\,2} + a_3\theta_c^{\,3} + a_4\theta_c^{\,4} + a_5\theta_c^{\,5} \qquad (3)$$

Where, Y_c = Net lift of the Cam
H_c = Maximum lift of the Cam
θ^n = Angular displacement.
a_i = Constants

Pridgen and Singhose (2010) proposed an alternative method called input shaping for generating automated motion commands to reduce vibration and produce faster rise times than Cam profiles in which polynomial Cam profiles are taken as a smooth reference commands in single degree of freedom Cam and Follower system shown in Fig. 4.

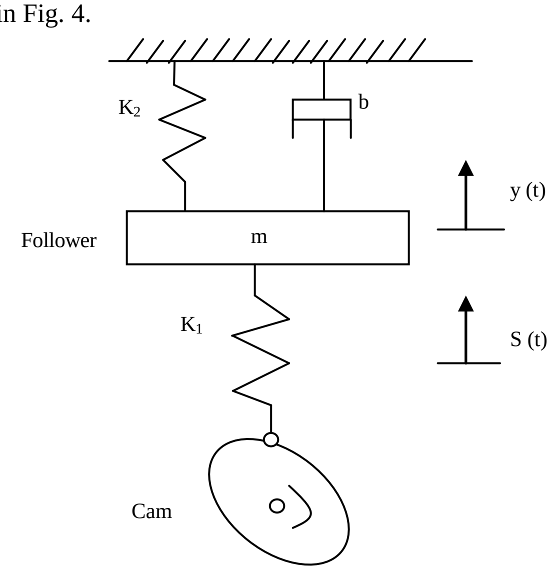

Figure 4 One degree of freedom Cam and follower system

They compared polynomial Cam profiles to input shaping for the application of reducing vibration in flexible systems.

3 Synthetic curves

Since the polynomial curve has some limitations like its harmonic content is not explicitly known and can be high enough to vibration problem. To overcome these problems Splines have been used by many researchers to develop Cam profiles. Splines are the mathematical equivalent of a French curve. It provides almost unlimited flexibility. Splines represent the lift curve as a number of functions, usually polynomials that are pieced together. Synthetic curve includes Bezier, B-spline and Non Uniform Rational B-splines (NURBS). In past Synthetic curves have been widely used by researchers for Cam designing. This is described below.

3.1 Bezier curve

The Bezier curve representation is one that is utilized most in computer graphics and geometric modeling. Bezier curves were formulated, around the same time, by Pierre Bezier and Paul de Faget de Casteljau (Jones, 2001). Mathematically a Bezier curve is defined as:

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

where, P_i = Control points.

$B_{i,n}(u)$ = Bernstein polynomial and can be represented mathematically as:

$$B_{i,n}(u) = \binom{n}{i} u^i (1-u)^{n-i} \qquad (3)$$

$$\binom{n}{i} = \frac{n!}{i!(n-i)!} \qquad (4)$$

For n=3,

$$P(u) = [1 \quad u \quad u^2 \quad u^3]\,[M]\begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix} \qquad (5)$$

where [M] is Blending functions for the curve P (u) i.e. the cubic Bernstein polynomials and P_0, P_1, P_2, and P_3 are Control points.

The degree of polynomial (n) defining the curve segment is one less than the number of control points (i). The tangent vectors at the ends of the curves have the same direction as the first and last polygon spans respectively. The curve is

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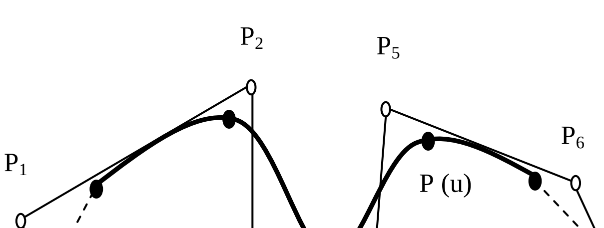
contained within the convex hull of the defining polygon. Bezier curves are the first spline curves applied to Cam design. Many researchers used the properties of Bezier curve in this field. Angeles (1983) used the periodic splines in the synthesis of planar curves expressed in function form or parametric form, with local geometric constraints at a set of finite points. Uses of periodic splines were also illustrated for the synthesis of displacement curve of the follower motion. Domain is divided into sub-intervals by specifying a series of "knots" at various Cam angles and the profile is represented as a polynomial within each sub-interval (McCarthy and Burns, 1985). Depending on the order of the spline, various derivatives have been matched at the knots where two polynomials come together. Ting et *al*. (1994) has used Bezier curve to synthesize the motion of Cam follower mechanism. The Bezier curve interpolates the first and last end points of the whole curve and approximates or approaches the given control points. Srinivasan and Ge (1996) used a recently developed family of curve refers to as Bernstein–Bezier harmonics curves, as opposed to polynomial curves for kinematic synthesis of Cam displacement curves. They extended their work and designed dynamically compensated robust Cam profiles with Bernstein–Bezier harmonics curves by modifying the traditional Polydyne method. Their proposed harmonic curves have low harmonic contents and therefore the resulting Cam profiles are less prone to induce the resonant vibrations in the follower mechanism. Kegl and Muller (1998) developed a procedure for optimizing the conventional diesel fuel injection system by employing an approximation method of mathematical programming. Bezier curve is used to represent the shape of the Cam profile and some of the coordinates of the control points are adopted as design variables. They have described their developed theory with certain specific numerical examples. The design procedure is based on the range of Camshaft speed variation. Liu et *al.* (2007) presented an optimal design of the Bezier motion curve with continuous angular jerk constraint of open/close blow-station Cam using Augmented Lagrange Multiplier (ALM) optimal approach. Based on Envelope theory, they obtained the profile of the open/close blow-station Cam and analyzed the motion of the follower and the pressure angle of the Cam according to the vector loop method and the definition of pressure angle.

3.2 B-Splines

One of the most versatile tools for modelling curves is the B-splines. B-splines are the synthetic curves which not only interpolate the given set of data points but also approximate them (Cox, 1972). The letter 'B' stands for 'basis' because every spline function can be represented as a linear combination of B-Spline shown in fig. 5.



It has been widely used in modelling of curves and surfaces in CAD/CAM as a standard. It is a smooth spline which offers a common mathematical form for representation and is used for designing standard curves (conic and quadrics, etc), free form curves and surfaces. One method of improving the follower motion characteristics would be to represent the curves by B-Splines. Mathematically B-splines can be defined by having (k-1) degree and n+1 control point as:

$$P(u) = \sum_{i=0}^{n} N_{i,k}(u) P_i \qquad 0 \le u \le u_{max} \tag{6}$$

where P (u) = Position on the curve at parameter u,
Pi = Control points,
$N_{i,k}$ (u) = Blending function and can be defined as:

$$N_{i,k}(u) = \frac{[(u-u_i)N_{i,k-1}(u)]}{[u_{i+k-1}-u_i]} + \frac{[(u_{i+k}-u)N_{i+1,k-1}(u)]}{[u_{i+k}-u_{i+1}]} \tag{7}$$

$$\begin{matrix} N_{i,1}(u) = 1 & \text{if } u_i < u < u_{i+1} \\ N_{i,1} = 0 & \text{otherwise} \end{matrix} \tag{8}$$

where, k= Order of curve,
u_i= Knot values and defined as

$$\begin{Bmatrix} u_j = 0 & \text{if } j < k \\ u_j = j-k+1 & \text{if } k \le j \le n \\ u_j = n-k+2 & \text{if } j > n \end{Bmatrix} \tag{9}$$

with $0 \le j \le n + k$, number of knot values (m) = n+ k+ 1, i.e. $u_j = [u_0, u_1, u_2, u_3, \dots\dots\dots\dots\dots, u_{n+k}]$.

Blending function is important property of B-spline as it provides the local support. B-spline curve has been widely used in the Cam and follower motion synthesis by many researchers in their work. Tsay and Huey (1988) have used piecewise continuous polynomials called B-splines to

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define the displacement curves in order for the motion curve to be synthesized and refined locally to satisfy the discrete motion constraints. MacCarthy (1988) has proposed a very general spline construction in kinematic design. They generated an arbitrary acceleration profile for the Cam follower acceleration using a B-spline representation. This representation provides for local control of the acceleration profile which is required in order to generate reliable optimization results. Sandgren and West (1989) imposed constraints to place appropriate limits on the lift, duration, acceleration, jerk, radius of curvature, and to avoid Cam-follower separation. They used a gradient based penalty function algorithm to optimize their problems. A specific example has been presented for an internal combustion engine. Yoon and Rao (1993) presented general procedure for synthesis of Cam motion using piecewise cubic spline functions for representing the follower displacement and found that cubic splines are more convenient and simpler to use compared to general spline functions and also result in smaller peak acceleration and jerk due to the application of the minimum norm principle. Yu and Lee (1995) employed B-splines for unsymmetrical Cam design in particular piecewise continuous polynomials to have continuous derivatives up to any order and often need only cubic functions regardless of the number of constraints present. Masood and Lau (1998) developed a computer-aided design and manufacturing system (CAD/CAM) system using half angle search algorithm (Fig. 6) for design of complex Cam profiles within a user specified tolerance for optimization of CNC part programming of Cam profile.

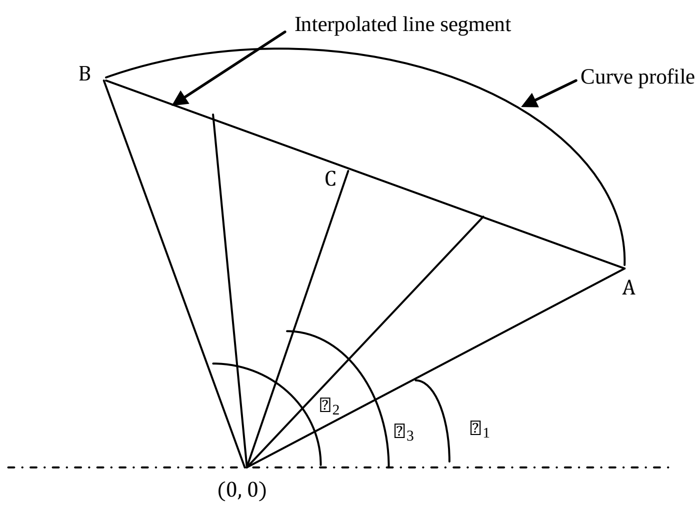

Fig. 6 Half angle algorithm

This work includes the generation of a displacement diagram, the simulation of Cam tool path generation and the generation of actual CNC codes. Masood (1999) developed CAD/CAM system for the design and production of complex profiles for high-performance drum Cams within the specified tolerance. Developed system graphically generates the Cam profile on the cylindrical drum after performing an analysis of the kinematic performance for eight different type of follower motion, using a B-spline representation of follower curves. Kim et *al*. (2002) presented the kinematic performance based on the criteria of achieving the lowest levels of velocity and acceleration for each curve. The optimal synthesis for a Cam with non-constant angular velocity has been presented based on the dynamic model of a complete spring-actuated Cam system. They optimized follower motion using a cubic spline to satisfy asymmetric constraints and guarantee continuous contact at the Cam-follower interface and verified that the dynamic behavior of the optimized Cam is superior to polynomial Cams. Kuang et *al*. (2004) developed dynamic equations of the intermittent-motion of a Globoidal Cam-driven system and studied the effects of roller mesh flexibility and Cam profile curve on the residual vibration of a Globoidal Cam system experimentally and numerically. Time varying roller mesh stiffness and damping coefficients have been used to account for the periodic variation of the mesh stiffness in the dwell and the active periods respectively. Qiu et *al*. (2005) proposed a universal optimal approach to Cam curve design. It consists of four issues that include a Cam curve description using uniform B-splines, an objective function in a universal weighting form to integrate the design requirements, an automatic adjusting technique for weighting coefficient values and an improved complex search algorithm to optimize the control points of B-splines. This approach is useful to deal simultaneously with multiple objectives for either kinematical or dynamic optimization. Some specific examples were presented on both kinematical and dynamical optimization of Cam curves together with detailed discussions which sufficiently illustrate the effectiveness of the proposed approach. Demeulenaere and De Schutter (2007) introduced a novel design procedure that explicitly takes into account the Camshaft speed variation and inertially compensated Cams, of which the motion law is adapted to the Camshaft speed fluctuation. Nguyen et *al*. (2009) developed a new method to smoothen existing Cam profiles which is based on modified spline curves that constrain displacement, velocity and acceleration at boundaries so that boundary values of the smoothed Cam event can be connected exactly with the original motions up to the second order derivatives. High frequency components and excessive jerks in a Cam profile, which are important sources of Cam-follower vibration, can be reduced by profile smoothing. Sateesh et *al*. (2009) generated a new follower velocity curve by using cubic B-spline with six control

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points. This velocity curves are represented by following equations for the three segments of Cam and follower motion

$$V_1(u) = (3u^2 - u^3 - 3u + 1)V_0 + \{(7u^3/4) - (9u^2/2) + 3u\}V_1 + \{(3u^2/2) - (11u^3/12)\}V_2 + (u^3/6)V_3$$

$$V_2(u) = \{(3u^2/2) - (u^3/4) - 3u + 2\}\ V_1 + \{(7u^3/12) - 3u^2 + (9u/2) - (3/2)\}V_2 + \{(9u^2/4) - (7u^3/12) - (9u/4) + (3/4)\}V_3 + \{(u^3/4) - (3u^4/4) + (3u/4) - (1/4)\}V_4$$

$$V_3(u) = \{-(u^3/6) + (3u^2/2) - (9u/2) + (9/2)\}V_2 + \{(11u^3/12) - (27u^2/4) + (63u/4) - (45/4)\}V_3 + \{-(7u^3/4) + (45u^2/4) - (93u/4) + (63/4)\}V_4 + \{u^3 - 6u^2 + 12u - 8\}V_5 \quad (10)$$

They have developed a CAD/CAM system by approximating various basic curves which have better motion characteristics in design of follower velocity curve which graphically and numerically generate follower motion curves, i.e. displacement, velocity, acceleration, jerk and Cam profiles shown in Fig. 7.

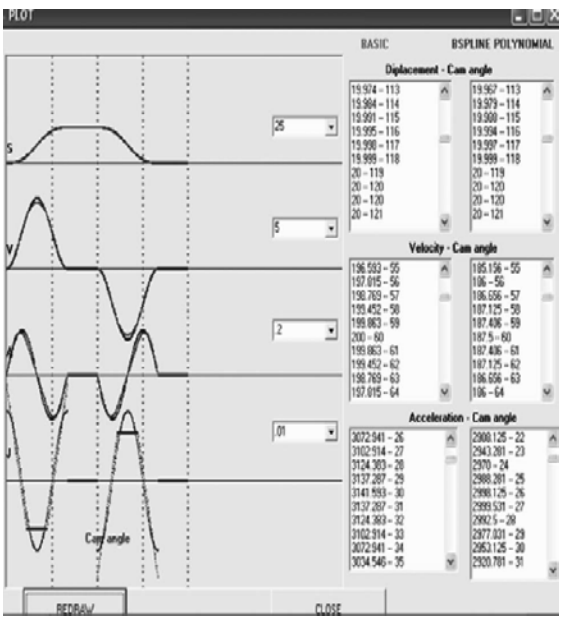

Fig. 7 Cam-follower characteristics for basic (cycloidal motion) curve and its approximate B-spline curve.

The maximum acceleration found in their work is less than that of other basic motion programs. Xiao and Zu (2009) developed a complex Cam shape optimization problems to optimize a unique Cam mechanism for a new Cam drive engine by using both a classical optimization technique and a genetic algorithm (GA) based method to solve the complex optimization problem. They used a combination of the B-spline representation and the GA-based method to generate the best profiles. Jiang and Iwai (2009) developed an improved B-spline method with a variety of Cam design requirements and reduced residual vibrations. Jamkhande et *al*. (2012) discussed The impact of various Cam profile options designed using Polydyne, N-Harmonic and B-Spline methodologies on a field problem of Cam wear for high speed engine application is discussed. B-spline curve algorithm is adopted for Cam profile design of High Speed engines in order to control excessive jerks which were the major cause of vibrations.

3.3 Non Uniform Rational B-splines (NURBS)

NURBS are the generalization of B-spline that is invariant under projective transformations. NURBS, like B-spline, are defined by some control points and knot vector. The difference being that control points are specified in homogeneous co-ordinates. A NURBS curves can be mathematically expressed as (Tiller, 1983).

$$P(u) = \sum_{i=1}^{k} R_{i,n}(u) P_i \quad (11)$$

where, $R_{i,n}$ = Rational basis function which can be expressed as:

$$R_{i,n}(u) = \frac{N_{i,n}(u) w_i}{\sum_{j=1}^{k} N_{j,n}(u) w_i} \quad (12)$$

with k=Number of control points P_i and
w_i = Corresponding weight.

Some researchers have used these curves as a replacement of B-spline curves for improving the design characteristics. NURBS has been used for curve and surface representation (Tiller, 1983). A typical survey on the NURBS is presented by Piegl (1991). Tsay and Huey (1993) developed a Cam-follower motion programs using rational B-spline functions. It differs from earlier techniques that employ spline functions by using rational B-spline basis functions to interpolate motion constraints. Their proposed rational B-splines permit greater flexibility in refining motion programs. Some examples were given to illustrate application of their approach. Tsay and Lin (1996) presented a procedure for the synthesis and analysis of the surface geometry of cylindrical Cams with oscillating roller followers by using NURBS to refine the DRD motion. To justify the method, they compared maximum acceleration and velocity of B-spline Cams with those using traditional curves of cycloidal and modified sine types. Tsay and Hwang (1996) developed a tool to synthesize the motion functions of the Camoids follower mechanisms using non-parametric B-splines. Neamtu et *al*. (1998) designed Non-Uniform Rational B-Splines (NURBS) Cam profiles using trigonometric splines and discussed the design of Cams with various conditions of practical interest, such as interpolation conditions, constant diameter, minimal acceleration or jerk and constant dwells. In contrast to general Polynomial curves, these NURBS curves have the useful property that offset are of the same type, and hence also have an exact NURBS representation.

4 Conclusions

This paper survey the past and present research in the field of Cam design for low as well as high speed machinery requirements using analytical and synthetic motion curves. The nature of curve improves the design, performance & machining propertied of Cams. From current reviews it has been noticed that Cam design has changed dramatically over the past two decades by taking the advantage of the tremendous advance of computing devices and mathematics tools especially for splines. In recent year, the trend of modern Cam design is that splines are replacing polynomials as the mathematical representation of the Cam profile because of their versatility, ease of application and flexibility. Follower motion curve shape can be easily changed by varying the control points that define the curve. Follower motion characteristics can further be improved by making the existing B spline polynomial more smooth & flexible by increasing its degree. Other synthetic curves like Bezier, NURBS helps for increasing the accuracy of Cam profile.

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