Development of an Integrated System for Cam Profile Generation and Manufacturing using SLS Process

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Abstract- **CAM mechanisms are widely used in automatic machines because of their high speed, stability and reliability motion transmissions. Requirements for high performance of such machines are demand efficient methods for the design and manufacture of cams. Conventional methods of design and machining cam profile within a given accuracy are tedious and time consuming. Generally Simple Harmonic, Cycloidal, 3-4-5 polynomial and 4-5-6-7 polynomials are used for cam profile generations. Cycloidal motion has the smoothest motion among all of the basic curves, and therefore, it is suitable for high-speed applications. The paper work aims to development of an integrated system for cam profile generation and manufacturing using Selective Laser Sintering (SLS) process. The system is developed in three phases. In the first phase two types of cam profiles viz. Cycloidal and Bezier curves are generated. The corresponding coding is done in JAVA. The output obtained from the first phase is used as input for the second phase. In the second phase the 3D CAM profile model of the Cycloidal and Bezier curves are developing in CATIA. Then it is converted into STL file. The STL file obtained from the second phase is used as input for the third phase. In the third phase the Cycloidal and Bezier 3D CAM profile models are manufacturing using Selective Laser Sintering (SLS) Rapid Prototyping (RP) machine.**

Keywords – **Bezier, Cycloidal, CAM, SLS.**

I. INTRODUCTION

Cam mechanisms are widely used in automatic machines because of their high speed, stability and reliability motion transmissions. Requirements for high performance of such machines are demand efficient methods for the design and manufacture of cams. Conventional methods (e.g. CNC) of design and machining cam profile within a given accuracy are tedious and time consuming.

A plate cam is a disc cam which is cut out of a piece of flat metal or plate and used to transform a rotary motion into a translating or oscillating motion to its follower. Applications of these cams found in packaging machines, wire-forming machines and Internal Combustion engines, mechanical and electrical computers.

The Bezier curve is defined in terms of the locations of n+1 control points. These points are called data or control points. The n+1 control points form n^{th} degree curve. They form the vertices of the control points called Bezier characteristic polygon which is uniquely defines the curve shape. Only the first and the last control points or vertices of the polygon actually lie on the curve. The vertices define the order, derivatives, and shape of the curve. The curve is also always tangent to the first and last polygon segments. In addition, the curve shape tends to follow the polygon shape. These three observations should enable the user to sketch or predict the curve shape once its control points are given.

Mathematically for $n+1$ control points,

the Bezier curve is defined by the following

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polynomial of degree n:

$$P(u)=\sum_{i=0}^{n} P_i B_{i,n}(u) \qquad 0 \le u \le 1$$

$P(u)$ = Point on the curve, P_i = Control point,

$B_{i,n}(u)$ = Bernstein polynomials are given by,

$$B_{i,n}(u)=C(n,i)u^i(1-u)^{n-i}$$

II. EXPERIMENTAL WORK

1. DESIGN OF CAM PROFILE

This phase discusses the generation of Cycloidal and Bezier curve CAM profiles. The code for generation of CAM profile is done using JAVA. The JAVA program is developing which generates follower motion curves (i.e. displacement, velocity, acceleration, and jerk characteristics) and cam profiles of the Bezier curve and Cycloidal curve. An approximation of the Bezier curve, equivalent to a basic Cycloidal curve is carried which has better motion. Based on maximum accelerations to select the best cam follower motion by comparing Bezier curve with basic Cycloidal curve. The system also provides cam profile coordinates to manufacture a cam on SLS machine.

1a. BEZIER DISPLACEMENT CURVE FOLLOWER CHARACTERISTICS

The program is evaluated for following typical input data.

Lift = 20mm, Rise angle = 120˚, Dwell 1 = 60˚, Return angle = 120˚, Dwell 2 = 60˚. Speed (n) =100 rpm.

The lift 20 mm is divided into six displacement control points over a range of 120˚ rise angle.

P_0 = [0, 0], P_1 = [0, 0], P_2 = [5, 30], P_3 =[15, 90], P_4 = [20, 120], P_5 = [20, 120]

Figure 1.Input data of the Bezier displacement curve

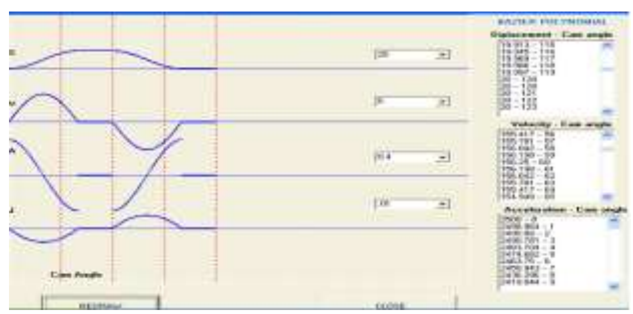

Figure 2. Graphical and numerical representation of Bezier curve follower characteristics

1b. COMPARISON BETWEEN BEZIER AND CYCLOIDAL CURVES

A JAVA program is developed, which provides graphical and numerical representation of basic Cycloidal curve and their approximated Bezier curve. The input data and control points are same.

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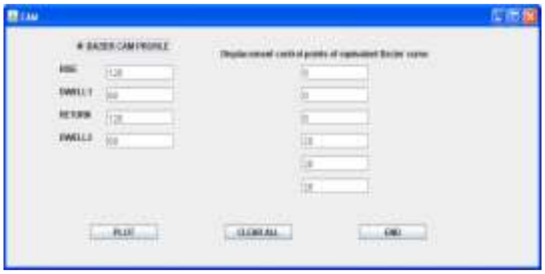

Figure 3. Input data for Cycloidal motion curve and its approximated Bezier curve

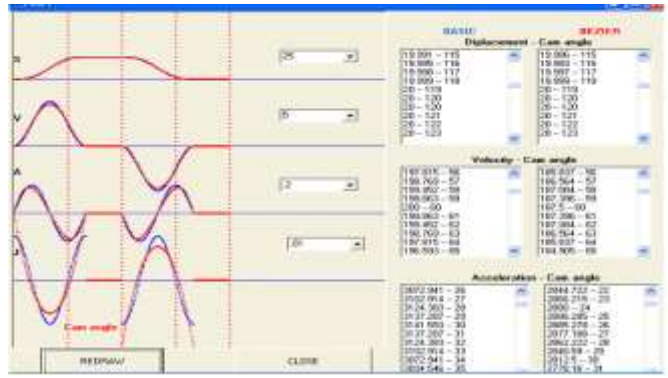

Figure 4. Graphical and numerical representation of Cycloidal motion and its approximated Bezier motion follower characteristics

1c. BEZIER CAM PROFILE

A JAVA program developed to generate Bezier cam profile graphically and numerically.

Input Data Selected for the Development of Bezier CAM Profile

Lift in mm, Rise angle in degrees, Dwell1 angle in degrees, Return angle in degrees, Dwell 2 angle in degrees, Prime circle radius in mm, Type of follower, Bezier curve displacement control points.

Using cam profile equations and below input data, JAVA program is developed.
The JAVA program provides two dimensional (2D) cam profile graphically and its Cartesian co-ordinates (X, Y) about the cam centre numerically. The program is tested to generate the Bezier cam profile which has follower characteristics better than the Cycloidal motion. Rise angle =120˚, Dwell 1 = 60˚, Return angle= 120˚, Dwell 2 = 60˚, Prime circle radius = 30 mm, Follower = Translating roller follower.

The lift 20mm is divided into six Bezier displacement control points.

P_0 = [0, 0], P_1 = [0, 0], P_2 = [0, 0], P_3 = [20, 120], P_4 = [20, 120], P_5 = [20, 120]

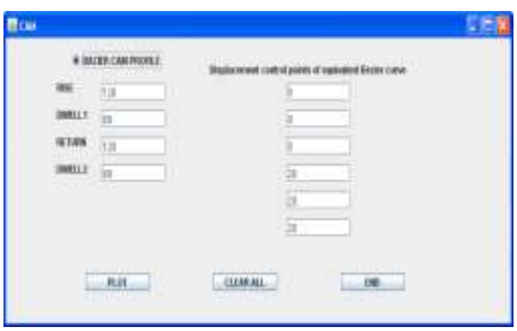

Figure 5. Input data for Bezier cam profile

Figure 6. Input data for Bezier cam profile

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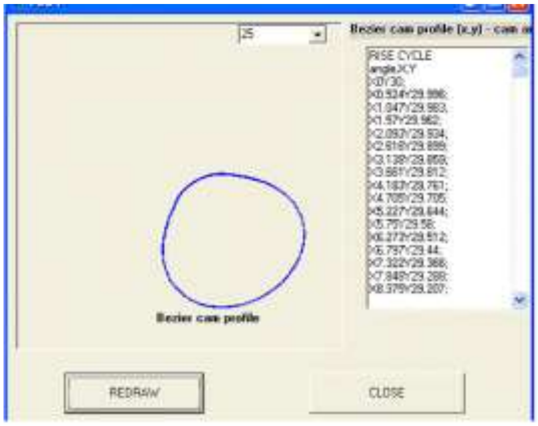

Figure 7.Graphical and numerical representation of Cycloidal motion equivalent Bezier cam profile (pitch profile and its x, y coordinates in mm).

1d. CYCLOIDAL CAM PROFILE

A JAVA program developed to generate Cycloidal cam profile graphically and numerically as above same manner.

Figure 8. Input data for Cycloidal motion cam profile

Figure 9. Input data for Cycloidal motion cam profile

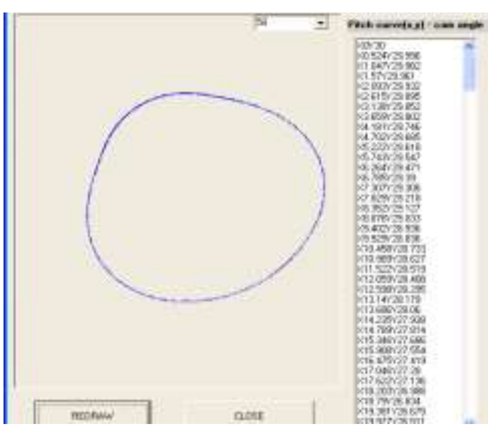

Figure10.Graphical and numerical representation of cycloidal cam profile and its x, y coordinates in mm.

2. 3D MODELLING OF CAM PROFILE

This phase discusses the development of integrated system for CAM profile generation. The 3D model of the CAM for Bezier and Cycloidal profiles is developing using CATIA V5R20.

The following procedure is adopted for generating the CAM profiles (i.e. Bezier and Cycloidal).

Step 1: The 2D coordinates (X, Y) values of Bezier obtained as output from first phase are entered in the CATIA software.

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Step 2: All 360 coordinates (X, Y) means element point coordinates and converting into construction element point coordinates.

Step 3: Using PROFILE icon connects all points and select EXIT WORKBENCH icon.

Step 4: Then using PAD icon convert from 2D Bezier cam profile to 3D solid Bezier cam profile model.

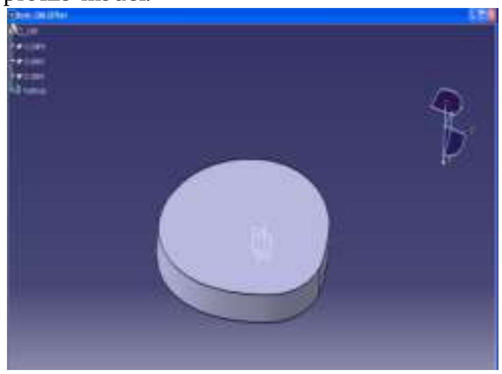

Figure 11.A Bezier cam profile model in CATIA V5R20.

Step 5: 3D solid Bezier cam profile model convert into STL file format and can be transferred directly to the SLS machine through MAGICS software.

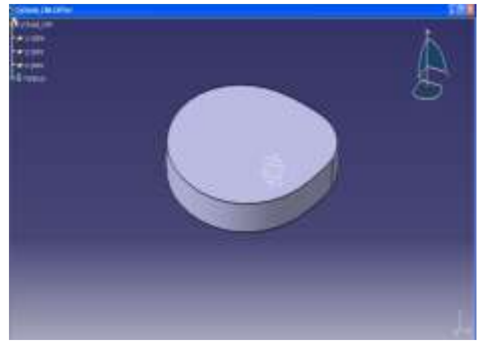

Figure 12.A Cycloidal cam profile model in CATIA V5R20.

3. MANUFACTURING OF CAM USING SLS PROCESS

This phase discusses the development of integrated system for CAM profile generation. The Rapid Prototyping (RP) 3D model of the Bezier and Cycloidal profiles is manufacturing using FORMIGA P100 SLS machine through MAGICS software. Conventional methods (e.g. CNC) of design and machining CAM profile within a given accuracy are tedious and time consuming. These are overcome using SLS method.

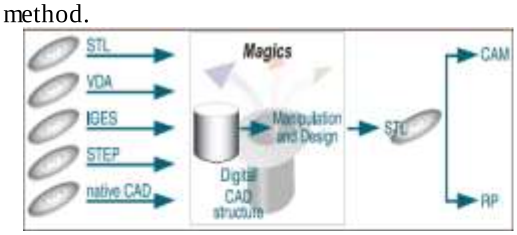

Figure 13. Overview of MAGICS–RP.

Preparing the part - The CAM profile models developed must first be aligned and positioned in software MAGICS-RP software. There are some special aspects that must be taken into account for the laser sintering process. After this, the CAM profile models data is transformed into layer data using the EOS RP-Tools.

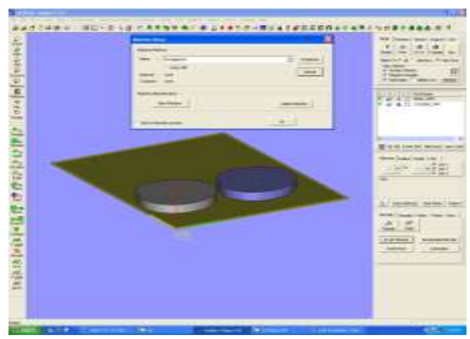

Figure 14. Orientation of CAM models in MAGICS

EOS RP-Tools - EOS RP-Tools are used for preparing CAM models data in STL format or layer data in CLI format for the building process. During this process the data are converted into layer data in the EOS SLI format with the file extension ".sli".

The following work sequence is employed for the preparation of the CAM models:

(1) Slice the 3D CAM model using the Slicer module.
(2) Analyze and rectify data errors using the Slifix module.
(3) If necessary, generate skin/core using the Skincore module.

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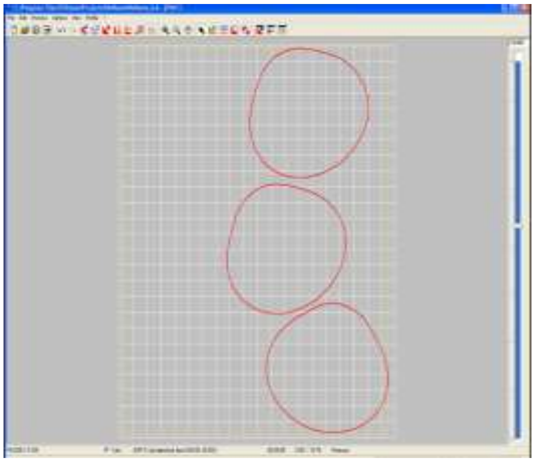

Figure 15. Loading the CAM models in PSW

Figure 16. RP Model of Cycloidal CAM on SLS process

Figure 17. RP Model of Bezier CAM on SLS process

III. RESULT AND DISCUSSIONS

The paper work deals with the development of an integrated system for cam profile generation and manufacturing using SLS process. The system is developed in three phases. In the first phase two types of cam profiles viz. Cycloidal and Bezier curves are generated. The corresponding coding is done in JAVA. The output obtained from the first phase is used as input for the second phase. In the second phase the 3D model of the Cycloidal and Bezier curves are developed in CATIA. Then it is converted into STL file. The output obtained from the second phase is used as input for the third phase. In the third phase to manufactured both Cycloidal and Bezier CAM models on SLS machine through MAGICS software.

The results are adopted in the following way.

In the first phase using JAVA, the graphical and numerical two dimensional (2D) Bezier cam profile and Cycloidal cam profile coordinates (X, Y) for each angle of cam rotation (0˚ to 360˚). All these 360 coordinates can be selected from the output figures and stored as a text file.

The below Table-1 shows the maximum acceleration of basic Cycloidal motion and Bezier motion for different cam speeds (100rpm, 200rpm, and 500rpm). Cycloidal curve has maximum acceleration of **3141.55 mm/sec^2** and that of Bezier curve of **2838.38 mm/sec^2** for cam speed of 100 rpm. Since Bezier curve has low maximum acceleration and continuous curve for the follower compared to basic Cycloidal, the jerk of the follower is minimum which is also clear from the Figure 4.

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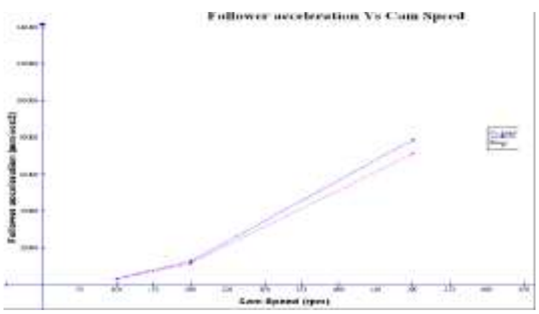
Type of Motion	Maximum Acceleration(mm/sec2)		
Cam Speed (rpm)	100	200	500
Cycloidal curve	3141.55	12557.37	78537.71
Bezier curve	2838.38	11545.41	70927.41

Table -1 Experiment Result

As cam speed increases, the difference in maximum acceleration values between Cycloidal curve and Bezier curve also increases. For 100 rpm the percent decreases by **9.65%** and 500 rpm the percent decreases by **9.69%.** That is, if speed increases the Bezier motion characteristics will also improve.



The graph shows the Cam speed Vs Follower maximum acceleration.

IV. CONCLUSIONS

The development of an integrated system for cam profile generation and manufacturing using Selective Laser Sintering (SLS) process is presented in this project work. The system is developed in three phases.

The Bezier and Cycloidal displacement curves are developed for CAM profile generation. The Bezier polynomial of 5^{th} degree i.e. six control points is used in design of cam-follower displacement curve. A follower displacement curve is developed by varying displacement control points for a given lift. Keeping the same lift and varying the displacement control points an optimum acceleration curve shape is obtained in improving the cam-follower performance. Basic Cycloidal motion approximated Bezier motion is obtained which low jerk has compared to the basic Cycloidal motion. The maximum acceleration of basic Cycloidal motion and Bezier motion for different cam speeds (100 rpm, 200 rpm, and 500 rpm). Cycloidal curve has maximum acceleration of **3141.55 mm/sec^2** and that of Bezier curve of **2838.38 mm/sec^2** for cam speed of 100 rpm. Since Bezier curve has low maximum acceleration and continuous curve for the follower compared to basic Cycloidal, the jerk of the follower is minimum. As cam speed increases, the difference in maximum acceleration values between Cycloidal curve and Bezier curve also increases. For 100 rpm the percent decreases by **9.65%** and 500 rpm the percent decreases by **9.69%.** That is, if speed increases the Bezier motion characteristics will also improve.

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