# The Development of CAD Software for Manufacturing Flat-face and Roller Cam Systems

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Abstract. Computers have made the greatest impact in the advancement and development of almost all aspect of human endeavour, particularly in the engineering field. In this research, effort is geared towards improving the universal design and final manufacturing of commercial cams in many automotive and other related companies around the world. A software package for the design and profile simulation of plate cams with a possible choice of two followers (Roller and Flat-Face) using eight standard cam motions for over one hundred and eighty-nine different follower profiles has been developed. The developed software provides the tools to analyze critical aspects of cam design before physical prototyping or production of such cams and followers, thereby increasing their reliability and performance. The developed software does not only remove the tedium associated with cam design process but also speeds it up dramatically thereby making the process of comparative design analysis and optimization easier and faster.



## Introduction

The general objective of this work is to assist cam designers and manufacturers design cams in less time by developing a Computer-Aided Design (CAD) software package that could be used for better design analysis; and to generate good cam profiles having smooth dynamics at their operating speeds. The required versatility and flexibility in the design of cam systems due to the different types of cams, followers, follower profiles and cam motions in existence underlies the need for the development of application software to handle their design, analysis and simulation. It is in this context that the present research work has been undertaken. The software developed for the design of cam in this research work has overcome notable problems in cam design as various profiles can be synthesized and tested within seconds during the design and manufacturing stages respectively.

Works have been done in almost all aspects relating to cam systems since their invention and introduction into the engineering world. Some of these works include; computational approach to profile generation of planar cam mechanisms [1]; object oriented cam design through internet [2]; profile simulation software for trigonometric and polynomial cams design, [3]; the development of an analysis-intensive software for improved cams systems design [4]; design and simulation algorithm for cam system analysis [5]; synthesis of inertially compensated variable-speed cams [6]; dynamically compensated cams for rigid forces [7]

## Design Steps and Manufacturing Criteria for Cam Systems

Cams have been said, over the years, to be easy to design but hard to make [8]. This is because various tests must be carried out on the cam systems at the manufacturing stage before their final production; one of such is the profile test for discontinuity. This test involves the generation of several profiles of a particular cam (using various input design criteria) so as to see if there are discontinuities in their profiles. Synthesized cam systems with noticed discontinuities on the profiles of higher derivatives of motion such as acceleration will be inadequate for high-speed operations because of resulting high vibrations. Thus the process of designing, prototyping and manufacturing an adequate cam will naturally take a very long time if these profiles have to be generated repeatedly during the process of test for discontinuity.

The design combination considered in this work covers plate cam with two follower types (flat-face and roller), one follower-frame output motion, eight motion segments and eight cam motions. This means that for the plate cam, any of the two followers can be chosen. Also for any of the followers chosen the reciprocating follower/frame output is chosen for design. Furthermore for the follower-frame output motion any of the motion segments between two-eight can be selected for design. The design choice finally ends with the choice of any of the eight cam motions for each of the selected motion segments. This gives a 1 x 2 x 1 x 8 x 8 (i.e.128) design combinations.

The design of plate cams using flat-face follower are discussed in six steps. (i) *Obtaining input specification:* The input parameters necessary for design are the follower displacement profile; type of cam motion; the lift value (L); the cam angle(θ) ; the increment of cam (β) (ii) *Calculating values of follower displacements and their derivatives:* These values are the values of displacement (y), velocity (y'), and acceleration (y") The follower displacements and derivatives are obtained for the different cam motions using the cam angle increment specified. The smaller the increment, the better the final overall designs. (iii) *Determining minimum and maximum values of y, y', y"*. These minimum and maximum parameters are used to obtain the prime circle radius ($R_o$) and follower face width ($F_w$). (iv) *Estimating the values for prime circle radius and follower face width:* The prime circle radius Ro and follower face width Fw are calculated. (v) *Generating the cam coordinates:* the rectangular coordinates of the cam profile are generated, (vi) *Plotting generated values of follower motions and cam coordinates.* The parameters y, y', y" are plotted against cam angle to produce the follower motion profiles, while the rectangular coordinates (u against v) are plotted to give the cam profile.

Equations 1(a) – (b) and 2(a) – (b) are those for obtaining *y, y' and y"* for the 3-4-5 and 4-5-6-7 Polynomial cam motions respectively [11]. Other cam motions handled by the developed software are cycloid, Simple harmonic, modified harmonic, double harmonic, modified trapezoidal, 4-5-6-7 Polynomial and 8th order Polynomial [3, 4, 5, 8, 9, 10].

$$y = h\left[10\left(\frac{\theta}{\beta}\right)^3 - 15\left(\frac{\theta}{\beta}\right)^4 + 6\left(\frac{\theta}{\beta}\right)^5\right]$$

$$y' = \frac{h}{\beta}\left[30\left(\frac{\theta}{\beta}\right)^2 - 60\left(\frac{\theta}{\beta}\right)^3 + 30\left(\frac{\theta}{\beta}\right)^4\right] \qquad \text{(Rise motion) ............. (1a)}$$

$$y'' = \frac{h}{\beta^2}\left[60\left(\frac{\theta}{\beta}\right) - 180\left(\frac{\theta}{\beta}\right)^2 + 120\left(\frac{\theta}{\beta}\right)^3\right]$$

$$y = h\left[1 - 10\left(\frac{\theta}{\beta}\right)^3 - 15\left(\frac{\theta}{\beta}\right)^4 + 6\left(\frac{\theta}{\beta}\right)^5\right]$$

$$y' = -\frac{h}{\beta}\left[30\left(\frac{\theta}{\beta}\right)^2 - 60\left(\frac{\theta}{\beta}\right)^3 + 30\left(\frac{\theta}{\beta}\right)^4\right] \qquad \text{(Return motion) .......... (1b)}$$

$$y'' = -\frac{h}{\beta^2}\left[60\left(\frac{\theta}{\beta}\right) - 180\left(\frac{\theta}{\beta}\right)^2 + 120\left(\frac{\theta}{\beta}\right)^3\right]$$

$$y = L\left[35\left(\frac{\theta}{\beta}\right)^4 - 84\left(\frac{\theta}{\beta}\right)^5 + 70\left(\frac{\theta}{\beta}\right)^6 - 20\left(\frac{\theta}{\beta}\right)^7\right]$$

$$y' = \frac{L}{\beta}\left[140\left(\frac{\theta}{\beta}\right)^3 - 420\left(\frac{\theta}{\beta}\right)^4 + 420\left(\frac{\theta}{\beta}\right)^5 - 140\left(\frac{\theta}{\beta}\right)^6\right] \qquad \text{(RISE MOTION)......... (2A)}$$

$$y'' = \frac{L}{\beta^2}\left[420\left(\frac{\theta}{\beta}\right)^2 - 1680\left(\frac{\theta}{\beta}\right)^3 + 2100\left(\frac{\theta}{\beta}\right)^4 - 840\left(\frac{\theta}{\beta}\right)^5\right]$$

$$y = h\left[1 - 35\left(\frac{\theta}{\beta}\right)^4 - 84\left(\frac{\theta}{\beta}\right)^5 + 70\left(\frac{\theta}{\beta}\right)^6 - 20\left(\frac{\theta}{\beta}\right)^7\right]$$

$$y' = -\frac{h}{\beta}\left[140\left(\frac{\theta}{\beta}\right)^3 - 420\left(\frac{\theta}{\beta}\right)^4 + 420\left(\frac{\theta}{\beta}\right)^5 - 140\left(\frac{\theta}{\beta}\right)^6\right] \qquad \text{(Rise motion).......... (2b)}$$

$$y'' = -\frac{h}{\beta^2}\left[420\left(\frac{\theta}{\beta}\right)^2 - 1680\left(\frac{\theta}{\beta}\right)^3 + 2100\left(\frac{\theta}{\beta}\right)^4 - 840\left(\frac{\theta}{\beta}\right)^5\right]$$

Where y is the follower displacement, h is maximum lift on displacement graph for follower motion; θ is angle of cam rotation; β is angular intervals between stages of cam angles or follower motion. Equations 3, 4, 5 and 6 are used in calculating $R_o$, $F_w$, coordinates u and v respectively [12].

$$Face\ Width > y'(max) - y'(min) \quad \ldots\ldots\ldots\ldots (3)$$

$$Ro > (\rho min - y - y'')max \quad \ldots\ldots\ldots\ldots (4)$$

$$u = (Ro + y)\sin\theta + y'\cos(\theta) \quad \ldots\ldots\ldots\ldots (5)$$

$$v = (Ro + y)\cos\theta - y'\sin(\theta) \quad \ldots\ldots\ldots\ldots (6)$$

Considering the roller follower design option, the basic geometric parameters needed as input/output values are: Pressure angle ϕ, Prime circle radius $R_o$, Radius of the roller follower $R_r$ and Cam coordinates u, v. All these parameters are calculated with equations 7, 8, 9, 10 and 11 respectively. Where ε is the eccentricity and $\rho min$ is the minimum radius of curvature for cam profile.

$$\phi = \tan^{-1}\frac{y' - \varepsilon}{\sqrt{Ro^2 - \varepsilon^2 + y}} \quad \ldots\ldots\ldots\ldots (7)$$

$$Ro = \left(\left[\frac{y' - \varepsilon - y(\tan\theta)}{\tan\theta}\right]^2 + \varepsilon^2\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (8)$$

$$R_r = \frac{\left[(R_o + y)^2 + (y')^2\right]^{3/2}}{\left[\ (R_o + y)^2 + 2(y')^2 - (R_o + y)y''\ \right]} - \rho_{min} \quad \ldots\ldots (9)$$

$$u = \left(\sqrt{R_o - \varepsilon^2} + y\ \right)\sin\theta + \varepsilon\cos + R_r\sin(\phi - \theta\ ) \ldots\ldots (10)$$

$$v = \left(\sqrt{R_o - \varepsilon^2} + y\ \right)\sin\theta - \varepsilon\cos - R_r\sin(\phi - \theta\ ) \ldots\ldots (11)$$

**Software Design**

The structure of the software algorithm (Fig. 1) was implemented using the Visual Basic (VB) [13} for setting up the menu and performing computations. The 3 D and $2^1/_2$ D models were generated using VB while the Excel was used in producing life scale profiles. The following are distinct features of developed software when compared with others. (i) Ability to design for both rotational and linear follower motion derivatives for simulations performed. (ii) Segment by segment application of limitless choice of increment in generating cam and follower profiles and calculation of other design parameters. This means it is possible to vary the increments used within the different segments. (iii) Generation of $2^1/_2$ D model of all cams for the flat-face follower option. (iv) Distinct demarcation of different motion segments on every generated cam profile as shown in screen shots. (v) Limitless choice of degree increment in generating cam and follower profiles and in calculating all design parameters.

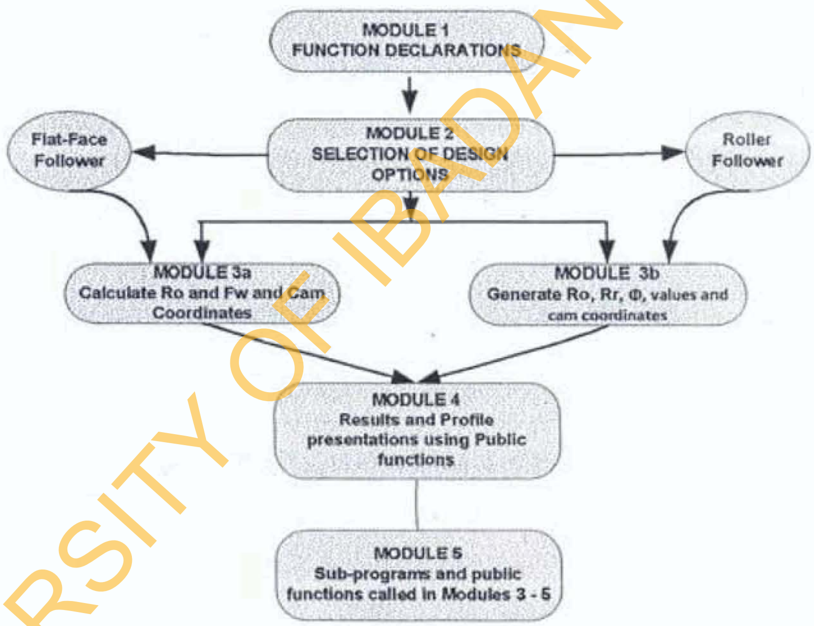


Figure 1: Structure and Modules of Software Algorithm

**Software Application and Results**

The software was applied in designing a four segmented motion (dwell-rise-dwell-return) for flat-face follower (Figs. 2and 3). The roller cam profile was also designed for a 6-segmentd motion (Fig. 4). The results obtained using the software compared favourably with those from literature with standard deviations ranging between 2.25% and 1.50%. The cusps appearing in figure 3 is eliminated at life size scale and by change of cam angles and increment.

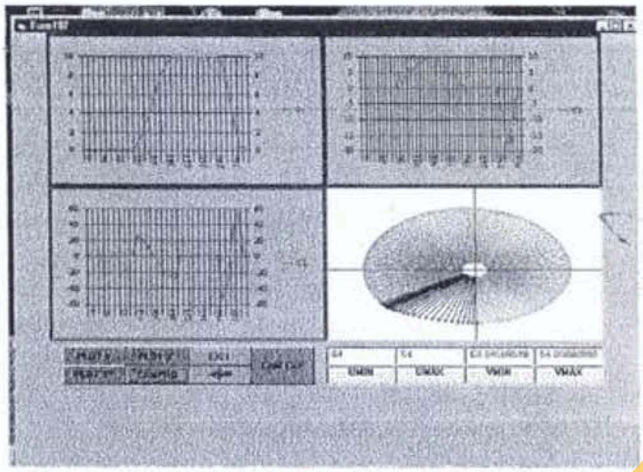


Figure 2 Display of Y, Y', Y" and cam Profile for 4-segmented motion (flat-face follower)

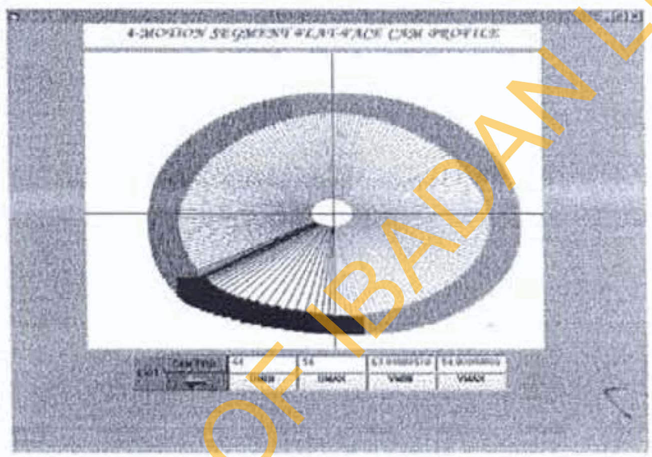


Figure 3: 2 $\frac{1}{2}$ D graphics display of cam profile for 4-segment motion (flat-face follower)

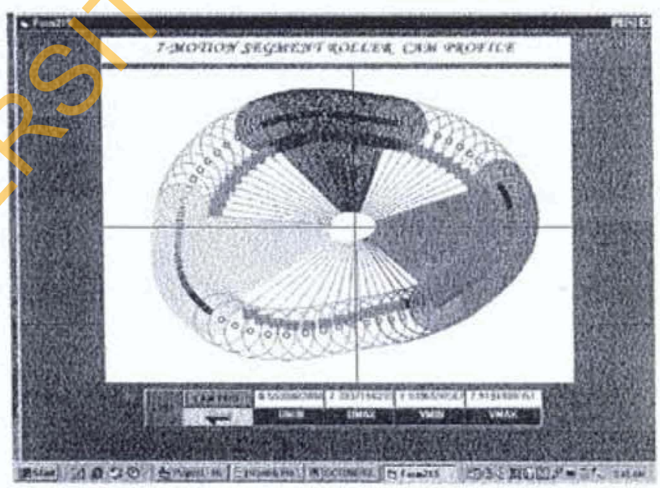


Figure 4: Segment application of different degree increment on Cartesian Plot of Roller Cam Profile For 6-Segment Motion

**Summary**

A Computer-Aided Design (CAD) package that can be used to assist cam designers and manufacturers in designing cams in lesser time has been developed. The software is configured to give better design analysis and to generate profiles that finally converge to good cams having smooth dynamics at their operating speeds. The many design combinations, repetition of calculations coupled with plotting of hundreds of cam and follower profile points involved in cam systems design has justified the need for the development of the software. The software design algorithm entailed the use of standard trigonometric and polynomial cam functions in simulating the follower motion derivatives; determining the follower and cam design parameters; generating the cam coordinates; and finally drawing the follower motions and cam profiles.

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