DESIGN AND SIMULATION ALGORITHM FOR CAM SYSTEM ANALYSIS

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ABSTRACT

Computational algorithm and various computer aided methods are now routinely being used in the design of numerous kinds of engineering systems, subsystems and components. In particular some of these computational methods perform dynamic and kinematics analysis of mechanisms. In this work an algorithm for the design and profile simulation of plate cams with flat-face followers using standard cam motions has been developed. The developed algorithm computes the two critical design output parameters among others namely; the prime circle radius and follower face width, and finally generates the cam coordinates for the cam profile being designed. The design algorithm developed in this work makes the design of cam systems less tedious, thereby, making various extensive studies on the comparative design analysis of such systems possible.

Key Words: Cam, Design, Algorithm, Simulation.

1.0 INTRODUCTION

The role of cams in modern machinery is of great importance. The contemporary designer in the field of machine systems centralization is faced with requirements for increased speed and reliability of operation. Such systems require intricate and precise positioning of the various elements throughout the cycle in a prescribed manner. One of the various methods by which the moving parts of such systems could be controlled is by the use of various mechanically constrained systems one of which is the cam system.

In cam design, the motion of the cam and its follower are normally prescribed. The designer needs not only to select the type of cam- follower combination required to produce those motions, but also the critical dimensions of both cam and follower. The computer algorithm described in this work could be extended to provide considerable flexibility in the choice of cam and follower types as well as their motions. Thereby, for a given plate cam and follower type, the methods when adapted allow the user to choose from different combinations of cam motions and follower motions. This is seen in works carried out on the effect of design parameters on cam profile (Simolowo and Udoh, 2003) and the computer aided design of cams (Udoh, 2001).

2. GENERAL DESIGN METHOD-OLOGY

In this section, the description of design procedures for cam profiles is done for an arbitrarily selected cam having the following design criteria.

(i) **Type of cam:-** Planer/Plate cam

(ii) **Type of follower:-** Reciprocating Flat- Face Follower.

(iii) **Type of cam motion:-** Simple Harmonic Motion

(iv) **Type of follower motion:-** Dwell (0^o-200^o); Rise (200^o-280^o); Dwell (280^o - 300^o) Return (300^o-360^o).

(v) **Maximum lift:-** 9.57mm.

The Simple Harmonic cam motion equation used in explaining the cam design procedure is given below (Shigley and Mishke, 1990) In the equations listed below; L= Maximum lift on displacement graph for follower motion ; θ = Angles of cam rotation and β= Angular intervals between stages of cam angles or follower motion.

Rise:

$$Y = \frac{L}{2}\left(1 - \cos\frac{\pi\theta}{\beta}\right);\ y = \frac{\pi L}{2\beta}\sin\frac{\pi\theta}{\beta};$$

$$y^{ii} = \frac{\pi^2 L}{2\beta^2}\cos\frac{\pi\theta}{\beta} \qquad (1)$$

Return:

$$y = \frac{L}{2}\left(1 + \cos\frac{\pi\theta}{\beta}\right);\ y = -\frac{\pi L}{2\beta}\sin\frac{\pi\theta}{\beta};$$

$$y^{ii} = -\frac{\pi^2 L}{2\beta^2}\cos\frac{\pi\theta}{\beta} \qquad (2)$$

2.1 Generation of Follower Motion Curves

First Dwell :- (0^o - 200^o) or (0 - 10π/9 radians)

Since, at this stage, the follower dwells for 10π/9 radians, i.e. For $0^o < \theta < 200^o$, Y=0 thus,

Y = Y' = Y" = 0

Rise :- (200^o - 280^o) or (10π/9 - 14π/9 radians)

The values of Y, Y^I, Y^{II} are generated using equation (1) for $200^o < \theta < 280^o$ in steps of 20^0.

β = 80^o (the cam angle interval for the rise motion)

Second Dwell :- (280^o - 300^o) or (14π/9 – 15/9π radians)

At this stage the follower dwells for π/9 rads. i.e. for $280^o < \theta < 300^o$, Y=L thus Y' = Y"= 0

Return :- (300^0 - 360^0) or ($15\pi/9$ - 2π radians)

The Return equation of the Simple Harmonic cam motion of sample study given as equation (2) above is applied at this stage. The values of Y, Y', and Y" are also generated for $300^0 < \theta < 360$

$\beta = 60^0$ (the cam angle interval for the return-motion)

2.2 Determination of design output parameters

Prime circle radius (Ro)

The equation for obtaining the prime circle radius is given as (shigley & Uicker) ;

$$Ro > (\rho min - Y - Y'' min) \quad \ldots\ldots\ldots\ldots \{3\}$$

Y is that at Y" min obtained from the values generated in section (2.1)

Follower face width (Fw)

The equation for obtaining the Follower face width is given as (shigley & Uicker);

$$Fw > y' max - y' min \quad \ldots\ldots\ldots\ldots\ldots \{4\}$$

2.3 Generation of cam coordinates

The equations used for generating the cam coordinates in all the stages of the follower motion are given below.

$$u = (Ro+Y) \sin\theta + Y'\cos(\theta) \quad \ldots\ldots\ldots\ldots\ldots \{5\}$$

$$v = (Ro+Y) \sin\theta + Y' \sin(\theta) \quad \ldots\ldots\ldots\ldots\ldots \{6\}$$

These values of u and v are also calculated for all cam angles (θ) from 0^0 - 360^0 for the four stages D-R-D-R as considered in section (2.1) in steps of 20^0 cam angles.

3. DEVELOPMENT OF COMPUTATIONAL ALGORITHM

The choice of an appropriate high-level language begins the process of developing a computational algorithm for the design and analysis of cams. The FORTRAN (Borse, 1991) was initially used to write the program algorithm while the C high-level language was later employed in the development of a more versatile software (Simolowo, 2004) for the design of cam profiles. The summary of flow chart for the developed program algorithm using the FOTRAN language (Olaniyi, 1997) is presented in the appendix.

3.1 Program Divisions and Description

The developed program algorithm is categorized into three parts as explained below.

(1) Input Design Values

The input values for the developed program includes;

The cam angle intervals based on the type of follower motion. These are represented by β_1 (first dwell motion); β_2 (rise motion); β_3 (second dwell motion); β_4 (return motion).

(i) Maximum displacement (L)

(ii) Minimum radius of curvature (ρ_{min})

(2) **Internally generated Values**

The values computed and generated by the program algorithm consist of the following.

(i) Follower motion profiles

(ii) Cam geometry coordinates

The follower motion profile parameters are the displacement (Y), velocity (Y^I) and acceleration (Y^{II}) for all cam angle intervals. These are calculated based on equations (1) and {2}. Also applying equations (5) and (6) the cam profile design coordinates u, v are computed and generated for the final plotting of the cam geometry being designed.

(3) **The output design parameters**

These include the prime circle radius Ro, and the follower face width Fw, and the Cam profile (geometry). Ro and Fw are determined using equations (3) and (4) where Y_{max}, Y_{min}, Y^I_{max}, Y^{II}_{min} are selected from values generated internally for the follower motion profiles. The cam coordinates generated internally are plotted to give the geometry (profile) of the cam.

3.2 Program Sequence

The sequence of the program operations is:

1. Start with first cam angle θ for the first stage of follower motion.
2. Compute the values for Y, Y', Y" from equations (1) and (2) for the first stage of Follower motion.
3. Determine Y'min., Y'max., Y"min
4. Calculate the next cam angle from step 1.
5. Compute the values for Y, Y', Y" from equations (1) and (2) for the next stage of Follower motion
6. Repeat steps 3-5 for 360°
7. Compute Ro and Fw using equations (3) and (4).
8. Compute cam coordinates U and V using equations (5) and (6).

3.3 Sample Designs and Simulations

In this section sample designs are carried out using the finally developed program. The plate cam with flat face follower described by the eight-order polynomial cam motion is hereby chosen arbitrarily for the sample simulations. Presented below are the follower profiles and cam angles chosen.

(a) Sample design specifications (1)

Follower motion:- Dwell (0°-200°); Rise (200°-280°); Dwell (280°- 300°); Return (300°–360°).

(b) Sample design specifications (2)

Follower motion:- Rise (0°-200°); Return (200°-360°)

(c) Sample design specifications (3)

Follower motion:- Dwell - Dwell (0° - 200°); Rise (200° -210°); Return (210°-360°)

4. RESULTS PRESENTATION

Shown in table (1) are the results obtained for the sample designs presented above using the final algorithm developed. Tables (2)-(4) and figures (1)-(6) are the results and profiles for the sample designs:

5. CONCLUSION

The main objective of this work which is to make the procedure in cam design less cumbersome and faster has been achieved. The algorithm for cam design developed in this project is applicable to plate cams with flat-[illegible] extended in its use to medium and low speed cams. However the high speed cams have been designed for in this work.

The development of the design algorithm has aided the commencement of comparative analysis of cam systems thereby resulting in more predictive design outputs. Sample simulated profiles in cam design using the developed computer algorithm and application software have been generated and presented in this paper as to show the extent of its design capabilities.

This project carried out has made the procedures involved in the design of an important system in automobile industries appreciable. Complete production and machining of the cam and its follower can be achieved by carrying out further works in stress analysis to determine the appropriate material to be used.

REFERENCES

(1) Shigley J.E. and Mishke C.R. (1990): "Mechanical Engineering Workbook on Mechanisms". McGraw Hill Book Company, New York..

(2) Olaniyi M. O. (1997): "Cam Design: Computer Approach". A Bachelor of [illegible] Department of Mechanical Engineering, University of Ibadan, Nigeria. (Unpublished).

(3) Borse G. J. (1991): "FORTRAN 77 and Numerical Methods for Engineers". PWS KENT Publishing Company, Boston.

(4) Udoh E. M. (2001): "Computer Aided Design of Cams" A Bachelor of Science Project. Department of Mechanical Engineering, University of Ibadan, Nigeria. (Unpublished).

(5) Simolowo O. E. & Udoh (2003): "Effect of Design Parameters on Cam Profiles" Nigerian Journal of Engineering Research and Development, Volume 1 No.2 Pages 33-42. Besade Publishing Press. Ondo, Nigeria.

(6) Shigley J.E. and Uicker J.J. (1980): "Theory of Machines and Mechanisms". McGraw-Hill Book Company.

(7) Simolowo O. E. (2004): Computer Aided Design of Cam Profiles. Master of Philosophy Dissertation. Department of Mechanical Engineering, University of Ibadan, Nigeria. (Unpublished)

Table 1: Design Results for Sample Designs

Sample design	Cam motion	Foll. motion	Ro(mm)	Fw (mm)	Y'max (mm/rad)	Y' min(mm/rad)
1	Eight-Order-polynomial	D-R-D-R	45.995937	34.252720	16.23632	-16.236359
2	Eight-Order-polynomial	D-R-R	55.722019	33.76537	13.708088	-18.277449
3	Eight-Order-polynomial	R-R	46.000546	21.263632	3.247272	-16.236359

Table 2: Design Results for Sample designs (1)

Degree	Lift	Beta(deg	Y(mm)	Y'(mm\rad	Y"(mm\rad)	U (mm)	V (mm)
0	0.00	220	0.0000	0.0000	0.0000	0.000000	46.000000
20	0.00	220	0.0000	0.0000	0.0000	15.732962	43.225848
40	0.00	220	0.0000	0.0000	0.0000	29.568288	35.237996
60	0.00	220	0.0000	0.0000	0.0000	39.837225	22.999902
80	0.00	220	0.0000	0.0000	0.0000	45.301183	7.987668
100	0.00	220	0.0000	0.0000	0.0000	45.301124	-7.988001
120	0.00	220	0.0000	0.0000	0.0000	39.837056	-23.000195
140	0.00	220	0.0000	0.0000	0.0000	29.568029	-35.238213
160	0.00	220	0.0000	0.0000	0.0000	15.732644	-43.225963
180	0.00	220	0.0000	0.0000	0.0000	-0.000338	-46.000000
200	0.00	220	0.0000	0.0000	0.0000	-15.733279	-43.225732
240	9.57	80	0.7726	5.9779	25.8292	-43.495405	-18.208925
260	9.57	80	4.1554	12.0834	4.1276	-51.491621	3.191015
280	9.57	80	8.0245	8.5990	-20.9860	-51.710335	17.850166
300	9.57	80	9.5700	-0.0009	-25.8610	-48.425122	27.784843
320	9.57	60	6.8938	-14.2823	26.4106	-44.939976	31.339061
340	9.57	60	1.6380	-11.7752	-39.6825	-27.357600	40.738076
360	9.57	60	0.0000	0.0000	0.0000	0.000676	46.000000

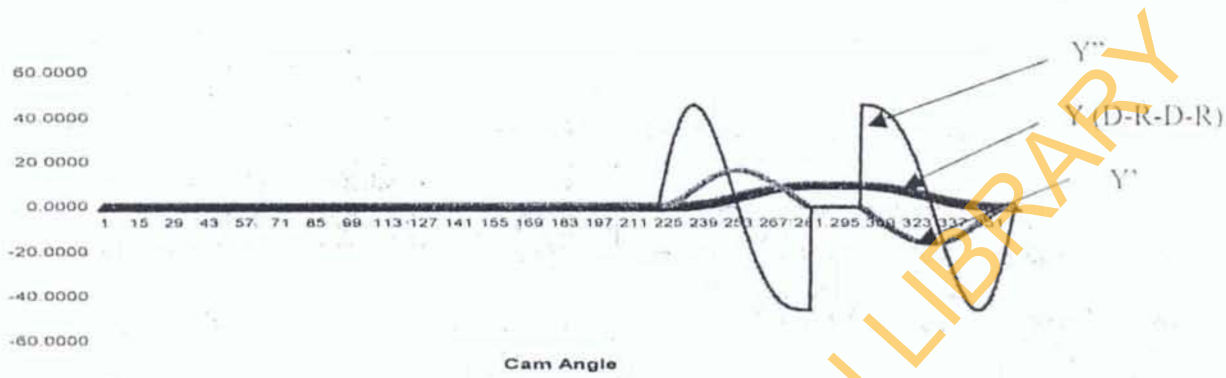

Figure 1: Motion profiles for sample design (1)

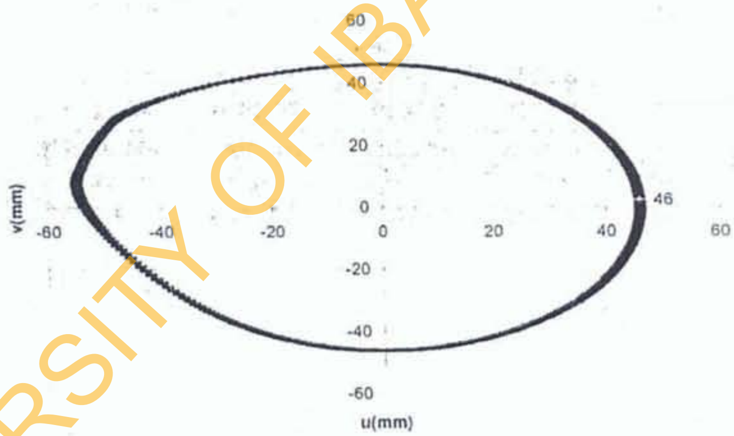

Figure 2: Cam Profile for sample design (1)

Table 3: Design Results for Sample designs (2)

Degree	Lift	Beta(deg	Y(mm)	Y'(mm\rad	Y"(mm\rad)	u	v
0	0.00	220	0.0000	0.0000	0.0000	0.000000	46.000000
20	0.00	220	0.0000	0.0000	0.0000	15.732962	43.225848
40	0.00	220	0.0000	0.0000	0.0000	29.568288	35.237996
60	0.00	220	0.0000	0.0000	0.0000	39.837225	22.999902
80	0.00	220	0.0000	0.0000	0.0000	45.301183	7.987668
100	0.00	220	0.0000	0.0000	0.0000	45.301124	-7.988001
120	0.00	220	0.0000	0.0000	0.0000	39.837056	-23.000195
140	0.00	220	0.0000	0.0000	0.0000	29.568029	-35.238213
160	0.00	220	0.0000	0.0000	0.0000	15.732644	-43.225963
180	0.00	220	0.0000	0.0000	0.0000	-0.000338	-46.000000
200	0.00	220	0.0000	0.0000	0.0000	-15.733279	-43.225732
240	9.57	80	0.7726	5.9779	25.8292	-43.495405	-18.208925
260	9.57	80	4.1554	12.0834	4.1276	-51.491621	3.191015
280	9.57	80	8.0245	8.5990	-20.9860	-51.710335	17.850166
300	9.57	80	9.5700	-0.0009	-25.8610	-48.125122	27.784843
320	9.57	60	6.8938	-14.2823	26.4106	-44.939976	31.339061
340	9.57	60	1.6380	-11.7752	-39.6825	-27.357600	40.738076
360	9.57	60	0.0000	0.0000	0.0000	0.000676	46.000000

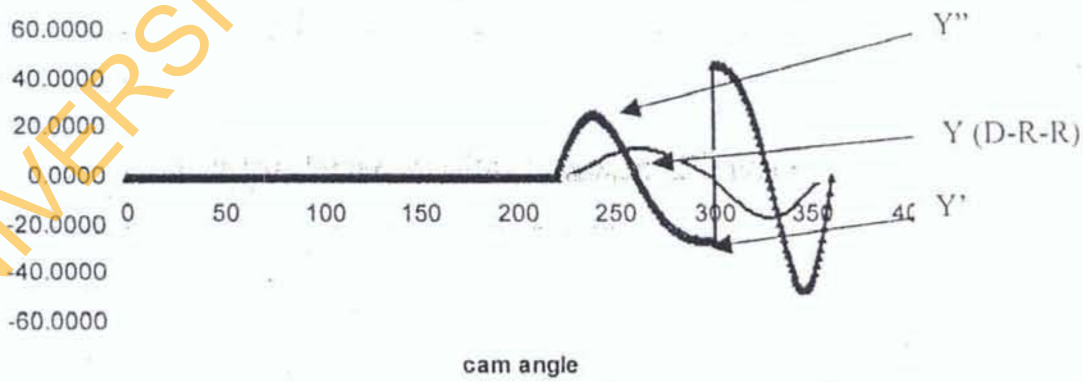

Figure 3: Motion profiles for sample design (2)

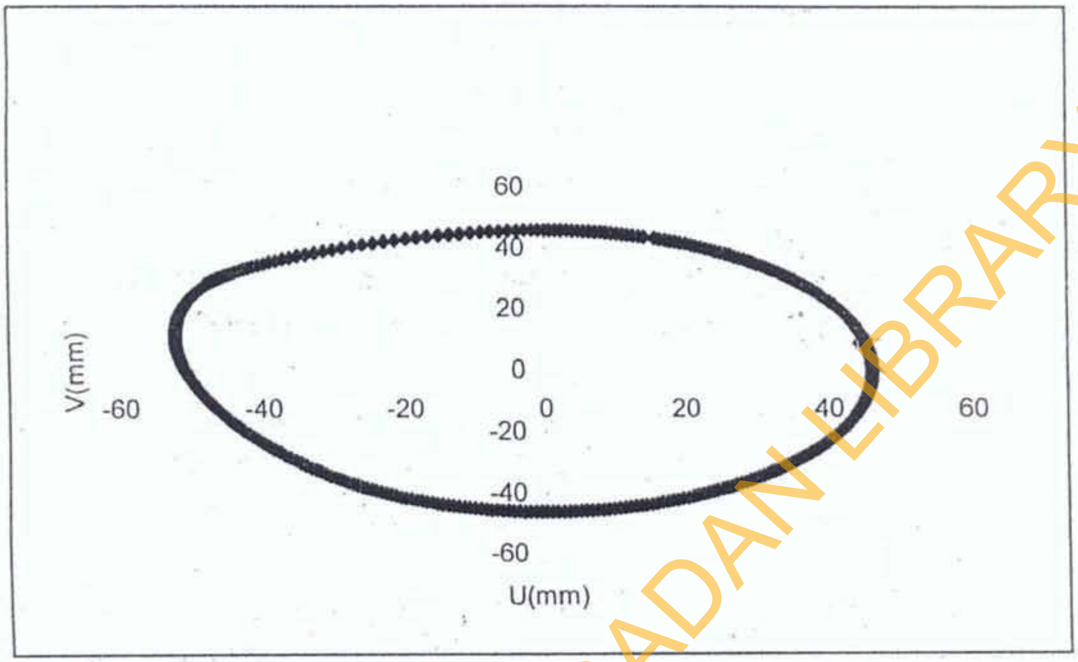

Figure 4: Cam profile for sample design (2)

Table 4: Design Results for Sample designs (3)

Degrees	Lift	Beta(deg)	Y(mm)	Y'(mm\rad)	Y"(mm\rad)	Ro(mm)	U (mm)	V (mm)
0	9.57	280	0.0000	0.0000	0.0000	46.00	0.000000	46.000000
20	9.57	280	0.0209	0.1780	0.9944	46.00	15.907414	43.184624
40	9.57	280	0.1603	0.6635	1.7295	46.00	30.179589	34.934330
60	9.57	280	0.5065	1.3406	2.0825	46.00	40.946154	22.092183
80	9.57	280	1.1024	2.0711	2.0410	46.00	46.746470	6.139422
100	9.57	280	1.9436	2.7265	1.6658	46.00	46.741700	-11.010534
120	9.57	280	2.9853	3.2071	1.0589	46.00	40.818882	-27.270266
140	9.57	280	4.1550	3.4524	0.3372	46.00	29.594091	-40.640259
160	9.57	280	5.3657	3.4421	-0.3886	46.00	14.333285	-49.445297
180	9.57	280	6.5299	3.1911	-1.0292	46.00	-3.191484	-52.529876
200	9.57	280	7.5702	2.7404	-1.5265	46.00	-20.897577	-49.402084
220	9.57	280	8.4262	2.1448	-1.8582	46.00	-36.627842	-40.313893
240	9.57	280	9.0573	1.4610	-2.0367	46.00	-48.411796	-26.262909
260	9.57	280	9.4414	0.7361	-2.1022	46.00	-54.727086	-8.901779
280	9.57	280	9.5700	0.0000	-2.1111	46.00	-54.725661	9.650231
300	0.00	20	9.5700	0.0000	0.0000	46.00	-48.124691	27.785589
320	9.57	60	6.8938	-14.2823	26.4106	46.00	-44.939976	31.339061
340	9.57	60	1.6380	-11.7752	-39.6825	46.00	-27.357600	40.738076
360	9.57	60	0.0000	0.0000	0.0000	46.00	0.000676	46.000000

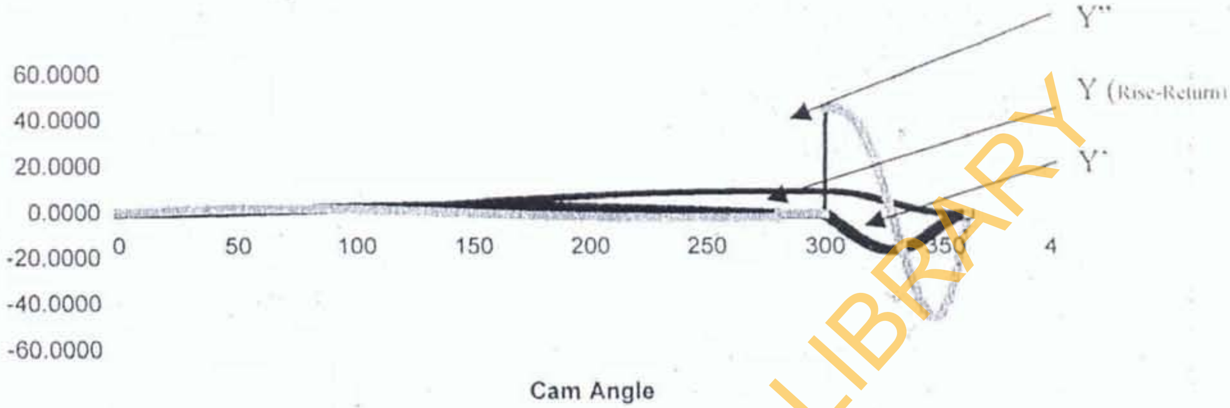

Figure 5:- Motion Profiles for Sample design 3

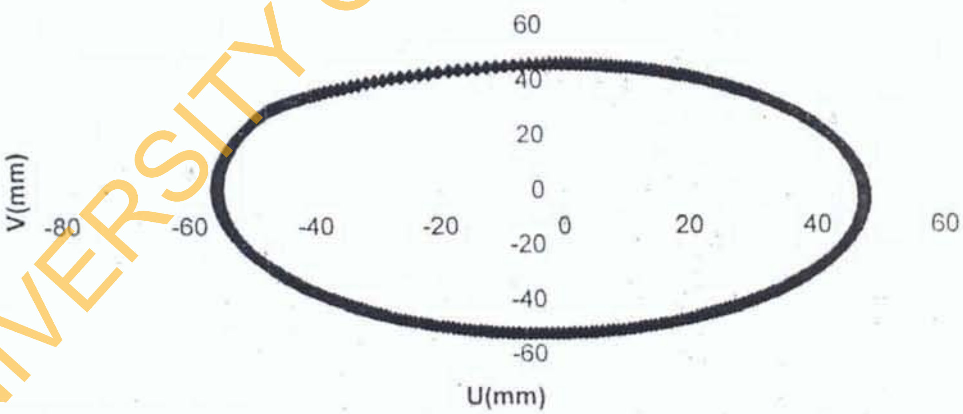

Figure 6: Cam Profile for Sample Design 3

APPENDIX

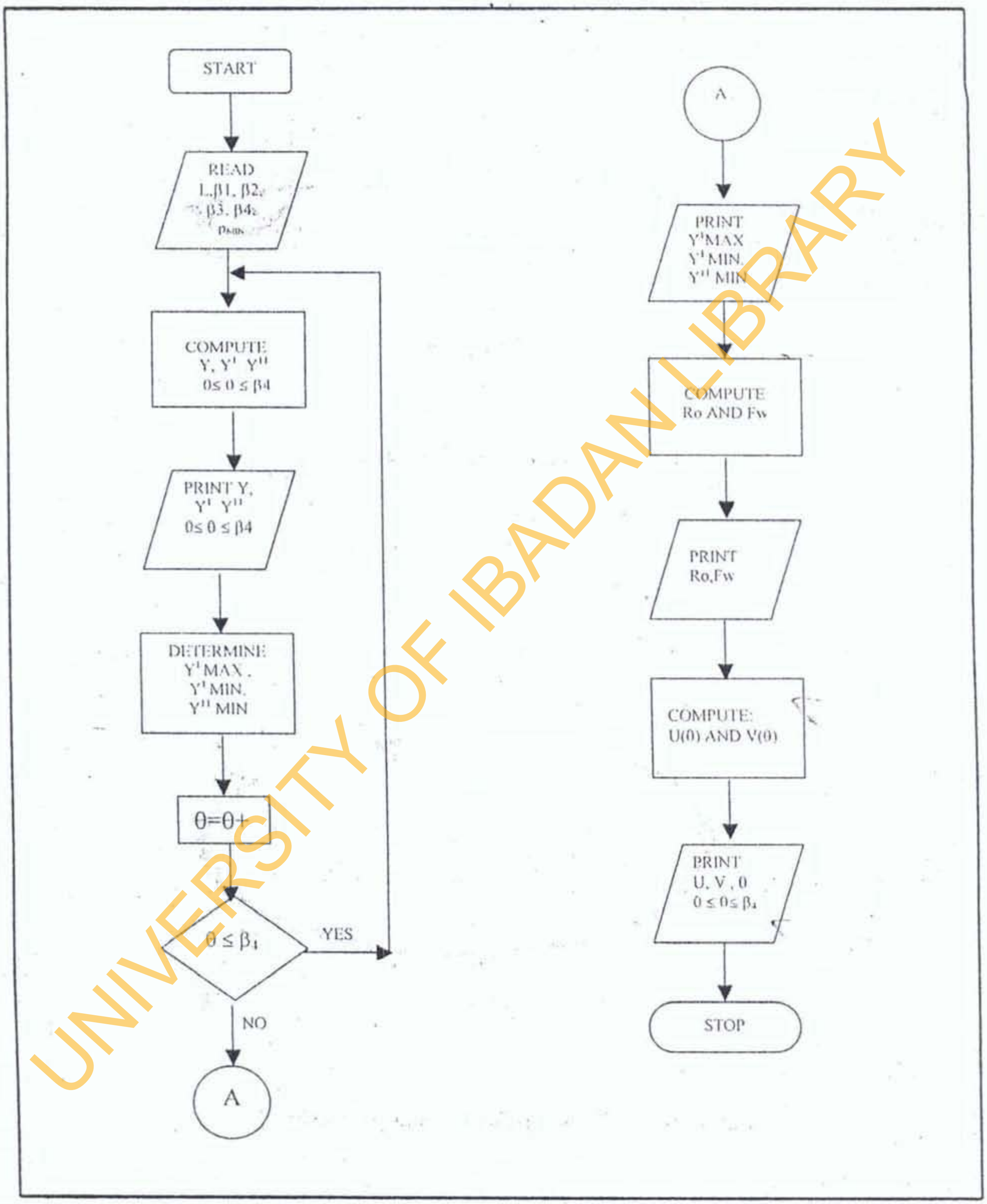

Figure 1: Main flow chart for cam design algorithm