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EFFECT OF DESIGN PARAMETERS ON CAM PROFILES

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ABSTRACT

In the process of generating a cam profile, input parameters such as lift, maximum allowable pressure angle, eccentricity and roller radius are subjected to variations. These variations are done in order to arrive at optimum output design parameters, cam profiles and ultimately optimum cam design. A computer aided analysis of cam profiles with eight – order – polynomial motion using a roller follower and having a Dwell – Rise – Return displacement profile has therefore being carried out in this work. The analysis, in a similar procedure, is also applicable to cam profiles with different standard cam motions, followers, displacement profiles and cam angles. The followers lift, maximum allowable pressure angle, eccentricity and roller radius were varied within and outside design limits and their effects analysed on the generated cam profiles and other design parameters. Optimum values for the parameters considered were obtained from the result of the variation analysis, while characteristic changes were also observed from the generated cam profiles.

Key words :- Cam Profile, Computer Analysis, Design Parameters.

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1.0 INTRODUCTION

Over the years, cam mechanisms have always played important roles in the synchronization, control and timing of various engineering systems, of which the internal combustion engine is one of the prominent areas of application. This work is based on studies that have been conducted in distant past and recent years on the design of cam mechanisms (Virgil, 1965; Tessar et al, 1976 : Oledzki, 1980; Shigley et al, 1990). These earlier works have shown that the design, synthesis and analysis of cam systems involve many steps, calculations, iterations and variation of parameters to arrive at optimum design.

An invaluable input to cam design and analysis has been made in this work by developing a computer aided method of designing and analyzing cam profiles (Olaniyi, 1997; Udoh, 2001) based on some of the standard equations developed earlier on (Shigley et al, 1995). Though the computer method developed is capable of analyzing designs for different displacement profiles, the analysis for the eight – order polynomial motion with Dwell-Rise-Dwell-Return (D-R-D-R) displacement profile using the reciprocating roller follower is here presented.

Various parameters such as lift, maximum allowable pressure angle, eccentricity and roller radius are inputted into the computer program that generates cam profiles and their effects on such profiles are observed with the aim of obtaining optimum design values.

2.0 OVERVIEW DESIGN METHODOLOGY FOR CAM PROFILES

The procedures to be followed in the design of cams with roller follower describing the eight order polynomial motion are:

I. Evaluation of the follower motion derivatives for various values of cam rotational angles θ
II. Generation of varying pressure angles Φ.
III. Choice of maximum pressure angle Φ_{max} and the determination of Prime Circle radius R_o
IV. Generation of varying radii of curvature.

V. Determination of maximum allowable radius of follower.
VI. Generation of coordinates of the cam of the cam profile u and v.
VII. Plotting of cam profile.

2.1 Evaluation of the Follower Motion Derivatives

The equations for the displacement y, first and second derivatives y^{1} and y^{11} of the eight order polynomial motion are as follows. For full rise motion:

$$y = L\,[6.09755(\theta/\beta)^3 - 20.78040(\theta/\beta)^5 + 26.73155(\theta/\beta)^6 - 13.60965(\theta/\beta)^7 + 2.56095(\theta/\beta)^8] \quad ...(1)$$

$$y^{1} = L/\beta[(18.29265(\theta/\beta)^2 - 103.90200(\theta/\beta)^4 + 160.3893(\theta/\beta)^5 - 95.26755(\theta/\beta)^6 + 10.48760(\theta/\beta)^7] \quad ...(2)$$

$$y^{11} = L/\beta^2\,[36.58530(\theta/\beta) - 415.6080(\theta/\beta)^3 + 801.94650(\theta/\beta)^4 - 571.60530(\theta/\beta)^5 + 143.41320(\theta/\beta)^6] \quad ...(3)$$

For full return motion:

$$y = L[1.00000 - 2.63415(\theta/\beta)^2 + 2.78055(\theta/\beta)^5 + 3.17060(\theta/\beta)^6 - 6.87795(\theta/\beta)^7 + 2.56095(\theta/\beta)^8] \quad ...(4)$$

$$y^{1} = L/\beta[\,5.2683(\theta/\beta) - 3.90275(\theta/\beta)^4 + 19.02360(\theta/\beta)^5 + 48.14565(\theta/\beta)^6 - 20.48760(\theta/\beta)^7] \quad ...(5)$$

$$y^{11} = L/\beta^2[5.26830 - 56.110(\theta/\beta)^3 - 95.11800(\theta/\beta)^4 + 288.8739(\theta/\beta)^5 - 143.41320(\theta/\beta)^6] \quad ...(6)$$

In equations (1) – (6) given above

L = maximum lift on displacement profile for follower motion

β = Angular intervals between stages of cam angles or follower motions.

2.2 Generation of Varying Pressure Angles

The pressure angle, Φ (as shown in Fig. 1) is given by (Shigley et al, 1995)

$$\Phi = \tan^{-1} (y^{1} - \varepsilon)/((R_o^{\,2} - \varepsilon^2)) + y)) \quad ...(7)$$

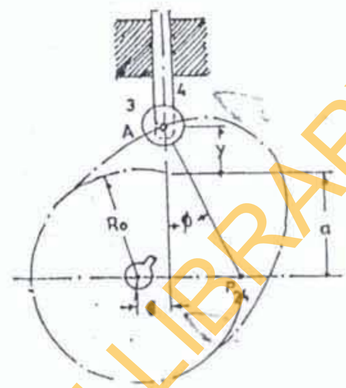

Fig. 1: Cam and roller follower at the point of contact

However, the conservative approach in which there is no eccentricity as recommended also by Shigley and Uicker is used in the generation of the pressure angles and is given as

$$\Phi = \tan^{-1} ((y^{1})/(R_o + y)) \quad ...(8)$$

2.3 Choice of Maximum Pressure Angle Φ and the Determination of The Prime Circle Radius

The maximum allowable pressure angle Φ_{max} is between 25^0 - 30^0 for the roller follower in order to avoid excessive friction, jamming of the follower and self – locking (Shigley et al, 1995). However in the course of this work, the equations inferred from Equation (8) above and used for determining the maximum pressure angle Φ_{max} and prime circle radius R_o are given below:

$$\Phi_{max} = \tan^{-1} (y^{1}_{max}/R_o) \quad ...(9)$$

$$\text{Giving } R_o = (y^{1}_{max}/\tan \Phi_{max}) \quad ...(10)$$

where in Equations (7) – (10), ε = eccentricity, y^{1}_{max} = maximum velocity

2.4 Generation of Varying Radii of Curvature

The radius of curvature of the cam profile at any point is given by:

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$[(Ro + y)^2 + (y^1)^{3/2}] / [(Ro + y)^2 + 2(y^1)^2 + (Ro + y) y^{11}]$ ...(11)

This equation is used to calculate the radius of curvature at each of the 360^0 during the rotation.

2.5 Determination of Maximum Allowable Radius of Roller Follower

The radius of the follower is chosen in such a way that it is at no time equal or greater than the absolute minimum value of the radius of curvature of cam profile. Hence, the input radius should be less than $R_{r\,max}$ given in Eqn. (12).

$R_{r\,max} = [(Ro + y)^2 + (y^1)^{3/2}] / [(R_o + y)^2 + 2(y^1)^2 + (R_o + y) y^{11}] - \rho_{min}$.........(12)

where R_r = maximum allowable roller radius. This value of R_r will avoid cusps or points on the profile and imperfect closure of cam profile. ρ_{min} is minimum radius of curvature of cam profile.

2.6 Generation of The Cam Profile Coordinates

The rectangular coordinates, u and v of the cam profile of a plate cam with reciprocating roller follower is given by:

$$u = ((Ro^2 - \varepsilon^2) + y)\sin\theta + \varepsilon\cos\theta + R - \sin(\Phi - \theta) \quad ...(13)$$

$$v = ((Ro^2 - \varepsilon^2)^{1/2} + y)\cos\theta + \varepsilon\sin\theta - R_r\cos(\Phi - \theta) \quad ...(14)$$

3.0 METHOD OF ANALYSIS

A computer program was developed using an ideal high-level language (Jesse, 1997) for analyzing the effect of the design parameters on cam profiles. The variation of the cam profile design parameters is such that as one parameter is varied, others are kept constant. During the variation of the lift, maximum allowable pressure angle, eccentricity and roller radius, the prime circle radius are not imputed but the program calculates them, so that the contribution of the four parameters on the prime circle radius circle are investigated.

Lift variation: The lift is arbitrarily varied from 20mm to 10mm in steps of 5mm and its effects on other design parameters are observed and documented.

The inputed maximum allowable pressure angle: This parameter is varied from 30 to 20 degrees in steps of 5 degrees; the variation is below the maximum practicable value, which is 30 – 35 degrees.

The eccentricity: The eccentricity is varied in steps of 5mm from 0 to 10mm. These values are below the maximum dictated by the factor $(R_o - \varepsilon^2)^{1/2}$ in the coordinate equations (13) and (14).

The roller radius: The roller radius is varied from 14mm to 38mm and 45mm. The value 14mm is far below the value suggested by the program, 38 is within design limits while 45mm is beyond design limits. The effect and contribution are observed and documented.

4.0 RESULTS OF ANALYSIS

4.1 Variation of Lift

Effect on Cam Profile: The higher the lift, the bigger the profile as evident in the increase of the prime circle radius. Variation of the lift does not introduce cusps, undercutting and incomplete closure. These profiles are shown in Fig. 2.

Effects on other Output Parameters: When the lift was increased from 10mm to 20mm, the maximum velocity and acceleration increased from 16.965mm/rad to 72.7365mm/rad and from 47.9824mm/rad to 95.9648mm/rad respectively while the prime circle radius increased from 36.38180mm to 72.73650mm. It can therefore be deduced that the lift exhibits linear and proportional relationship with the displacements, velocities, accelerations, and prime circle radii. Also, the increase in lift caused the maximum radius of curvature to rise from 1183.32mm to 2366.64mm while the suggested roller radius increased from 16.7817mm to 39.5635mm. It can therefore be further deduced that the lift varies proportionally to the radius of curvature and the suggested maximum roller radius. However, this variation does not affect the generated maximum and minimum pressure angles. The results for the analysis are presented in Table 1.

4.2 Variation of Inputed Maximum Allowable Pressure angle (Φ_{max})

Effect on Cam Profile: Increasing the maximum attainable pressure angle causes the appearance of cusps; and irregularities on the profile makes the profile smaller. These cusps and irregularities are removed and profile made bigger as the pressure angle is decreased. These effects are illustrated in Fig. 3.

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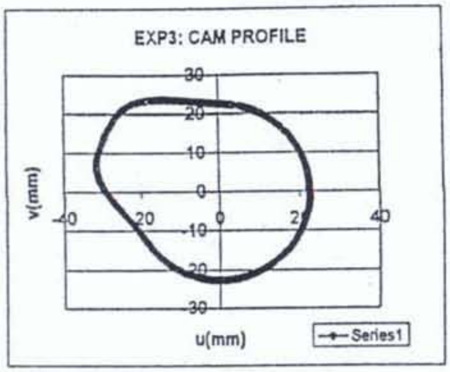
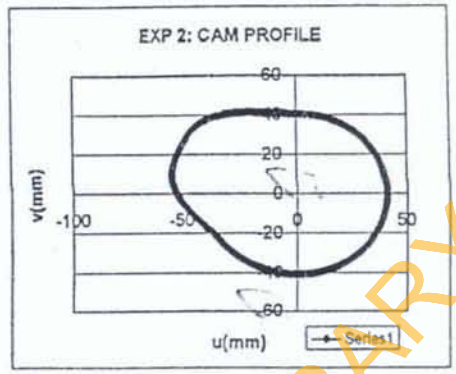
THE LIFT IS 10mm



//////////INPUT PARAMETERS//////////

FIRST DWELL 0 TO 220 degrees
RISE: 220 TO 280 degrees 36.3818mm
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY = 5 mm
ROLLER RADIUS = 14mm degrees
MAXIMUM PRESSURE ANGLE = 25 degrees
THE PRIME CIRCLE RADIUS IS = 72.7635mm

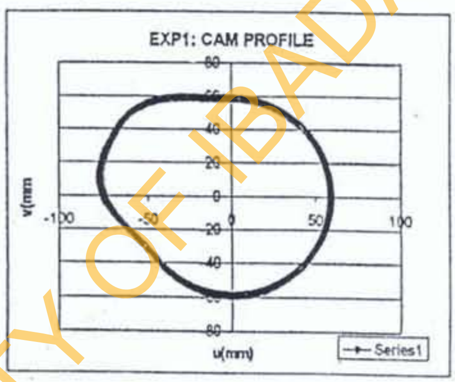
THE LIFT IS 15mm



//////////INPUT PARAMETERS//////////

FIRST DWELL 0 TO 220 degrees
RISE: 220 TO 280 degrees
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY = 5 mm
ROLLER RADIUS = 14mm degrees
MAXIMUM PRESSURE ANGLE = 25degrees
THE PRIME CIRCLE RADIUS IS 36.3518mm

THE LIFT IS 20mm



//////////INPUT PARAMETERS//////////

FIRST DWELL: 0 TO 220 degrees
RISE: 220 TO 280 degrees
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY = 5 mm
ROLLER RADIUS = 14mm degrees
MAXIMUM PRESSURE ANGLE = 25 degrees
THE PRIME CIRCLE RADIUS IS 54.5728mm

Figure 2: Effect of Variation of Lift On Cam Profiles

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Input parameters								Output parameters					
Lift (mm)	Dwell (Deg)	Rise (Deg)	Dwell (Deg)	Return (Deg)	ϕ_{max} (mm)	Eccentricity (mm)	Roller Radius (mm)	Ro (mm)	Rr (mm)	ϕ (Deg) Max Min	Velocities (mmrad^{-1}) Max Min	Accelerations (mmrad^{-2}) Max Min	Radii of Curvature (mm) Max Min
10	220	60	20	60	25	5	14	36.3818	16.781	22.4595 -22.5085	16.9651 -16.9924	47.9824 -48.0415	1183.32 -5977.94
15	220	60	20	60	25	5	14	54.5728	28.172	22.4595 -22.5085	25.4477 -25.4887	71.9736 -72.0623	1774.98 -8966.96
20	220	60	20	60	25	5	14	72.7365	39.563	22.4595 -22.5085	33.9332 -33.9849	95.9648 -96.083	2366.64 -11955.9

ϕ max: maximum allowable pressure angle Rr: maximum allowable roller radius ϕ : generated pressure angle

Table 1: Effect of lift on cam design output parameters

Input parameters								Output parameters					
ϕ_{max}	Dwell (Deg)	Rise (Deg)	Dwell (Deg)	Return (Deg)	Lift (mm)	Eccentricity (mm)	Roller Radius (mm)	Ro (mm)	Rr (mm)	ϕ (Deg) Max Min	Velocities Mmrad^{-1} Max Min	Accelerations (mmrad^{-2}) Max Min	Radii of curvature (mm) Max Min
20	220	60	20	60	20	5	14	93.32 225	55.23 34	18.3853 -183245	33.9302 33.9849	95.9648 -96.083	2366.64 -11955.9
30	220	60	20	60	20	5	14	58.76 89	29.48 45	26.5262 -26.5817	33.9302 -33.9849	95.9648 -96.083	808.367 -9558.67

ϕmax: maximum allowable pressure angle; Rr: maximum allowable roller radius; ϕ : generated pressure angles

Table 2: Effect of maximum allowable pressure angle on cam design output parameter

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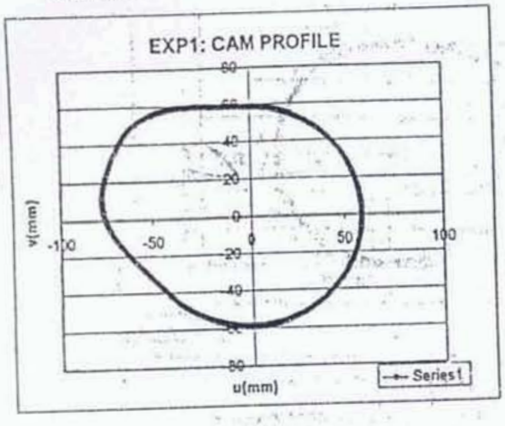
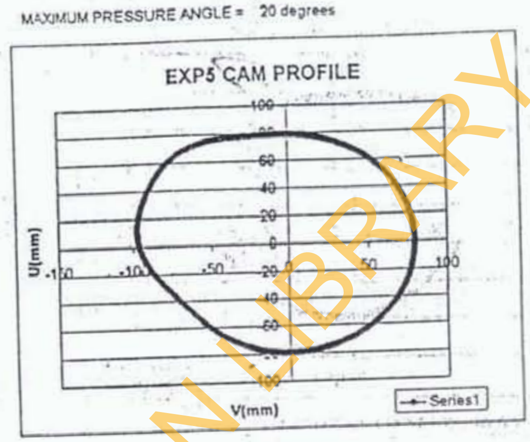
MAXIMUM PRESSURE ANGLE = 25 degrees



////////////INPUT PARAMETERS////////////

LIFT = 20mm
FIRST DWELL: 0 TO 220 degrees
RISE: 220 TO 280 degrees
LAST DWELL: 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY = 5 mm
ROLLER RADIUS = 14mm
PRIME CIRCLE RADIUS = 72.7635mm

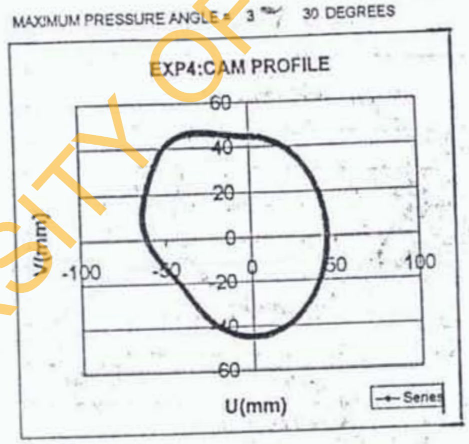
MAXIMUM PRESSURE ANGLE = 20 degrees



////////////INPUT PARAMETERS////////////

LIFT= 20mm
FIRST DWELL: 0 TO 220 degrees
RISE: 220 TO 280 degrees
LAST DWELL: 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY 5mm
SUPLLIED RADIUS = 14mm
PRIME CIRCLE RADIUS = 53.7659mm

MAXIMUM PRESSURE ANGLE = 3 30 DEGREES



////////////INPUT PARAMETERS////////////

LIFT = 20mm
FIRST DWELL: 0 TO 220 degrees
RISE: 220 TO 280 degrees
LAST DWELL: 280 TO 300 degrees
RETURN: 300 TO 360 degrees
ECCENTRICITY = 5 mm
ROLLER RADIUS = 14mm
PRIME CIRCLE RADIUS = 93.2225mm

Figure 3: Effect of Variation of Maximum Pressure Angle

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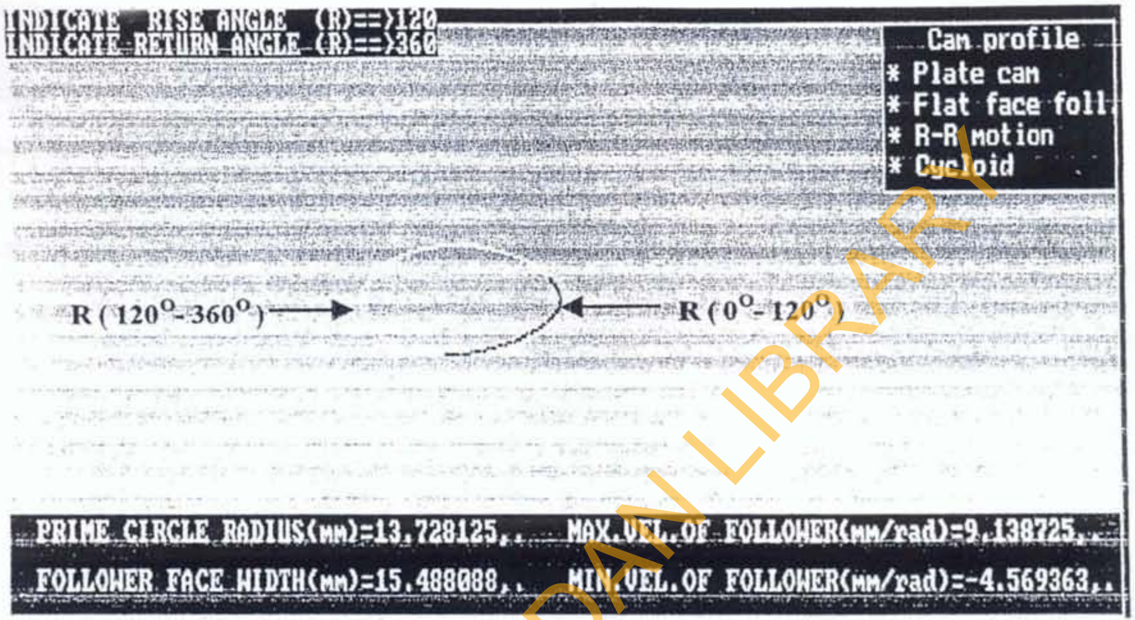

Software Output Screen Shot 3: Output cam profile for sample design 3

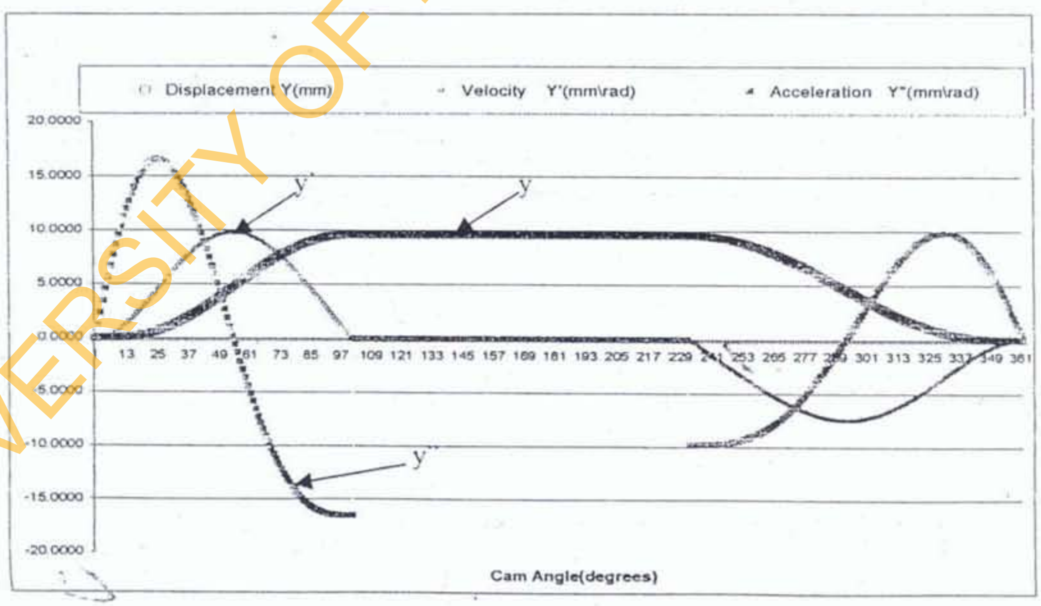

Fig. 3: Motion Profiles for Sample Design 1

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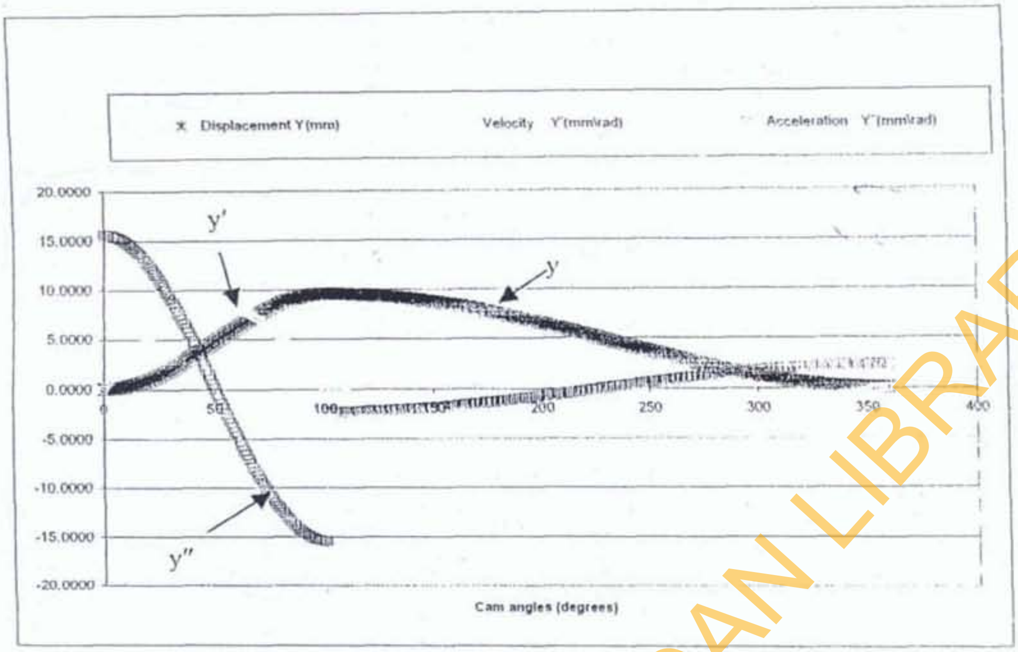

Fig. 4: Motion Profiles for Sample Design 2

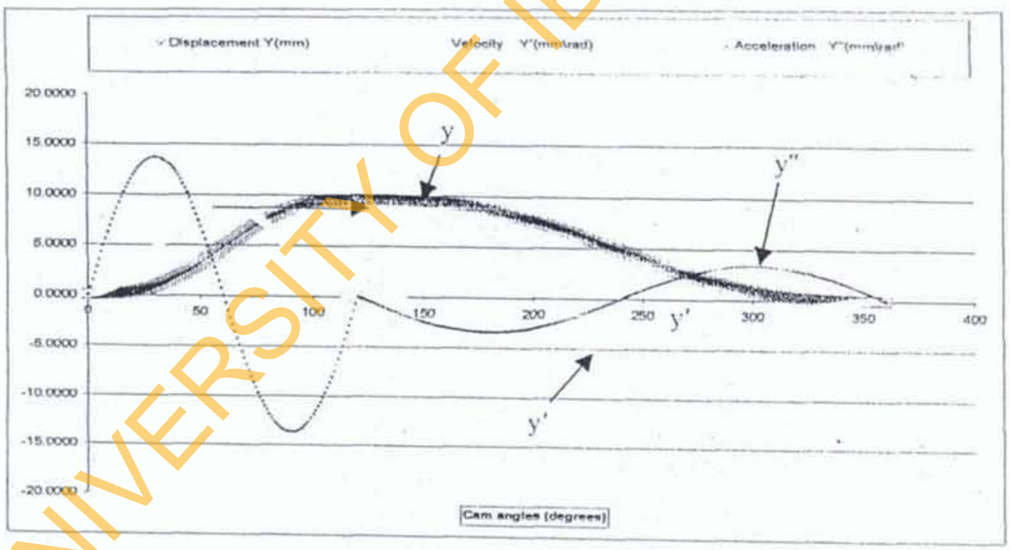

Fig.5: Motion Profiles for Sample Design 3

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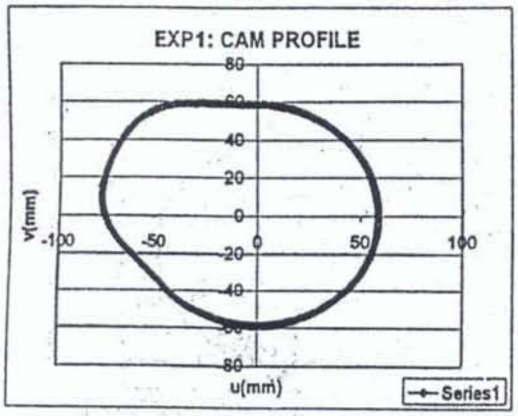
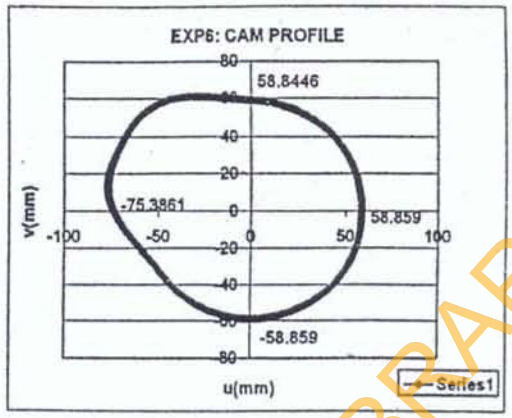
ECCENTRICITY = 5mm



//////////////INPUT PARAMETERS//////////////

LIFT = 20mm
FIRST DWELL: 0 TO 220 degrees
RISE : 220 TO 280 degrees
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
MAXIMUM PRESSURE ANGLE = 25 degrees
ROLLER RADIUS = 14mm
PRIME CIRCLE RADIUS = 72.7635mm

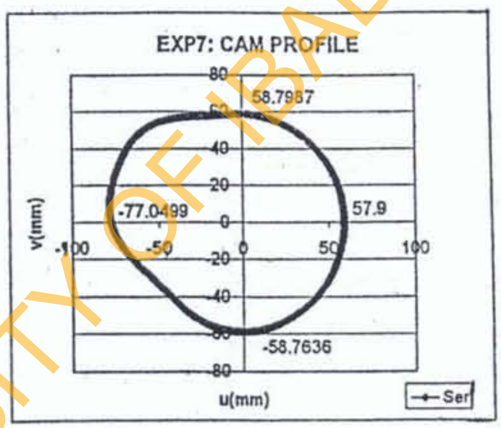
ECCENTRICITY = 10mm



//////////////INPUT PARAMETERS//////////////

LIFT = 20mm
FIRST DWELL: 0 TO 220 degrees
RISE : 220 TO 280 degrees
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
MAXIMUM PRESSURE ANGLE = 25 degrees
ROLLER RADIUS = 14mm
PRIME CIRCLE RADIUS = 72.7635mm

ECCENTRICITY = 0mm



//////////////INPUT PARAMETERS//////////////

LIFT = 20mm
FIRST DWELL 0 TO 220 degrees
RISE : 220 TO 280 degrees
LAST DWELL 280 TO 300 degrees
RETURN: 300 TO 360 degrees
MAXIMUM PRESSURE ANGLE = 25 degrees
ROLLER RADIUS = 14mm
PRIME CIRCLE RADIUS = 72.7635mm

Figure 4: Effect of Variation of Eccentricity

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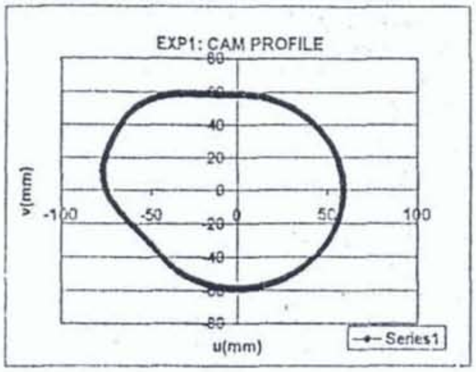
ROLLER RADIUS = 14mm



///////////INPUT PARAMETERS///////////

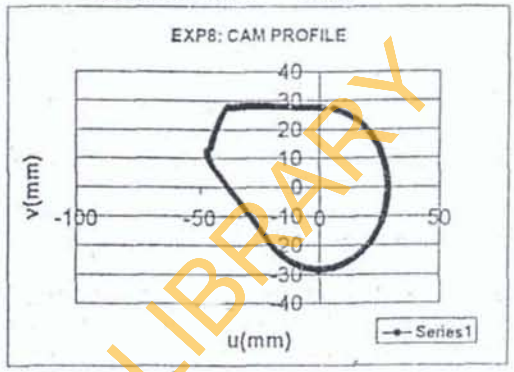
LIFT =	20mm
FIRST DWELL:	0 TO 220 degrees
RISE :	220 TO 280 degrees
LAST DWELL	280 TO 300 degrees
RETURN:	300 TO 360 degrees

ECCENTRICITY = 5 mm

MAXIMUM PRESSURE ANGLE = 25 degrees

PRIME CIRCLE RADIUS = 72.7635mm

ROLLER RADIUS = 45mm



///////////INPUT PARAMETERS///////////

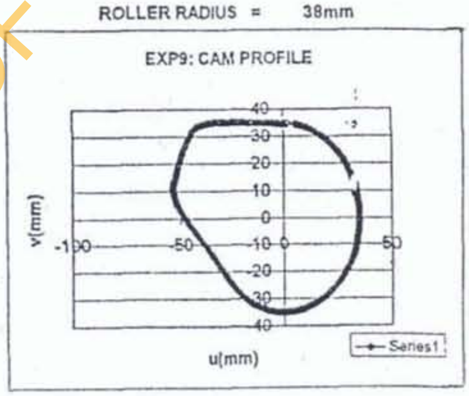
LIFT =	20mm
FIRST DWELL:	0 TO 220 degrees
RISE :	220 TO 280 degrees
LAST DWELL	280 TO 300 degrees
RETURN	300 TO 360 degrees

ECCENTRICITY = 5 mm

MAXIMUM PRESSURE ANGLE = 25 degrees

PRIME CIRCLE RADIUS = 72.7635mm

ROLLER RADIUS = 38mm



///////////INPUT PARAMETERS///////////

LIFT =	20mm
FIRST DWELL:	0 TO 220 degrees
RISE :	220 TO 280 degrees
LAST DWELL	280 TO 300 degrees
RETURN :	300 TO 360 degrees

ECCENTRICITY = 5 mm

MAXIMUM PRESSURE ANGLE = 25 degree

PRIME CIRCLE RADIUS = 72.7635m

Figure 5: Effect of Variation of Roller Radius

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Effect on Other Parameters: The prime circle radius R_o displays a proportional relationship with the maximum allowable pressure angles (increasing Φ_{max} from $20^0 - 30^0$ causes R_o to decrease from 93.225mm to 58.7689mm). The radii of curvature and generated pressure angles also changed from 2366.64mm to 808.367mm and from 18.3853 to 26.52620 respectively. These results are presented in Table 2.

4.3 Variation of Eccentricity (ε)

Effect on Cam Profile: Increase the eccentricity causes the profile to decrease in the negative x-direction and increase in the other directions. The eccentricity should not be increases above the prime circle radius because of the $(Ro^2 - \varepsilon^2)^{1/2}$ term in the coordinate equation. Exceeding this limit will physically imply that the follower goes beyond the cam profile. The program does not allow this situation. This is shown in Fig. 4.

Effect on Other Output Parameters: Varying the eccentricity has effect on only the values of u and v coordinates and hence on only the profile. The variation does not have effects on other output parameters as shown in Table 3.

4.4 Variation of Roller Radius

Effects on Cam Profile: Increasing the roller radius decreases the size of the profile and causes the appearance of cusps, irregularities and incomplete closure. Decreasing the roller radius makes the profile bigger and the shape more refined. These effects are evident in Fig. 5.

Effects on Other Output Parameters: Varying the roller radius has effect on only the u and v coordinates, hence only on the profile. The variation does not have effect on other parameters as shown on Table 4.

5.0 CONCLUSION AND RECOMMENDATIONS

The main objectives of this work, which is the computer aided analysis of four design parameters namely; lift, maximum allowable pressure, angle eccentricity and roller radius for plate cams with eight-order polynomial follower motion, has been achieved. The results of analysis show that variation of the four parameters within and outside design limits produced notable changes on the generated cam profile.

The cam profiles decreased in size with increase in eccentricity, while cusps and irregularities appeared on the profiles with increase in maximum allowable pressure and roller radius. However, the higher the lift, the bigger the profile as is also evident in the increase in the prime circle radius.

The analysis carried out serves as a guide as regards the extent and limit of the above mentioned variations so as to achieve optimum design objectives in the least possible time. This work can further be adapted for the computer – aided design of medium and low speed cam systems as well as for other follower motions. A means of computerizing different types should be sought. For instance, the combination of simple harmonic motion an cycloid motion or other motions.

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