THE MINIMUM BASE CIRCLE RADISUS FOR PLANE CAMS

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هذا البحث يختص باتباع طريقة مستحدثة لتحديد معادلات الكامات المستوية ، وهذه المعادلات في صورتها الحالية تسهل رسم الكامات خاصة عند استخدام الحاسبات الألكترونية .

من العوامل الهامة في تصميم الكامات هو تلافي الانحناءات الحادة مما يضع شروطا معينة بخصوص قطر دائرة الاساس . وبناء على هذا استنبطت معادلات الانحناء لجميع أنواع التوابع واستخدمت للحصول على منحنيات تساعد على تحديد الحجم المناسب للكامات .

A new approach using vector analysis is used to derive equations representing the cam profile and are presented in Cartesian coordinates. With the use of digital computers, these equations are very helpful in drafting and manufacturing cams with considerable accuracy.

An important factor in designing a cam is to eliminate sharp convex corners. This imposes a restriction upon the minimum base circle radius.
Equations for the radii of curvature for cams with all types of followers are derived. Also design curves for some basic follower motions are presented which help in determining the suitable cam size.

Introduction

The contour of specified motion cams is usually obtained graphically [4]. The procedure consists of locating the follower at several positions, according to the type of motion, then drawing a smooth curve tangent to it at all these positions. Usually, this method is not accurate because the tangent points are not exact. Another graphical procedure was developed [1] to obtain the exact tangent points, and a smooth curve passing through them determines the contour. This method , though more accurate than the preceding one, still lacks precision because of the limited number of points that can be located. Furthermore it is still a graphical method.

Equation representing the cam profile are available in polar coordinates [1,3]. Now it is a common practice to use computers either to plot the profile or assist in manufacturing cams by programmed machine tools. For this method of manufacture the equations representing the contour are better presented in Cartesian coordinates which is developed in this work.

An important factor in designing a cam is the minimum base circle radius. It affects the pressure angle, and the radius of curvature of the cam. Limiting pressure angles during the rise and return strokes were used [2] to determine the suitable base circle radius. However, a check must be made regarding the minimum radius of curvature otherwise a sharp convex corner results in the cam. Analyses for determining the minimum radius of curvature are presented in the literature [3,4]. The author feels that these analyses are not sophisticated and are criticized at the end of the text.

The purpose of this work is to derive formulae for the radii of curvature for cams with all types of followers, then obtain design curves to help determining the minimum base circle radius for the basic type of follower motions.

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Nomenclature

X,Y	fixed coordinate system
x,y	coordinate system rotating with the cam
$\vec{I}, \vec{J}, \vec{K}$	unit vectors along fixed coordinate system. The cam rotates about $\vec{K}$
$\vec{i}, \vec{j}$	unit vectors along rotating coordinate system
$\vec{r}$	position vector of the point of contact between the pitch contour and the follower.
ξ, η	coordinates of the point of contact in the fixed coordinate system
θ	the cam rotational angle
r_o	radius of the base circle of the pitch contour
ρ	the radius of curvature of the pitch contour
R	radius of the roller of the follower. = normal distance from the pivot of an oscillating follower to its flat face. = zero for translating flat-faced follower.
h	eccentricity of roller translating follower
$f(\theta)$	function representing the motion of the follower
s	lift of translating followers
S	distance between cam center and follower pivot for oscillating followers
L	Length of roller oscillating followers
γ	lift angle for oscillating followers
β	rise angle

Analysis of Plane Cams

Consider a disk cam rotating about 0 in the counter-clockwise direction, Fig. 1. The relation between the unit vectors in the two coordinate systems ie

$$\begin{Bmatrix} \vec{I} \\ \vec{J} \end{Bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{Bmatrix} \vec{i} \\ \vec{j} \end{Bmatrix} \tag{1}$$

Suppose that the cam is held stationary, the vectors $\vec{I}$, and $\vec{J}$ can be considered to be rotating relative to $\vec{i}$, and $\vec{j}$ in the opposite sense, i.e. clockwise. From Eq. (1) it is easy to show that

$$\frac{d\vec{I}}{d\theta} = -\vec{J} \qquad \frac{d\vec{J}}{d\theta} = \vec{I} \tag{2}$$

The position vector of the contact point on the pitch contour is given by

$$\vec{r} = \xi\vec{I} + \eta\vec{J} \tag{3}$$

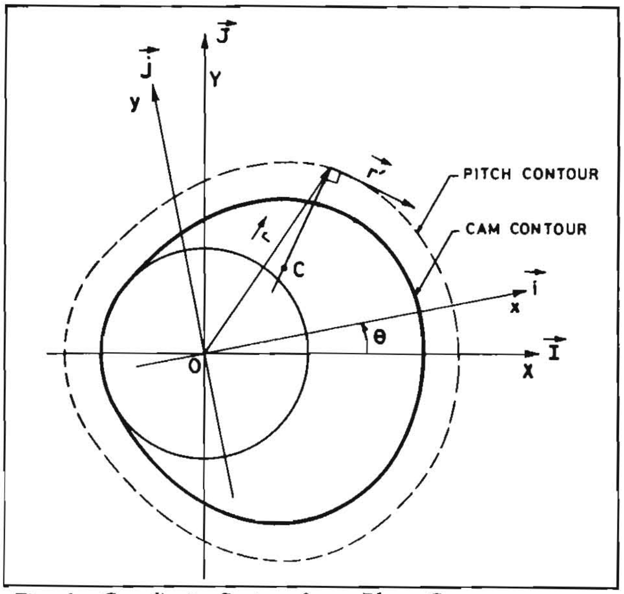

Fig. 1 Coordinate System for a Plane Cam.

In order to obtain the radius of curvature, the first and second derivatives of r should be obtained. Differentiating Eq. (3) with respect to θ, and making use of Eq. (2), then

$$\vec{r}' = (\xi' + \eta)\vec{I} + (\eta' - \xi)\vec{J} \tag{4}$$

$$\vec{r}'' = (\xi'' + 2\eta' - \xi)\vec{I} + (\eta'' - 2\xi' - \eta)\vec{J} \tag{5}$$

Where the dash means differentiation with respect to θ. The normal vector to the pitch contour towards the center of curvature (point C) is given by

$$\vec{N} = \vec{r}' \times \vec{K} = (\eta' - \xi)\vec{I} - (\xi' + \eta)\vec{J} \tag{6}$$

The radius of curvature of the pitch contour is given by [5]

$$\rho = \frac{(\vec{r}' \cdot \vec{r}')^{3/2}}{[(\vec{r}' \times \vec{r}'') \cdot (\vec{r}'' \times \vec{r}'')]^{\frac{1}{2}}}$$

From Eq. (4)

$$\vec{r}' \cdot \vec{r}' = (\xi' + \eta)^2 + (\eta' - \xi)^2$$

From Eqs. (4), and (5)

$$\vec{r}' \times \vec{r}'' = [(\xi'+\eta)(\eta''-2\xi-\eta)-(\eta'-\xi)(\xi''+2\eta'-\xi]\vec{K}$$

Thus

$$\rho = \frac{[(\xi'+\eta)^2 + (\eta'-\xi)^2]^{3/2}}{(\xi'+\eta)(\eta''-2\xi'\eta)-(\eta'-\xi)(\xi''+2\eta'-\xi)} \tag{7}$$

The position vector of the point of contact on the cam itself is denoted by $\vec{r}_c$ and is given by

$$\vec{r}_c = \vec{r} + R\,\frac{\vec{N}}{N}$$

where

$$N = |\vec{N}| = |\,(\xi'+\eta)^2 + (\eta'-\xi)^2\,|^{\frac{1}{2}} \qquad (8)$$

Hence

$$\vec{r}_c = \left[\xi + \frac{R(n'-\xi)}{N}\right]\vec{I} + \left[\eta - \frac{R(\xi'+\eta)}{N}\right]\vec{J}$$

Substituting for $\vec{I}$, and $\vec{J}$ from Eqs. (1) the cam contour can be represented by

$$x = \left[\xi + \frac{R(\eta-\xi)}{N}\right]\cos\theta + \left[\eta - \frac{R(\xi'+\eta)}{N}\right]\sin\theta \qquad (9\text{-a})$$

$$y = -\left[\xi + \frac{R(\eta'-\xi)}{N}\right]\sin\theta + \left[\eta - \frac{R(\xi'+\eta)}{N}\right]\cos\theta \qquad (9\text{-b})$$

Applications

1. **Cams with roller translating followers:**

In the case of roller translating followers the center line of the follower is assumed to be shifted an amount h from the center of the cam, Fig. 2. The coordinates of the point of contact at the pitch contour are

$$\xi = h$$

$$\eta = Y = Y_o + f\,(\theta)$$

where

$$Y_o = \sqrt{r_0^2 - h^2}$$

Thus

$$\xi' = \xi'' = 0$$

$$\eta' = f'\,(\theta)$$

$$\eta'' = f''\,(\theta)$$

Substituting into Eq. (7), then

$$\rho = \frac{[Y^2 + (f'-h)^2\,]^{3/2}}{Y(f''-Y) - (f'-h)\,(2f-h)} \qquad (10)$$

The coordinates of the cam contour is obtained from Eqs. (9); i.e.

$$x = \left[h + \frac{R(f'-h)}{N}\right]\cos\theta + Y\left[1 - \frac{R}{N}\right]\sin\theta \qquad (11\text{-a})$$

$$y = -\left[h + \frac{R(f'-h)}{N}\right]\sin\theta + Y\left[1 - \frac{R}{N}\right]\cos\theta \qquad (11\text{-b})$$

where

$$N = \sqrt{Y^2 + (f'-h)^2}$$

2. **Cams with roller oscillating followers**

A typical cam with an oscillating follower is shown in Fig. 3. Let ϕ denotes the anoular position of the follower,

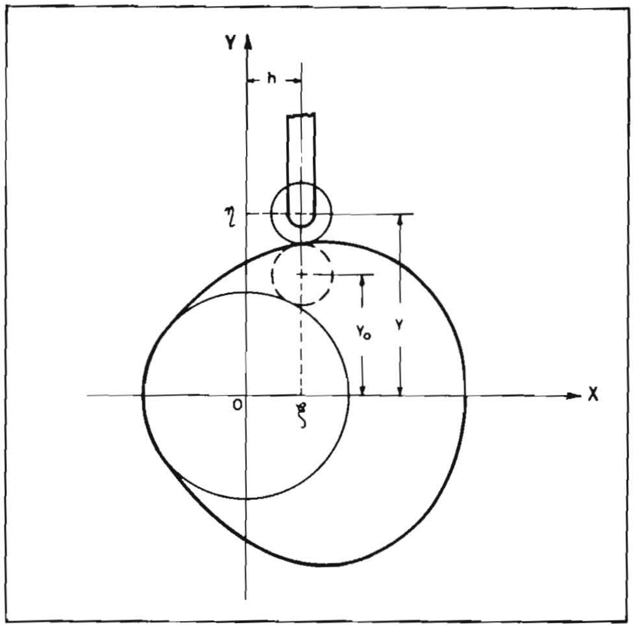

Fig. 2 A Cam with a Roller - Translating Follower

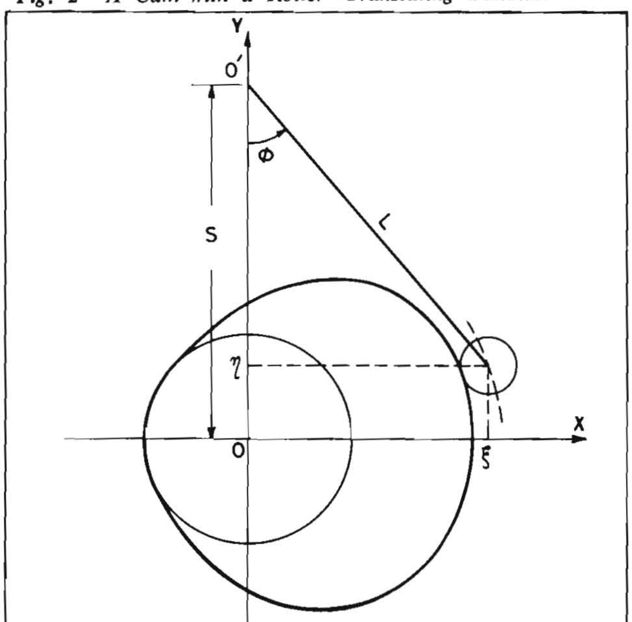

Fig. 3 A Cam with a Roller - Oscillating Follower

$$\phi = \phi_o + f(\theta)$$

where ϕ_o is the minimum value of ϕ. In this case

$$\xi = L\sin\phi$$

$$\eta = S - L\cos\phi$$

Substituting into Eqs. (7), and (9), then

$$\rho = \frac{[L^2(1-f')^2 + S^2 + 2LS(f'-1)\cos\phi]^{3/2}}{L^2(f'-1)^3 + S[Lf''\sin\phi + L\cos\phi(f'-1)(f'-2) - S]} \qquad (12)$$

$$x = L\left[1 + R\frac{(f'-1)}{N}\right]\sin\phi\,\cos\theta + \left[S - L\,\text{Cos}\phi - R\,\frac{S + L(f'-1)\cos\phi}{N}\right]\sin\theta \qquad (13\text{-a})$$

$$y = -L\left[1 + R\frac{(f'-1)}{N}\right]\sin\phi\,\sin\theta + \left[S - L\cos\phi - R\,\frac{S + L(f'-1)\cos\phi}{N}\right]\cos\theta \qquad (13\text{-b})$$

where

$$N = \left[S^2 + 2\,SL(f'-1)\cos\theta + L^2(f'-1)^2\right]^{\frac{1}{2}}$$

3. Cams with flat-faced translating followers

A cam with a reciprocating flat-faced follower is shown in Fig. 4. In this case

$$\eta = Y = r_o + f(\theta)$$

The face of the follower is tangent to the cam contour. Thus r' is proportional to $\vec{l}$. Thus, from Eq. (4)

$$\eta' - \xi = 0$$

or

$$\xi = f'(\theta)$$

Substituting into Eqs. (7), and (9), then

$$\rho = f'' + y \qquad (14)$$

$$x = f'\cos\theta + Y\sin\theta \qquad (15\text{-a})$$

$$y = -f'\sin\theta + Y\cos\theta \qquad (15\text{-b})$$

4. Cams with flat-faced oscillating followers

From Fig. 5, the pitch contour is tangent to a line parallel to the follower face and passing through its pivot. The distance from the pivot to the point of contact on the pitch contour is L, and the follower rational angle is ϕ. It is clear that:

$$\xi = L\sin\phi$$

$$\eta = S - L\cos\phi$$

where

$$\phi = \phi_o + f(\theta),$$

and ϕ_o is the minimum angle of the follower. Point Q is the instantaneous center of the follower relative to the cam.

Then

$$\frac{OQ}{O'Q} = \frac{d\phi/dt}{d\theta/dt} = \frac{d\phi}{d\theta} = f'(\theta) = f'$$

In this case

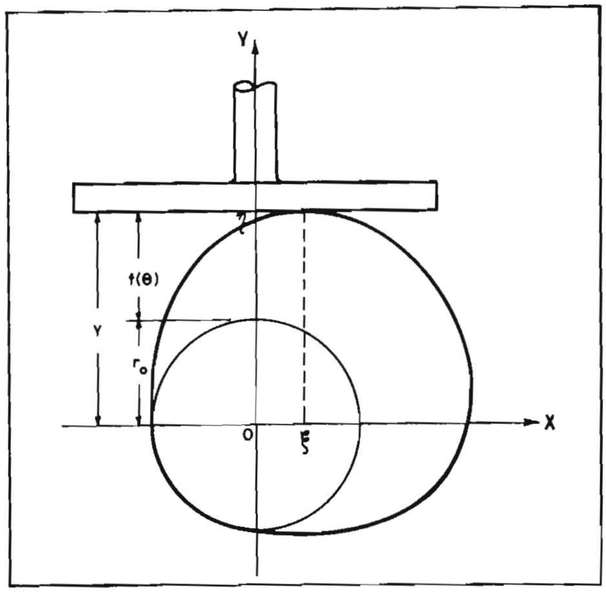

Fig. 4 A Cam with a Flat-Faced-Translating Follower

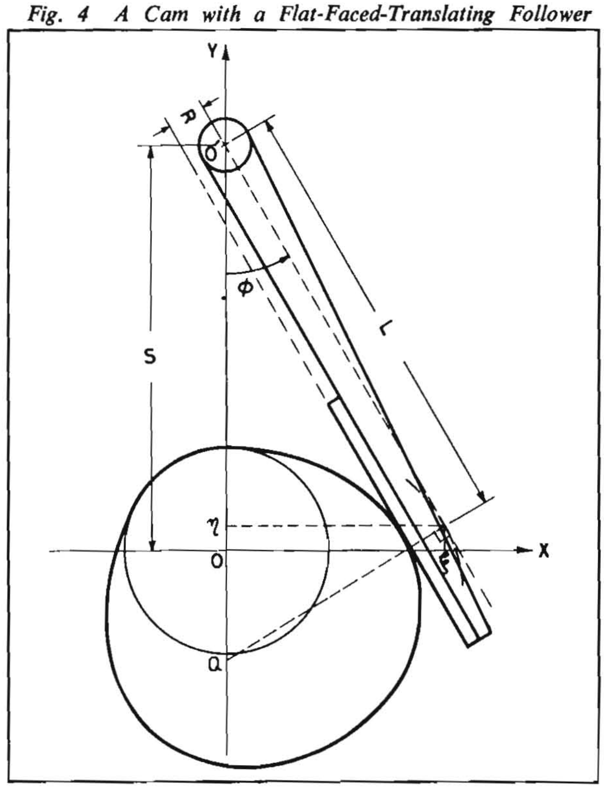

Fig. 5 A Cam with a Flat-Faced-Oscillating Follower

$$O'Q = \frac{S}{1 - f'}$$

Also

$$L = O'Q\cos\phi = \frac{S}{1 - f'}\cos\phi$$

From Eq. (7)

$$\rho = \frac{L' + S\sin\phi}{Lf'' - 2L'(1 - f') - S\sin\phi}$$

But

$$L' = \frac{dL}{d\theta} = S\,\frac{f''\cos\phi - (1-f')f'\sin\phi}{(1-f')^2}$$

Therefore

$$\rho = \frac{S}{(1-f')^3}\Big[f''\cos\phi + (1-f')(1-2f')\sin\phi\Big] \quad (16)$$

From Eqs. (9), hence

$$x = \left[\frac{S}{2(1-f')}\sin 2\phi - R\cos\phi)\right]\cos\theta + \left[\frac{S}{(1-f')}(\sin^2\phi - f') - R\sin\phi)\right]\sin\theta \quad (17\text{-a})$$

$$y = -\left[\frac{S}{2(1-f')}\sin 2\phi - R\cos\phi\right]\sin\theta + \left[\frac{S}{(1-f')}(\sin^2\phi - f') - R\sin\phi\right]\cos\theta \quad (17\text{-b})$$

The Minimum Cam Size

The radius of curvature of the cam "ρ_c" is given by $\rho_c = \rho - R$

In designing a cam one should worry about the radius of curvature of its convex part. The minimum value of ρ_c must be larger than zero in order to avoid sharp corners. Furthermore, this value can be specified from considerations of contact stresses. Thus, by determining the minimum values of ρ, it is possible to obtain information for selecting the proper base circle radius . This is done for all types of followers.

1. Cams with roller translating followers

The radius of curvature of the pitch contour is given by Eq. (10)

In this case

$$Y = \sqrt{r_0^2 - h^2} + f(\theta)$$

Usually $f(\theta)$ is proportional to the lift "s", i.e.

$$f(\theta) = s\,F(\theta)$$

where $F(\theta)$ is a function of θ only . Let

$$\frac{r_o}{s} = \lambda$$

$$\frac{h}{r_o} = \zeta$$

$$\lambda_1 = \lambda\sqrt{1-\zeta^2}$$

Thus, the radius of curvature can be written in the dimensionless form

$$\frac{\rho}{s} = -\frac{[(\lambda_1+F)^2 + (F' - \lambda\zeta)^2]^{3/2}}{(\lambda_1+F)(F''-\lambda_1-F) - (F'-\lambda\zeta)(2F'-\lambda\zeta)}$$

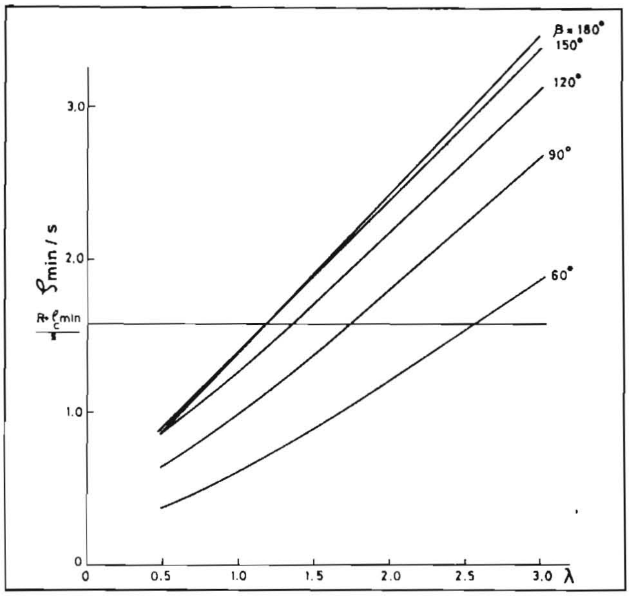

Fig. 6 Minimum Radius of Curvatures for Translating Followers-Simple Harmonic Motion.

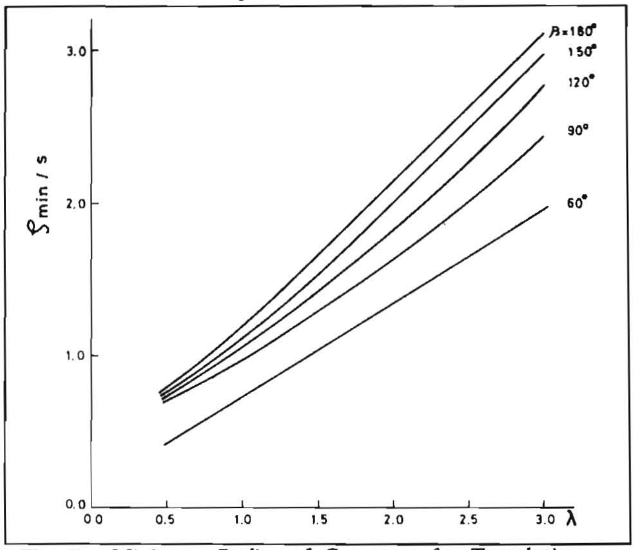

Fig. 7 Minimum Radius of Curvature for Translating Followers - Parabolic Motion.

The determination of the minimum convex radius of curvature by differentiation is tedious. A reasonable alternative is plotting $\frac{\rho}{s}$ against θ. This can be simplified by using digital computers. In this work, β was divided into 400 divisions, i.e. when $\beta=120°$, each division is 0.3°.

Graphs for the effect of λ, and β upon the minimum convex radius of curvature are shown in Fig. 6 for simple harmonic motion, in Fig. 7 for parabolic motion, and in Fig. 8 for cycloidal motion. The effect of eccentricity and the rise angle upon the minimum radius of curvature are shown in Figs. 9, and 10, respectively.

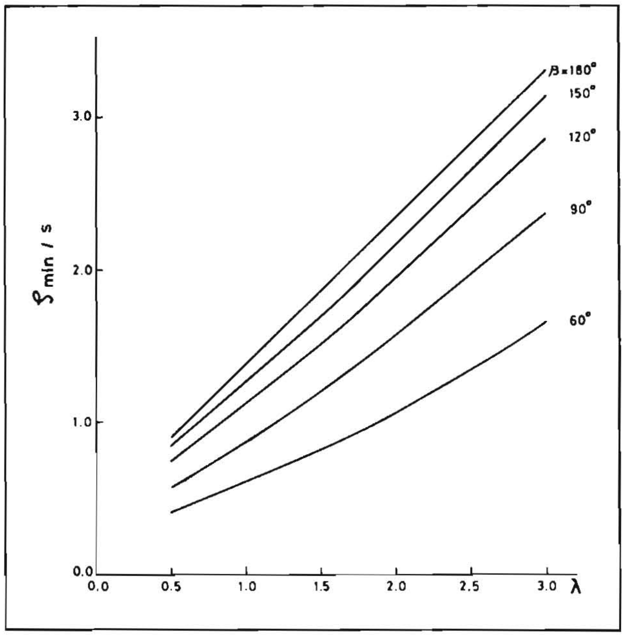

Fig. 8 Minimum Radius of Curvature for Translating Followers - Cycloidal Motion.

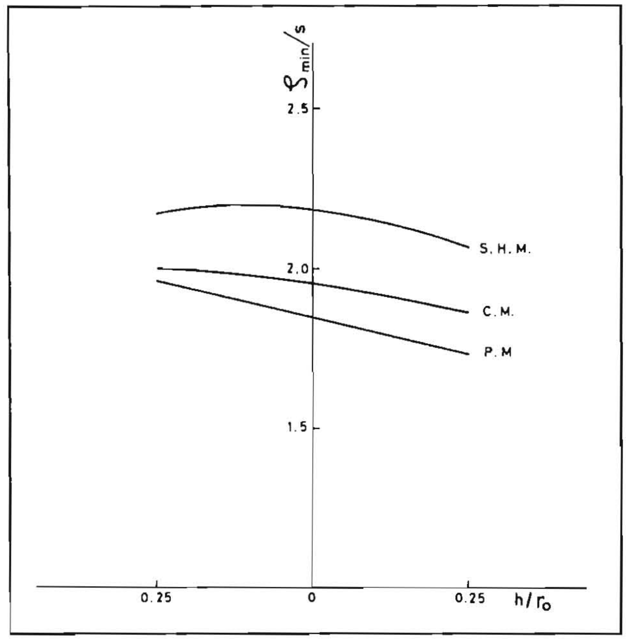

Fig. 9 Effect of Eccentricity upon the Minimum Radius of Curvature - $\lambda = 2.0$.

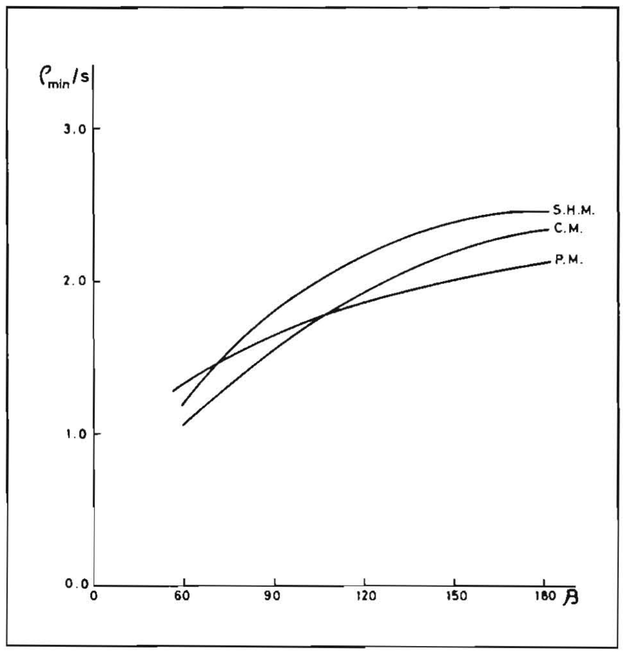

Fig. 10 Effect of the Rise Angle upon the Minimum Radius of Curvature — $\lambda = 2.0$

2. Cams with roller oscillating followers

The radius of curvature is given by Eq. (12).
where

$$\phi = \phi_o + f(\theta)$$

Let

$$\frac{r_o}{S} = \lambda'$$

$$\frac{L}{S} = \alpha$$

It is easy to show that

$$\cos\phi_o = \frac{1 + \alpha^2 - \lambda'^2}{2\alpha}$$

The radius of curvature can be put in the dimensionless form

$$\frac{\rho}{S} = \frac{[\alpha^2(f'-1)^2 + 1 + 2\alpha(f'-1)\cos\phi]^{3/2}}{\alpha^2(1-f')^3 - \alpha f'' \sin\phi - (f'-1)(f'-2)\cos\phi - 1}$$

The effect of the rise angle, and the base circle radius upon the minimum values of $\frac{\rho}{S}$ "for lift angle $\gamma = 20°$" are shown in Figs. 11, 12 and 13. In these figures, the effect of the lift angle "γ" for $\beta = 120°$ are shown in dotted line.

In order to obtain the proper cam size, the radius of the roller as well as the minimum convex radius of curvature of the cam "$\rho_{c\ min}$" are specified. A horizontal line of height $\frac{R + \rho_c}{S}$ min is drawn in the case of translating followers Fig. 6. The intersection of this line with the curve corresponding to the rise angle determines the value of λ. This value when multiplied by s and subtracted by R gives the minimum value of the base circle radius. The same thing applies for oscillating followers, Fig. 11, except S is used instead of s and the curve corresponding to the lift angle is used.

3. Cams with flat-faced translating followers

The radius of curvatures for the pitch contour is given by Eq. (14).

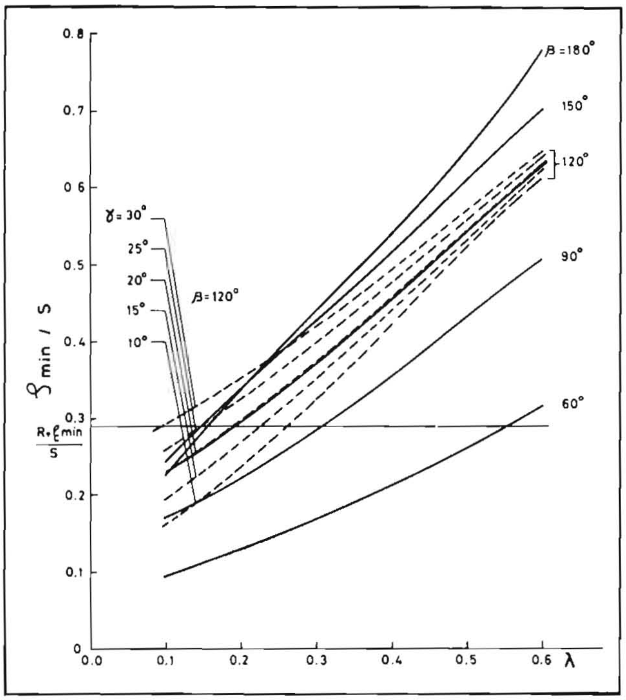

Fig. 11 Minimum Radius of Curvature for Roller Oscillating Followers - Simple Harmonic Motion.

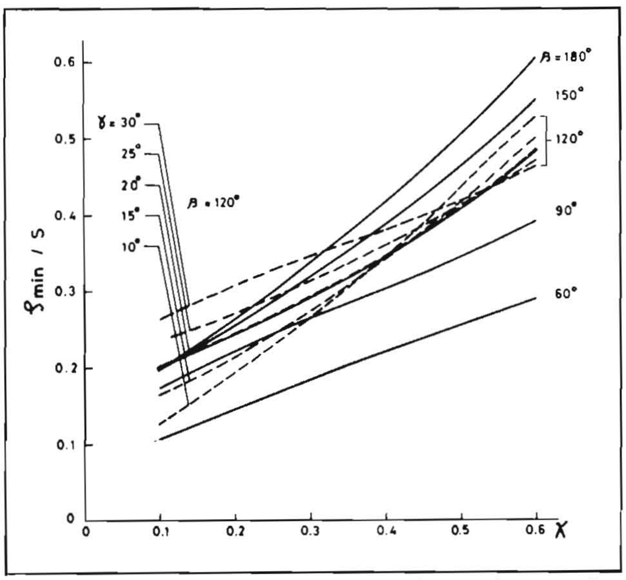

Fig. 12 Minimum Radius of Curvature for Roller Oscillating Followers - Parabolic Motion.

As in the case of roller followers

f=s F(θ)

Thus

$$\frac{\rho}{s} = \lambda + F(\theta) + F''(\theta)$$

where $\lambda = \frac{r_o}{s}$

For flat-faced followers, the contour be must convex. Thus

$$\frac{\rho}{s} = \lambda + F(\theta) + F''(\theta) \geq 0$$

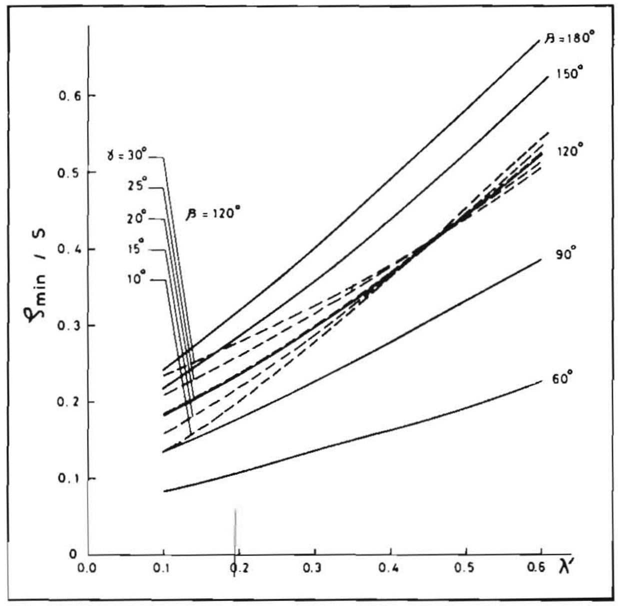

Fig. 13 Minimum Radius of Curvature for Roller Oscillating Followers - Cycloidal Motion.

Therefore

$$\lambda \geq -F(\theta) - F''(\theta)$$

It is clear that the region which determines the minimum value of λ is when F″(θ) is negative. The proper values of λ for some basic motions are derived below.

i) Simple harmonic motion

$$F(\theta) = \tfrac{1}{2}\left(1 - \cos\frac{\pi\theta}{\beta}\right)$$

$$F''(\theta) = \frac{\pi^2}{2\beta^2}\cos\frac{\pi\theta}{\beta}$$

Thus

$$\lambda \geq -\tfrac{1}{2} + \tfrac{1}{2}\left(1 - \frac{\pi^2}{\beta^2}\right)\cos\frac{\pi\theta}{\beta} \qquad (18)$$

The extrema of λ occur at $\frac{\theta}{\beta} = 0$, and $\frac{\theta}{\beta} = 1$. For large values of β the inequality (18) yields λ to be larger than a negative quantity. This means that any value for the minimum base circle radius is safe. A limiting value for β occurs when λ=0, and $\frac{\theta}{\beta} = 1$. In this case $\beta = \frac{\pi}{\sqrt{2}}$. For values of $\beta < \frac{\pi}{\sqrt{2}}$, $\lambda > \frac{\pi^2}{2\beta^2} - 1$

For example, when $\beta = \frac{\pi}{2}$, λ should be larger than 1.

If the minimum radius of curvature of the cam is specified, say equal to ρ_o' then

$$\lambda > -\rho_o - 1 + \frac{\pi^2}{2\beta^2}$$

for $\beta < \frac{\pi}{\sqrt{2(1-\rho_o)}}$

ii) Parabolic motion

The equation representing the motion, when the acceleration is negative, is given by

$$F(\theta) = 1-2(1-\frac{\theta}{\beta})^2$$

$$\tfrac{1}{2} \leq \frac{\theta}{\beta} \leq 1$$

$$F''(\theta) = -\frac{4}{\beta 2}$$

Thus

$$\lambda > \frac{4}{\beta^2} - 1 + 2(1-\frac{\theta}{\beta})^2 + \rho_o$$

The critical value of λ occurs when $\frac{\theta}{\beta}$ is minimum, i.e.

at $\frac{\theta}{\beta} = 1/2$. In this case

$$\lambda > \rho_o + \frac{4}{\beta^2} - \tfrac{1}{2}$$

iii) Cycloidal motion

For the cycloidal motion

$$F(\theta) = \frac{\theta}{\beta} - \frac{1}{2\pi} \sin \frac{2\pi\theta}{\beta}$$

$$F''(\theta) = \frac{2\pi}{\beta 2} \sin \frac{2\pi\theta}{\beta}$$

Hence

$$\lambda > \rho_o - \frac{\theta}{\beta} + (\frac{\beta^2-4\pi^2}{2\pi\beta^2}) \sin \frac{2\pi\theta}{\beta}$$

The maximum value of the term on the right hand side of this inequality occurs at

$$\cos \frac{2\pi\theta}{\beta} = \frac{\beta^2}{\beta^2 - 4\pi^2}$$

$$\tfrac{1}{2} < \frac{\theta}{\beta} < \frac{3}{4}$$

Therefore

$$\lambda > \rho_o + \frac{\sqrt{4\pi^2-2\beta^2}}{\beta^2} - \frac{1}{2\pi} \cos^{-1} \frac{\beta^2}{\beta^2-4\pi^2}$$

Notice that $\cos^{-1} \frac{\beta^2}{\beta^2 - 4\pi^2}$ occurs in the third quarter.

4. Cams with flat-faced oscillating followers

According to Eq. (16)

$$\frac{\rho}{S} = \frac{1}{(1-f')^3} \left[f'' \cos\phi + (1-f')(1-2f') \sin\phi \right] > 0$$

But

$$\phi = \phi_o + f(\theta)$$

$$\sin \phi_o = \frac{r_o}{S} = \lambda'$$

$$\cos \phi_o = \sqrt{1 - \lambda'^2}$$

Hence

$$[f'' (\sqrt{1 - \lambda'^2} \cos f - \lambda \sin f)] + (1-f')(1-2f') \times (\lambda' \cos f + \sqrt{1 - \lambda'^2} \sin f) > 0$$

or

$$\sqrt{1-\lambda'^2} \left[f'' \cos f + (1-f')(1-2f') \sin f \right] - \lambda' \left[f'' \sin f - (1-f')(1-2f') \cos f \right] > 0$$

Let

$$A = f'' \cos f + (1-f')(1-2f') \sin f$$

$$B = f'' \sin f - (1-f')(1-2f') \cos f$$

After simplifications, one arrives at

$$\lambda' > \pm \frac{A}{\sqrt{A^2 + B^2}}$$

It is clear that the minus sign is the proper sign λ', in this case, is determined from the negative values of f'' which is found in A. Therefore

$$\lambda' > \pm \frac{A}{\sqrt{A^2+B^2}}$$

The largest dimension of a cam cannot exceed S. In the limit, the maximum value of ϕ is 90° Thus, there is a limit on the value of λ' depending upon the value of the lift angle γ.

$$\phi_{max} = \gamma + \phi_o = 90°$$

or

$$\sin(\gamma+\phi_o) = \sin\gamma \cos\phi_o + \cos\gamma \sin\phi_o = 1$$

Substituting for the values of $\sin\phi_o$, and $\cos\phi_o$, then

$$1 - \lambda' \cos\gamma = \sqrt{1-\lambda'^2} \sin\gamma$$

After simplifications, one arrives at

$$\cos\gamma = \lambda'$$

The effect of the rise angle, and the lift angle, upon the minimum base circle radius of the pitch contour are shown in Figs. 14, 15 and 16. The dotted part of the curves are in the region where $\lambda' > \cos\gamma$.

The minimum base circle radius for a cam is determined by specifying the basic data which is β, γ, S, R, and the type of motion. From the curves corres-

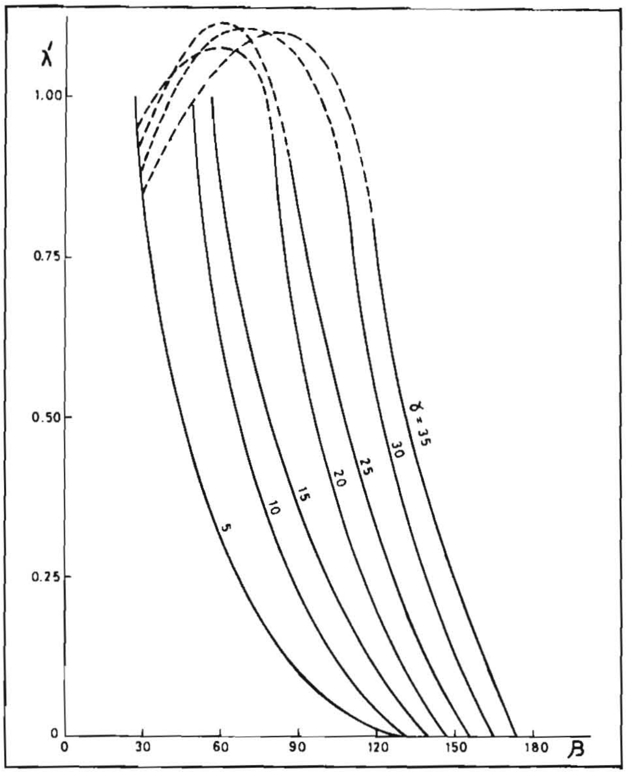

Fig. 14 Minimum Base Circle Radius for Cams with Flat-Faced Oscillating Follower - Simple Harmonic Motion.

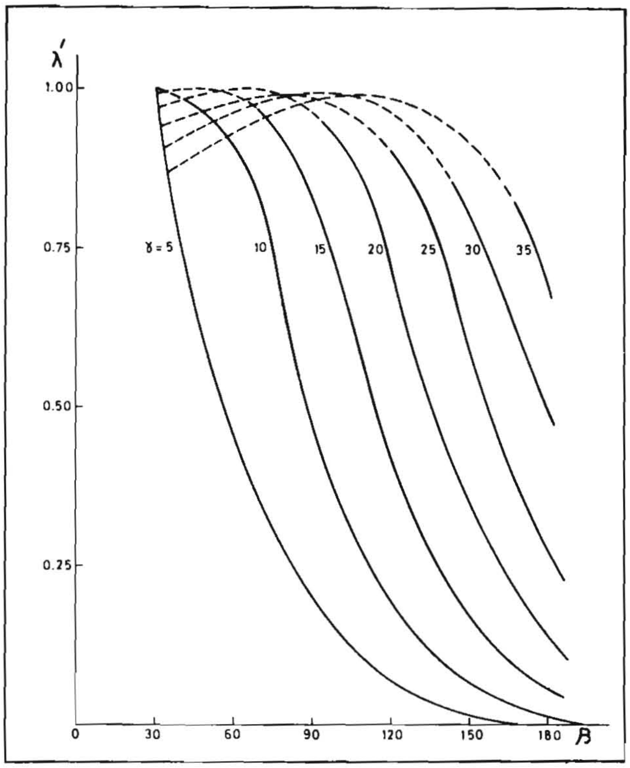

Fig. 15 Minimum Base Circle Radius for Cams with Flat-Faced Oscillating Follower - Parabolic Motion.

ponding to β, and γ, Figs. 14, 15, 16, the value of λ' is obtained. The minimum radius of the base circle is equal to $\lambda' S - R$.

In order to design a cam to give a minimum radius of curvature ρ_c' min a good approximation for the base circle is given by $\lambda' S + \rho_c \min - R$.

Discussion

In the previous analyses, equations for the contour of cams with various types of followers were derived. The equations are represented in cartesian coordinates. By using digital computers it is possible to draft and manufactured cams with appreciable accuracy.

The results obtained for the minimum base circle radius in this work are useful in designing cams with all types of followers. It helps not only in selecting the proper cam size, but also in comparing the basic types of motions. Although particular motions were considered, namely, simple harmonic, parabolic, and cycloidal motions, similar results can be obtained for any other type of motion.

The analysis presented in the literature [3,4] for determining the minimum base circle radius based upon the minimum radius of curvature are questionable in many aspects:

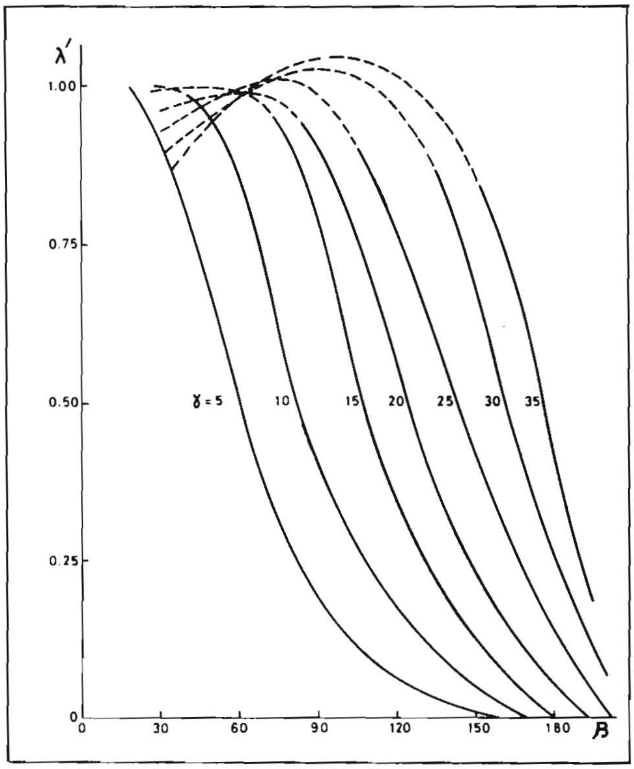

Fig. 16 Minimum Base Circle Radius for Cams with Flat Faced Oscillating Followers - Cycloidal Motion.

1. A general equation for the radius of curvature is presented in polar coordinates which makes the analysis difficult, specially for oscillating followers.

2. The equation of the radius of curvature for the concave part of the cams has a minus sign. This is strictly incorrect. The radius of curvatuie for any point of the cam should be represented by one equation. The sign of the radius determines whether this point is on a convex or a concave part. This depends mainly upon the magnitude and sign of the reduced acceleration of the follower. Furthermore, under certain conditions, the contour is all convex.

3. The minimum radius of curvature of the concave part of specified motion cams does not imposc undercutting problems since it is largei than the radius of the rollei.

4. The minimum convex radius of curvature does not always occur at the position of the maximum negative acceleration. For cxample, for reciprocating followers, and in the case of simplc harmonic motion ρ_{min} occurs at 0.4β to β depending on the base circlc radius and the rise angle. For parabolic motion ρ_{min} occurs at $\frac{\beta}{2}$. For cycloidal motion ρ_{min} occurs mostly at 0.7β.

5. Analyses for oscillating followers are not presented. It was stated [3] that cams with translating followers may be taken as a guide. This may lead to unsatisfactory results.

It is clear that if the base circle radius should be larger than the selected value, $(\rho_c)_{min}$ will be larger than the assigned value which makes the design safer.

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