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The estimation of basic dimensions of disc cams with translating followers

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THE ESTIMATION OF BASIC DIMENSIONS OF DISC CAMS WITH TRANSLATING FOLLOWERS

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THE ESTIMATION OF BASIC DIMENSIONS OF DISC CAMS WITH TRANSLATING FOLLOWERS

1. NOTATION AND UNITS

In this notation, units are given for both SI and a familiar British system. All angles are measured positively in an anti-clockwise sense, and the cam is considered to rotate in an anti-clockwise direction.

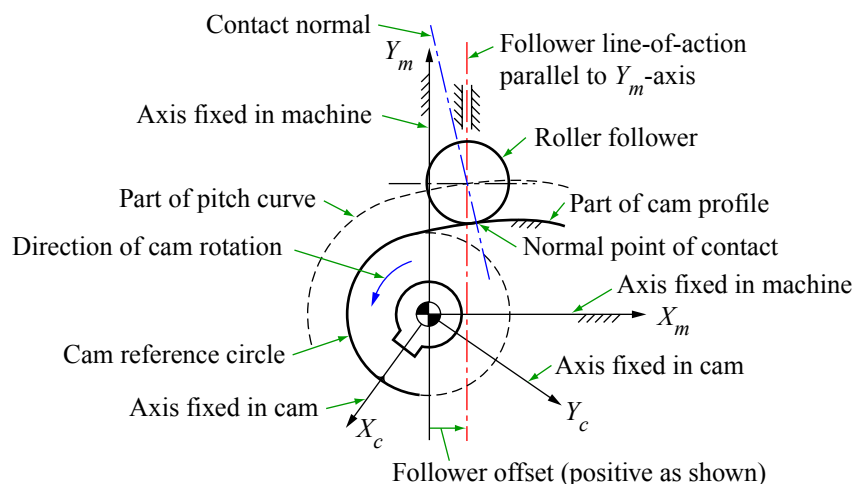
		SI	British
b	distance between cam centre of rotation and I point corresponding to maximum follower velocity	m	in
E	Young's modulus of elasticity	N/m ²	lbf/in ²
e	offset of translating follower	m	in
f_{zmax}	allowable compressive, or Hertzian, stress (smaller of values for cam and follower materials)	N/m ²	lbf/in ²
H	total follower rise (positive), or fall (negative), associated with one motion segment	m	in
I	instantaneous centre of rotation of the cam with respect to the follower (roller follower)	—	—
k_i	material constant, given by $(1 - \nu_i^2)/\pi E_i$, $i = 1, 2$	m ² /N	in ² /lbf
L	length of cam/follower contact width, <i>i.e.</i> smaller of cam width and follower (roller or face) width	m	in
O	centre of cam rotation and origin of co-ordinate axis system	—	—
P	total normal applied load	N	lbf
R_a	prime circle radius of cam, given by $(R_r + R_b)$	m	in
R_b	reference circle radius of cam	m	in
R_r	roller radius of follower	m	in
R_{REL}	relative radius of curvature between roller follower and cam profile, given by $(R_r \rho_p)/(R_r + \rho_p)$	—	—
u	normalised input displacement (cam rotation), given by $(\phi - \phi_0)/\Phi$	—	—
w	normalised output displacement	—	—
w'	non-dimensional output velocity	—	—

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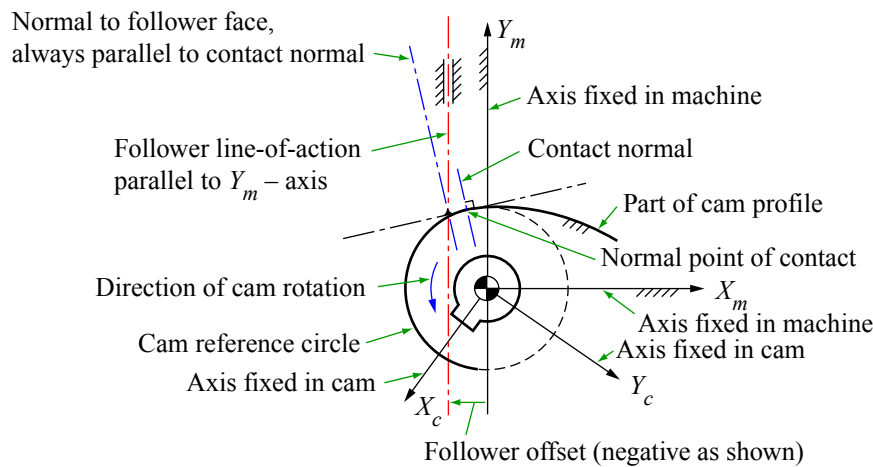
X_c, Y_c	axes fixed in cam	—	—
X_m, Y_m	axes fixed in machine	—	—
α	pressure angle ($-90^\circ \leq \alpha \leq 90^\circ$)	degree	degree
ν	Poisson's ratio	—	—
ρ	radius of curvature of pitch curve	m	in
ρ_p	radius of curvature of cam profile	m	in
σ_{co}	basic contact stress factor	N/m ²	lbf/in ²
Φ	cam angle of rotation for one motion segment producing follower lift H	degree	degree
ϕ	cam angle of rotation measured from X_m -axis to X_c -axis in an anti-clockwise sense	degree	degree
ϕ_0	value of ϕ at start of motion segment	degree	degree
ω	angular velocity of cam	rad/s	rad/s

2. INTRODUCTORY NOTES

This document is one of the comprehensive series of Engineering Sciences Data Items (see References 1 to 24) that deals with the design of cam and follower systems. This Item gives guidance on the estimation of the fundamental dimensions of a disc cam driving either a translating roller (see Sketch 2.1) or a translating flat faced follower (see Sketch 2.2). It will be necessary for the user to employ additional data presented in ESDU 95001 (Reference 16) when designing for a translating curved (usually roller) follower or when designing for a translating flat faced follower. Reference 3 gives guidance on the selection of a follower type.



Sketch 2.1 Translating roller follower



Sketch 2.2 Translating flat faced follower

For any given cam law and follower combination, the size of the cam, *i.e.* the radius of the reference circle, R_b , upon which it is generated will have a minimum practical value. This minimum value will be determined by a consideration of undercutting, cam shaft diameter, minimum radius of curvature, contact stress, pressure angle and cam profile interference. These factors can always be minimised or eliminated by increasing the radius of the cam reference circle, but only at the expense of increasing the sliding velocity between the cam and the follower or in the case of roller followers, the speed of rotation of the roller.

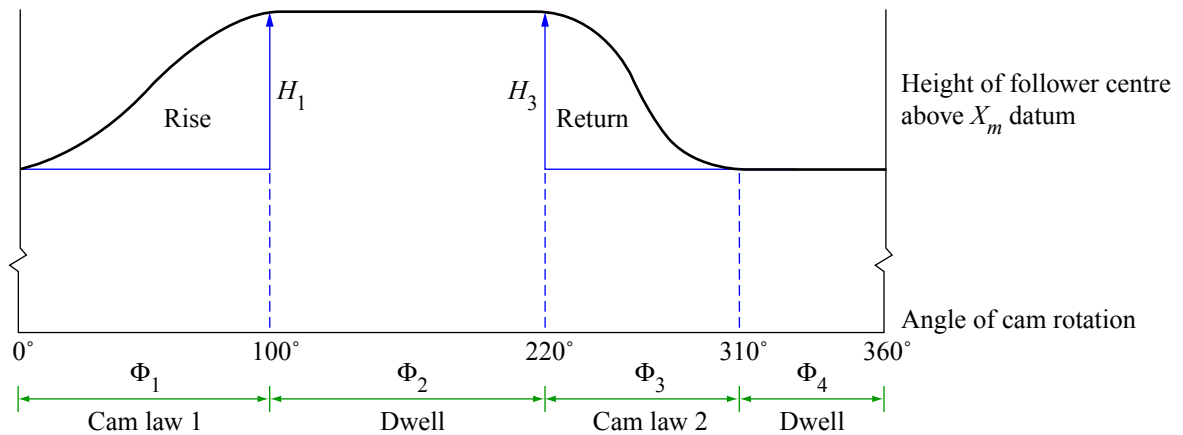
This Data Item guides the user in the design of the smallest cam that will produce the desired motion in a satisfactory manner assuming that the cam will operate with no backlash, crossover shock or over constraint. In cases where this does occur the associated additional loads, if quantifiable, can be incorporated into the general consideration of follower load (see Section 2.2). In general the user should aim to design the smallest practical cam since it not only saves space but also reduces weight and minimises out of balance and inertia effects. The additional benefits of reduced sliding velocity and hence reduced wear with flat faced followers and reduced angular velocity with roller followers further emphasise the advantage of achieving minimum cam size.

2.1 Specification of Requirements for the Cam

Several fundamental parameters must be selected or determined prior to employing the design method in this Item. Many of these are determined by the machine for which the cam is being designed and in particular by the timing requirements of that machine. It is necessary that the design for the machine and cam has been developed to a stage where the following factors have been provisionally specified.

- The rotational speed, or speed range, ω , of the cam shaft (*note, in some cases there may exist more than one critical operating speed within a range*).
- The cam angle of rotation, Φ_i , for each motion segment and whether a dwell, rise or return segment.
- The follower rise or fall, H , associated with each non-dwell motion segment.
- The cam law for each non-dwell motion segment (see References 2 and 21).
- The available space for the cam installation *i.e.*, the maximum allowable radius from the cam drive shaft axis of rotation.

Factors (b) and (c) can be defined in the form of a timing chart (see Reference 20), an example of which is shown in Sketch 2.3.



Sketch 2.3 Typical timing chart (DRDRD as shown)

2.2 Contact Force and Contact Stress

In order to make the initial estimate of cam size for a translating roller follower, it is necessary for the user to know the nature of the load on the follower for the entire cam motion (one complete revolution of the cam shaft).

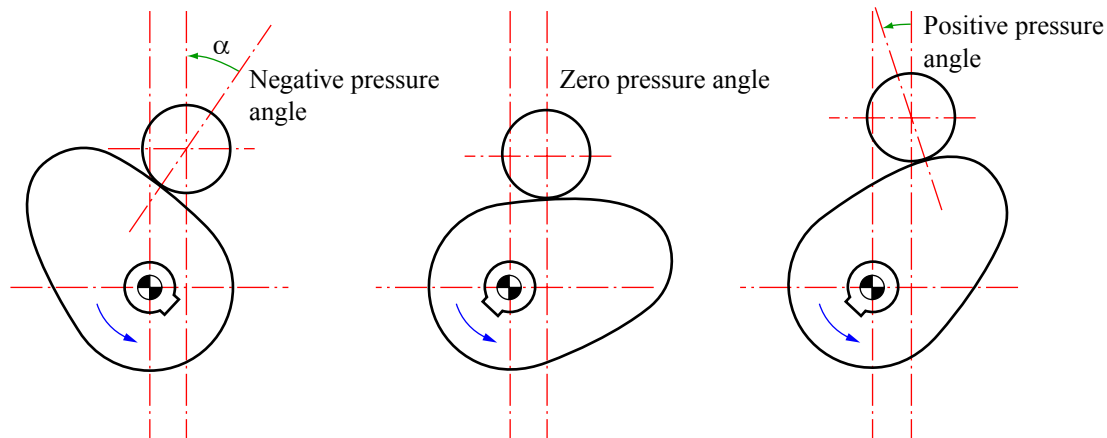
Once Section 3.1 has been studied the user will be aware that the optimum position of the follower line of action, *i.e.* the amount and sense of follower offset is dependent upon the position in the cam motion corresponding to maximum load at the follower.

At the stage of the design when size is estimated, the user need only know the nature of the load, *i.e.* whether it is inertia, constant or “spring” force dominated and hence, estimate the cam position corresponding to maximum cam profile stress. If the application requires that the cam should operate at several different shaft speeds then the nature of the load will indicate which of the speeds is critical from a stress point of view. For example, at a very low operating speed inertia forces will be negligible whilst spring forces may become critical. All operating speeds must be analysed when considering the follower load.

When the dimensions of the cam are being finalised it will be necessary for the user to know the actual value of the load acting on the follower. When used in association with the cam and follower material properties these data will enable the user to analyse the contact stress and make dimensional adjustments to compensate for extreme values. This is discussed in detail in Section 3.3 (roller followers) and in Section 4.1 (flat faced followers). Reference 15 discusses in detail the consideration of cam wear and operating life expectancy.

2.3 Pressure Angle

The pressure angle, α for a translating follower is the acute angle between the follower line of action and the normal to the cam profile passing through the nominal point of contact and as such, it is the angle between the driving force and the follower line of action. Pressure angles that are negative, zero and positive are illustrated in Sketch 2.4. The pressure angle must be considered since it is directly related to the cam loading. For a given set of conditions, a pressure angle of zero will result in a smaller follower/cam contact force than will any other value.



Sketch 2.4

The pressure angle with roller followers varies during a rise or return segment and should be limited in magnitude since high values will cause excessive contact stresses and in some cases, jamming or over-running during the return segment.

The size of the pressure angle is most critical during the active periods of the cam motion, *i.e.* when the load is acting against the motion. During the inactive periods of the motion when a spring return is required the pressure angle may be less significant if the forces involved are small.

It is good design practice to limit the angle during an active period to a maximum of 30° . With careful design of the follower assembly (*i.e.* low friction and stiff stem) considerably higher pressure angles may be successfully accommodated.

For a translating flat faced follower whose face is perpendicular to the follower line of action the pressure angle is zero throughout the cam motion. A pressure angle can be introduced with this type of follower by inclining the follower face. The angle at which the face is inclined will be the pressure angle and this will remain constant throughout the entire cam motion. With flat faced followers, high offset loading may occur which can cause the follower to jam in its guides.

2.4 Cutter Interference

The manufacturing techniques to be employed must also be considered. If the profile is to be cut with a milling cutter or grinding wheel then the user must ensure that a cutter is available with a radius that is smaller than the minimum negative radius of curvature of the cam profile.

3. DISC CAMS WITH TRANSLATING ROLLER FOLLOWERS

When designing a cam mechanism with a translating roller follower, the user may first employ a simple graphical approach (see Section 3.2) in order to arrive at an initial estimate of the key dimensions involved. It will then be necessary to “tune” the design by examining in detail several characteristics of that mechanism.

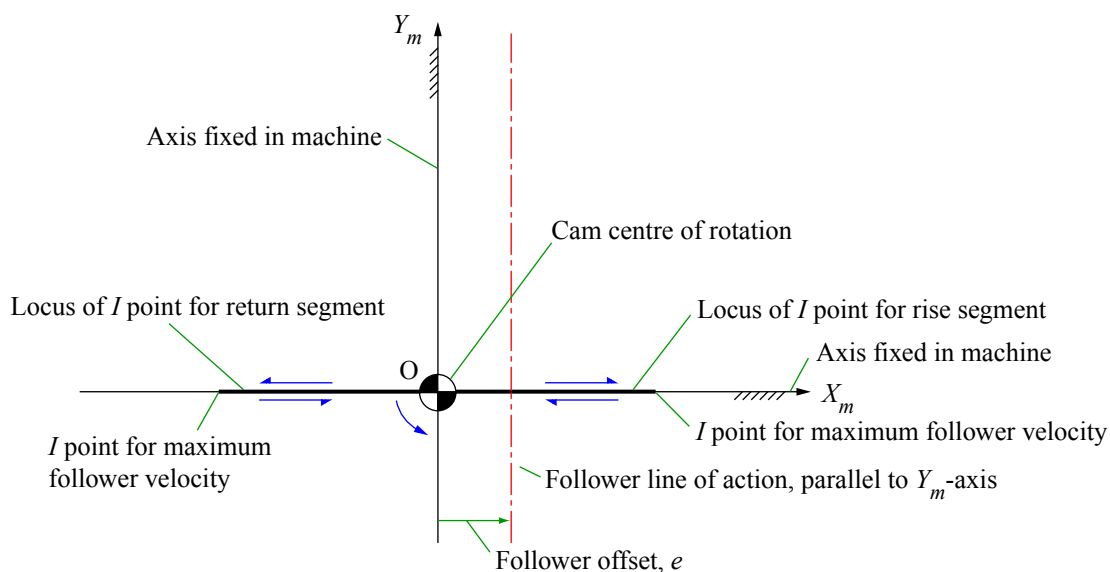
3.1 Instantaneous Centres of Rotation

The construction used in this Item to estimate the cam size achieves a condition of minimum contact force and is based upon the theory of instantaneous centres of rotation (Derivation 25). The user need not concern himself with the details of the theory since an understanding of the principles involved is not required to design a successful cam.

Notes on the theory of instantaneous centres of rotation

In a cam and follower mechanism there exists a point known as the instantaneous centre of rotation of the cam with respect to the follower. This point is designated the I point. At the beginning and end of a dwell-rise-dwell or dwell- return-dwell motion segment the I point will coincide with the centre of rotation of the cam disc. Assuming that the X_m -axis (see Sketch 3.1) has been drawn through the cam centre of rotation and perpendicular to the follower line of action then one of the following will also apply.

- If the follower is rising and the cam is rotating anti-clockwise then during the motion segment the I point will move along the X_m -axis to the right of the cam centre until an extreme point corresponding to the maximum follower velocity is reached. The I point will then move back to the cam centre along the same line (see Sketch 3.1).*
- If the follower is falling and the cam is rotating anti-clockwise then the I point will have a locus as in (a) above but to the left of the cam centre of rotation (see Sketch 3.1).*



Sketch 3.1 Loci of I point (rise and return segments)

3.2 Cam Size Estimation

The layout of the cam and follower is determined as follows, (refer also to Sketch 3.2).

- (a) Draw the X_m , Y_m axes, intersecting at the cam centre of rotation, and ensure that the Y_m -axis is parallel to the required follower direction of action.
- (b) The extreme position of the I point along the X_m -axis is determined from Equation (3.1),

$$b = w'_{max} \cdot H \frac{180}{\pi \Phi} \quad (3.1)$$

where w'_{max} is the maximum value of the non-dimensional follower velocity as defined by the cam law for the motion segment (guidance on cam law selection is given in References 2 and 21). Whether the motion segment is a rise or a return will determine the sign of the total follower displacement, H , and hence whether the locus of the I point is to the left or the right of the Y_m -axis. Mark a point B on the X_m -axis a distance b from the Y_m -axis (positive to the right of the cam centre of rotation, O).

- (c) Examine the nature of the load at the follower (see Section 2.2) and hence determine the value of u (the normalised input parameter), u_1 , corresponding to the position of the maximum load at the follower.
- (d) Determine the non-dimensional follower velocity, w'_1 , corresponding to this value of u_1 and hence calculate the optimum follower offset, e , from Equation (3.2).

$$e = w'_1 \cdot H \frac{180}{\pi \Phi} \quad (3.2)$$

Mark a point B_1 , on the X_m -axis (Sketch 3.2) a distance e from the Y_m -axis (positive to the right of the cam centre of rotation, O). To ensure that the contact force on the cam and hence the contact stress is a minimum throughout the motion segment for the given load, the mechanism should be constructed with the follower line of action passing through the point B_1 , parallel to the Y_m -axis. This arrangement will ensure that the pressure angle α , will be zero at the position in the cam motion corresponding to maximum load.

- (e) Once the position of the follower line of action has been determined, a consideration of pressure angle will yield the value of the cam prime circle radius R_a . The user should limit the pressure angle during a particular motion segment to a maximum value, α_{max} , (see Section 2.3), and then proceed with the construction as follows.

Draw a line from the point B at an angle α_{max} to the vertical to intercept the follower line of action at a point R . The point R is the position of the roller centre corresponding to maximum follower velocity ($u = 0.5$ for a symmetrical cam law). For a symmetrical cam law application, mark off the points R_1 and R_2 , a distance $H/2$ below and $H/2$ above the point R , respectively. R_1 and R_2 correspond to the extreme positions of the roller centre in the motion segment. For an application where a non-symmetrical cam law is being used the expression for the normalised follower displacement will yield the position of points R_1 and R_2 .

Draw in the line OR_1 and measure the angle α_1 . If $\alpha_1 > \alpha_{max}$ then repeat the construction but begin by drawing the line OR_1 , at an angle α_{max} to the vertical to intercept the follower line of action. In this latter case, the points R and R_2 are located a distance $H/2$ and H above R_1 respectively for a symmetrical cam law or as required if a non-symmetrical cam law is used.