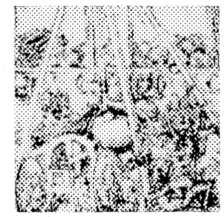
CAMS

Chapter 20



LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Recognize cam types and motions.
2. Demonstrate an understanding of cam drawing practices.
3. Communicate cam data by means of ANSI-standard dimensioning and notation.
4. Demonstrate familiarity with cam follower functions and terminology.
5. Identify cam motions, and describe them through displacement diagrams.
6. Explore the use of CAD in cam design.

20.1 INTRODUCTION

Cams (Fig. 20.1) are machine elements designed to transmit or change motion by direct rolling or sliding contact with another part, called a **follower.** Cams can translate rotary motion into rotary or linear motion, and linear motion into rotary or linear motion. Cams are either radial or cylindrical. **Radial cams** move followers perpendicular to the cam shaft; **cylindrical cams** move followers parallel to the shaft.

Most cams are designed to transform rotary motion into **reciprocating** motion. An example is the automobile engine cam shaft [Fig. 20.2(a)], which is called a *lobe cam* and which can be seen in the close-up in Figure 20.2(b). The cam raises and lowers the valve lifters of the motor. The movement of the cam imparts motion to the follower. Cams are designed to accomplish a wide variety of motion changes and are manufactured in an almost unlimited number of configurations (Fig. 20.3). A detail of a cam is provided in Figure 20.4.

For most cams, the follower moves perpendicular to the axis about which the cam is rotating. This type of cam has a **translating follower**, which might be a roller, though it is

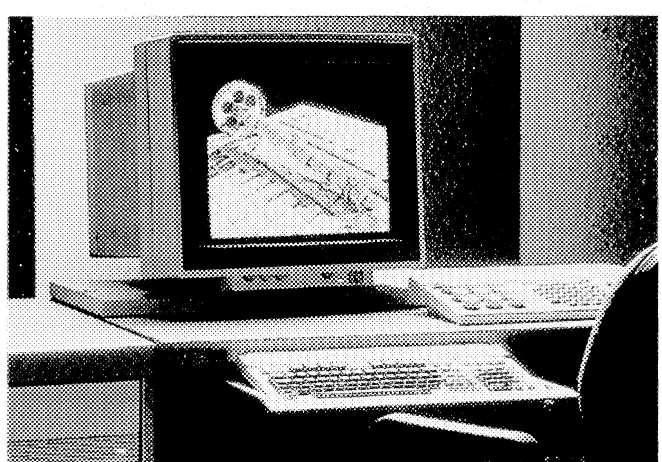
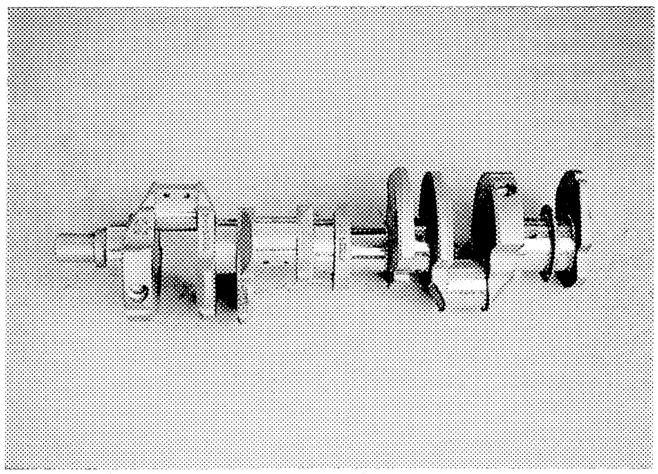
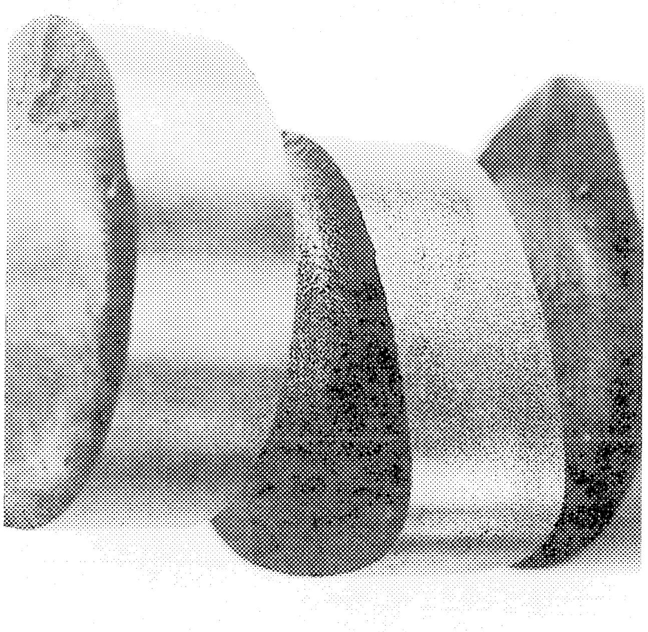


FIGURE 20.1 Computer-Aided Cam Design



(a) Automobile engine crank shaft



(b) Lobe cam on an engine crank shaft

FIGURE 20.2 Crank Shaft

normally a **flat plate cam.** A cam that moves the follower axially, or parallel to the axis of the cam, is called a **cylindrical cam** or **drum cam.** Follower systems of a cam mechanism usually consist of one or more rods, gears, levers, springs, and/or other mechanical devices.

Some cams perform other types of work, such as clamping. Figure 20.5 shows a standard cam-clamp assembly that can be ordered off the shelf from a tooling fixture company (Carr Lane) in this instance. The cam design on the end of the clamp allows the machinist to secure and release quickly and easily a workpiece requiring machining.

Cams are sometimes mounted on shafts with keys (Fig. 20.6). In some cases, the drive mechanism employs a gear.

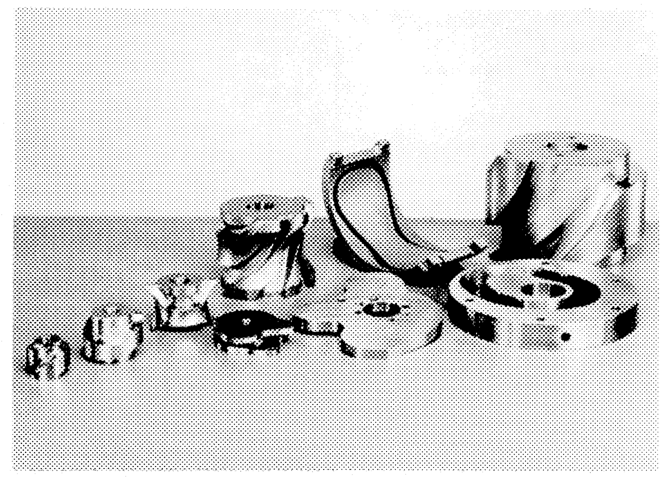


FIGURE 20.3 Cam Styles

20.1.1 Cam Terminology

The following terms are used when describing cams (Fig. 20.7).

Base circle A circle drawn with the center line of the shaft as its center and a radius equal to the distance to the center of the follower wheel when it is in its lowest position.

Cam profile The cam surface edge on which the follower moves.

Displacement diagram A curve that illustrates the movement of a cam. The diagram is drawn by laying out a stretch-out line equal to the circumference of the working circle. The line is divided into even units, based on angular divisions on the cam, and then plotted as a series of points corresponding to the cam's outline.

Dwell When a cam's follower rests or stops movement. A dwell is designed into the cam profile by allowing the cam outline to be a constant distance from its center for a period of time.

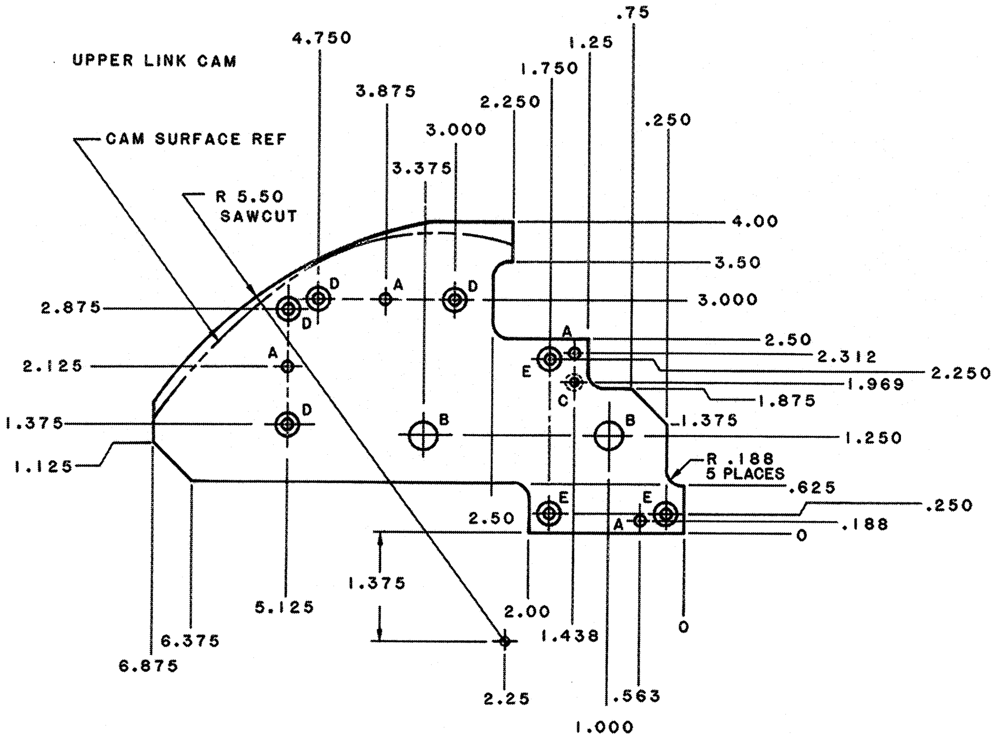
Follower A machine element that moves with reciprocating motion by following the cam as it rotates. Followers usually move up and down, although followers on drum cams move back and forth.

Harmonic motion A type of motion that produces a smooth start and stop with nonuniform speed.

Height The total vertical rise of the follower during operation of the cam. Its value is established by subtracting the base circle from the working circle.

Pitch curve (pitch line) A curve generated by the motion of the follower about the cam. The distance between the shaft center and each position of the follower's center generates the pitch curve as it moves about the cam profile.

Reciprocating motion Linear movement of the follower, either back and forth or up and down, that is caused by the rotary movement of the shaft-and-cam assembly. A follower can also oscillate in rotation.



.25 ALY ALUM ANODIZE BLACK

HOLE	DESCRIPTION	QTY
A	Ø .125 THRU	4
B	Ø .375 THRU	2
C	8-32 UNC-2B	1
D	Ø .149 Ø .266 CBORE X .138 DP	4
E	Ø .171 Ø .313 CBORE X .164 DP	3

FIGURE 20.4 Cam Detail

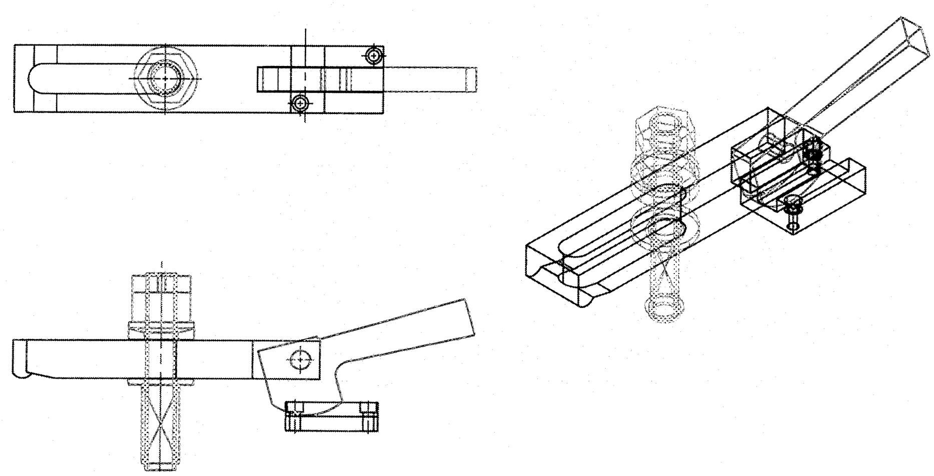


FIGURE 20.5 Carr Lane Cam-Clamp Assembly

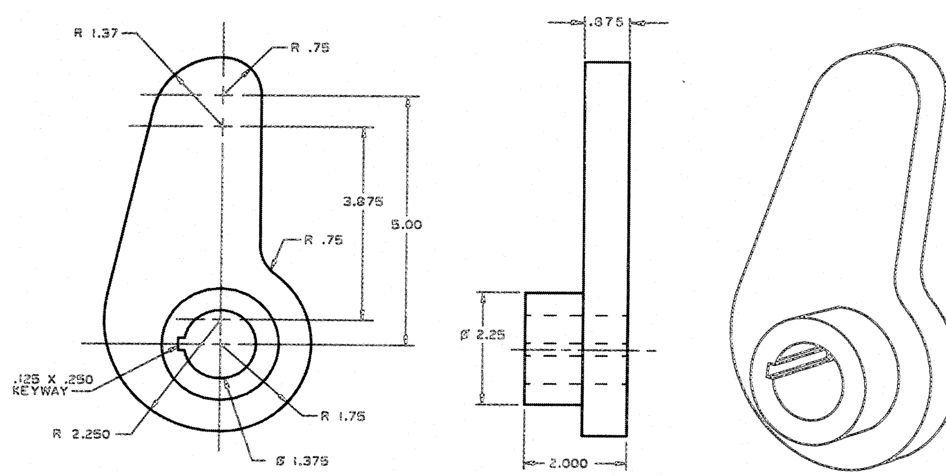
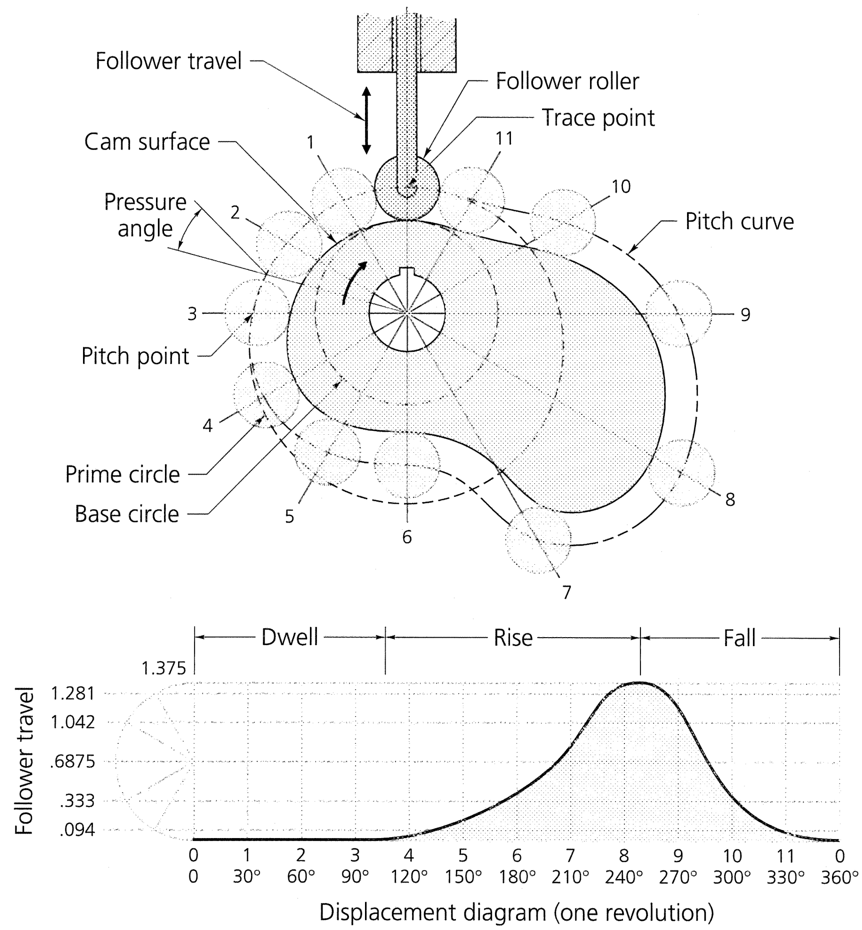


FIGURE 20.6 Cam

FIGURE 20.7 Cam Terminology



Rise and fall Movement of the cam through one cycle.

Roller A cylindrical element mounted at the end of a follower to follow the cam outline.

Time interval The time needed to move the follower from its lowest to its highest position.

Transition point The position where the acceleration changes from plus to minus and the follower reverses directions.

Uniform acceleration Change in speed that is constant throughout the cam movement.

Uniform velocity The constant speed at which a cam follower might rise and fall.

Working circle A circle with the center of the shaft as its center and a radius equal to the distance to the center of the follower wheel when it is in its highest position. The working circle is not normally shown on the cam drawing. The distance between the base circle and the working circle is equal to the follower displacement (rise, or height).

20.1.2 Classes of Cams

Cams can usually be divided into two classes: **uniform motion cams** and **accelerated motion cams.** The uniform motion cam moves the follower at the same speed from the beginning to the end of the stroke. Because the movement is started and stopped abruptly, a shock can occur. If the movement is rapid, there is a significant shock at the beginning and at the end of the stroke. Therefore, in high-speed machinery, cams must be designed so that sudden shocks are avoided throughout the motion of the follower. The various cam motions can be described in diagrams (Fig. 20.8):

Uniform motion Equal distances are traveled in equal intervals of time [Fig. 20.8(a)].

Uniform motion modified A radius is introduced at the beginning and the end to smooth the starting and stopping [Fig. 20.8(b)].

Parabolic motion (a) The displacement curve is created through parabolic construction [Fig. 20.8(c)]. (b) The displacement curve is constructed using the uniformly accelerated and retarded method, in which the ratio of increase and decrease is 1:3:5:5:3:1 [Fig. 20.8(d)].

Harmonic motion The distances moved vertically are obtained by projecting from the equally divided semicircle; **gravity motion** is the motion of a falling body [Fig. 20.8(e)].

Cycloidal motion The displacement curve is generated from a cycloid that is the locus of a point on a circle rolling on a straight line [Figure 20.8(f)].

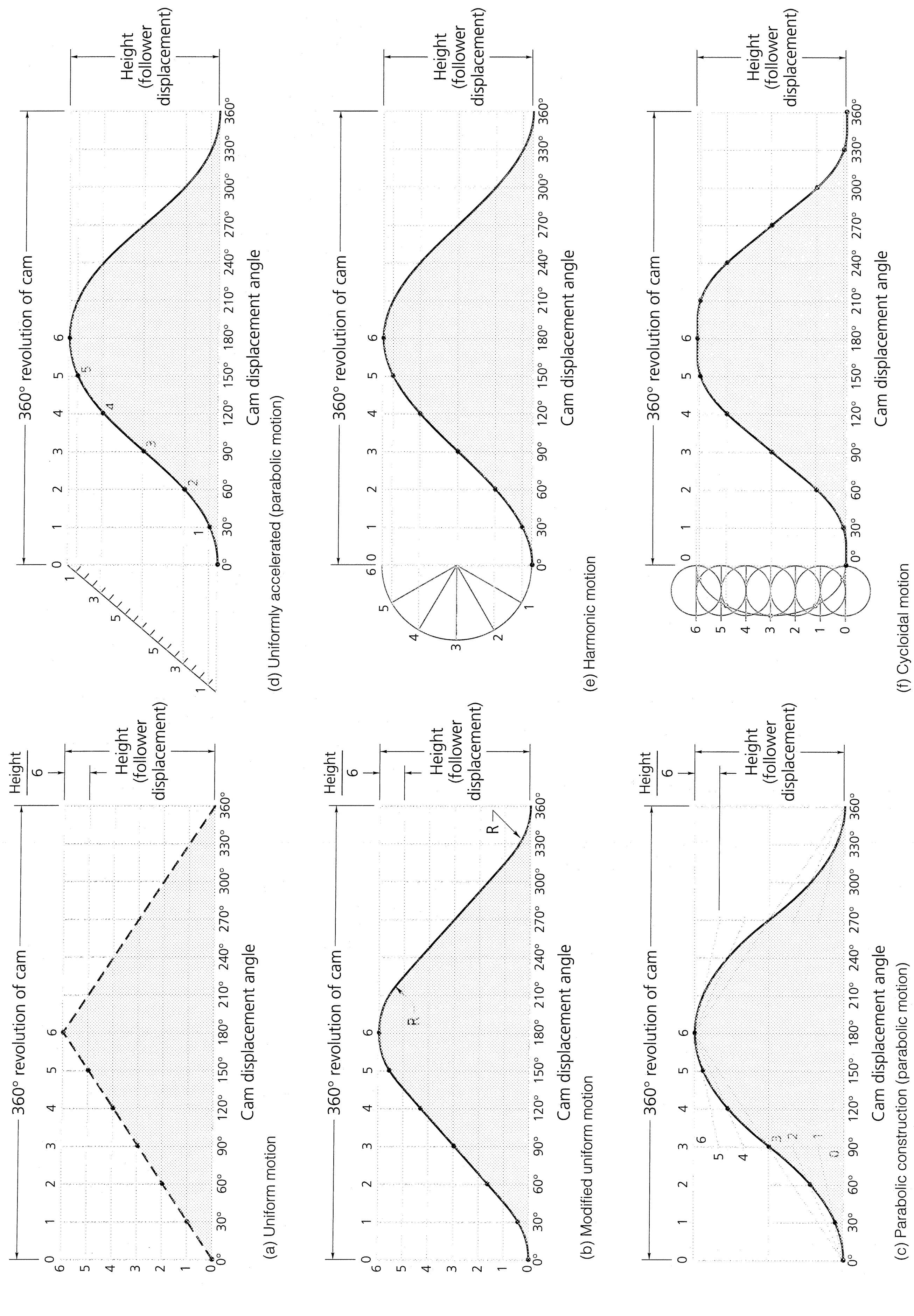


FIGURE 20.8 Displacement Diagrams for Cam Motions

Focus On . . .

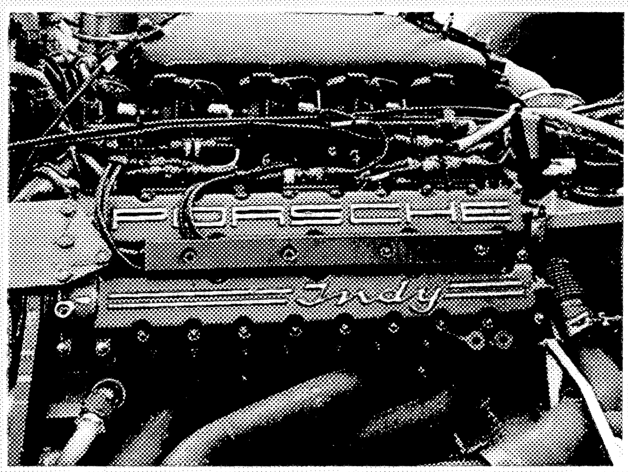
ENGINE CAMSHAFTS

In its most basic form, a camshaft would be a simple shaft with an eccentric lobe or cam on it. One cylinder of an engine would use two such simple camshafts: one for the inlet valve, the other for the exhaust valve. However, multiple-cylinder engines usually have as many cams as there are valves to be operated. For a multi-valve engine, all the cams are placed at intervals on one shaft (the camshaft). On most engines, the camshaft is directly above the crankshaft or is located to one side and is placed in the crankcase. In this type of design, the camshaft is driven directly from the crankshaft by gears or by a silent chain.

Although the cams appear simple in shape, cam designs are actually worked out in painstaking mathematical detail and then verified by experimentation in the laboratory. If the shape of the cam is altered by wear, then the efficiency of the engine drops dramatically. The desired smooth running of the engine is also quickly destroyed.

There is a lot more to cam design than simply opening and closing a valve. The cam is designed to lift the valve at precisely the correct position of the piston movement and keep it open long enough to obtain the most efficient filling and emptying of the cylinder. For a passenger car, the cams open the valves smoothly and gently to make for quiet operation of the engine, and the design is usually a compromise between efficiency and quiet operation. For a race car engine, however, noise is acceptable, so cams are designed for the highest possible efficiency, deliberately aiming to open the valve faster, wider, and longer and to close it more quickly. Of course, race car engines are noisy, idle roughly, and wear more quickly. A camshaft designed for a race car engine would be totally unacceptable for a family sedan. Many sports cars on the market today offer a compromise between efficiency and operating parameters.

The design of the cams on camshafts is vitally important to the basic operation of the engine and also affects how the customer perceives the smooth operation of the car.



Porsche Indy car racing engine in Porsche chassis.

A displacement diagram of a cam might utilize many types of motions to accomplish specific design tasks. Figure 20.9 shows a displacement diagram that has three dwells and three types of motion: modified, parabolic, and harmonic. *Modified motion* is simply a straight line that has radii introduced at each end. *Harmonic motion* is plotted by drawing a half circle and dividing it evenly, with each division corresponding to a division on the diagram (horizontally). The points are projected from the half circle to the vertical lines and connected with a smooth curve (using an irregular curve). *Parabolic motion* is plotted by proportionally dividing the vertical distance of the rise or fall using a ratio of 1:3:5:5:3:1 and projecting the points to the vertical lines, as shown.

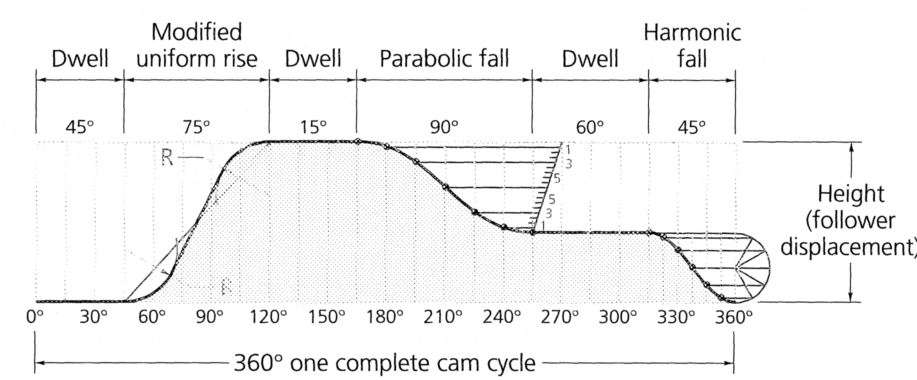


FIGURE 20.9 Cam Displacement Diagram Showing a Variety of Motions and Dwells

Applying Parametric Design . . .

SPLINE CAMS

Cams in parametric design are created by sketching a **spline** (similar to an irregular curve) feature through a series of specific points and then giving the depth of the protrusion-cam thickness. To create a spline:

- Choose **Spline** from the GEOMETRY menu
- The SPLINE MODE menu appears with the following commands:

  Sketch Points Create a spline by picking screen points for the spline to pass through.

  Select Points Create a spline by selecting existing sketcher points. Once the point has been selected, there is no further link between the point and the spline.

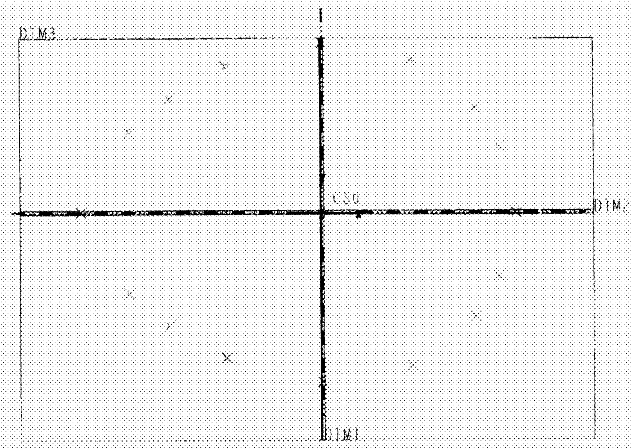


FIGURE C Sketching Points

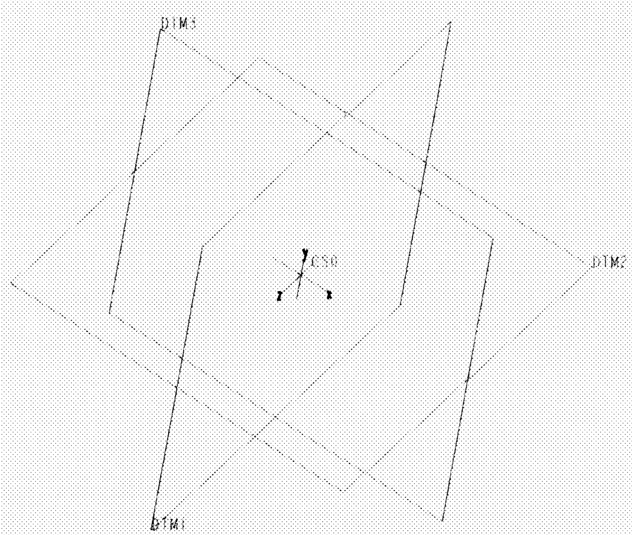


FIGURE A Default Datums

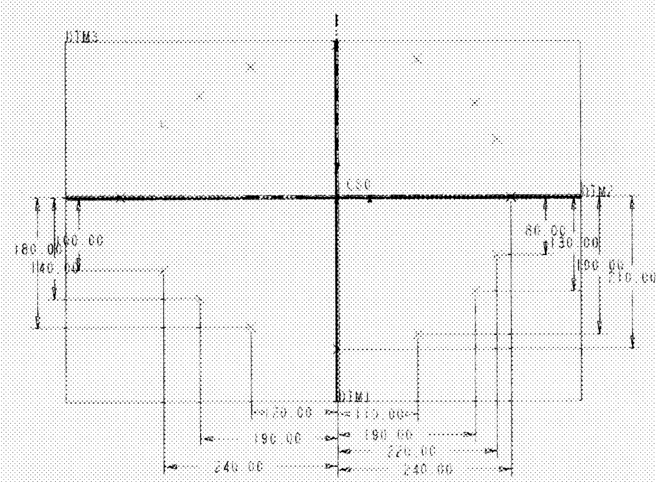


FIGURE D Dimensioning and Modifying Points

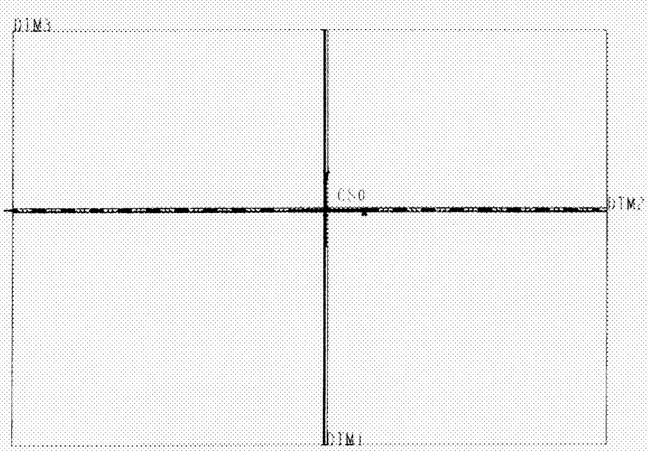


FIGURE B Datum Planes Oriented for Sketching

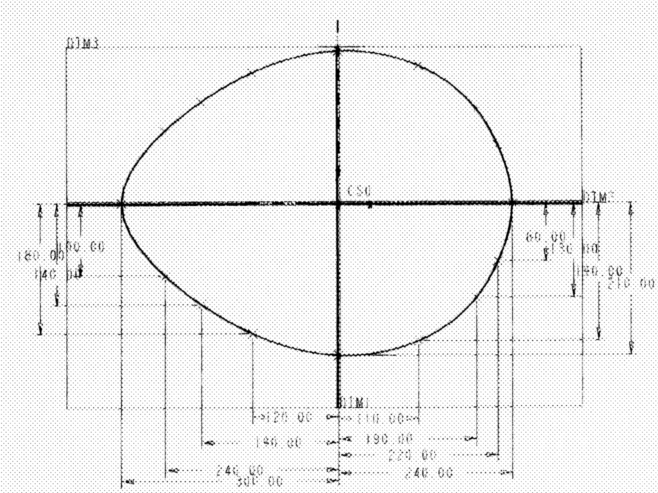


FIGURE E Create Spline Through Selected Points

The cam in the example shown here was created through the following commands.

1. Define a set of default planes (Fig. A).
2. Orient datum planes for sketching (Fig. B).
3. Sketch points approximately (Fig. C).
4. Dimension points and modify them to required coordinates (Fig. D).
5. Create a spline via **Select Points** (Fig. E).
6. Use point locations for dimensioning the spline (Fig. F).
7. Regenerate the part and add depth (Fig. G).
8. Orient the view to see depth (Fig. H).
9. Add the hole, and then cut the keyseat (Fig. I).
10. Display the part in a pictorial orientation (Fig. J).

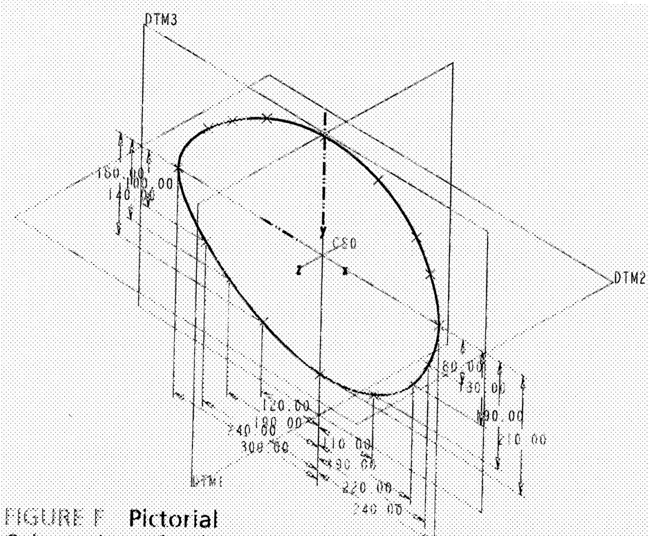


FIGURE F Pictorial Orientation of Spline and Dimensions

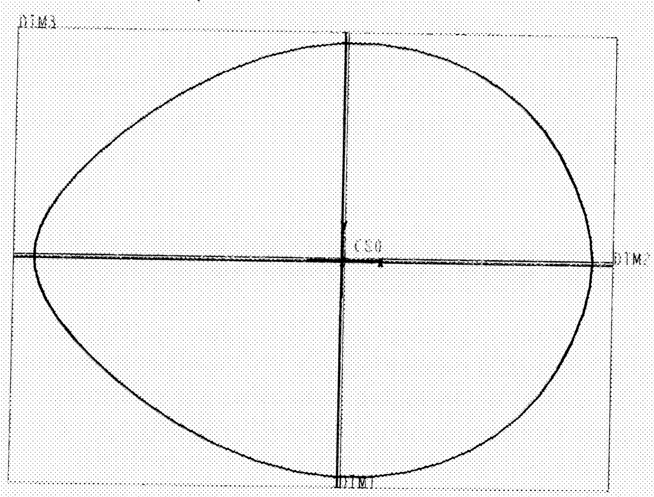


FIGURE G Completed Spline Feature

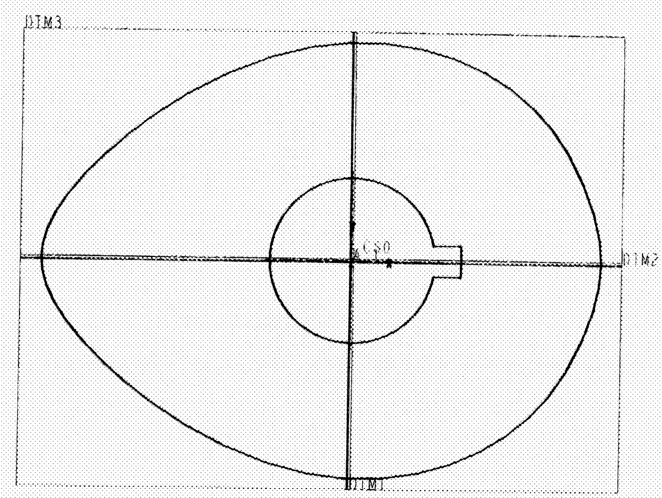


FIGURE I Hole Added to Cam Center and Keyseat Cut Through the Part

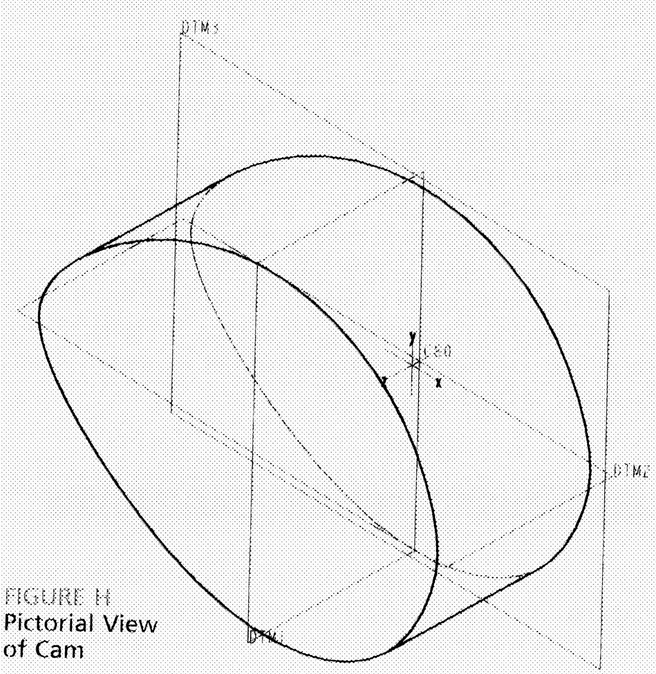


FIGURE H Pictorial View of Cam

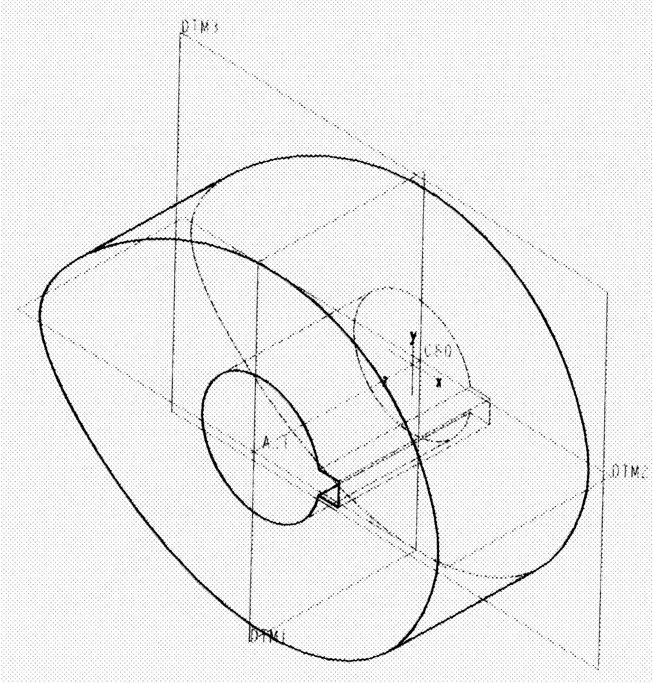


FIGURE J Pictorial View of Cam

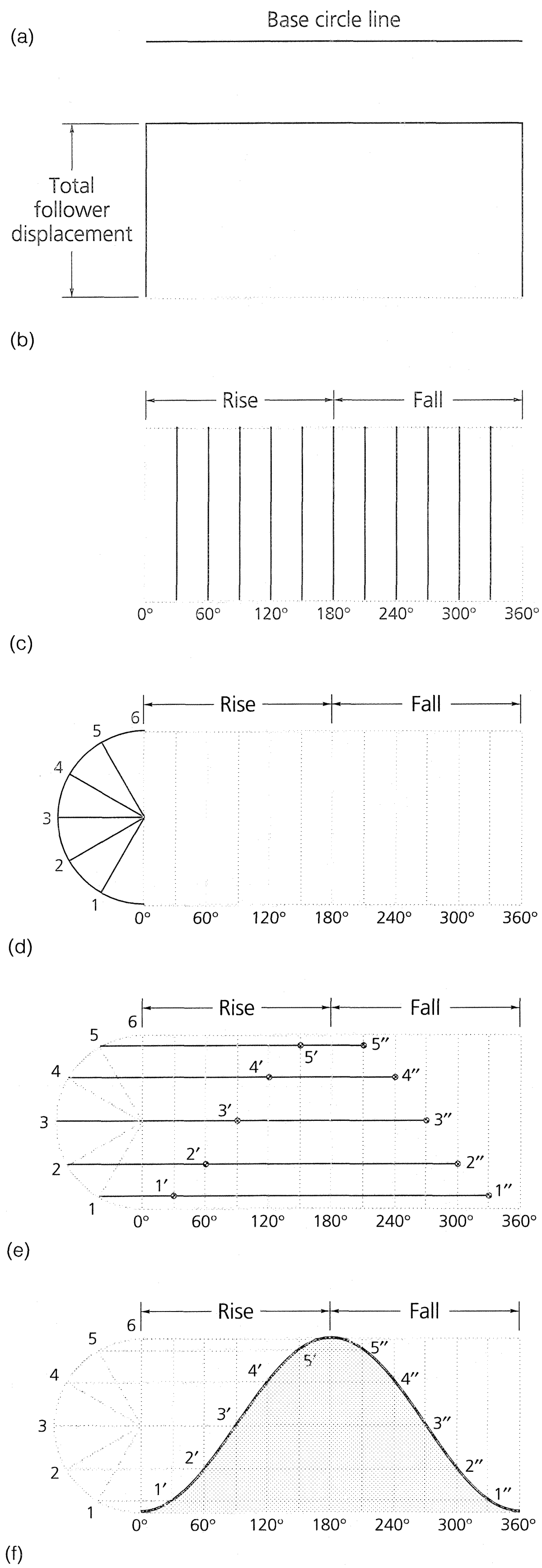


FIGURE 20.10 Constructing Displacement Diagrams

Figure 20.10 presents the step-by-step construction of a harmonic motion displacement diagram:

(a) First draw the base circle line, with the circle's circumference as the length of the layout line.
(b) The height of the displacement diagram represents the distance covered by the total follower displacement, also known as the *follower travel*.
(c) Lay off the rise and the run on the the base circle line and locate the angles there.
(d) Draw the half circle, and divide it as shown.
(e) Project points on the half circle to the corresponding "degrees" lines.
(f) Connect the points with an irregular curve.

Some cams are designed to employ **gravity motion**, that is, uniformly accelerated motion. The **uniformly accelerated motion cam** is appriate in cam designs requiring moderate speeds. However, if sudden changes in acceleration occur at the beginning, the middle, or the end of the stroke, this type of cam is not the best design. A **cycloidal motion curve cam**, since it results in low noise, produces no abrupt changes in acceleration and is often used in high-speed machinery.

20.2 CAM FOLLOWERS

The three most common cam roller followers (Fig. 20.11) are (a) the **radial translating** style, (b) the **offset translating** style, and (c) the **swinging** style. When the cam rotates, it imparts a translating motion to the roller followers in (a) and (b) and a swinging motion to the roller follower in (c).

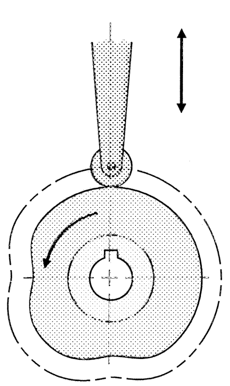
Figure 20.12(a) shows a **closed-track single roller** cam. In (b), the roller is forced to move in a **closed-track double roller.** Open-track cams are usually smaller than closed-track cams, but, in general, springs are necessary to keep the roller in contact with the cam at all times. Closed-track cams require no spring and have the advantage of positive drive throughout the rise-and-return cycle.

Flat-faced, **spherical-faced**, and **pointed** followers (Fig. 20.13) are good styles for when the cam is not moving at high speeds and when heat buildup and wear of the follower are not factors in the machine's design.

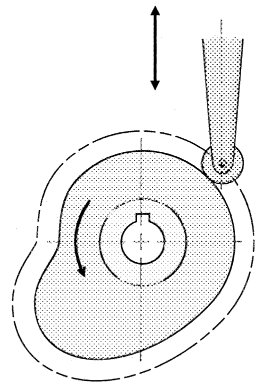
As a cam moves with a rotating motion, its curved-edge surface moves the reciprocating follower as in Figure 20.14, where five positions of the roller follower are shown, from the lowest to the highest.

20.3 DISPLACEMENT DIAGRAMS

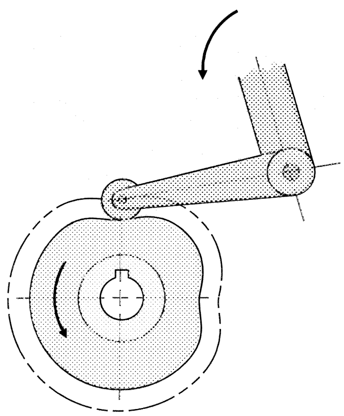
The design of a cam usually begins with the **displacement diagram.** A simplified displacement diagram is shown in Figure 20.15. One cycle means one 360° revolution of the



(a) Radial translating

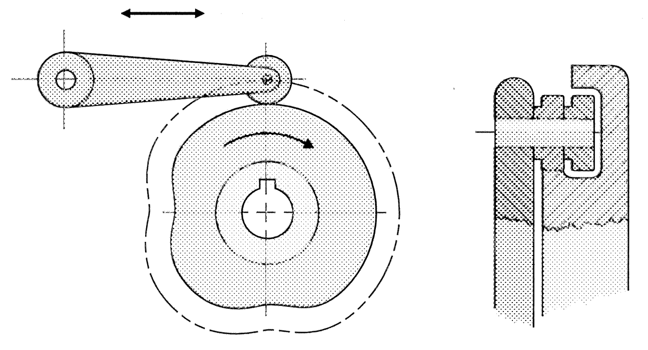


(b) Offset translating



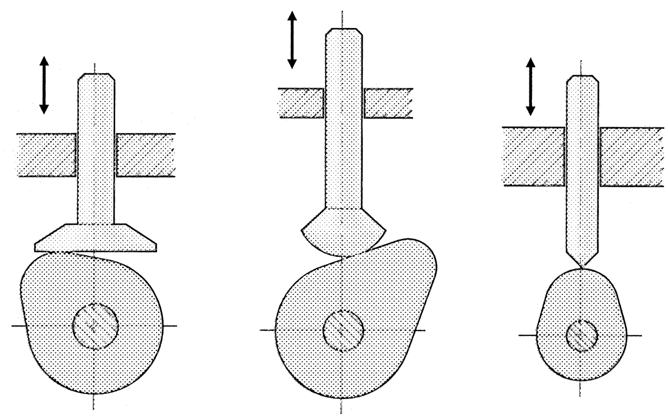
(c) Swinging

FIGURE 20.11 **Roller Follower Styles**



(a) With one follower (b) With two followers

FIGURE 20.12 **Closed-Track Followers**



(a) Flat-Faced (b) Spherical-Faced (c) Pointed

FIGURE 20.13 **Nonrolling Cam Followers**

cam. The horizontal distances A, B, C, and D are expressed in either units of time (seconds), radians, or degrees. The vertical distance (height) represents the maximum "rise" (stroke) of the follower.

The time-displacement diagram for a cam with a radial translating roller follower is shown in Figure 20.16(a). This diagram is read from left to right, as follows: For 100° of cam shaft rotation, the follower rises (AB), dwells in its upper position for 20° (BC), returns over 180° (CD), and finally dwells in its lowest position for 60° (DE).

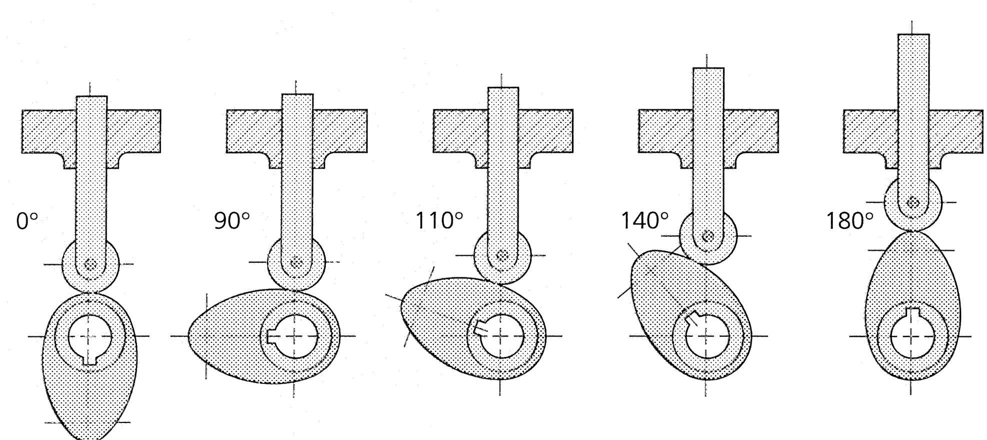


FIGURE 20.14 **Five Positions of a Lobe Cam and Roller Follower**

FIGURE 20.15 Simplified Displacement Diagram

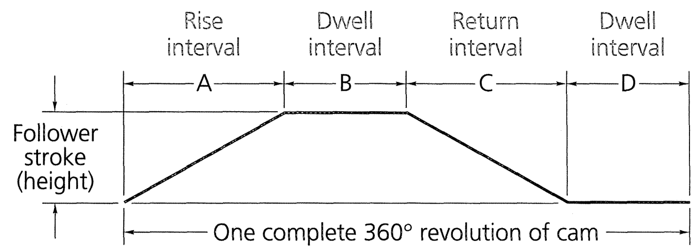
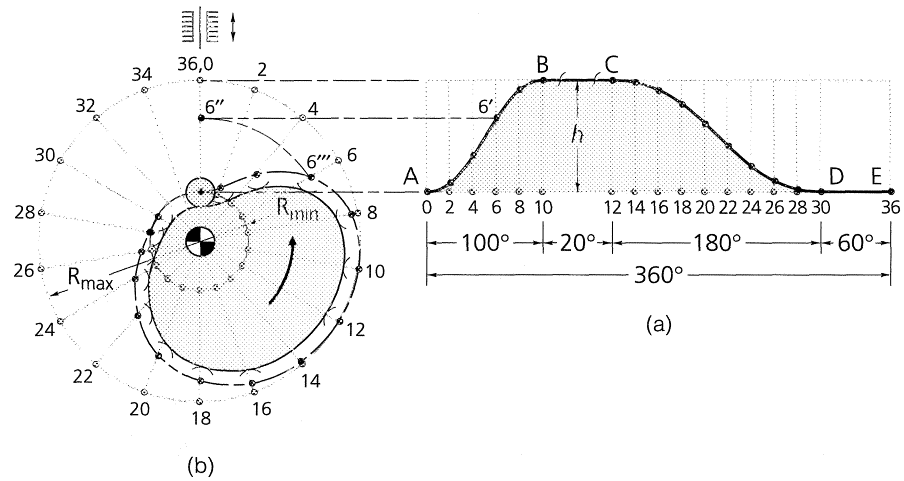


FIGURE 20.16 (a) Displacement Diagram and (b) Cam Layout



20.4 DRAWING CAMS

When drawing the cam and follower, instead of revolving the cam, it is assumed that the follower rotates around the fixed cam. This requires the drawing of many follower positions, but because this is accomplished more or less diagrammatically, it is relatively simple.

When a roller, rather than a point, is used as the follower, the cam outline will be smaller. The **pitch curve** (pitch line) becomes the line of centers of the roller (Fig. 20.17). With the radius of the roller and the centers on the pitch line, a number of arcs are drawn to which a tangent working curve

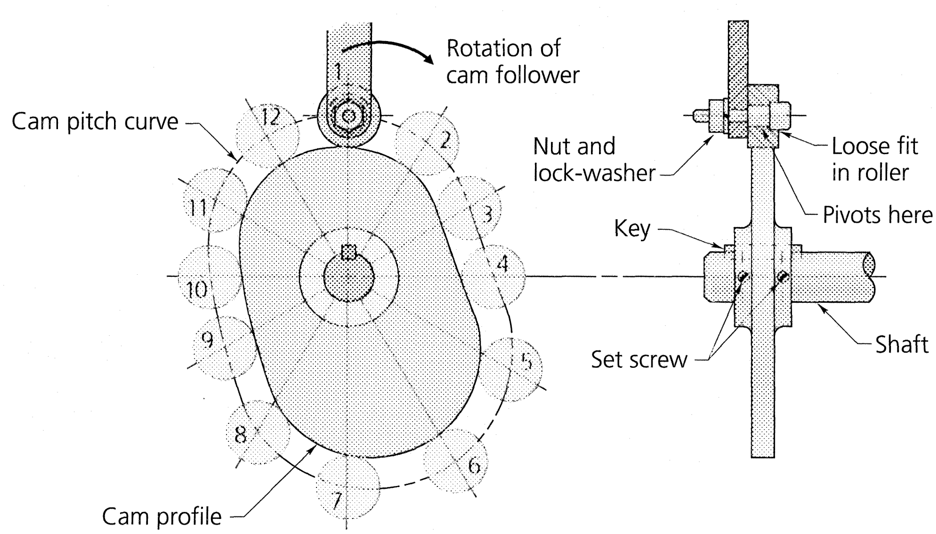


FIGURE 20.17 Cam-and-Roller-Follower Assembly

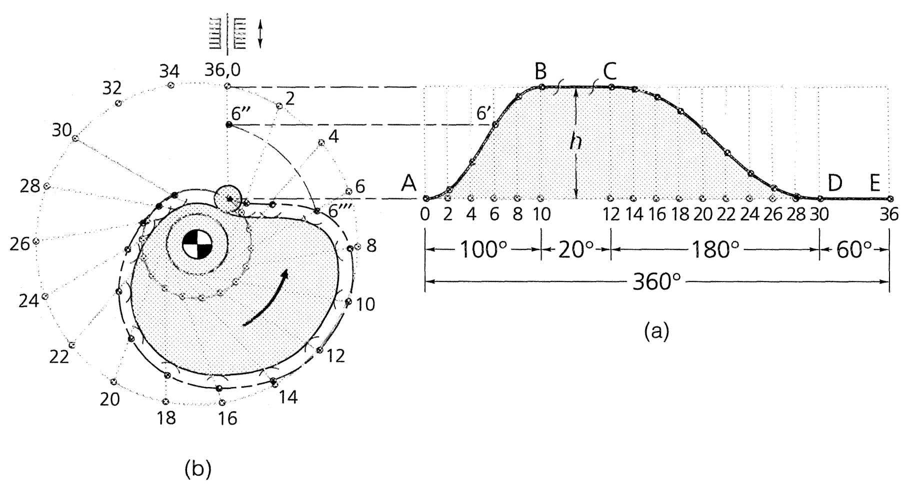


FIGURE 20.18 Cam with Offset Translating Roller Follower

can be drawn to give the cam outline. You can also transfer the distances with a compass or dividers. The **cam pitch curve** is the actual profile or working surface when a flat, pointed, or spherical follower is involved. To obtain the profile or working surface for a cam with a roller follower, a series of circles is drawn, with centers on the pitch curve and radii equal to the radius of the roller. The inner envelope drawn tangent to these arcs is the cam working surface or profile.

As part of the inversion process, the direction of rotation is important. To preserve the correct sequence of events, the artificial rotation of the follower must be the reverse of the cam's prescribed rotation. Thus, in Figure 20.17, the cam rotation is counterclockwise, whereas the artificial rotation of the follower is clockwise.

Figure 20.16 shows the cam construction layout with the cam pitch curve as a centerline. To locate a point on this curve, a point on the displacement curve, such as 6′ at the 60° position, is projected horizontally to point 6″ on the 0° position of the cam construction diagram. Using the center of cam rotation, an arc is struck from point 6″ to intercept the 60°-position radial line. This gives point 6″ on the cam pitch curve. The smaller circle in the cam construction layout has a radius R_{min} equal to the smallest distance from the center of cam rotation to the pitch curve. The larger circle has a radius R_{max} equal to the largest distance to the pitch curve. The difference in radii of these two circles is equal to the maximum rise (height) of the follower.

Figure 20.18 shows the construction of a cam with an offset translating roller follower. The time-displacement diagram, the cam layout, and an offset follower are also shown. The follower's angular position lines are not drawn radially from the cam shaft center in the construction of this type of cam. Instead, they are tangent to a circle having a radius equal to the amount of offset of the centerline of the cam follower from the center of the cam shaft.

Figure 20.19 shows a timing cam and displacement diagram used in a paper copier. This cam was designed and modeled on a CAD system. After the points were established on the cam layout, a **SPLINE** command was used to draw a smooth curve through the points. This eliminates the need for an irregular curve.

20.4.1 Dimensioning Cams

Standard ANSI dimensioning practices are employed to dimension all cams (Fig. 20.20). When a displacement diagram is not provided, the detail must show all radii for the cam profile outline. In this detail, the cam's shaft hole must be perpendicular to surface A within .002 in. The cam is held in place on the shaft with a keyseat and set screw. The eight 1.00 in. diameter holes reduce the total mass weight of the cam. In Figure 20.21, a cylindrical drum or cam is detailed and a displacement diagram provided. This is a typical industrial cam detail drawn on a CAD system.

You May Complete Exercises 20.1 Through 20.3 at This Time

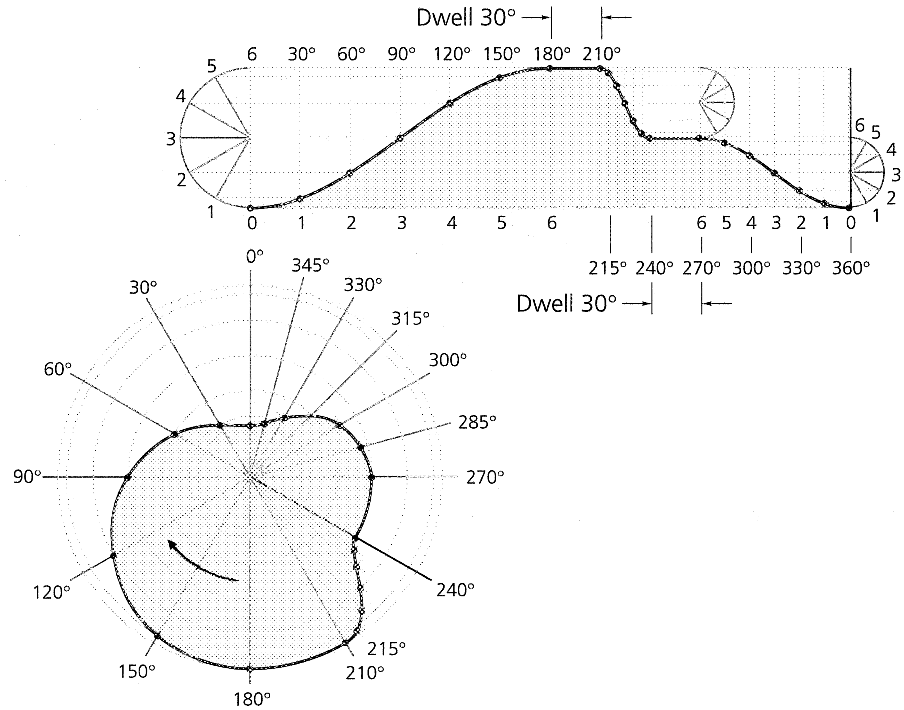
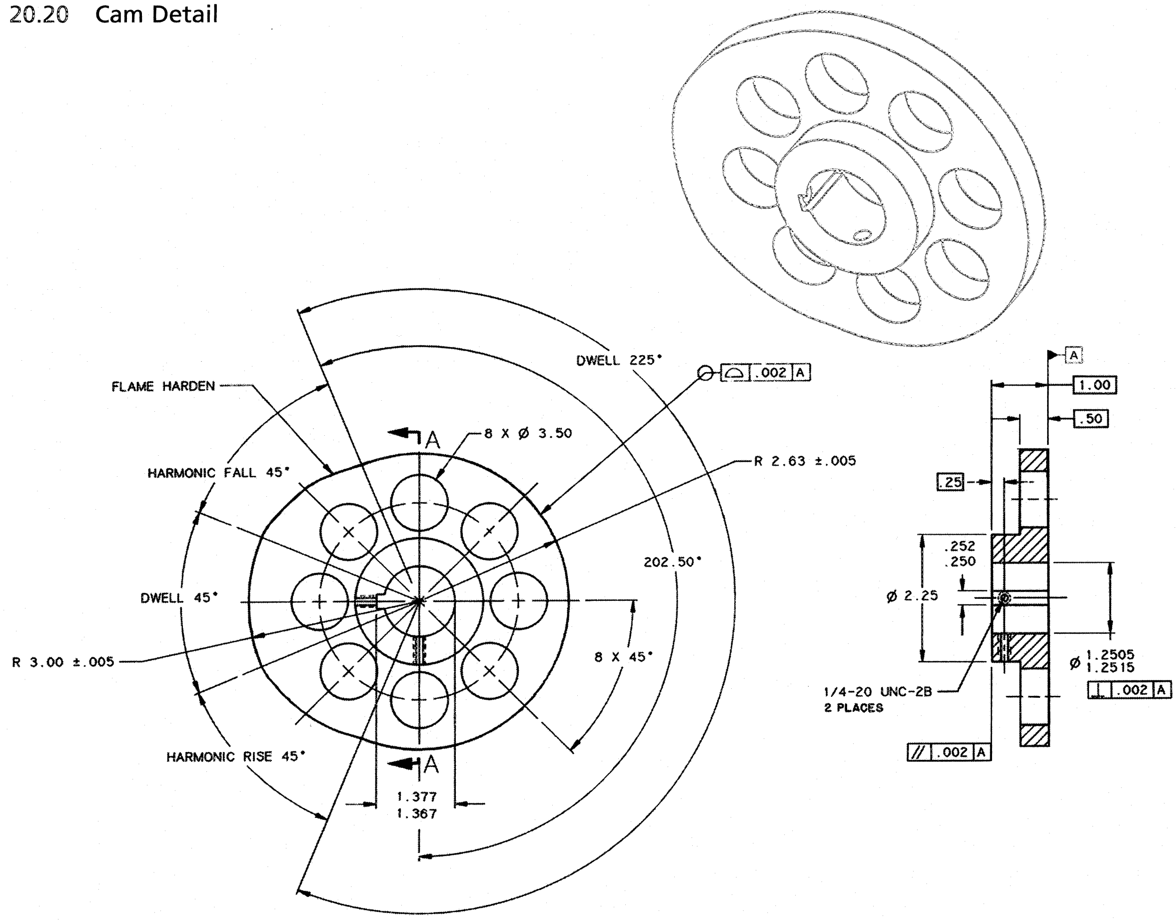
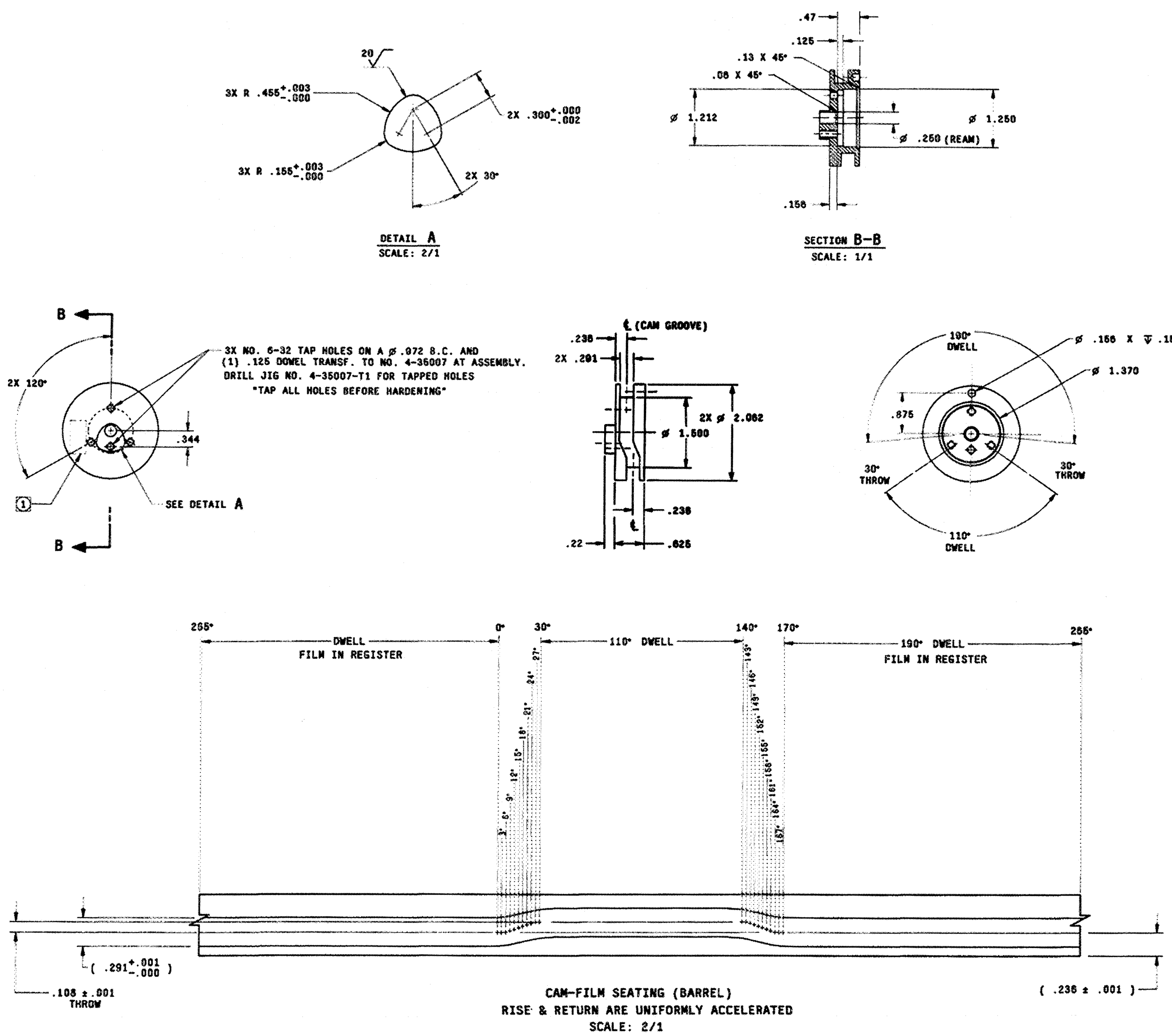


FIGURE 20.19 Construction of a Cam Using a Displacement Diagram

FIGURE 20.20 Cam Detail





170°	.000"
167°	.002
164°	.009
161°	.019
158°	.035
155°	.054
152°	.073
149°	.089
146°	.099
143°	.105
140°	.108
30°	.108
27°	.105
24°	.099
21°	.089
18°	.073
15°	.054
12°	.035
9°	.019
6°	.009
3°	.002
0°	0"
DEGREES	TOTAL RISE FROM DWELL
DEVELOPMENT SEATING (BARREL CAM)	

NOTES: UNLESS OTHERWISE SPECIFIED.

(1) PERMANENT MARK PART NO. (600-660123-001) AND LATEST REVISION LETTER AND VENDOR LOGO APPROXIMATELY WHERE SHOWN. CHARACTERS AND LOGO TO BE .10 MIN .13 MAX HEIGHT.

2. THIS DRAWING SHALL BE INTERPRETED PER ANSI Y14.5M, 1982.

(3) CAM MANUFACTURING PROCEDURE:
3.1 ROUGH FINISH BLANK & CORE HARDEN TO Rc 40.
3.2 SEMI FINISH MACHINE, TAP ALL HOLES & NITRIDE TO SUFFICIENT PENETRATION TO LEAVE .010 TO .012 DEPTH AFTE GRINDING.
3.3 BORE & FINISH GRIND CENTER HOLE.
3.4 FINISH GRIND ALL DIAMETERS CONCENTRIC WITHIN .0005 T.I.R. TO THE ø 1.218.

4 MATERIAL: ALUMINUM,AA ALLOY 6061-T6.

FIGURE 20.21 Detail of a Cylindrical Cam

QUIZ

True or False

1. Cams are designed to change reciprocating motion into revolving motion.
2. A rolling follower is a machine element used on designs that operate at a high speed. It is also employed where there is considerable wear, and when friction (heat) buildup is a factor in the operation of the machine.
3. The working circle of a cam is the distance from the shaft centerline to the highest position on the edge of the cam profile.
4. Cylindrical cams transmit motion perpendicular to the cam's shaft.
5. Drum cams serve to move the follower axially.
6. The time interval is the time needed to move the follower through its motion from its highest to its lowest position and back again to the starting position at the top.
7. There are three classes of cams.
8. In uniform motion the displacement curve is created through parabolic construction.

Fill in the Blanks

9. An __________ __________ is not in line with the cam centerline.
10. Harmonic motion of a cam is ______________, but the __________ is not __________.
11. The __________ command can be used to draw the cam profile if a CAD system is available.
12. ____________ ____________ follower designs require no springs.
13. One cycle of a cam's movement plotted on a displacement diagram means a __________ revolution of the cam.
14. When a roller, instead of a point, is used as the follower, the __________ __________ becomes __________.
15. __________ motion is plotted by drawing a __________ circle and __________ it evenly.
16. __________ are normally mounted on __________ and secured with __________. The drive mechanism may be a __________.

Answer the Following

17. Name four types of cam motion, and give a short description of each.
18. What are displacement diagrams? Why are they used in cam design?
19. Name and describe the classes of cams.
20. What is a cam's dwell?
21. What are the three most common types of followers?
22. When are flat-faced followers not used?
23. What is the difference between open-track and closed-track follower systems? Which requires the use of a spring?
24. Describe the difference between the cam profile and the base circle.

EXERCISES

Exercises may be assigned as sketching, instrument, or CAD projects. Transfer the given information to an "A"-size sheet of .25 in. grid paper. Complete all views, and solve for proper visibility, including centerlines, object lines, and hidden lines. Exercises that are not assigned by the instructor can be sketched in the text to provide practice and to enhance understanding of the preceding material.

After Reading the Chapter Through Section 20. 4.1 You May Complete the Following Exercises

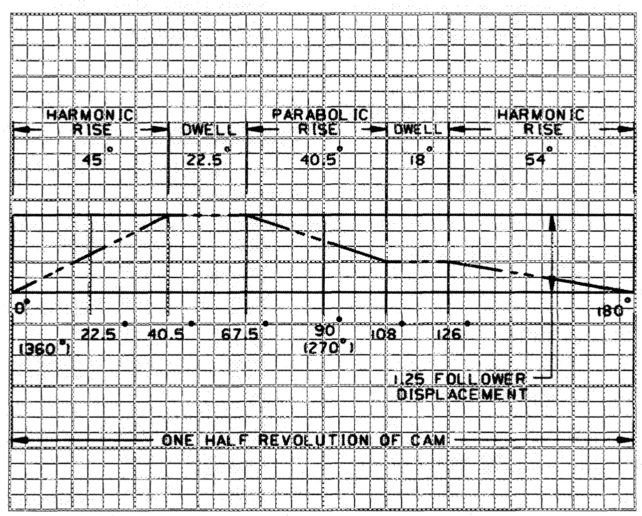
Exercise 20.1 Draw the displacement diagram using the given cam motions, dimensions, and displacement. The cam is symmetrical about its vertical centerline. Use the diagram for both halves to construct the cam in Exercise 20.2.

Exercise 20.2 Using the displacement diagram from Exercise 20.1, lay out the cam and follower as shown. Calculate the proper keyseat and set screw for the shaft. The set screw is to be at 90° to the keyseat.

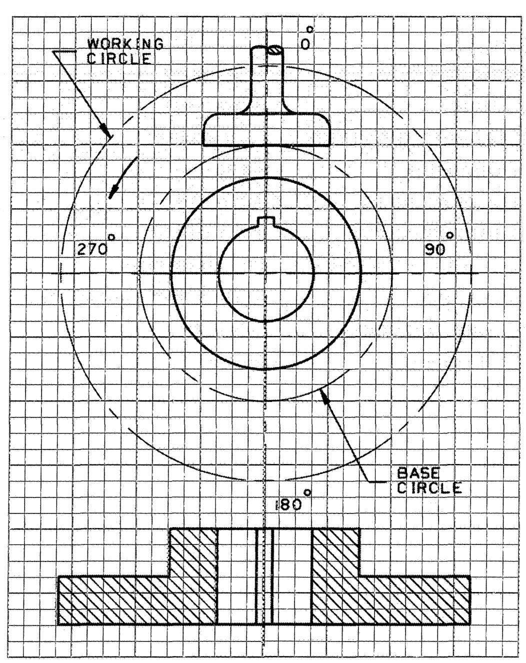
Exercise 20.3 Lay out the offset cam with the following specifications:

0°–90° modified uniform motion rise, total 1.50 displacement
90°–120° dwell
120°–180° parabolic motion fall, 100
180°–300° harmonic motion rise, .50
300°–330° dwell
330°–360° harmonic fall, 1.00

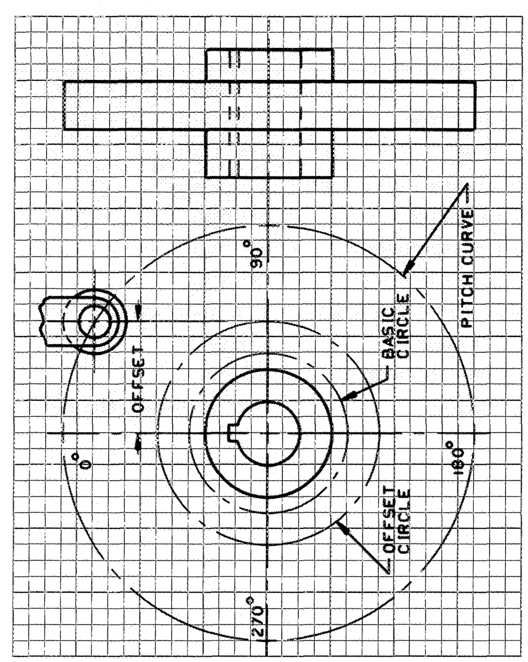
Construct a displacement diagram on a separate sheet to establish the cam's outline. Show the follower at 30° intervals. Design a proper-size keyseat, and secure the cam to a shaft with two set screws at 90° to the keyseat.



EXERCISE 20.1



EXERCISE 20.2



EXERCISE 20.3

PROBLEMS

Problem 20.1 Redraw the upper link cam shown in Figure 20.5.

Problem 20.2 On a CAD system, model the cam in Figure 20.7 in 3D. Dimension completely using geometric tolerancing.

Problem 20.3 Design a cam based on the displacement diagram shown in Figure 20.10(f). The cam will have a shaft diameter of 1.50 and an appropriately sized keyseat. The cam will be .75 thick and have a 1.50 thick shaft hub with a 3.00 diameter. Design the shaft hub to have two appropriately sized set screws to secure the cam to the shaft. The cam will employ a radial translating roller follower. The roller is 1.25 in diameter. Show the roller in twelve positions using phantom lines. The height of the displacement diagram (the rise of the follower) is 4.00. The working circle is 10.00 diameter, and the base circle is 6.00. Dimension the cam completely using two views. If you're working with a 3D CAD system, model the part and display it as a rotated (pictorial, isometric) view. For modifying the uniform rise use a radius value of one-third the rise. The harmonic fall will be 1.625, and the parabolic fall will be 2.375.

Problem 20.4 Redraw the cam shown in Figure 20.20, and construct a displacement diagram for the cam.

Problem 20.5 Redraw the cylindrical cam detail shown in Figure 20.21.

Problem 20.6 Draw a displacement diagram and construct a cam with the following specifications:

Rise	20°, harmonic motion, 50 mm
Dwell	30°
Rise	60°, harmonic motion, 24 mm
Dwell	30°
Fall	60°, modified uniform motion, 40 mm
Dwell	15°
Fall	45°, harmonic motion, to starting level

Height	100 mm
Working circle	280 mm
Base circle	100 mm
Cam rotation direction	Clockwise
Shaft diameter	40 mm
Shaft hub diameter	78 mm
Shaft hub thickness	60 mm
Keyseat and set screws	Per shaft size
Follower type	Pointed
Cam plate thickness	30 mm
Cam cutouts	Six at 24 mm diameter

Problem 20.7 Draw a displacement diagram and cam with the following specifications (for metric cam use SI dimensions in parentheses):

Rise	90°, harmonic motion, 1.50 (38)
Dwell	15°
Rise	60°, uniform acceleration, 1.50 (38)

Height	4.00 (100)
Working circle	12.50 (318)
Base circle	4.50 (114)
Cam rotation direction	Counterclockwise
Shaft diameter	1.75 (45)
Shaft hub diameter	2.75 (70)
Shaft hub thickness	2.50 (64)
Keyseat and set screws	Per shaft size
Follower type	Flat face
Cam plate thickness	1.00 (25)
Cam cutouts	Six holes at .75 (20) diameter

Problem 20.8 Draw a displacement diagram and cam with the following specifications (for metric cam use SI dimensions in parentheses):

Rise	45°, modified uniform motion, 2.00 (50)
Dwell	45°
Fall	45°, harmonic motion, .75 (19)
Dwell	45°
Fall	45°, modified uniform motion, 1.00 (25)
Dwell	15°
Rise	°60, harmonic motion, 1.50 (38)
Dwell	15°
Fall	45°, parabolic motion, to starting level

Height	2.00 (50)
Working circle	7.50 (187)
Base circle	3.50 (89)
Cam rotation direction	Clockwise
Shaft diameter	1.00 (25)
Shaft hub diameter	1.875 (48)
Shaft hub thickness	1.75 (45)
Keyseat and set screws	Per shaft size
Follower type	Radial translating roller
Cam plate thickness	.75 (18)
Cam cutouts	None