Chapter 15

CAM DYNAMICS

TOPIC/PROBLEM MATRIX

SECT	TOPIC	PROBLEMS
15.1	Dynamic Force Analysis	15-6
15.3	Kinetostatic Force Analysis	15-7, 15-8, 15-9, 15-10, 15-11, 15-12, 15-13, 15-14, 15-18, 15-19
15.5	Camshaft Torque	15-1, 15-2, 15-3, 15-4, 15-5, 15-15, 15-16, 15-17

PROBLEM 15-1

Statement: Design a double-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE	DWELL	FALL	DWELL
$\beta_1 := 60 \cdot deg$	$\beta_2 := 120 \cdot deg$	$\beta_3 := 30 \cdot deg$	$\beta_4 := 150 \cdot deg$
$h_1 := 2.5 \cdot in$	$h_2 := 0 \cdot in$	$h_3 := 2.5 \cdot in$	$h_4 := 0 \cdot in$
Mod. sine		Cycloidal	

Cycle time: $\tau := 4 \cdot sec$ Damping ratio: $\zeta := 0.2$ Follower mass: $m_f := 2.2$

Solution: See DYNACAM files P1501a and P1501b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 1.571 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 15.000\, rpm$$

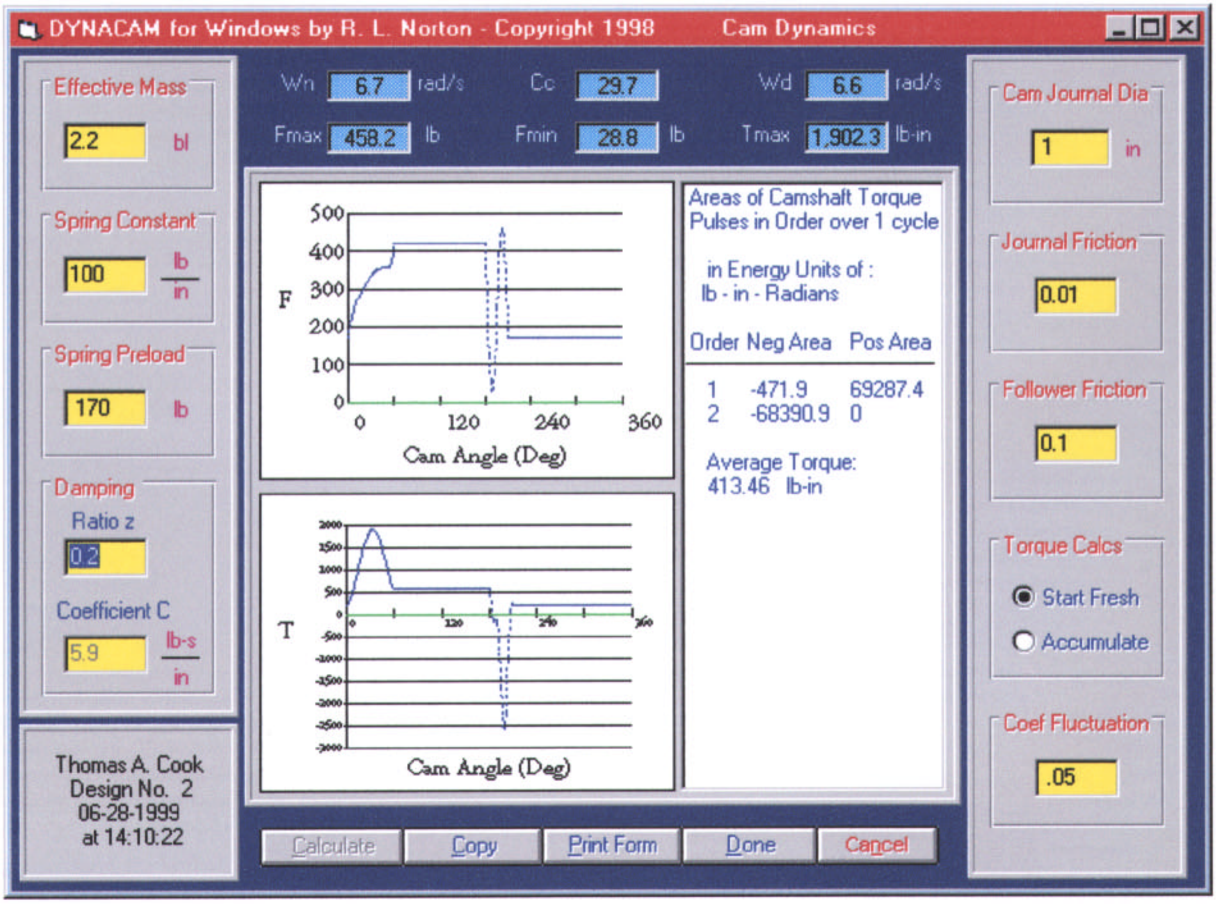
2. Load the noted files into program DYNACAM. P1501a is the force-closed solution and P1501b is the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

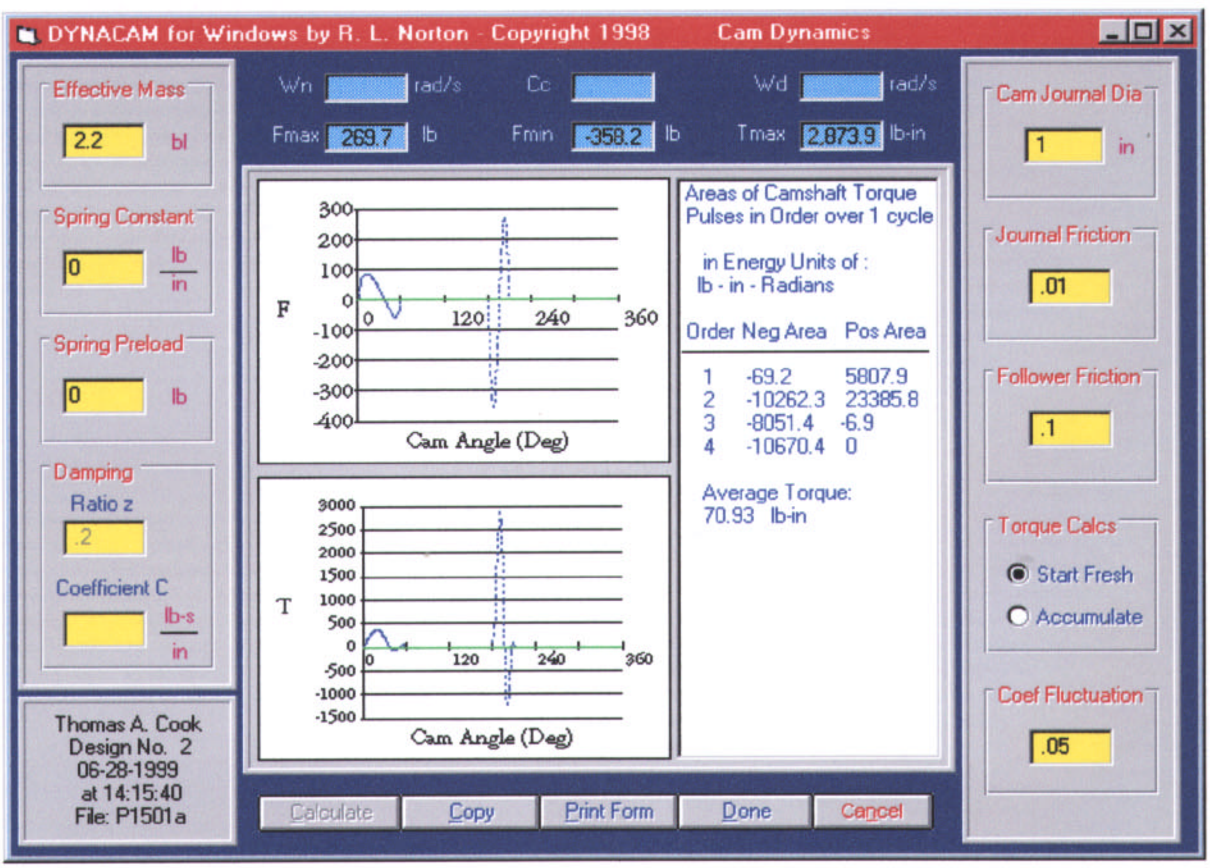
3. The cam is sized with an 11.125-in prime circle radius and -2.64 in eccentricity, which gives balanced pressure angles of 29.8 deg and a minimum radius of curvature of 2.94 in. The roller radius is 1.00 in.

4. For the force-closed case, a spring constant of 100 lb/in with a preload of 170 lb is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 4.3 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case, the peak follower force is greater and the driving torque excursions are lower than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower but a larger drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
2.2 bl
Spring Constant
100 lb/in
Spring Preload
170 lb
Damping
Ratio z
0.2
Coefficient C
5.9 lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 14:10:22
Wn 6.7 rad/s
Cc 29.7
Wd 6.6 rad/s
Fmax 458.2 lb
Fmin 28.8 lb
Tmax 1,902.3 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -471.9 69287.4
2 -68390.9 0
Average Torque:
413.46 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
2.2 bl
Spring Constant
0 lb/in
Spring Preload
0 lb
Damping
Ratio z
.2
Coefficient C
lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 14:15:40
File: P1501a
Wn rad/s
Cc
Wd rad/s
Fmax 269.7 lb
Fmin -358.2 lb
Tmax 2,873.9 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -69.2 5807.9
2 -10262.3 23385.8
3 -8051.4 -6.9
4 -10670.4 0
Average Torque:
70.93 lb-in
Cam Journal Dia
1 in
Journal Friction
.01
Follower Friction
.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-2

Statement: Design a double-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE	DWELL	FALL	DWELL
$\beta_1 := 45 \cdot deg$	$\beta_2 := 150 \cdot deg$	$\beta_3 := 90 \cdot deg$	$\beta_4 := 75 \cdot deg$
$h_1 := 1.5 \cdot in$	$h_2 := 0 \cdot in$	$h_3 := 1.5 \cdot in$	$h_4 := 0 \cdot in$
3-4-5 poly		4-5-6-7 poly	

Cycle time: $\tau := 6 \cdot sec$ Damping ratio: $\zeta := 0.1$ Follower mass: $m_f := 1.4$

Solution: See DYNACAM files P1502a and P1502b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 1.047 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 10.000\, rpm$$

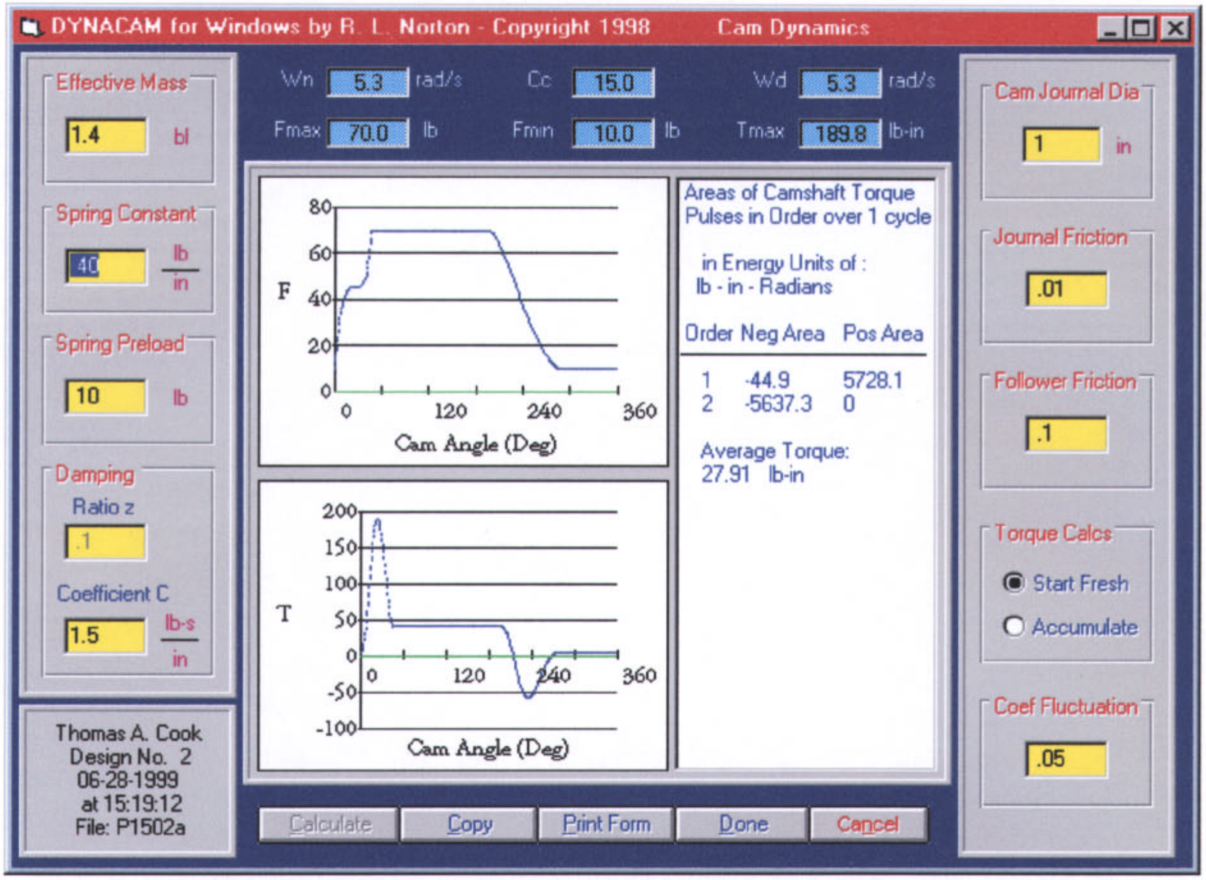
2. Load the noted files into program DYNACAM. Diskfile P1502a contains the force-closed solution and P1502b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

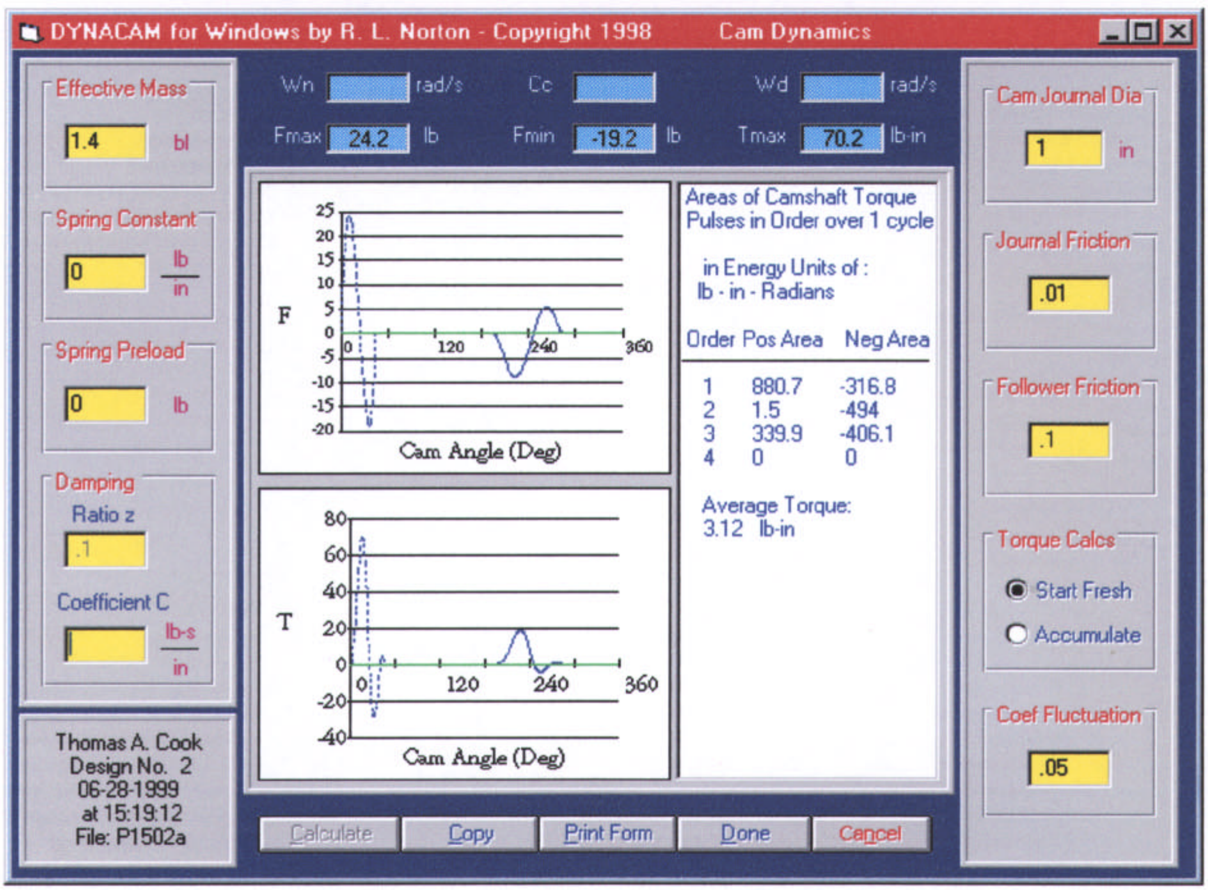
3. The cam is sized with an 4.25-in prime circle radius and 0.75 in eccentricity, which gives balanced pressure angles of 30 deg and a minimum radius of curvature of 1.75 in. The roller radius is 1.00 in.

4. For the force-closed case, a spring constant of 40 lb/in with a preload of 10 lb is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 5.3 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998
Cam Dynamics
Effective Mass
1.4 bl
Spring Constant
40 lb/in
Spring Preload
10 lb
Damping
Ratio z
.1
Coefficient C
1.5 lb-s/in
Wn 5.3 rad/s
Cc 15.0
Wd 5.3 rad/s
Fmax 70.0 lb
Fmin 10.0 lb
Tmax 189.8 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -44.9 5728.1
2 -5637.3 0
Average Torque:
27.91 lb-in
Cam Journal Dia
1 in
Journal Friction
.01
Follower Friction
.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Thomas A. Cook
Design No. 2
06-28-1999
at 15:19:12
File: P1502a
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998
Cam Dynamics
Effective Mass
1.4 bl
Spring Constant
0 lb/in
Spring Preload
0 lb
Damping
Ratio z
.1
Coefficient C
lb-s/in
Wn rad/s
Cc
Wd rad/s
Fmax 24.2 lb
Fmin -19.2 lb
Tmax 70.2 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Pos Area Neg Area
1 880.7 -316.8
2 1.5 -494
3 339.9 -406.1
4 0 0
Average Torque:
3.12 lb-in
Cam Journal Dia
1 in
Journal Friction
.01
Follower Friction
.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Thomas A. Cook
Design No. 2
06-28-1999
at 15:19:12
File: P1502a
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-3

Statement: Design a single-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE	FALL	DWELL
$\beta_{11} := 60 \cdot deg$	$\beta_{12} := 90 \cdot deg$	$\beta_2 := 210 \cdot deg$
$h_1 := 2 \cdot in$		$h_2 := 0 \cdot in$

Seventh degree polynomial

Cycle time: $\tau := 5 \cdot sec$ Damping ratio: $\zeta := 0.15$ Follower mass: $m_f := 3.2$

Solution: See DYNACAM files P1503a and P1503b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 1.257 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 12.000\, rpm$$

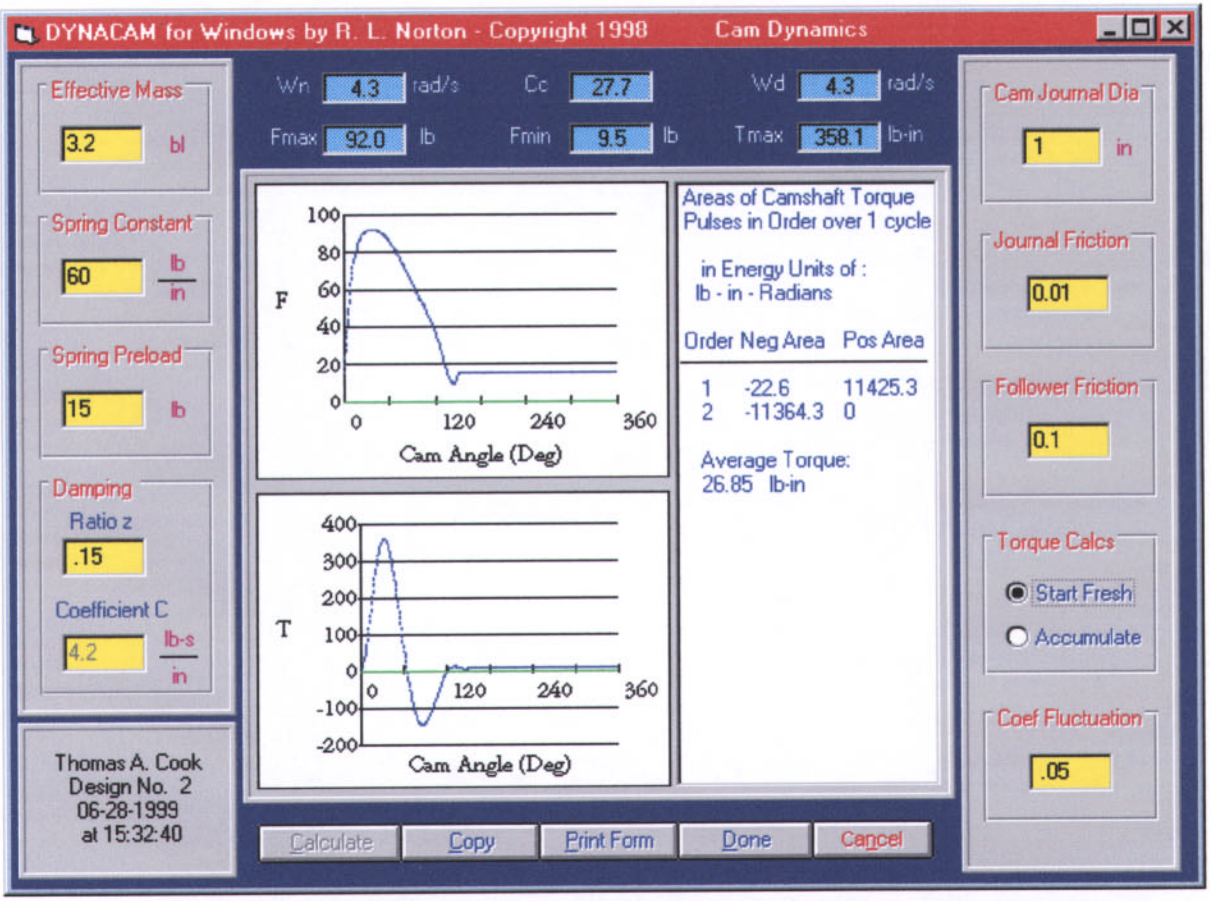
2. Load the noted files into program DYNACAM. Diskfile P1503a contains the force-closed solution and P1503b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

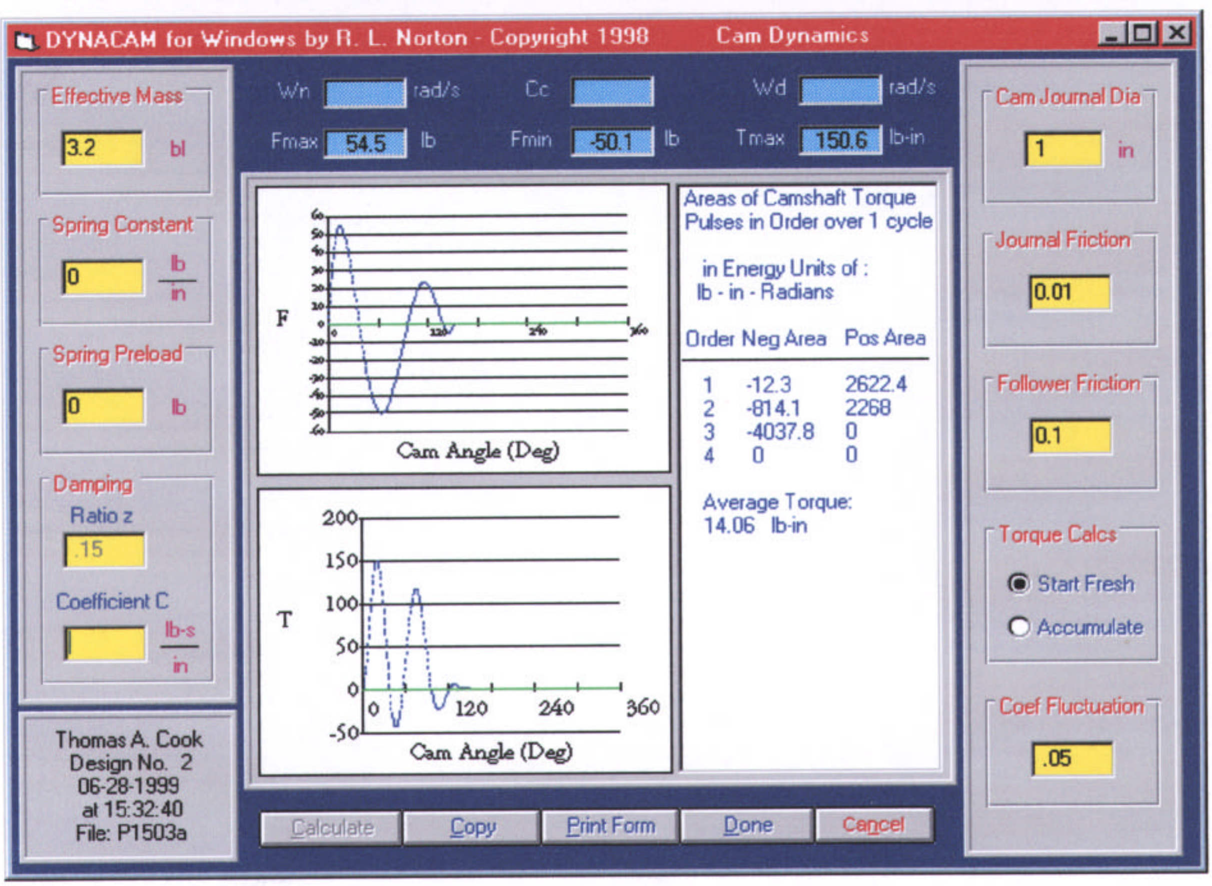
3. The cam is sized with an 4.40-in prime circle radius and 0.22 in eccentricity, which gives balanced pressure angles of 29.9 deg and a minimum radius of curvature of 2.53 in. The roller radius is 1.00 in.

4. For the force-closed case, a spring constant of 60 lb/in with a preload of 15 lb is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 3.4 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998
Cam Dynamics
Effective Mass
3.2 bl
Spring Constant
60 lb/in
Spring Preload
15 lb
Damping
Ratio z
.15
Coefficient C
4.2 lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 15:32:40
Wn 4.3 rad/s
Cc 27.7
Wd 4.3 rad/s
Fmax 92.0 lb
Fmin 9.5 lb
Tmax 358.1 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -22.6 11425.3
2 -11364.3 0
Average Torque:
26.85 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998
Cam Dynamics
Effective Mass
3.2 bl
Spring Constant
0 lb/in
Spring Preload
0 lb
Damping
Ratio z
.15
Coefficient C
lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 15:32:40
File: P1503a
Wn rad/s
Cc
Wd rad/s
Fmax 54.5 lb
Fmin -50.1 lb
Tmax 150.6 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -12.3 2622.4
2 -814.1 2268
3 -4037.8 0
4 0 0
Average Torque:
14.06 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

✍ PROBLEM 15-4

Statement: Design a three-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE/FALL	DWELL	FALL	DWELL
$\beta_1 := 40 \cdot deg$	$\beta_2 := 100 \cdot deg$	$\beta_3 := 90 \cdot deg$	$\beta_4 := 20 \cdot deg$
$h_1 := 2.5 \cdot in$	$h_2 := 0.0 \cdot in$	$h_3 := 1.5 \cdot in$	$h_4 := 0.0 \cdot in$
$\beta_5 := 30 \cdot deg$	$\beta_6 := 80 \cdot deg$		
$h_5 := 1.0 \cdot in$	$h_6 := 0.0 \cdot in$		

Cycle time: $\tau := 10 \cdot sec$ Damping ratio: $\zeta := 0.12$ Follower mass: $m_f := 0.4$

Solution: See DYNACAM files P1504a and P1504b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 0.628 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 6.000\, rpm$$

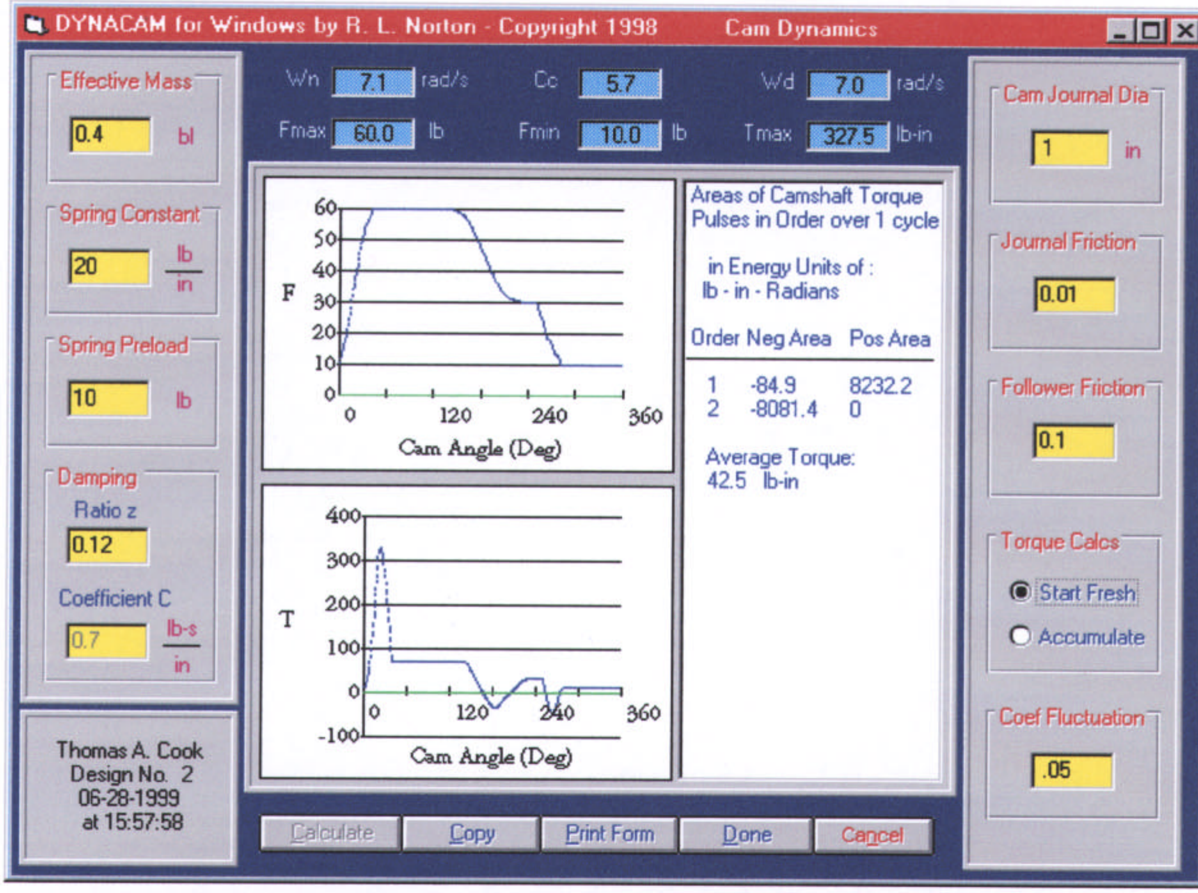
2. Load the noted files into program DYNACAM. Diskfile P1504a contains the force-closed solution and P1504b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

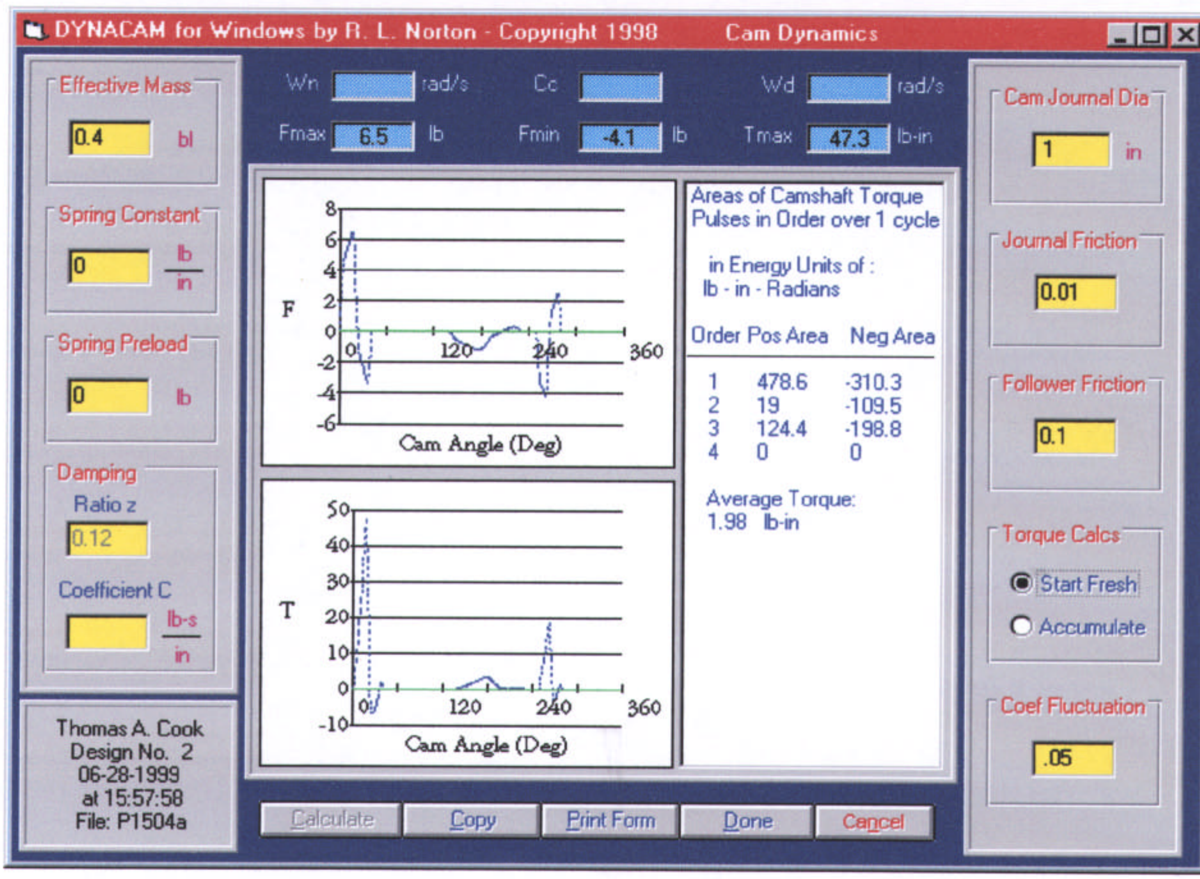
3. Modified trapezoidal acceleration was used for the rise and both falls. The cam is sized with an 8.875-in prime circle radius and 1.45 in eccentricity, which gives balanced pressure angles of 29.7 deg and a minimum radius of curvature of 3.59 in. The roller radius is 1.00 in.

4. For the force-closed case, a spring constant of 20 lb/in with a preload of 10 lb is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 11.3 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.4 bl
Spring Constant
20 lb/in
Spring Preload
10 lb
Damping
Ratio z
0.12
Coefficient C
0.7 lb-s/in
Wn 7.1 rad/s
Cc 5.7
Wd 7.0 rad/s
Fmax 60.0 lb
Fmin 10.0 lb
Tmax 327.5 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of : lb - in - Radians
Order Neg Area Pos Area
1 -84.9 8232.2
2 -8081.4 0
Average Torque: 42.5 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Thomas A. Cook
Design No. 2
06-28-1999
at 15:57:58
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.4 bl
Spring Constant
0 lb/in
Spring Preload
0 lb
Damping
Ratio z
0.12
Coefficient C
lb-s/in
Wn rad/s
Cc
Wd rad/s
Fmax 6.5 lb
Fmin -4.1 lb
Tmax 47.3 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of : lb - in - Radians
Order Pos Area Neg Area
1 478.6 -310.3
2 19 -109.5
3 124.4 -198.8
4 0 0
Average Torque: 1.98 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Thomas A. Cook
Design No. 2
06-28-1999
at 15:57:58
File: P1504a
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-5

Statement: Design a four-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE/FALL	DWELL	FALL	DWELL
$\beta_1 := 40 \cdot deg$	$\beta_2 := 100 \cdot deg$	$\beta_3 := 90 \cdot deg$	$\beta_4 := 20 \cdot deg$
$h_1 := 2.5 \cdot in$	$h_2 := 0.0 \cdot in$	$h_3 := 1.5 \cdot in$	$h_4 := 0.0 \cdot in$
$\beta_5 := 30 \cdot deg$	$\beta_6 := 40 \cdot deg$	$\beta_7 := 30 \cdot deg$	$\beta_8 := 10 \cdot deg$
$h_5 := 0.5 \cdot in$	$h_6 := 0.0 \cdot in$	$h_7 := 0.5 \cdot in$	$h_8 := 0.0 \cdot in$

Cycle time: $\tau := 15 \cdot sec$ Damping ratio: $\zeta := 0.18$ Follower mass: $m_f := 1.25$

Solution: See DYNACAM files P1505a and P1505b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 0.419 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 4.000\, rpm$$

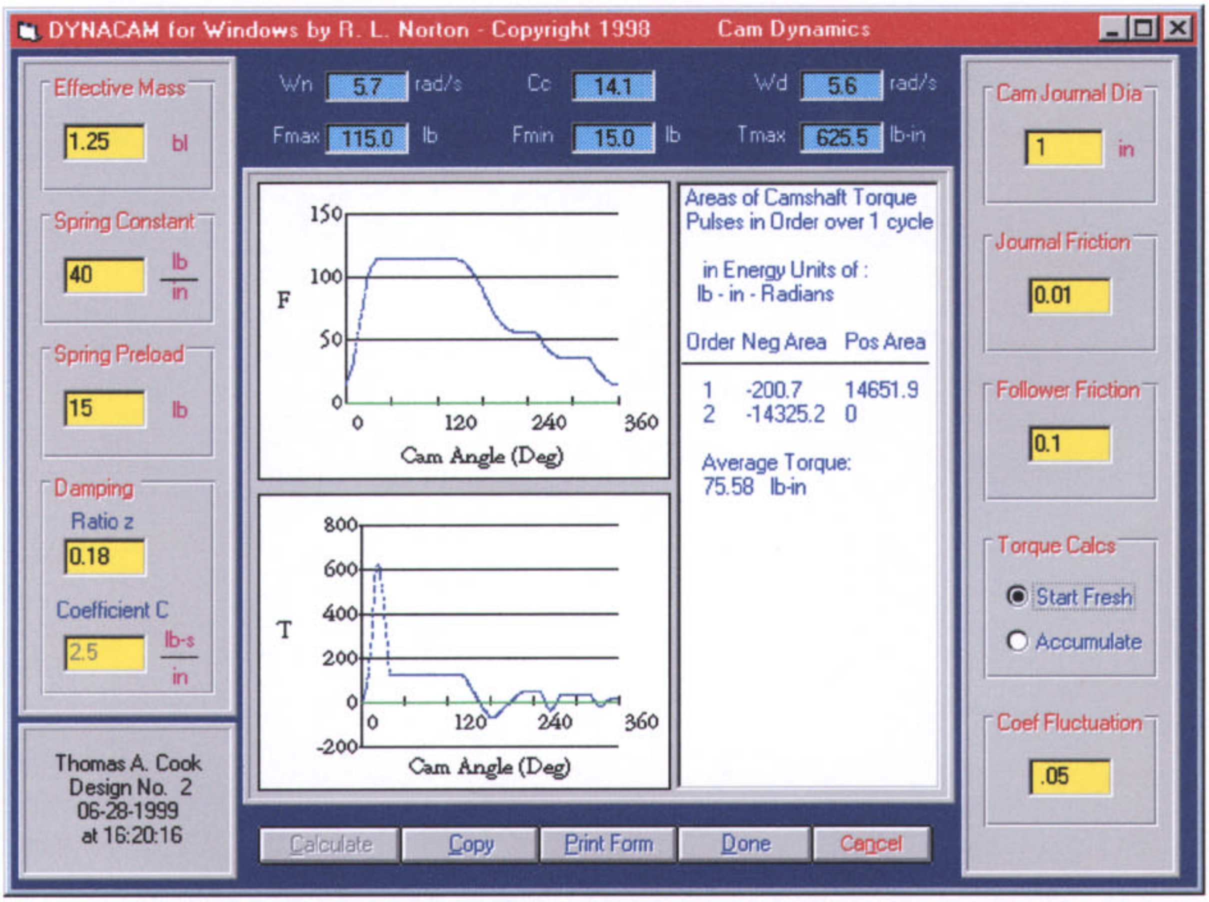
2. Load the noted files into program DYNACAM. Diskfile P1505a contains the force-closed solution and P1505b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

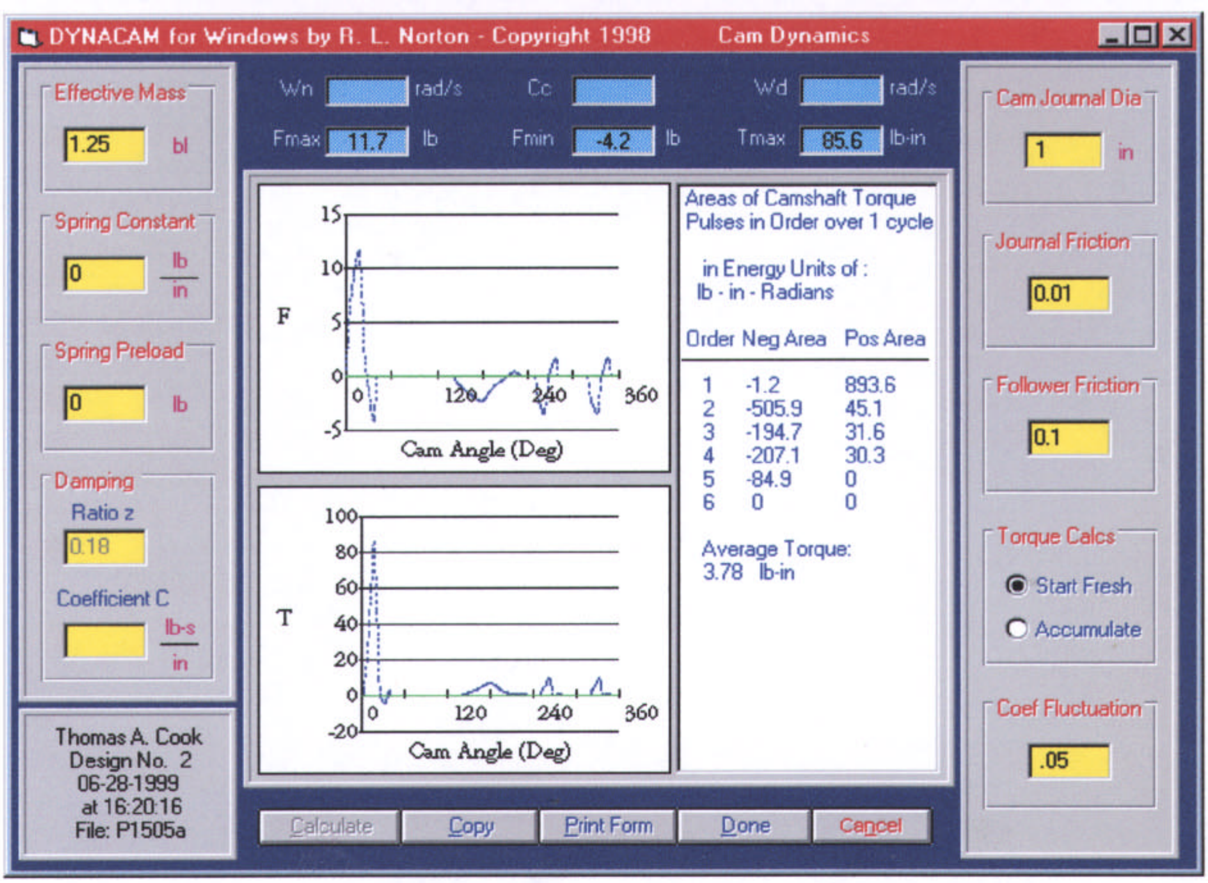
3. Modified trapezoidal acceleration was used for the rise and all falls. The cam is sized with an 7.500-in prime circle radius and 2.35 in eccentricity, which gives balanced pressure angles of 30 deg and a minimum radius of curvature of 3.01 in. The roller radius is 1.00 in.

4. For the force-closed case, a spring constant of 40 lb/in with a preload of 15 lb is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 13.6 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
1.25 bl
Spring Constant
40 lb/in
Spring Preload
15 lb
Damping
Ratio z
0.18
Coefficient C
2.5 lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 16:20:16
Wn 5.7 rad/s
Cc 14.1
Wd 5.6 rad/s
Fmax 115.0 lb
Fmin 15.0 lb
Tmax 625.5 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -200.7 14651.9
2 -14325.2 0
Average Torque:
75.58 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
1.25 bl
Spring Constant
0 lb/in
Spring Preload
0 lb
Damping
Ratio z
0.18
Coefficient C
lb-s/in
Thomas A. Cook
Design No. 2
06-28-1999
at 16:20:16
File: P1505a
Wn rad/s
Cc
Wd rad/s
Fmax 11.7 lb
Fmin -4.2 lb
Tmax 85.6 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -1.2 893.6
2 -505.9 45.1
3 -194.7 31.6
4 -207.1 30.3
5 -84.9 0
6 0 0
Average Torque:
3.78 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-6a

Statement: A mass-spring-damper system as shown in Figure 15-1b has the values shown in Table P15-1. Find the undamped and damped natural frequencies and the value of critical damping for the system in row *a* of the table.

Given: $M := 1.2 \cdot kg$ $\quad k := 14 \cdot N \cdot m^{-1}$ $\quad c := 1.1 \cdot N \cdot sec \cdot m^{-1}$

Solution: See Figure 15-1b, Table P15-1, and Mathcad file P1506a.

1. Calculate the undamped natural frequency using equation 15.1d.

$$\omega_n := \sqrt{\frac{k}{M}} \qquad \omega_n = 3.416 \frac{rad}{sec}$$

2. Calculate the damped natural frequency using equation 15.3c.

$$\omega_d := \sqrt{\frac{k}{M} - \left(\frac{c}{2 \cdot M}\right)^2} \qquad \omega_d = 3.385 \frac{rad}{sec}$$

3. Calculate the critical damping factor using equation 15.2i.

$$c_c := 2 \cdot M \cdot \omega_n \qquad c_c = 8.198 \frac{N \cdot sec}{m}$$

PROBLEM 15-6

Row	ω_n	ω_d	c_c
a	3.42	3.38	8.2
b	4.68	4.65	19.7
c	0.26	0.26	15.5
d	2.36	2.33	21.2
e	5.18	5.02	29.0
f	2.04	1.96	49.0

PROBLEM 15-7

Statement: Figure P15-1 shows a cam-follower system. The dimensions and other data are given below. Find the arm's mass, center of gravity location and mass moment of inertia about both its CG and arm pivot. Create a linear, one-DOF lumped mass model of the dynamic system referenced to the cam follower and calculate the cam-follower force for one revolution. The cam is a pure eccentric with eccentricity and speed given below. Ignore damping.

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$ $\quad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given:

Arm dimensions:

- Width (Z-direction): $a := 2 \cdot in$
- Height (Y-direction): $b := 2.5 \cdot in$
- Length (X-direction): $c := 28 \cdot in$

Cutout dimensions:

- Width (Z-direction): $a' := 1.5 \cdot in$
- Height (Y-direction): $b' := 2.5 \cdot in$
- Length (X-direction): $c' := 3 \cdot in$

Distance from arm pivot to spring: $L_s := 19 \cdot in$

Distance from arm pivot to roller center: $L_r := 12 \cdot in$

Cam eccentricity and speed: $e := 0.5 \cdot in$ $\quad \omega_2 := 500 \, rpm$

Cam radius and thickness: $r_c := 3 \cdot in$ $\quad w_c := 0.75 \cdot in$ (measured from Figure)

Roller follower dimensions: $r_f := 1 \cdot in$ $\quad w_f := 1.5 \cdot in$

Spring rate and preload: $k_s := 123 \cdot lbf \cdot in^{-1}$ $\quad F_{50} := 173 \cdot lbf$

Solution: See Figure P15-1 and Mathcad file P1507.

1. The effective mass and spring constant of the arm referenced to the cam follower were determined in Problem 10-16 as:

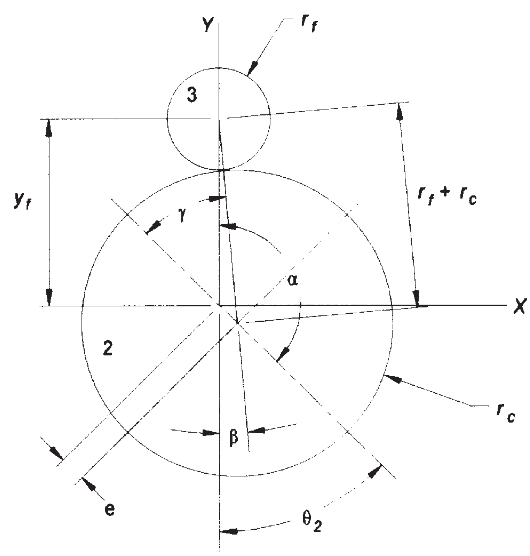
$$m_{eff} := 0.04652 \cdot blob \qquad k_{aeff} := 1.0131 \cdot 10^5 \cdot \frac{lbf}{in}$$

2. The spring rate and preload referenced to the cam follower are:

$$k_{eff} := \left[\frac{1}{k_{aeff}} + \left(\frac{L_r}{L_s} \right)^2 \cdot \frac{1}{k_s} \right]^{-1} \qquad k_{eff} = 307.418 \frac{lbf}{in} \qquad F_{pl} := \frac{L_s}{L_r} \cdot F_{50} \qquad F_{pl} = 273.917 \, lbf$$

3. Calculate the motion of the roller follower center with respect to the X axis, which goes through the center of rotation of the cam.

The cam and follower are shown at right. The origin of the coordinate frame is at the center of rotation. The cam, link 2, is shown rotated an amount θ_2 from the position at which the follower, link 3, is at its lowest position. A triangle is formed with sides e, $r_f + r_c$, and y_f. This triangle will be used to determine the displacement of the follower, y_f, with respect to the cam rotation angle, θ_2.



Using the law of sines,

$$\beta(\theta_2) := asin\left(\frac{e}{r_f + r_c} \cdot sin(\theta_2) \right)$$

From the relationship among the angles of a triangle, $\gamma(\theta_2) := \theta_2 - \beta(\theta_2)$

And, using the law of cosines, $y_f(\theta_2) := \left[e^2 + (r_f + r_c)^2 - 2 \cdot e \cdot (r_f + r_c) \cdot \cos(\gamma(\theta_2))\right]^{\frac{1}{2}} \ldots$
$+e - (r_f + r_c)$

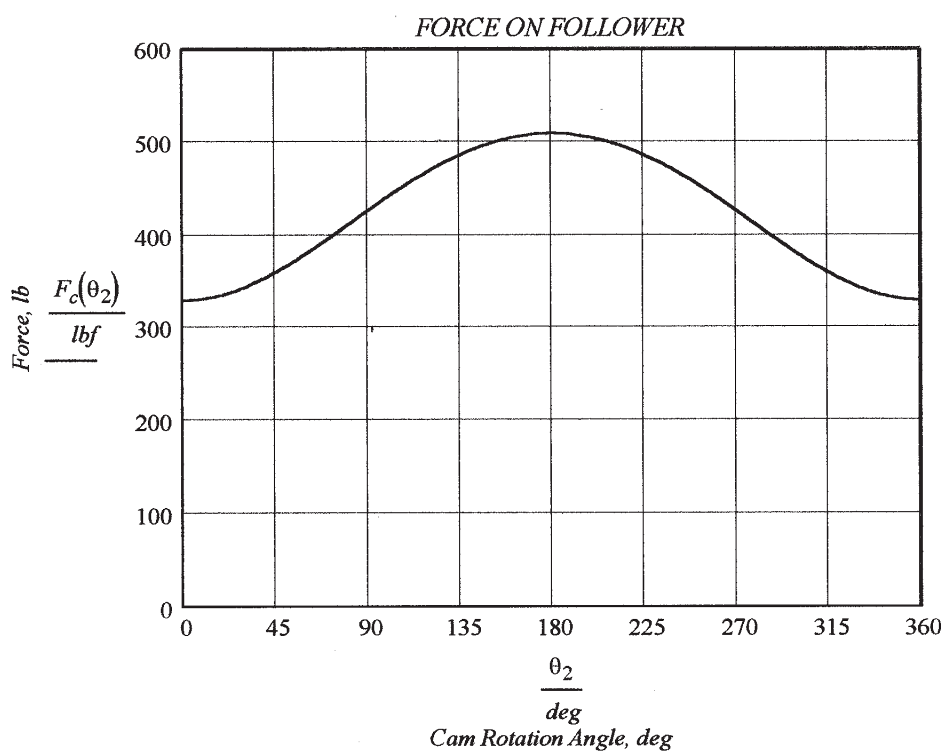
4. Differentiate the displacement function twice to get the velocity and acceleration functions.

$$v_f(\theta_2) := \left(\frac{d}{d\theta_2} y_f(\theta_2)\right) \cdot \omega_2 \qquad a_f(\theta_2) := \left(\frac{d}{d\theta_2} v_f(\theta_2)\right) \cdot \omega_2$$

5. Substitute the expressions for displacement, acceleration and spring preload into equation 15.9 and solve for the force on the follower as a function of cam angle.

$$F_c(\theta_2) := m_{eff} \cdot a_f(\theta_2) + k_{eff} \cdot y_f(\theta_2) + F_{pl}$$

6. Plot the force on the follower for one revolution of the cam. $\theta_2 := 0 \cdot deg, 2 \cdot deg .. 360 \cdot deg$



✍ PROBLEM 15-8

Statement: Repeat Problem 15-7 for a double-dwell cam to move the roller follower from 0 to 2.5 inches in 60 deg with modified sine acceleration, dwell for 120 deg, fall 2.5 inches in 30 deg with cycloidal motion, and dwell for the remainder. Cam speed is 100 rpm. Choose a suitable spring rate and preload to maintain follower contact. Select a spring from Appendix D. Assume a damping ratio of 0.10.

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$ $\quad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given:

Arm dimensions:

Width (Z-direction): $a := 2 \cdot in$

Height (Y-direction): $b := 2.5 \cdot in$

Length (X-direction): $c := 28 \cdot in$

Cutout dimensions:

Width (Z-direction): $a' := 1.5 \cdot in$

Height (Y-direction): $b' := 2.5 \cdot in$

Length (X-direction): $c' := 3 \cdot in$

Distance from arm pivot to spring: $L_s := 19 \cdot in$

Distance from arm pivot to roller center: $L_r := 12 \cdot in$

Cam lift and speed: $h := 2.5 \cdot in$ $\quad \omega_2 := 100 rpm$

Roller follower dimensions: $r_f := 1 \cdot in$ $\quad w_f := 1.5 \cdot in$

Solution: See Figure P15-1, Problem 15-7, and DYNACAM file P1508.cam.

1. The effective mass and spring constant of the arm referenced to the cam follower were determined in Problem 10-16 as:

$$m_{eff} := 0.04652 \cdot blob \qquad k_{aeff} := 1.0131 \cdot 10^5 \cdot \frac{lbf}{in}$$

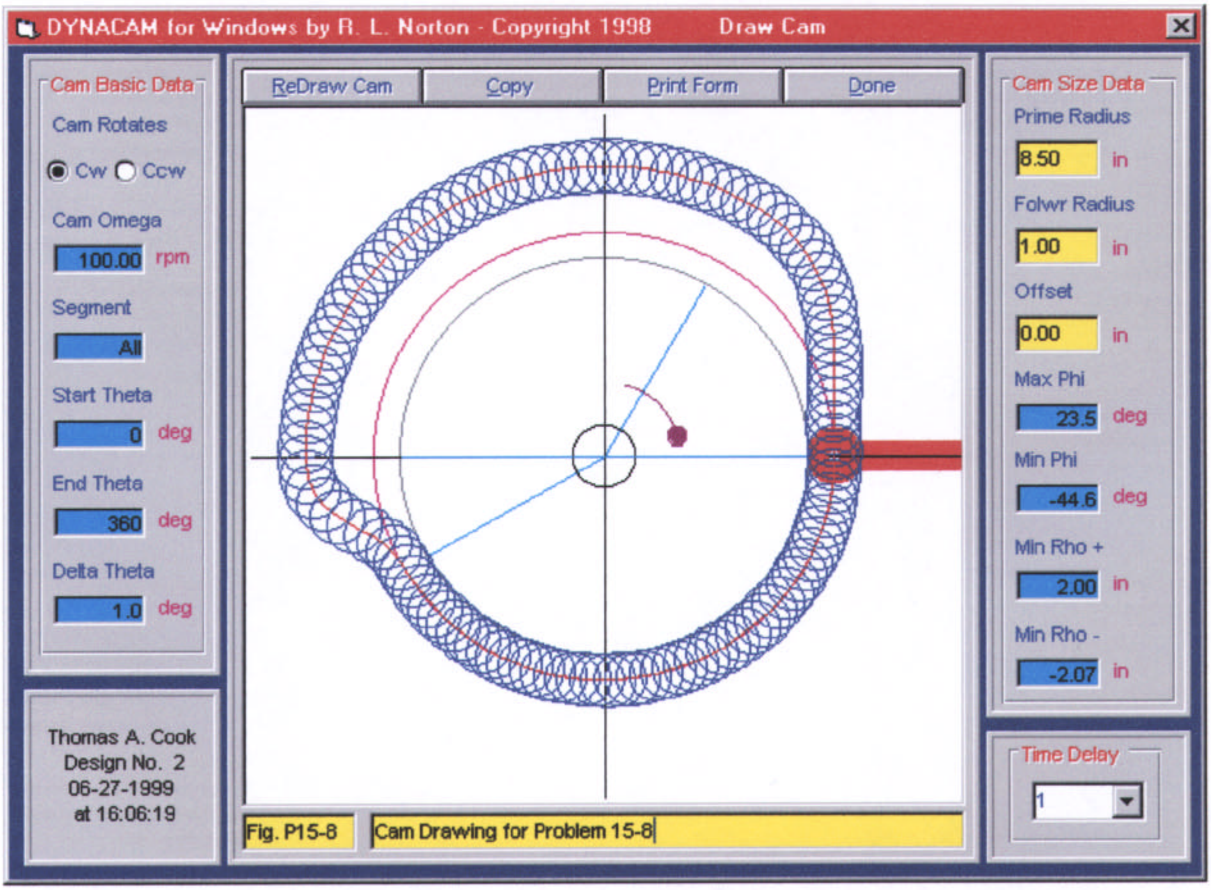
2. There is no extension spring listed in Appendix D that is acceptable. A 2.5-in follower lift is nearly 4 in at the end of the arm where the spring attaches. There is no spring that has a safe maximum load that is 4 times the spring rate. We will, therefore, have to have a custom made spring with the following rate and preload when installed.

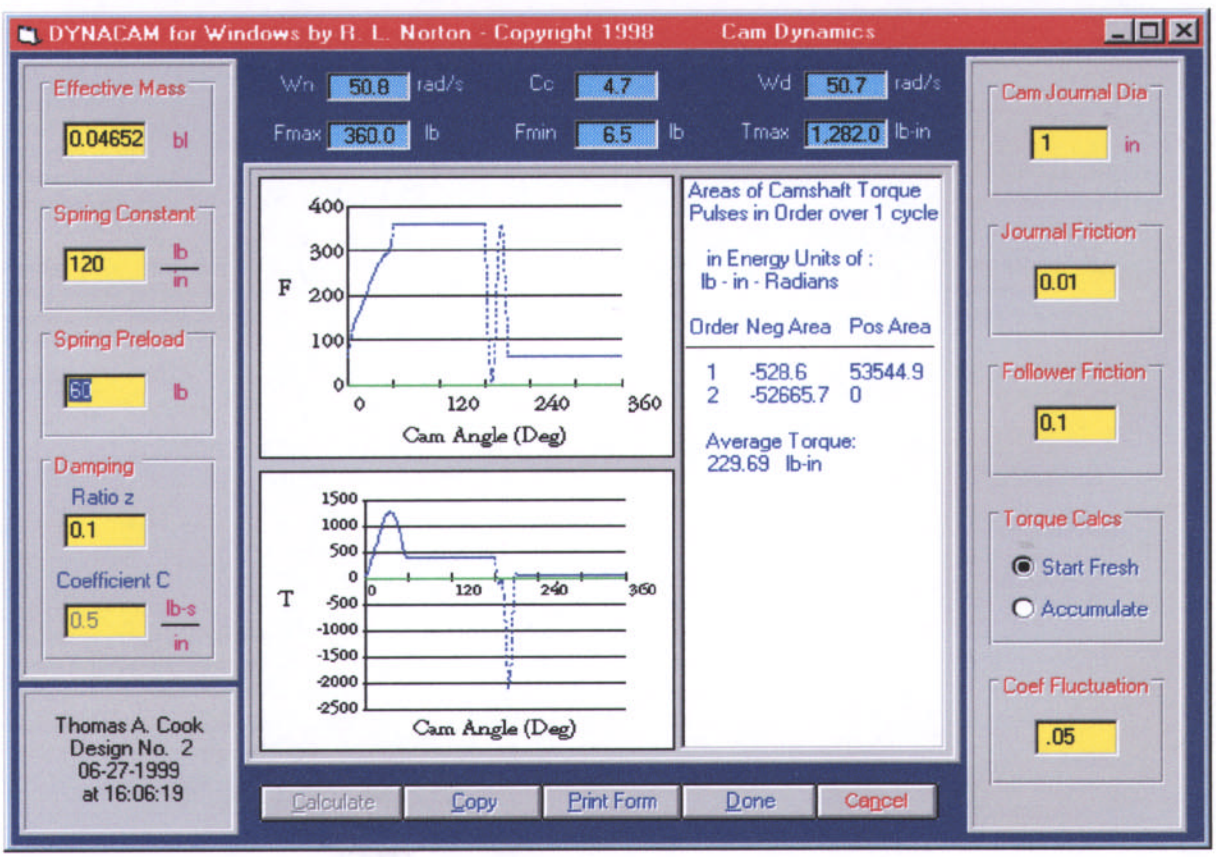
Spring rate and preload: $k_s := 75.8 \cdot lbf \cdot in^{-1}$ $\quad F_{50} := 37.9 \cdot lbf$

3. The spring rate and preload referenced to the cam follower are:

$$k_{eff} := \left[\frac{1}{k_{aeff}} + \left(\frac{L_r}{L_s} \right)^2 \cdot \frac{1}{k_s} \right]^{-1} \qquad k_{eff} = 190 \frac{lbf}{in} \qquad F_{pl} := \frac{L_s}{L_r} \cdot F_{50} \qquad F_{pl} = 60\, lbf$$

4. Enter the given cam data into the program DYNACAM and create a cam with acceptable pressure angles and radius of curvature. A cam drawing from DYNACAM that meets the requirements is shown on the next page. Find a suitable spring rate and preload to keep the minimum cam force positive and minimize the maximum cam force. One solution is shown in the Cam Dynamics screen shown below the cam drawing.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Draw Cam
Cam Basic Data
Cam Rotates
Cw Ccw
Cam Omega
100.00 rpm
Segment
All
Start Theta
0 deg
End Theta
360 deg
Delta Theta
1.0 deg
Thomas A. Cook
Design No. 2
06-27-1999
at 16:06:19
ReDraw Cam
Copy
Print Form
Done
Fig. P15-8
Cam Drawing for Problem 15-8
Cam Size Data
Prime Radius
8.50 in
Folwr Radius
1.00 in
Offset
0.00 in
Max Phi
23.5 deg
Min Phi
-44.6 deg
Min Rho +
2.00 in
Min Rho -
-2.07 in
Time Delay
1


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.04652 bl
Spring Constant
120 lb/in
Spring Preload
60 lb
Damping
Ratio z
0.1
Coefficient C
0.5 lb-s/in
Thomas A. Cook
Design No. 2
06-27-1999
at 16:06:19
Wn 50.8 rad/s
Cc 4.7
Wd 50.7 rad/s
Fmax 360.0 lb
Fmin 6.5 lb
Tmax 1,282.0 lb-in
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -528.6 53544.9
2 -52665.7 0
Average Torque:
229.69 lb-in
Calculate
Copy
Print Form
Done
Cancel
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05

PROBLEM 15-9

Statement: Repeat Problem 15-7 for a double-dwell cam to move the roller follower from 0 to 1.5 inches in 45 deg with 3-4-5 polynomial motion, dwell for 150 deg, fall 1.5 inches in 90 deg with 4-5-6 polynomial motion, and dwell for the remainder. Cam speed is 250 rpm. Choose a suitable spring rate and preload to maintain follower contact. Select a spring from Appendix D. Assume a damping ratio of 0.15.

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$ $\quad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given:

Arm dimensions:

Width (Z-direction): $a := 2 \cdot in$

Height (Y-direction): $b := 2.5 \cdot in$

Length (X-direction): $c := 28 \cdot in$

Cutout dimensions:

Width (Z-direction): $a' := 1.5 \cdot in$

Height (Y-direction): $b' := 2.5 \cdot in$

Length (X-direction): $c' := 3 \cdot in$

Distance from arm pivot to spring: $L_s := 19 \cdot in$

Distance from arm pivot to roller center: $L_r := 12 \cdot in$

Cam lift and speed: $h := 2.5 \cdot in$ $\quad \omega_2 := 100 rpm$

Roller follower dimensions: $r_f := 1 \cdot in$ $\quad w_f := 1.5 \cdot in$

Solution: See Figure P15-1, Problem 15-7, and DYNACAM file P1509.cam.

1. The effective mass and spring constant of the arm referenced to the cam follower were determined in Problem 10-16 as:

$$m_{eff} := 0.04652 \cdot blob \qquad k_{aeff} := 1.0131 \cdot 10^5 \cdot \frac{lbf}{in}$$

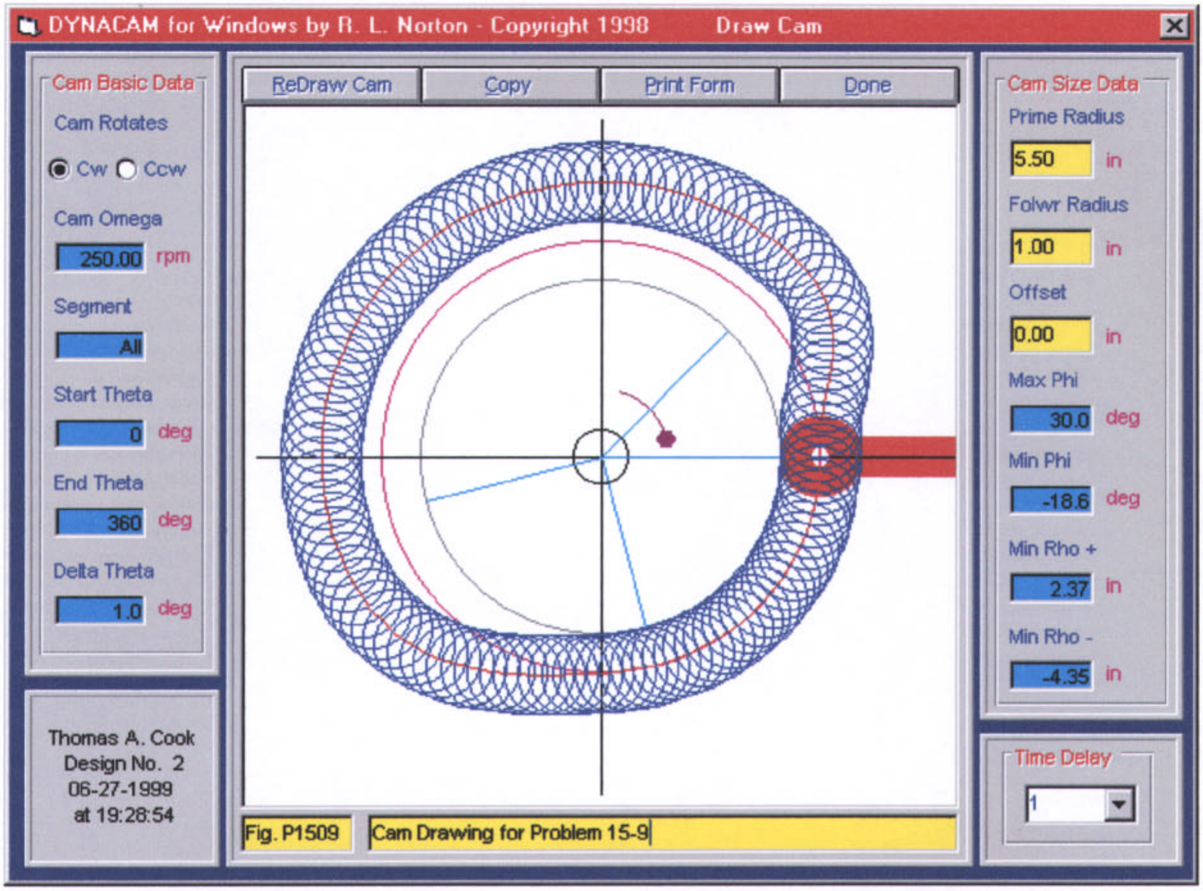
2. There is no extension spring listed in Appendix D that is acceptable. A 1.5-in follower lift is nearly 2.5 in at the end of the arm where the spring attaches. There is no spring that has a safe maximum load that is 2.5 times the spring rate. We will, therefore, have to have a custom made spring with the following rate and preload when installed.

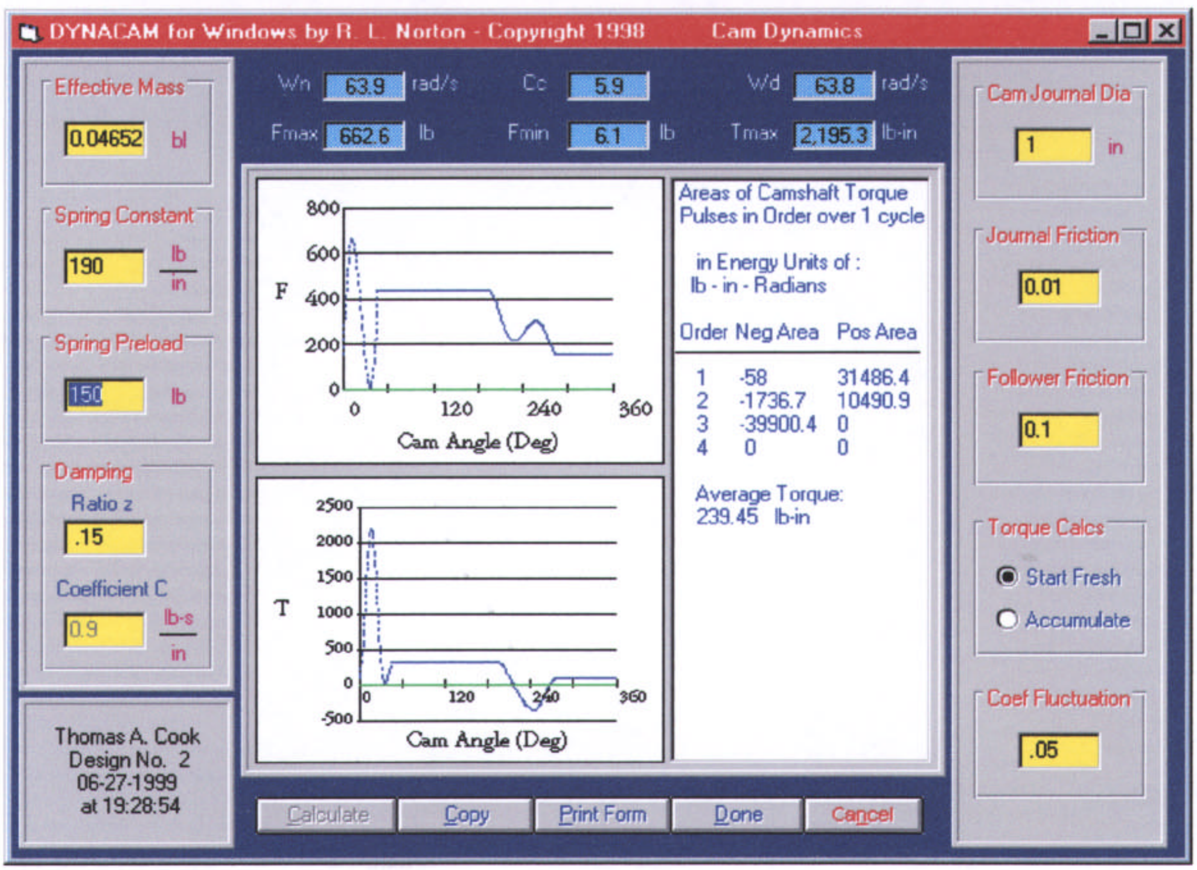
Spring rate and preload: $k_s := 120 \cdot lbf \cdot in^{-1}$ $\quad F_{50} := 94.7 \cdot lbf$

3. The spring rate and preload referenced to the cam follower are:

$$k_{eff} := \left[\frac{1}{k_{aeff}} + \left(\frac{L_r}{L_s} \right)^2 \cdot \frac{1}{k_s} \right]^{-1} \qquad k_{eff} = 300 \frac{lbf}{in} \qquad F_{pl} := \frac{L_s}{L_r} \cdot F_{50} \qquad F_{pl} = 150\, lbf$$

4. Enter the given cam data into the program DYNACAM and create a cam with acceptable pressure angles and radius of curvature. A cam drawing from DYNACAM that meets the requirements is shown on the next page. Find a suitable spring rate and preload to keep the minimum cam force positive and minimize the maximum cam force. One solution is shown in the Cam Dynamics screen shown below the cam drawing.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Draw Cam
Cam Basic Data
Cam Rotates
Cw Ccw
Cam Omega
250.00 rpm
Segment
All
Start Theta
0 deg
End Theta
360 deg
Delta Theta
1.0 deg
Thomas A. Cook
Design No. 2
06-27-1999
at 19:28:54
ReDraw Cam
Copy
Print Form
Done
Fig. P1509
Cam Drawing for Problem 15-9
Cam Size Data
Prime Radius
5.50 in
Folwr Radius
1.00 in
Offset
0.00 in
Max Phi
30.0 deg
Min Phi
-18.6 deg
Min Rho +
2.37 in
Min Rho -
-4.35 in
Time Delay
1


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.04652 bl
Spring Constant
190 lb/in
Spring Preload
150 lb
Damping
Ratio z
.15
Coefficient C
0.9 lb-s/in
Thomas A. Cook
Design No. 2
06-27-1999
at 19:28:54
Wn 63.9 rad/s
Cc 5.9
Wd 63.8 rad/s
Fmax 662.6 lb
Fmin 6.1 lb
Tmax 2,195.3 lb-in
F
800
600
400
200
0
0
120
240
360
Cam Angle (Deg)
T
2500
2000
1500
1000
500
0
-500
0
120
240
360
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -58 31486.4
2 -1736.7 10490.9
3 -39900.4 0
4 0 0
Average Torque:
239.45 lb-in
Calculate
Copy
Print Form
Done
Cancel
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05

PROBLEM 15-10

Statement: Repeat Problem 15-7 for a single-dwell cam to move the roller follower from 0 to 2 inches in 60 deg, fall 2 inches in 90 deg, and dwell for the remainder. Use a seventh degree polynomial. Cam speed is 250 rpm. Choose a suitable spring rate and preload to maintain follower contact. Select a spring from Appendix D. Assume a damping ratio of 0.15.

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$ $\qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given:

Arm dimensions:

Width (Z-direction): $a := 2 \cdot in$

Height (Y-direction): $b := 2.5 \cdot in$

Length (X-direction): $c := 28 \cdot in$

Cutout dimensions:

Width (Z-direction): $a' := 1.5 \cdot in$

Height (Y-direction): $b' := 2.5 \cdot in$

Length (X-direction): $c' := 3 \cdot in$

Distance from arm pivot to spring: $L_s := 19 \cdot in$

Distance from arm pivot to roller center: $L_r := 12 \cdot in$

Cam lift and speed: $h := 2.5 \cdot in$ $\qquad \omega_2 := 100 rpm$

Roller follower dimensions: $r_f := 1 \cdot in$ $\qquad w_f := 1.5 \cdot in$

Solution: See Figure P15-1, Problem 15-7, and DYNACAM file P1510.cam.

1. The effective mass and spring constant of the arm referenced to the cam follower were determined in Problem 10-16 as:

$$m_{eff} := 0.04652 \cdot blob \qquad k_{aeff} := 1.0131 \cdot 10^5 \cdot \frac{lbf}{in}$$

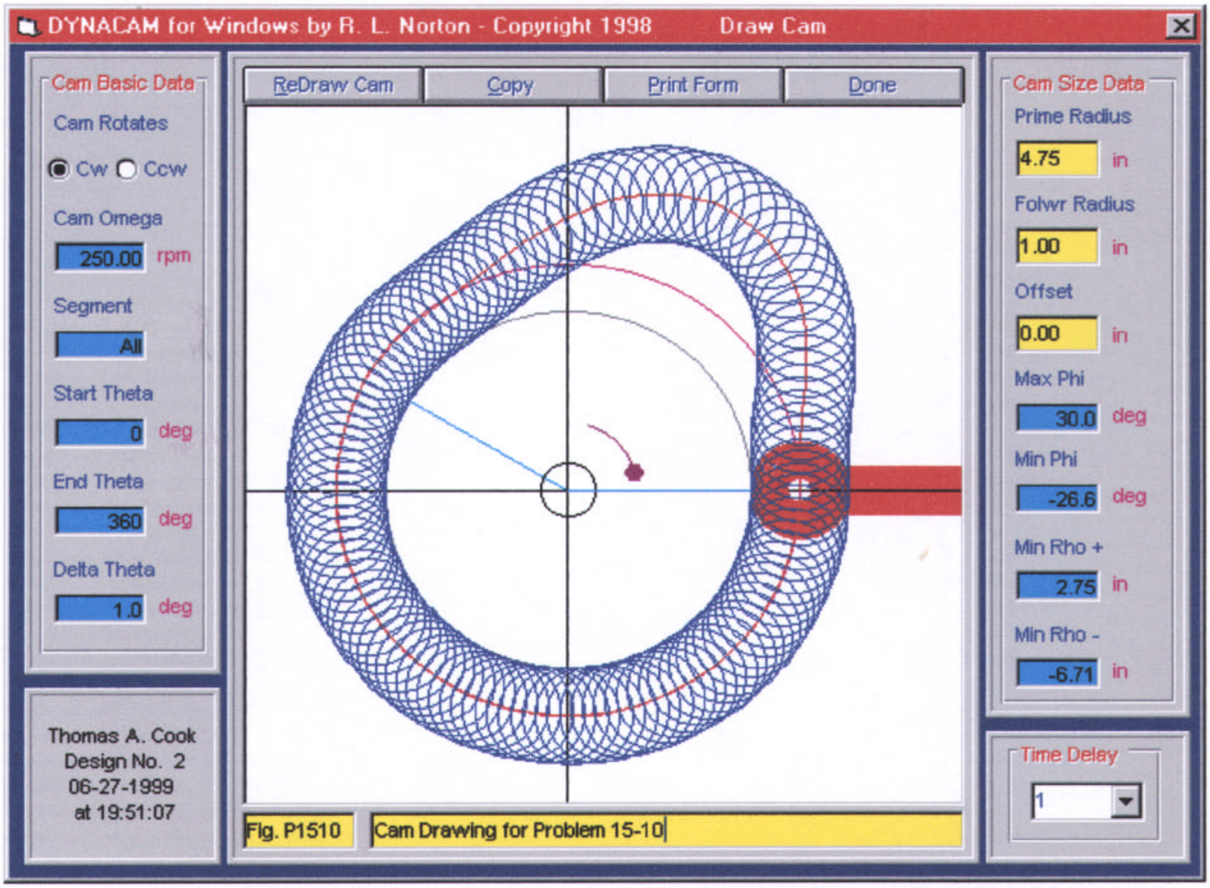
2. There is no extension spring listed in Appendix D that is acceptable. A 2-in follower lift is over 3 in at the end of the arm where the spring attaches. There is no spring that has a safe maximum load that is 3 times the spring rate. We will, therefore, have to have a custom made spring with the following rate and preload when installed.

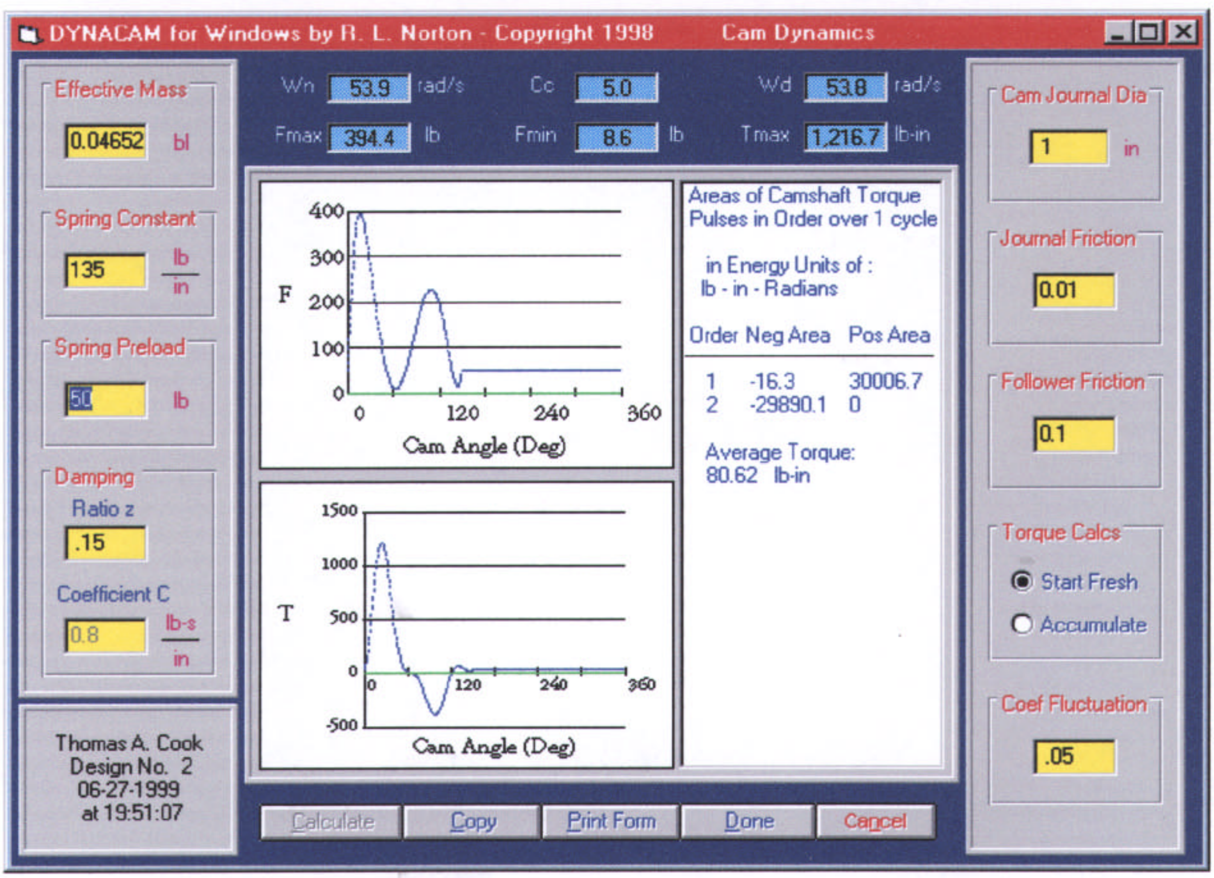
Spring rate and preload: $k_s := 85.3 \cdot lbf \cdot in^{-1}$ $\qquad F_{50} := 31.6 \cdot lbf$

3. The spring rate and preload referenced to the cam follower are:

$$k_{eff} := \left[\frac{1}{k_{aeff}} + \left(\frac{L_r}{L_s} \right)^2 \cdot \frac{1}{k_s} \right]^{-1} \qquad k_{eff} = 213 \frac{lbf}{in} \qquad F_{pl} := \frac{L_s}{L_r} \cdot F_{50} \qquad F_{pl} = 50 \, lbf$$

4. Enter the given cam data into the program DYNACAM and create a cam with acceptable pressure angles and radius of curvature. A cam drawing from DYNACAM that meets the requirements is shown on the next page. Find a suitable spring rate and preload to keep the minimum cam force positive and minimize the maximum cam force. One solution is shown in the Cam Dynamics screen shown below the cam drawing.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Draw Cam
Cam Basic Data
Cam Rotates
Cw Ccw
Cam Omega
250.00 rpm
Segment
All
Start Theta
0 deg
End Theta
360 deg
Delta Theta
1.0 deg
Thomas A. Cook
Design No. 2
06-27-1999
at 19:51:07
ReDraw Cam
Copy
Print Form
Done
Fig. P1510
Cam Drawing for Problem 15-10
Cam Size Data
Prime Radius
4.75 in
Folwr Radius
1.00 in
Offset
0.00 in
Max Phi
30.0 deg
Min Phi
-26.6 deg
Min Rho +
2.75 in
Min Rho -
-6.71 in
Time Delay
1


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.04652 bl
Spring Constant
135 lb/in
Spring Preload
50 lb
Damping
Ratio z
.15
Coefficient C
0.8 lb-s/in
Thomas A. Cook
Design No. 2
06-27-1999
at 19:51:07
Wn 53.9 rad/s
Cc 5.0
Wd 53.8 rad/s
Fmax 394.4 lb
Fmin 8.6 lb
Tmax 1,216.7 lb-in
F
400
300
200
100
0
0
120
240
360
Cam Angle (Deg)
T
1500
1000
500
0
-500
0
120
240
360
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
lb - in - Radians
Order Neg Area Pos Area
1 -16.3 30006.7
2 -29890.1 0
Average Torque:
80.62 lb-in
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-11

Statement: Repeat Problem 15-7 for a double-dwell cam to move the roller follower from 0 to 2 inches in 60 deg with cycloidal motion, dwell for 150 deg, fall 2 inches in 90 deg with modified sine acceleration, and dwell for the remainder. Cam speed is 200 rpm. Choose a suitable spring rate and preload to maintain follower contact. Select a spring from Appendix D. Assume a damping ratio of 0.15.

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$ $\quad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given: Arm dimensions:

Width (Z-direction): $a := 2 \cdot in$

Height (Y-direction): $b := 2.5 \cdot in$

Length (X-direction): $c := 28 \cdot in$

Cutout dimensions:

Width (Z-direction): $a' := 1.5 \cdot in$

Height (Y-direction): $b' := 2.5 \cdot in$

Length (X-direction): $c' := 3 \cdot in$

Distance from arm pivot to spring: $L_s := 19 \cdot in$

Distance from arm pivot to roller center: $L_r := 12 \cdot in$

Cam lift and speed: $h := 2.5 \cdot in$ $\quad \omega_2 := 100 rpm$

Roller follower dimensions: $r_f := 1 \cdot in$ $\quad w_f := 1.5 \cdot in$

Solution: See Figure P15-1, Problem 15-7, and DYNACAM file P1511.cam.

1. The effective mass and spring constant of the arm referenced to the cam follower were determined in Problem 10-16 as:

$$m_{eff} := 0.04652 \cdot blob \qquad k_{aeff} := 1.0131 \cdot 10^5 \cdot \frac{lbf}{in}$$

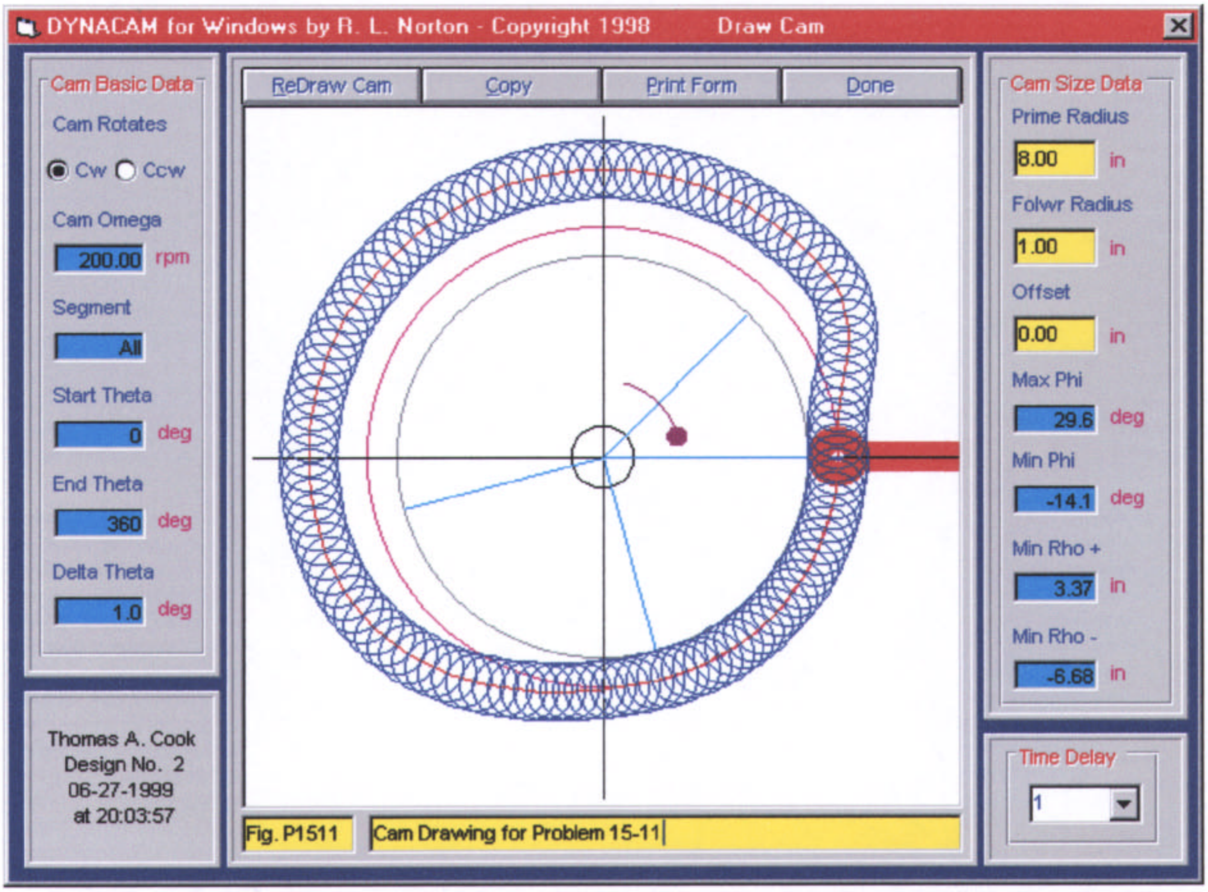
2. There is no extension spring listed in Appendix D that is acceptable. A 2-in follower lift is over 3 in at the end of the arm where the spring attaches. There is no spring that has a safe maximum load that is 3 times the spring rate. We will, therefore, have to have a custom made spring with the following rate and preload when installed.

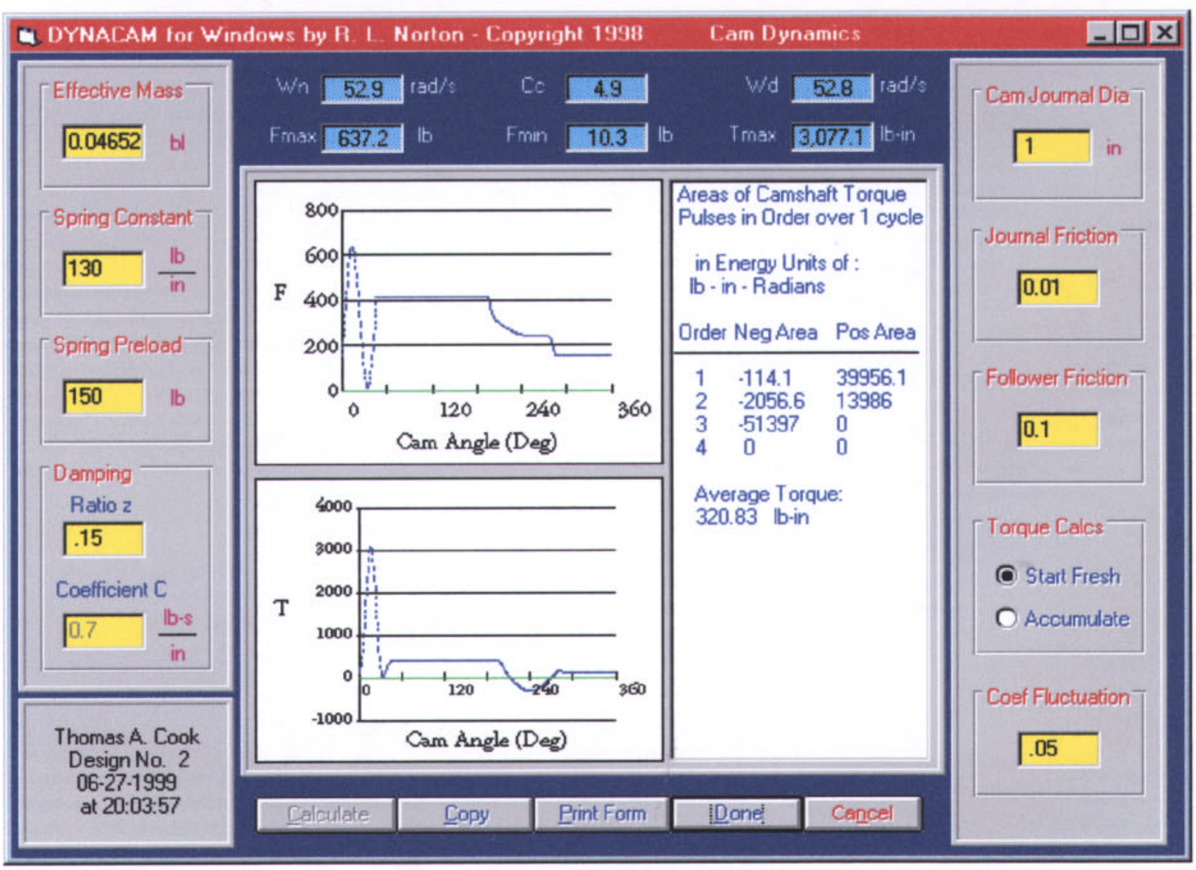
Spring rate and preload: $k_s := 82.1 \cdot lbf \cdot in^{-1}$ $\quad F_{50} := 94.7 \cdot lbf$

3. The spring rate and preload referenced to the cam follower are:

$$k_{eff} := \left[\frac{1}{k_{aeff}} + \left(\frac{L_r}{L_s} \right)^2 \cdot \frac{1}{k_s} \right]^{-1} \qquad k_{eff} = 205 \frac{lbf}{in} \qquad F_{pl} := \frac{L_s}{L_r} \cdot F_{50} \qquad F_{pl} = 150\, lbf$$

4. Enter the given cam data into the program DYNACAM and create a cam with acceptable pressure angles and radius of curvature. A cam drawing from DYNACAM that meets the requirements is shown on the next page. Find a suitable spring rate and preload to keep the minimum cam force positive and minimize the maximum cam force. One solution is shown in the Cam Dynamics screen shown below the cam drawing.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Draw Cam
Cam Basic Data
Cam Rotates
Cw Ccw
Cam Omega
200.00 rpm
Segment
All
Start Theta
0 deg
End Theta
360 deg
Delta Theta
1.0 deg
Thomas A. Cook
Design No. 2
06-27-1999
at 20:03:57
ReDraw Cam
Copy
Print Form
Done
Fig. P1511
Cam Drawing for Problem 15-11
Cam Size Data
Prime Radius
8.00 in
Folwr Radius
1.00 in
Offset
0.00 in
Max Phi
29.6 deg
Min Phi
-14.1 deg
Min Rho +
3.37 in
Min Rho -
-6.68 in
Time Delay
1


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
0.04652 bl
Spring Constant
130 lb/in
Spring Preload
150 lb
Damping
Ratio z
.15
Coefficient C
0.7 lb-s/in
Thomas A. Cook
Design No. 2
06-27-1999
at 20:03:57
Wn 52.9 rad/s
Cc 4.9
Wd 52.8 rad/s
Fmax 637.2 lb
Fmin 10.3 lb
Tmax 3,077.1 lb-in
F
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of : lb - in - Radians
Order Neg Area Pos Area
1 -114.1 39956.1
2 -2056.6 13986
3 -51397 0
4 0 0
Average Torque: 320.83 lb-in
Calculate
Copy
Print Form
Done
Cancel
Cam Journal Dia
1 in
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05

PROBLEM 15-12

Statement: The cam in Figure P15-2 is a pure eccentric with eccentricity = 20 mm and turns at 200 rpm. The mass of the follower is 1 kg. The spring has a rate of 10 N/m and a preload of 0.2 N. Find the follower force over one revolution. Assume a damping ratio of 0.10. If there is follower jump, respecify the spring rate and preload to eliminate it.

Units: $rpm := 2\cdot\pi\cdot rad\cdot min^{-1}$

Given: Cam eccentricity and speed: $a := 20\cdot mm$ $\omega := 200\cdot rpm$

Follower mass: $m_f := 1\cdot kg$ Damping ratio: $\zeta := 0.10$

Spring: $k := 10\cdot N\cdot m^{-1}$ $F_{pl} := 0.2\cdot N$

Solution: See Figure P15-2 and Mathcad file P1512.

1. Using the equation given in the figure, write functions for the displacement, velocity, and acceleration of the follower. Note that the displacement function is written such that at it is zero at $t = 0$.

   Displacement: $s(\theta) := a\cdot(1 - cos(\theta))$

   Velocity: $v(\theta) := a\cdot\omega\cdot sin(\theta)$

   Acceleration: $a(\theta) := a\cdot\omega^2\cdot cos(\theta)$

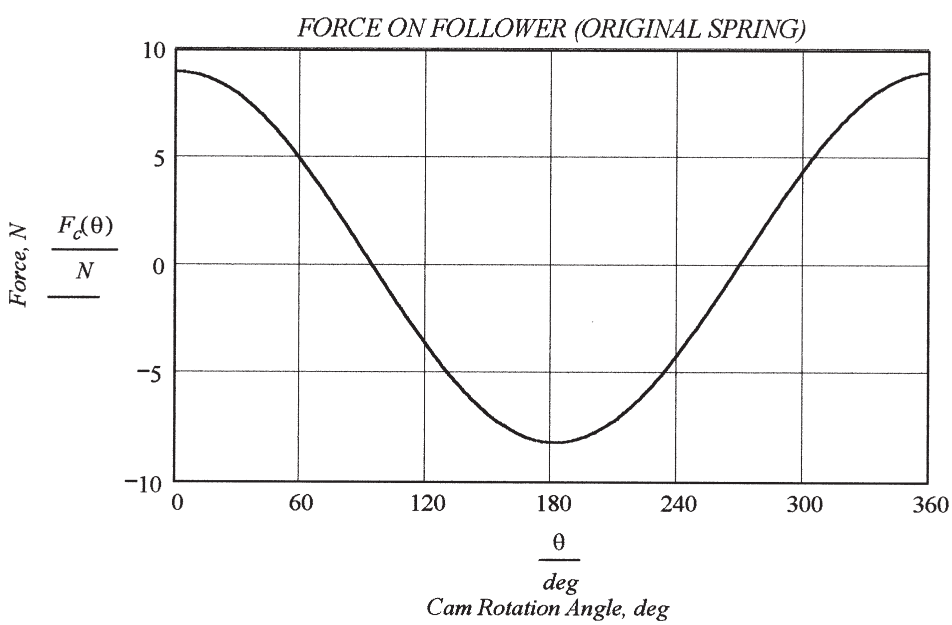
2. Calculate the damping coefficient using equations 15.2i and 15.3a.

   $c := 2\cdot\zeta\cdot\sqrt{m_f\cdot k}$ $c = 0.632\,\frac{N\cdot sec}{m}$

3. Substitute the expressions for displacement, velocity, acceleration, and spring preload into equation 15.9 and solve for the force on the follower as a function of cam angle.

   $F_c(\theta) := m_f\cdot a(\theta) + c\cdot v(\theta) + k\cdot s(\theta) + F_{pl}$

4. Plot the force on the follower for one revolution of the cam. $\theta := 0\cdot deg, 2\cdot deg .. 360\cdot deg$

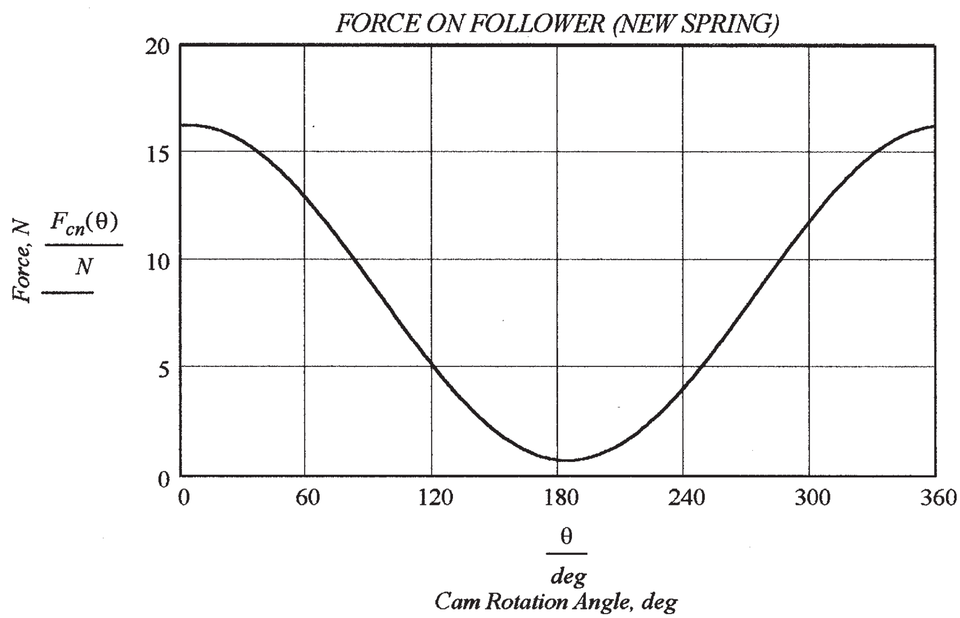


5. The cam force becomes negative, which indicates that the follower will jump or lose contact with the cam. New values of spring rate and/or preload will be tried iteratively to make the force always positive.

Let the new spring parameters be: $k := 50 \cdot N \cdot m^{-1}$ $F_{pl} := 7.5 \cdot N$

$c := 2 \cdot \zeta \cdot \sqrt{m_f \cdot k}$ $c = 1.414 \frac{N \cdot sec}{m}$

$$F_{cn}(\theta) := m_f \cdot a(\theta) + c \cdot v(\theta) + k \cdot s(\theta) + F_{pl}$$



PROBLEM 15-13

Statement: The cam in Figure P15-2 has a symmetric double harmonic rise and fall of 20 mm and turns at 200 rpm. The mass of the follower is 1 kg. The spring has a rate of 10 N/m and a preload of 0.2 N. Find the follower force over one revolution. Assume a damping ratio of 0.10. If there is follower jump, respecify the spring rate and preload to eliminate it.

Units: $rpm := 2\cdot\pi\cdot rad\cdot min^{-1}$

Given: Cam rise/fall and speed: $h := 20\cdot mm$ $\quad \omega := 200\cdot rpm$

Follower mass: $m_f := 1\cdot kg$ $\quad$ Damping ratio: $\zeta := 0.10$

Spring: $k := 10\cdot N\cdot m^{-1}$ $\quad F_{pl} := 0.2\cdot N$

Solution: See Figure P15-2 and Mathcad file P1513.

1. Using equations 8.25, write functions for the displacement, velocity, and acceleration of the follower. The value of β for both the rise and the fall is $\beta := 180\,deg$. To write the global equations, define a range function that has a value of unity between the limits of a and b and is zero elsewhere.

$$R(\theta,a,b) := if[(\theta > a)\cdot(\theta \le b),1,0]$$

Displacement:

$$s(\theta) := R(\theta,0,\beta)\cdot\frac{h}{2}\cdot\left[\left(1-\cos\left(\pi\cdot\frac{\theta}{\beta}\right)\right)-\frac{1}{4}\left(1-\cos\left(2\cdot\pi\cdot\frac{\theta}{\beta}\right)\right)\right]\ldots$$
$$+R(\theta,\beta,2\cdot\pi)\cdot\left[\frac{h}{2}\left[1+\cos\left(\pi\cdot\frac{\theta-\beta}{\beta}\right)-\frac{1}{4}\left(1-\cos\left(2\cdot\pi\cdot\frac{\theta-\beta}{\beta}\right)\right)\right]\right]$$

Velocity:

$$v(\theta) := \omega\cdot\frac{\pi}{\beta}\cdot\frac{h}{2}\cdot\begin{bmatrix}R(\theta,0,\beta)\cdot\left(\sin\left(\pi\cdot\frac{\theta}{\beta}\right)-\frac{1}{2}\cdot\sin\left(2\cdot\pi\cdot\frac{\theta}{\beta}\right)\right)\ldots\\ +-R(\theta,\beta,2\cdot\pi)\cdot\left(\sin\left(\pi\cdot\frac{\theta-\beta}{\beta}\right)+\frac{1}{2}\cdot\sin\left(2\cdot\pi\cdot\frac{\theta-\beta}{\beta}\right)\right)\end{bmatrix}$$

Acceleration:

$$a(\theta) := \omega^2\cdot\frac{\pi^2}{\beta^2}\cdot\frac{h}{2}\cdot\begin{bmatrix}R(\theta,0,\beta)\cdot\left(\cos\left(\pi\cdot\frac{\theta}{\beta}\right)-\cos\left(2\cdot\pi\cdot\frac{\theta}{\beta}\right)\right)\ldots\\ +-R(\theta,\beta,2\cdot\pi)\cdot\left(\cos\left(\pi\cdot\frac{\theta-\beta}{\beta}\right)+\cos\left(2\cdot\pi\cdot\frac{\theta-\beta}{\beta}\right)\right)\end{bmatrix}$$

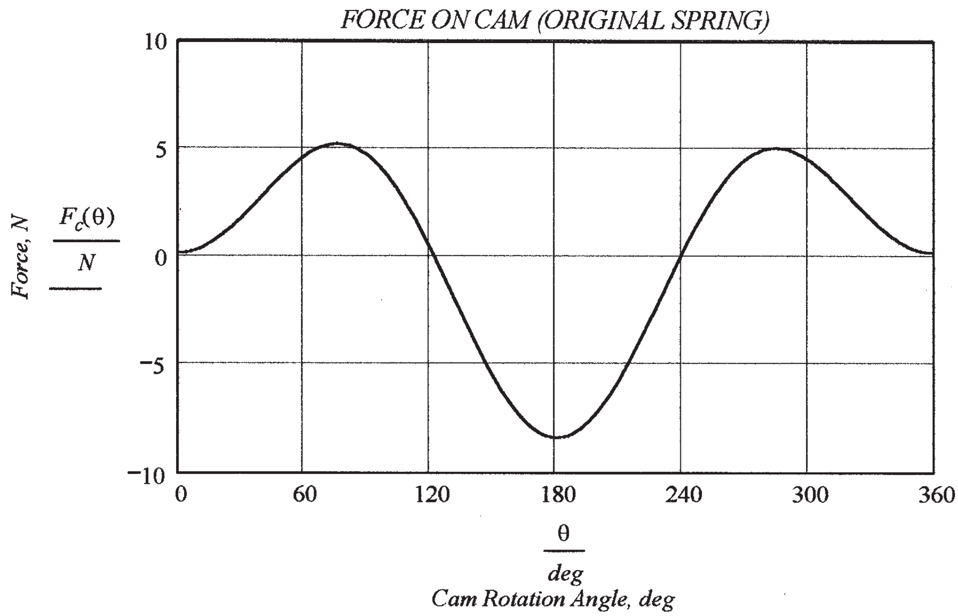
2. Calculate the damping coefficient using equations 15.2i and 15.3a.

$$c := 2\cdot\zeta\cdot\sqrt{m_f\cdot k} \qquad c = 0.632\,\frac{N\cdot sec}{m}$$

3. Substitute the expressions for displacement, velocity, acceleration, and spring preload into equation 15.9 and solve for the force on the cam as a function of cam angle.

$$F_c(\theta) := m_f\cdot a(\theta) + c\cdot v(\theta) + k\cdot s(\theta) + F_{pl}$$

4. Plot the force on the cam for one revolution of the cam. $\quad \theta := 0\cdot deg, 2\cdot deg\,..\,360\cdot deg$

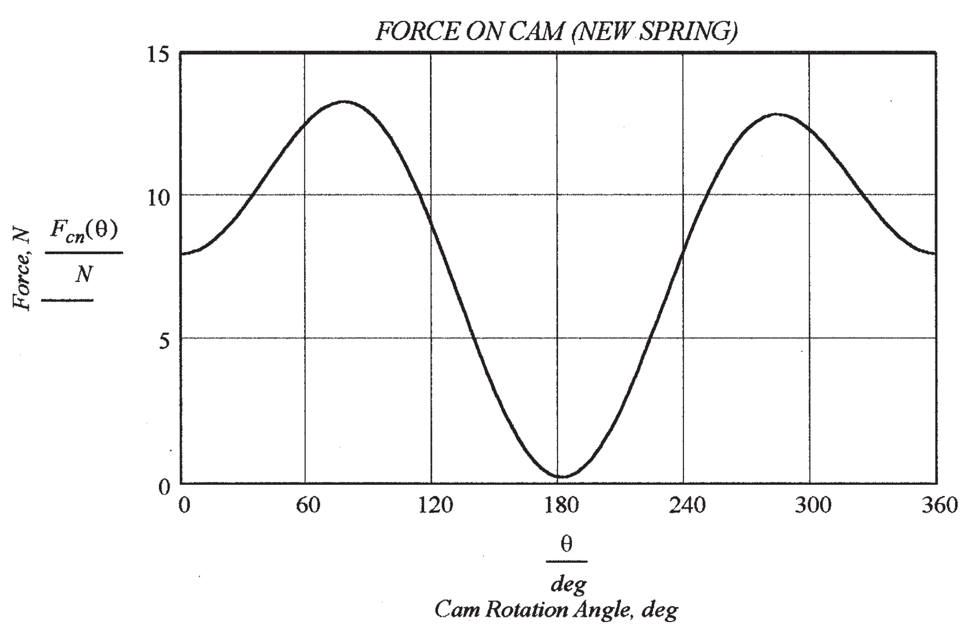


5. The cam force becomes negative, which indicates that the follower will jump or lose contact with the cam. New values of spring rate and/or preload will be tried iteratively to make the force always positive.

Let the new spring parameters be: $k := 50 \cdot N \cdot m^{-1}$ $\qquad F_{pl} := 8 \cdot N$

$$c := 2 \cdot \zeta \cdot \sqrt{m_f \cdot k} \qquad c = 1.414 \frac{N \cdot sec}{m}$$

$$F_{cn}(\theta) := m_f \cdot a(\theta) + c \cdot v(\theta) + k \cdot s(\theta) + F_{pl}$$



PROBLEM 15-14

Statement: The cam in Figure P15-2 has a symmetric 3-4-5-6 polynomial rise and fall of 20 mm and turns at 200 rpm. The mass of the follower is 1 kg. The spring has a rate of 10 N/m and a preload of 0.2 N. Find the follower force over one revolution. Assume a damping ratio of 0.10. If there is follower jump, respecify the spring rate and preload to eliminate it.

Units: $rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$

Given: Cam rise/fall and speed: $h := 20 \cdot mm$ $\quad \omega := 200 \cdot rpm$

Follower mass: $m_f := 1 \cdot kg$ $\quad$ Damping ratio: $\zeta := 0.10$

Spring: $k := 10 \cdot N \cdot m^{-1}$ $\quad F_{pl} := 0.2 \cdot N$

Solution: See Figure P15-2 and Mathcad file P1514.

1. Using equations 8.26, write functions for the displacement, velocity, and acceleration of the follower. The value of β for the total rise and fall is $\beta := 360 \cdot deg$.

Displacement: $$s(\theta) := h \cdot \left[64 \cdot \left(\frac{\theta}{\beta}\right)^3 - 192 \cdot \left(\frac{\theta}{\beta}\right)^4 + 192 \cdot \left(\frac{\theta}{\beta}\right)^5 - 64 \cdot \left(\frac{\theta}{\beta}\right)^6 \right]$$

Velocity: $$v(\theta) := \omega \cdot \frac{h}{\beta} \cdot \left[192 \cdot \left(\frac{\theta}{\beta}\right)^2 - 768 \cdot \left(\frac{\theta}{\beta}\right)^3 + 960 \cdot \left(\frac{\theta}{\beta}\right)^4 - 384 \cdot \left(\frac{\theta}{\beta}\right)^5 \right]$$

Acceleration: $$a(\theta) := \omega^2 \cdot \frac{h}{\beta^2} \cdot \left[384 \cdot \left(\frac{\theta}{\beta}\right) - 2304 \cdot \left(\frac{\theta}{\beta}\right)^2 + 3840 \cdot \left(\frac{\theta}{\beta}\right)^3 - 1920 \cdot \left(\frac{\theta}{\beta}\right)^4 \right]$$

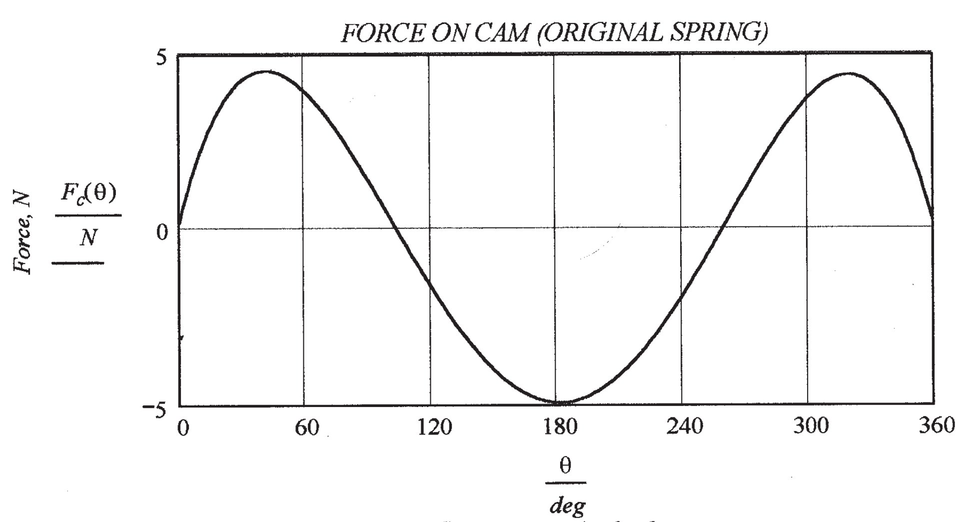
2. Calculate the damping coefficient using equations 15.2i and 15.3a.

$$c := 2 \cdot \zeta \cdot \sqrt{m_f \cdot k} \qquad c = 0.632 \frac{N \cdot sec}{m}$$

3. Substitute the expressions for displacement, velocity, acceleration, and spring preload into equation 15.9 and solve for the force on the cam as a function of cam angle.

$$F_c(\theta) := m_f \cdot a(\theta) + c \cdot v(\theta) + k \cdot s(\theta) + F_{pl}$$

4. Plot the force on the cam for one revolution of the cam. $\theta := 0 \cdot deg, 2 \cdot deg .. 360 \cdot deg$



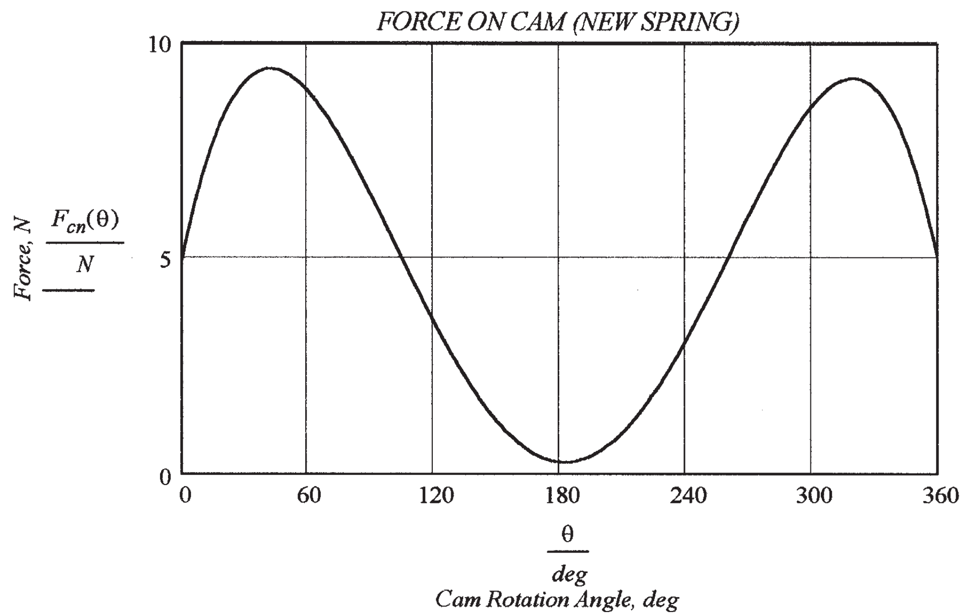
Cam Rotation Angle, deg

5. The cam force becomes negative, which indicates that the follower will jump or lose contact with the cam. New values of spring rate and/or preload will be tried iteratively to make the force always positive.

Let the new spring parameters be: $k := 30 \cdot N \cdot m^{-1}$ $F_{pl} := 5 \cdot N$

$c := 2 \cdot \zeta \cdot \sqrt{m_f \cdot k}$ $c = 1.095 \frac{N \cdot sec}{m}$

$$F_{cn}(\theta) := m_f \cdot a(\theta) + c \cdot v(\theta) + k \cdot s(\theta) + F_{pl}$$



PROBLEM 15-15

Statement: Design a double-dwell cam to meet the specifications given below. Size a return spring, selected from Appendix D, and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE	DWELL	FALL	DWELL
$\beta_1 := 60 \cdot deg$	$\beta_2 := 120 \cdot deg$	$\beta_3 := 90 \cdot deg$	$\beta_4 := 90 \cdot deg$
$h_1 := 45 \cdot mm$	$h_2 := 0 \cdot mm$	$h_3 := 45 \cdot mm$	$h_4 := 0 \cdot mm$
Mod. sine		3-4-5 poly	

Cycle time: $\tau := 1 \cdot sec$ Damping ratio: $\zeta := 0.25$ Follower mass: $m_f := 2 \cdot kg$

Solution: See DYNACAM files P1515a and P1515b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 6.283 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 60.000\, rpm$$

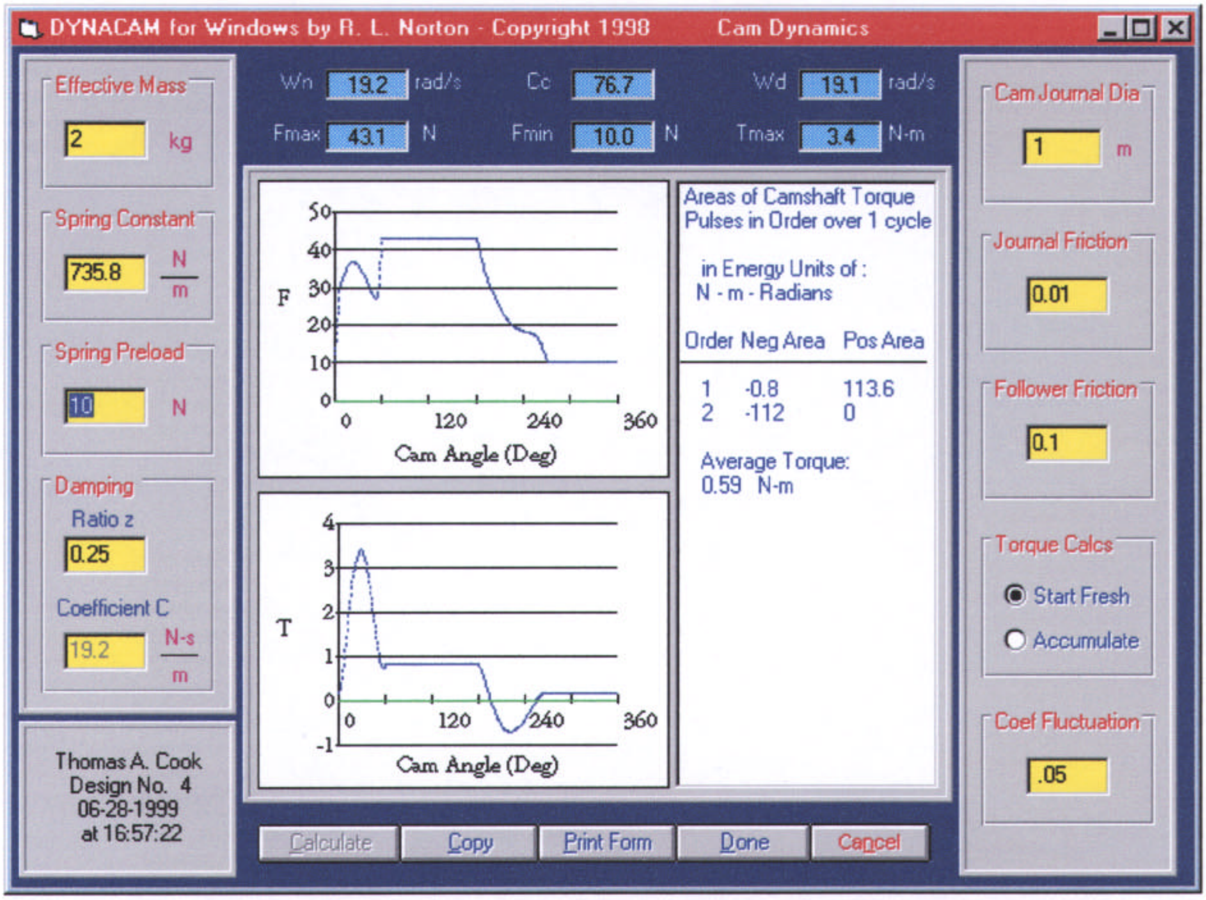
2. Load the noted files into program DYNACAM. Diskfile P1515a contains the force-closed solution and P1515b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

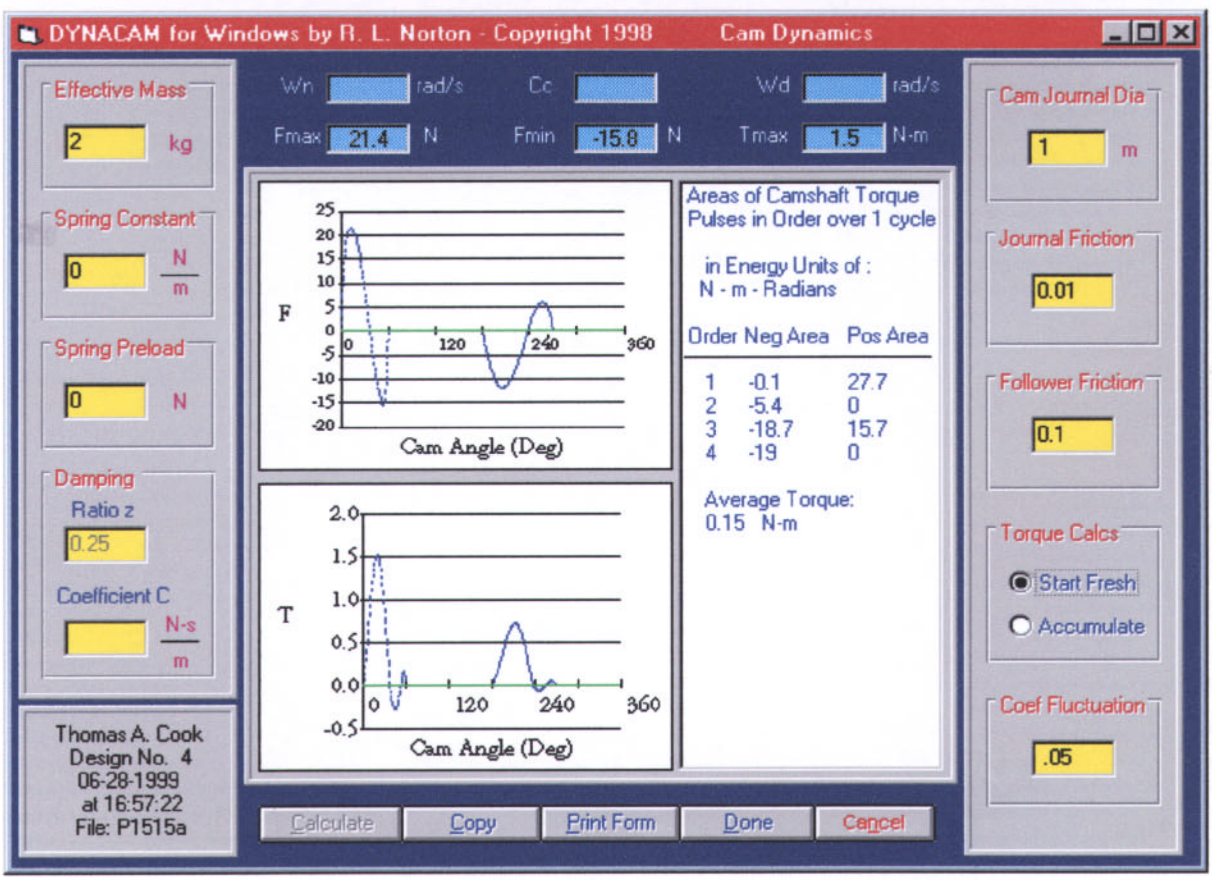
3. The cam is sized with an 92.5-mm prime circle radius and 10.8-mm eccentricity, which gives balanced pressure angles of 29.9 deg and a minimum radius of curvature of 52.4 mm. The roller radius is 25 mm.

4. For the force-closed case, choose catalog number 447 from with a spring constant of 4.2 lb/in (735.8 N/m) with a preload of 10 N to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 5.3 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
2 kg
Spring Constant
735.8 N/m
Spring Preload
10 N
Damping
Ratio z
0.25
Coefficient C
19.2 N-s/m
Thomas A. Cook
Design No. 4
06-28-1999
at 16:57:22
Wn 19.2 rad/s
Cc 76.7
Wd 19.1 rad/s
Fmax 43.1 N
Fmin 10.0 N
Tmax 3.4 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Neg Area Pos Area
1 -0.8 113.6
2 -112 0
Average Torque:
0.59 N-m
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
2 kg
Spring Constant
0 N/m
Spring Preload
0 N
Damping
Ratio z
0.25
Coefficient C
N-s/m
Thomas A. Cook
Design No. 4
06-28-1999
at 16:57:22
File: P1515a
Wn rad/s
Cc
Wd rad/s
Fmax 21.4 N
Fmin -15.8 N
Tmax 1.5 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Neg Area Pos Area
1 -0.1 27.7
2 -5.4 0
3 -18.7 15.7
4 -19 0
Average Torque:
0.15 N-m
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-16

Statement: Design a single-dwell cam to meet the specifications given below. Size a return spring, selected from Appendix D, and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE	FALL	DWELL
$\beta_{11} := 60 \cdot deg$	$\beta_{12} := 90 \cdot deg$	$\beta_2 := 210 \cdot deg$
$h_1 := 25 \cdot mm$		$h_3 := 0 \cdot mm$

Seventh-degree polynomial

Cycle time: $\tau := 2 \cdot sec$ Damping ratio: $\zeta := 0.15$ Follower mass: $m_f := 10 \cdot kg$

Solution: See DYNACAM files P1516a and P1516b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 3.142 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 30.000\, rpm$$

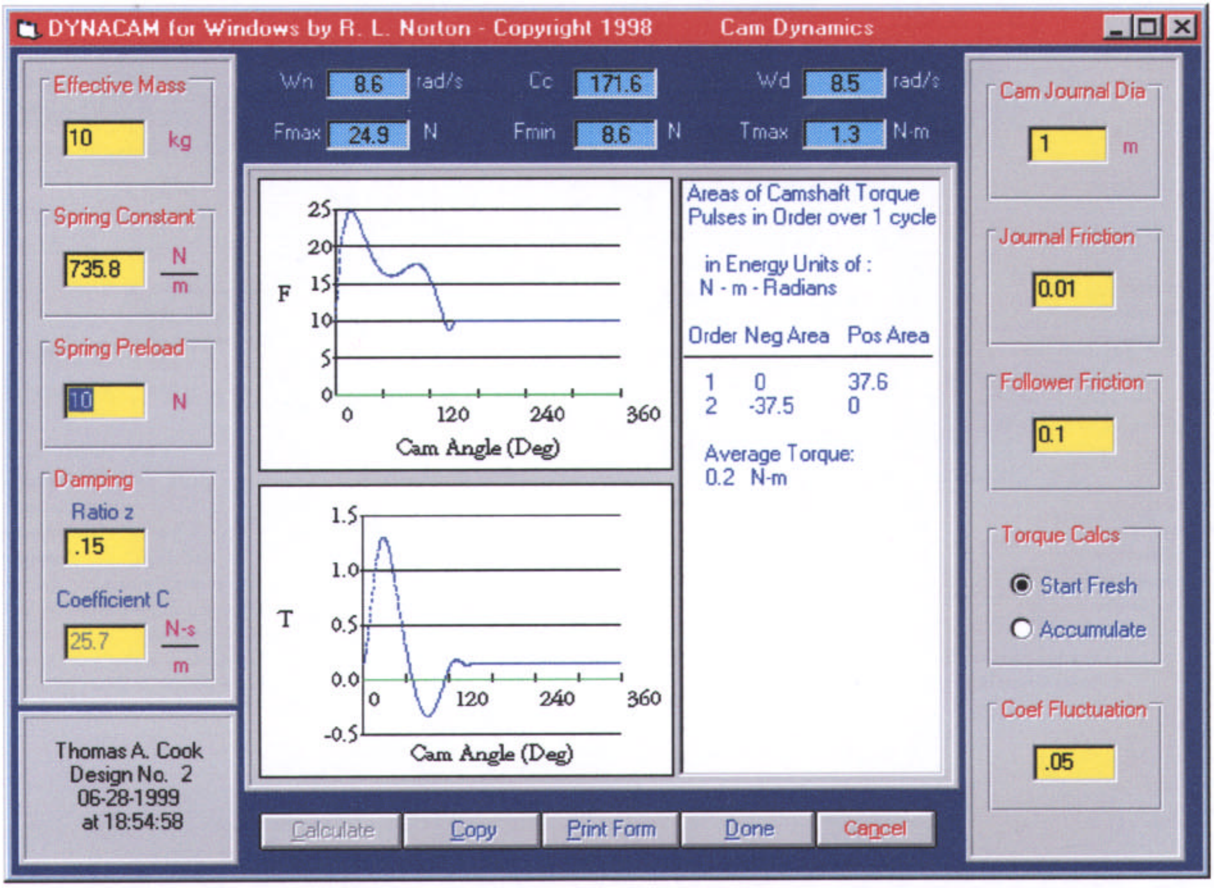
2. Load the noted files into program DYNACAM. Diskfile P1516a contains the force-closed solution and P1516b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

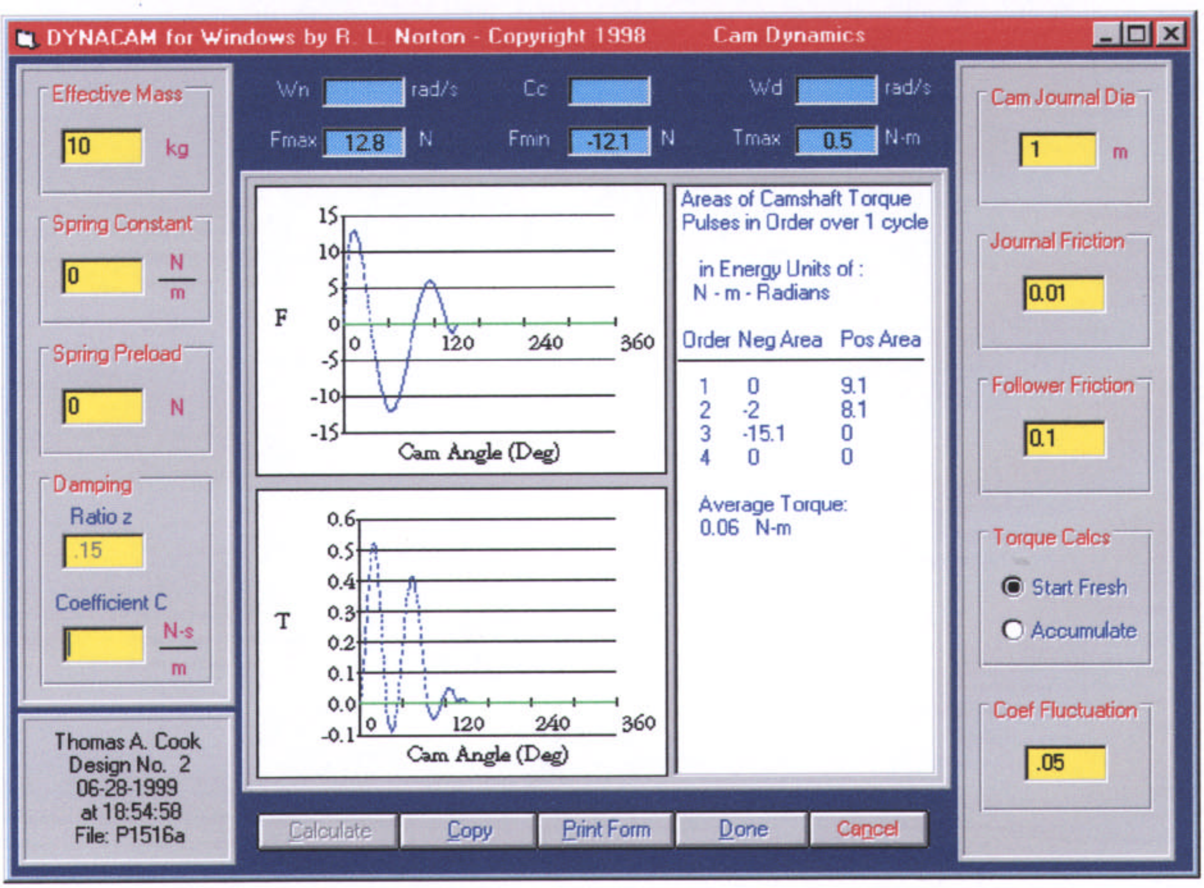
3. The cam is sized with an 85-mm prime circle radius and 2.8-mm eccentricity, which gives balanced pressure angles of 21.5 deg and a minimum radius of curvature of 50.0 mm. The roller radius is 25 mm.

4. For the force-closed case, choose catalog number 447 from with a spring constant of 4.2 lb/in (735.8 N/m) with a preload of 10 N to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 2.7 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
10 kg
Spring Constant
735.8 N/m
Spring Preload
10 N
Damping
Ratio z
.15
Coefficient C
25.7 N-s/m
Thomas A. Cook
Design No. 2
06-28-1999
at 18:54:58
Wn 8.6 rad/s
Cc 171.6
Wd 8.5 rad/s
Fmax 24.9 N
Fmin 8.6 N
Tmax 1.3 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Neg Area Pos Area
1 0 37.6
2 -37.5 0
Average Torque:
0.2 N-m
Calculate
Copy
Print Form
Done
Cancel
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
10 kg
Spring Constant
0 N/m
Spring Preload
0 N
Damping
Ratio z
.15
Coefficient C
N-s/m
Thomas A. Cook
Design No. 2
06-28-1999
at 18:54:58
File: P1516a
Wn rad/s
Cc
Wd rad/s
Fmax 12.8 N
Fmin -12.1 N
Tmax 0.5 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Neg Area Pos Area
1 0 9.1
2 -2 8.1
3 -15.1 0
4 0 0
Average Torque:
0.06 N-m
Calculate
Copy
Print Form
Done
Cancel
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05

PROBLEM 15-17

Statement: Design a four-dwell cam to meet the specifications given below. Size a return spring and specify its preload to maintain contact between cam and follower. Calculate and plot the dynamic force and torque. Repeat for a form-closed cam. Compare the dynamic force, torque, and natural frequency for the form-closed design and the force-closed design.

Given:

RISE/FALL	DWELL	FALL	DWELL
$\beta_1 := 40 \cdot deg$	$\beta_2 := 100 \cdot deg$	$\beta_3 := 90 \cdot deg$	$\beta_4 := 20 \cdot deg$
$h_1 := 40 \cdot mm$	$h_2 := 0.0 \cdot in$	$h_3 := 20 \cdot mm$	$h_4 := 0.0 \cdot in$
$\beta_5 := 30 \cdot deg$	$\beta_6 := 40 \cdot deg$	$\beta_7 := 30 \cdot deg$	$\beta_8 := 10 \cdot deg$
$h_5 := 10 \cdot mm$	$h_6 := 0.0 \cdot in$	$h_7 := 10 \cdot mm$	$h_8 := 0.0 \cdot in$

Cycle time: $\tau := 10 \cdot sec$ Damping ratio: $\zeta := 0.25$ Follower mass: $m_f := 3 \cdot kg$

Solution: See DYNACAM files P1517a and P1517b.

1. The camshaft turns 2π rad during the time for one cycle. Thus, its speed is

$$\omega := \frac{2 \cdot \pi \cdot rad}{\tau} \qquad \omega = 0.628 \frac{rad}{sec} \qquad rpm := 2 \cdot \pi \cdot rad \cdot min^{-1} \qquad \omega = 6.000\, rpm$$

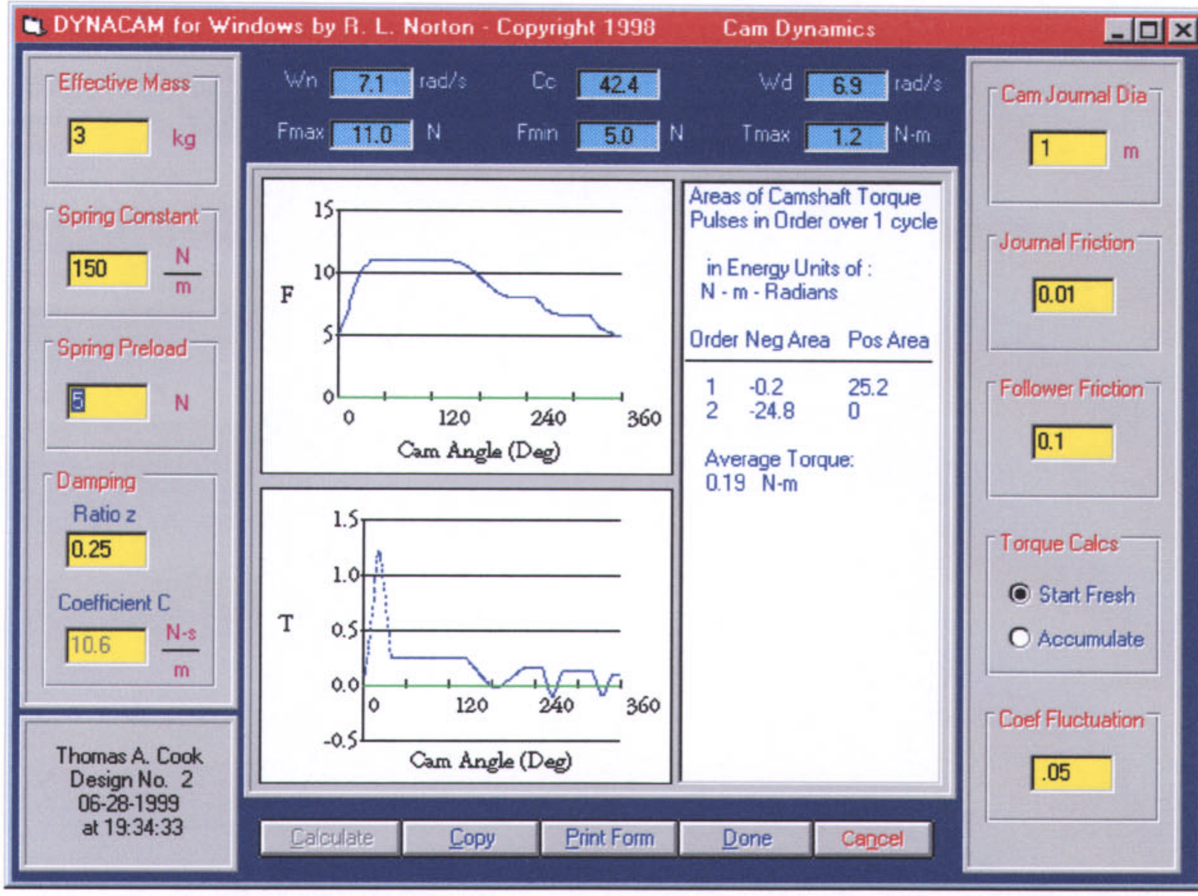
2. Load the noted files into program DYNACAM. Diskfile P1517a contains the force-closed solution and P1517b the form-closed solution. In each case, after opening the file, click on the *Size Cam* button and then click *Calculate* to see the pressure angle and minimum radius of curvature. Then click the *Done* button and you will see the cam drawing. After clicking the *Done* button on that screen, click the *Dynamics* button on the *Home* screen. Click its *Calculate* button to see the fully developed *Dynamics* screen. Once this sequence of commands has been entered, you may see further data by clicking on the *Print* or *Plot* buttons on the home screen. Accept all default values, which have been brought in from the file. It is not necessary to go to the *SVAJ* screen as that data has been brought in from the files.

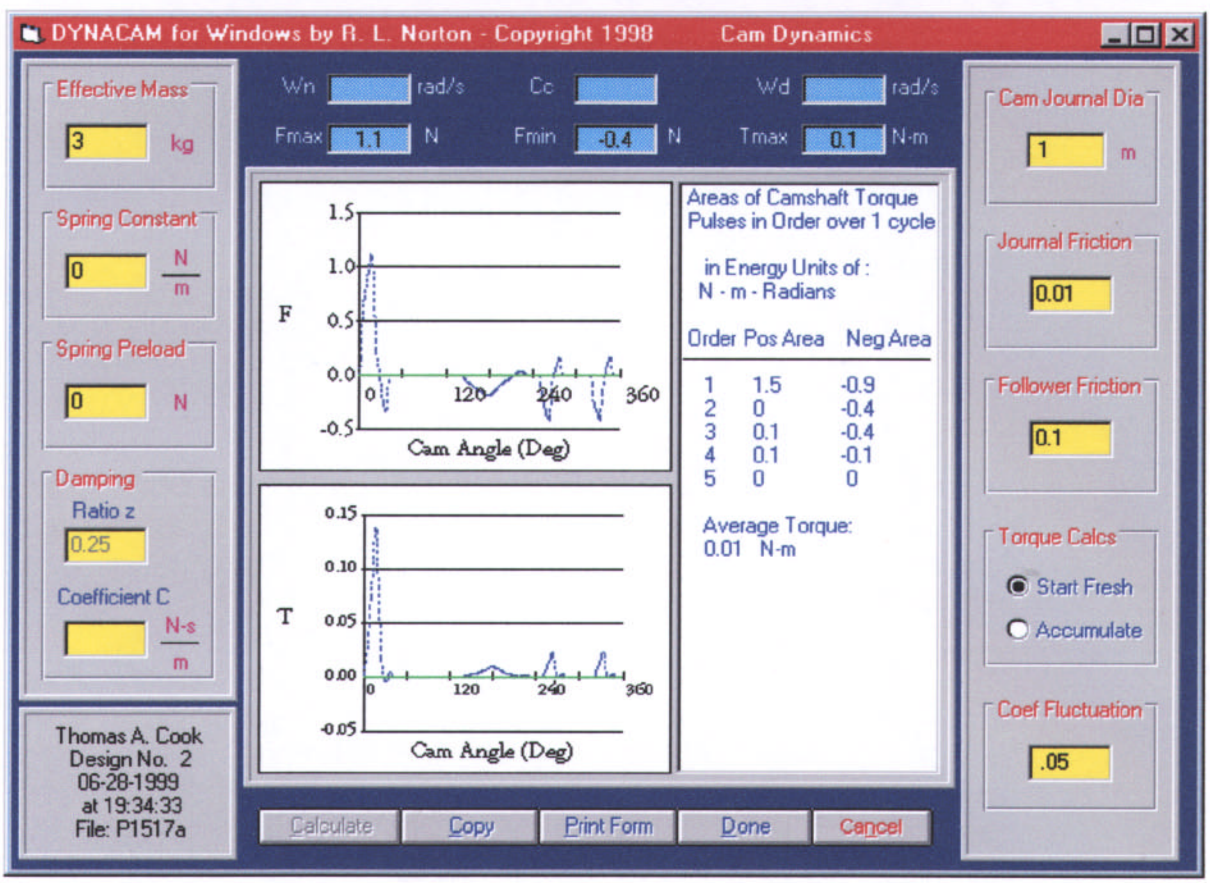
3. Modified trapezoidal acceleration was used for the rise and all falls. The cam is sized with an 130-mm prime circle radius and 34-mm eccentricity, which gives balanced pressure angles of 29 deg and a minimum radius of curvature of 50 mm. The roller radius is 25 mm.

4. For the force-closed case, a spring constant of 150 N/mm with a preload of 5 N is chosen to keep the follower force positive and prevent jump. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient are shown on the *Cam Dynamics* screen, which is shown below on the next page. The system natural frequency is about 11.3 times the driving frequency. This ratio could be increased at the expense of larger follower force by increasing the spring constant.

5. For the form-closed case, it is only necessary to define spring constant and preload values of zero. The "b" diskfile does this. The maximum and minimum follower force, maximum driving torque, undamped and damped natural frequencies, and damping coefficient for this case are shown on the second *Cam Dynamics* screen, which is shown below on the next page.

6. Comparing these two cases shows that in the force-closed case both the peak follower force and driving torque excursions are greater than in the form-closed case. This gives the form-closed cam the advantage in terms of lower stresses in cam and follower and a smaller drive motor. However, this advantage comes at the expense of a more difficult and costly cam to make, since two cam surfaces must be machined instead of one.


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
3 kg
Spring Constant
150 N/m
Spring Preload
5 N
Damping
Ratio z
0.25
Coefficient C
10.6 N-s/m
Thomas A. Cook
Design No. 2
06-28-1999
at 19:34:33
Wn 7.1 rad/s
Cc 42.4
Wd 6.9 rad/s
Fmax 11.0 N
Fmin 5.0 N
Tmax 1.2 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Neg Area Pos Area
1 -0.2 25.2
2 -24.8 0
Average Torque:
0.19 N-m
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel


DYNACAM for Windows by R. L. Norton - Copyright 1998 Cam Dynamics
Effective Mass
3 kg
Spring Constant
0 N/m
Spring Preload
0 N
Damping
Ratio z
0.25
Coefficient C
N-s/m
Thomas A. Cook
Design No. 2
06-28-1999
at 19:34:33
File: P1517a
Wn rad/s
Cc
Wd rad/s
Fmax 1.1 N
Fmin -0.4 N
Tmax 0.1 N-m
F
Cam Angle (Deg)
T
Cam Angle (Deg)
Areas of Camshaft Torque Pulses in Order over 1 cycle
in Energy Units of :
N - m - Radians
Order Pos Area Neg Area
1 1.5 -0.9
2 0 -0.4
3 0.1 -0.4
4 0.1 -0.1
5 0 0
Average Torque:
0.01 N-m
Cam Journal Dia
1 m
Journal Friction
0.01
Follower Friction
0.1
Torque Calcs
Start Fresh
Accumulate
Coef Fluctuation
.05
Calculate
Copy
Print Form
Done
Cancel

PROBLEM 15-18

Statement: Design a cam to drive an automotive valve train whose parameters are given below. Select a spring constant and preload to avoid jump to 3500 rpm. Fast opening and closing and maximum open time are desired.

Units: $rpm := 2 \cdot \pi \cdot rad \cdot min^{-1}$ $\quad kN := 10^3 \cdot N$

Given: Cam rise/fall and speed: $h := 12 \cdot mm$ $\quad \omega := 3500 rpm$

Valve train mass: $m_v := 0.2 \cdot kg$ $\quad$ Damping ratio: $\zeta := 0.30$

Roller follower: $R_f := 5 \cdot mm$

Open-close event is 160 deg, low dwell is 200 deg.

Solution: See Mathcad file P1518.

1. Use a 3-4-5 polynomial for both the rise and the fall. Although peak jerk is higher with this choice than with the 4-5-6-7 polynomial, peak acceleration is considerably lower. Using equation 8.24, write functions for the displacement, velocity, and acceleration of the follower. The value of β for the both the rise and fall is $\beta := 40 \cdot deg$. To write the global equations, define a range function that has a value of unity between the limits of a and b and is zero elsewhere.

$$R(\theta, a, b) := if[(\theta > a) \cdot (\theta \le b), 1, 0]$$

Displacement:

Rise: $\beta_1 := \beta$ $\qquad \beta_1 = 40.000\, deg$

$$s_1(\theta) := h \cdot \left[10 \cdot \left(\frac{\theta}{\beta_1}\right)^3 - 15 \cdot \left(\frac{\theta}{\beta_1}\right)^4 + 6 \cdot \left(\frac{\theta}{\beta_1}\right)^5\right]$$

High dwell: $\beta_2 := 160 \cdot deg - 2 \cdot \beta$ $\qquad \beta_2 = 80.000\, deg$ $\qquad s_2(\theta) := h$

Fall: $\beta_3 := \beta$ $\qquad \beta_3 = 40.000\, deg$

$$s_3(\theta) := h \cdot \left[1 - \left[10 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^3 - 15 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^4 \ldots + 6 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^5\right]\right]$$

Global equation:

$$s(\theta) := R(\theta, 0, \beta_1) \cdot s_1(\theta) + R(\theta, \beta_1, \beta_1 + \beta_2) \cdot s_2(\theta) \ldots + R(\theta, \beta_1 + \beta_2, \beta_1 + \beta_2 + \beta_3) \cdot s_3(\theta)$$

Velocity:

Rise:
$$v_1(\theta) := \omega \cdot \frac{h}{\beta_1} \cdot \left[30 \cdot \left(\frac{\theta}{\beta_1}\right)^2 - 60 \cdot \left(\frac{\theta}{\beta_1}\right)^3 + 30 \cdot \left(\frac{\theta}{\beta_1}\right)^4\right]$$

High dwell:
$$v_2(\theta) := 0 \cdot \frac{m}{sec}$$

Fall:
$$v_3(\theta) := -\omega \cdot \frac{h}{\beta_3} \cdot \left[30 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^2 - 60 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^3 + 30 \cdot \left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^4\right.$$

Global equation:
$$v(\theta) := R(\theta, 0, \beta_1)\cdot v_1(\theta) + R(\theta, \beta_1, \beta_1 + \beta_2)\cdot v_2(\theta) \ldots + R(\theta, \beta_1 + \beta_2, \beta_1 + \beta_2 + \beta_3)\cdot v_3(\theta)$$

Acceleration:

Rise:
$$a_1(\theta) := \omega^2 \cdot \frac{h}{\beta_1^2} \cdot \left[60\cdot\left(\frac{\theta}{\beta_1}\right) - 180\cdot\left(\frac{\theta}{\beta_1}\right)^2 + 120\cdot\left(\frac{\theta}{\beta_1}\right)^3\right]$$

High dwell:
$$a_2(\theta) := 0\cdot\frac{m}{sec^2}$$

Fall:
$$a_3(\theta) := -\omega^2 \cdot \frac{h}{\beta_3^2} \cdot \left[60\cdot\left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right) - 180\cdot\left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^2 \ldots + 120\cdot\left(\frac{\theta - \beta_1 - \beta_2}{\beta_3}\right)^3\right]$$

Global equation:
$$a(\theta) := R(\theta, 0, \beta_1)\cdot a_1(\theta) + R(\theta, \beta_1, \beta_1 + \beta_2)\cdot a_2(\theta) \ldots + R(\theta, \beta_1 + \beta_2, \beta_1 + \beta_2 + \beta_3)\cdot a_3(\theta)$$

2. Iteratively choose spring parameters that will prevent follower jump and then, calculate the damping coefficient using equations 15.2i and 15.3a.

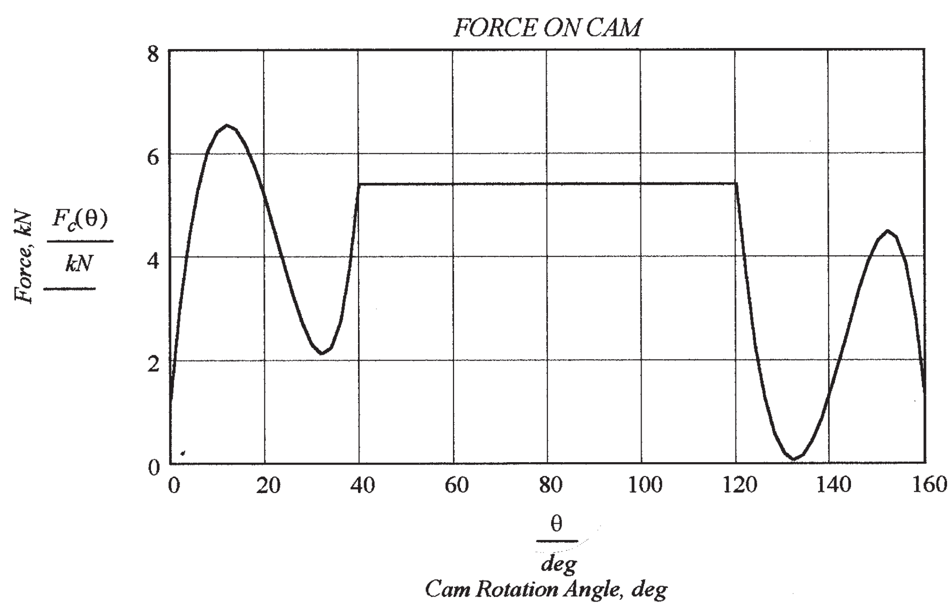
Spring: $k := 350\cdot N\cdot mm^{-1}$ $\quad F_{pl} := 1200\cdot N$

$c := 2\cdot\zeta\cdot\sqrt{m_v\cdot k}$ $\quad c = 158.745\,\frac{N\cdot sec}{m}$

3. Substitute the expressions for displacement, velocity, acceleration, and spring preload into equation 15.9 and solve for the force on the cam as a function of cam angle.

$$F_c(\theta) := m_v\cdot a(\theta) + c\cdot v(\theta) + k\cdot s(\theta) + F_{pl}$$

4. Plot the force on the cam for one revolution of the cam. $\theta := 0\cdot deg, 2\cdot deg .. 360\cdot deg$



PROBLEM 15-19

Statement: For the cam-follower train described in Problems 10-30 and 10-31, determine and plot the kinetostatic follower force and camshaft torque over one cycle if the cam provides a 3-4-5 polynomial double dwell angular motion to roller arm 2 with a rise of 10 deg in 90 camshaft degrees, dwell for 90 deg, fall 10 deg in 90 deg and dwell for the remainder. The camshaft turns 100 rpm.

Units: $rpm := 2\cdot\pi\cdot rad\cdot min^{-1}$ $\quad blob := lbf\cdot sec^2\cdot in^{-1}$

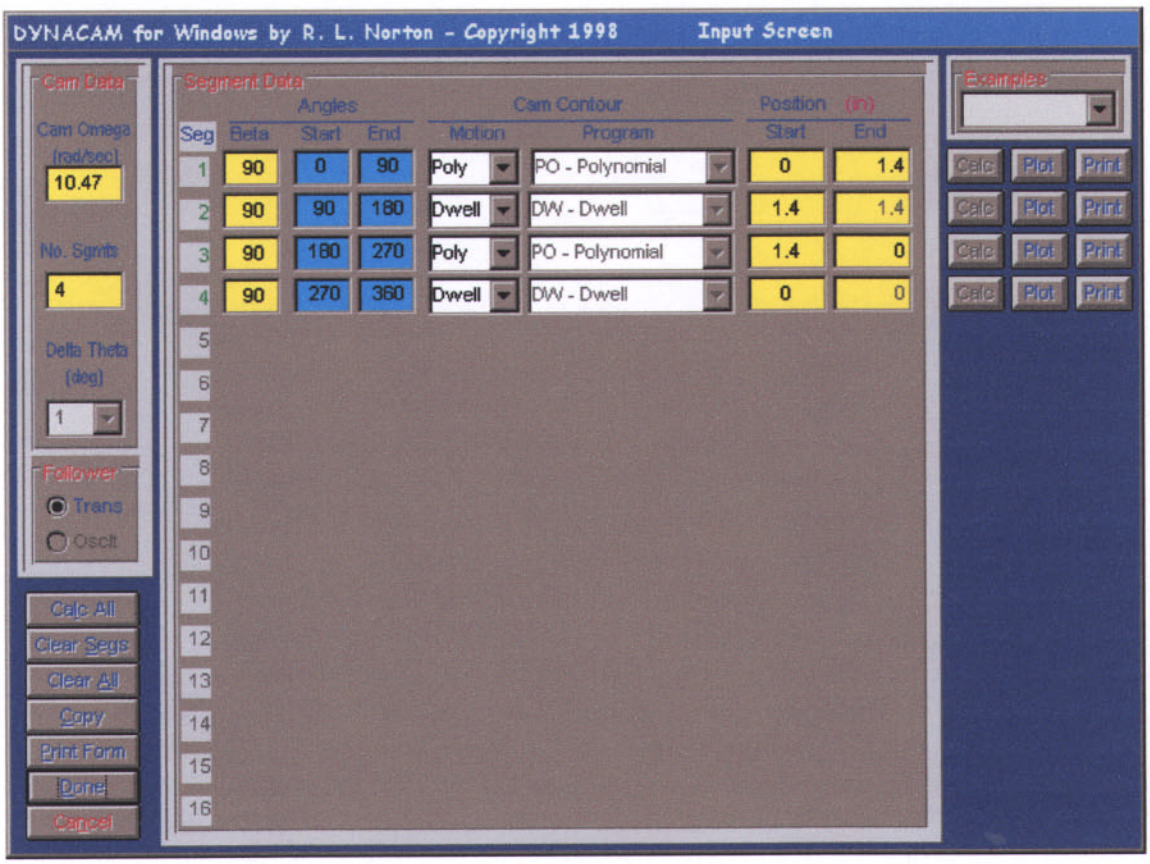
Given: Follower rise: $\sigma := 10\cdot deg$ Cam speed: $n := 100\cdot rpm$ Roller arm radius: $r := 8\cdot in$

From problems 10-30 and 10-31: $m_{eff} := 0.165\cdot blob$ $\quad k_{eff} := 52600\cdot\dfrac{lbf}{in}$ $\quad F_{oeff} := 120\,lbf$

Solution: See Figure P10-5 and Mathcad file P1519.

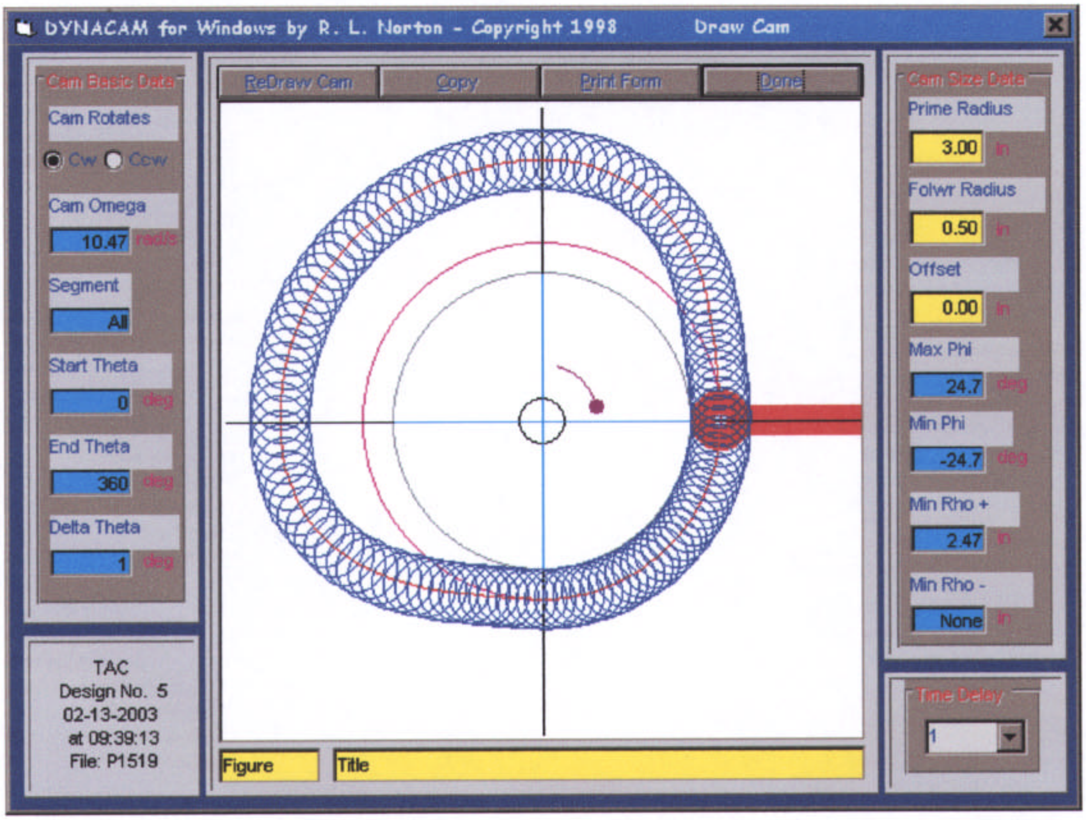
1. The program DYNACAM will be used for this solution. Calculate the speed in rad/sec and the effective lift in inches for input to the SVAJ screen of DYNACAM.

$$\omega := n \qquad \omega = 10.472\,\frac{rad}{sec} \qquad h := r\cdot\sigma \qquad h = 1.4\,in$$



Choose poly functions for the rise and fall segments and, when calculating these segments, choose 6 BCs, setting V and A to zero at the beginning and end of the segments. This will result in 3-4-5 polynomials for the rise and fall.

2. Click *Done* and then, at the *Home* screen, click *Size Cam*. Choose a follower radius and then a prime circle radius that will make the radius of curvature, ρ_{min}, significantly larger than the follower radius.



3. Click *Done* and then, at the *Home* screen, click *Dynamics*. Enter the effective mass, spring rate, and spring preload. The results are shown below.