Chapter 14

MULTICYLINDER ENGINES

TOPIC/PROBLEM MATRIX

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14.6	Even Firing	14-1, 14-2, 14-3, 14-4, 14-5, 14-6, 14-7, 14-19, 14-20
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PROBLEM 14-1

Statement: Draw a crank phase diagram for a three-cylinder inline engine with a 0, 120, 240-deg crankshaft and determine all possible firing orders for

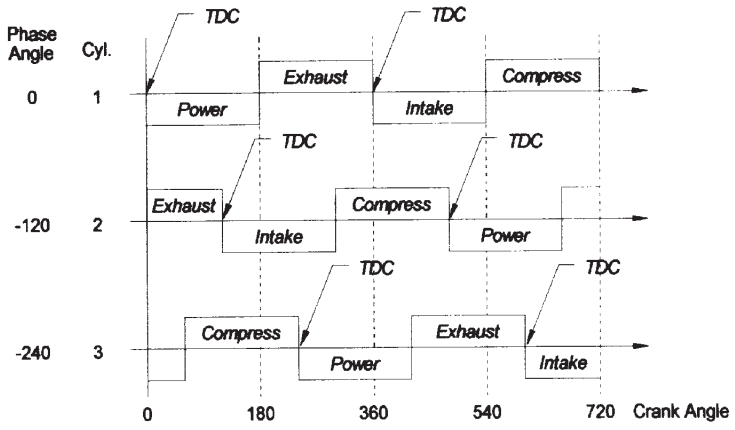
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

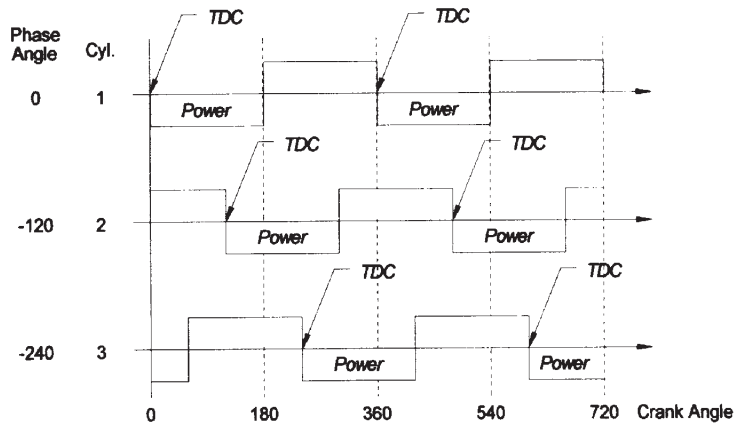
Solution: See Mathcad file P1401.

1. Even firing is possible with both two and four stroke designs. A 1, 2, 3 firing order is required for the two-stroke and a 1, 3, 2 firing order for the four-stroke.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-2

Statement: Draw a crank phase diagram for an inline four-cylinder inline engine with a 0, 90, 270, 180-deg crankshaft and determine all possible firing orders for

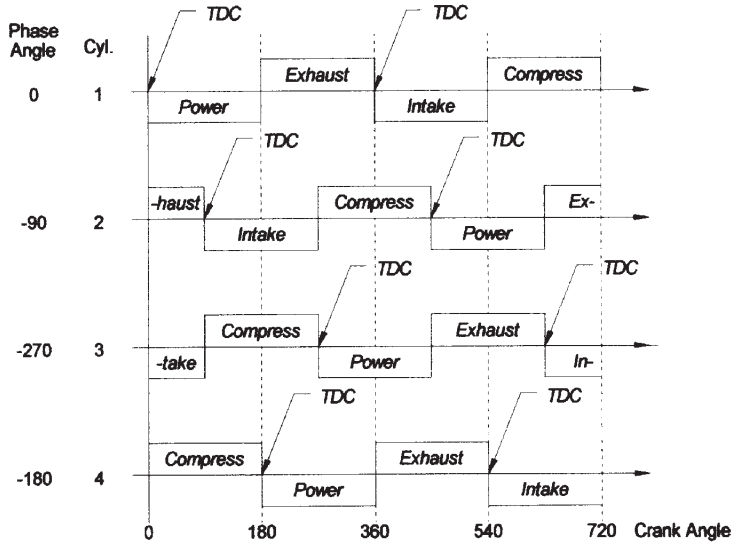
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

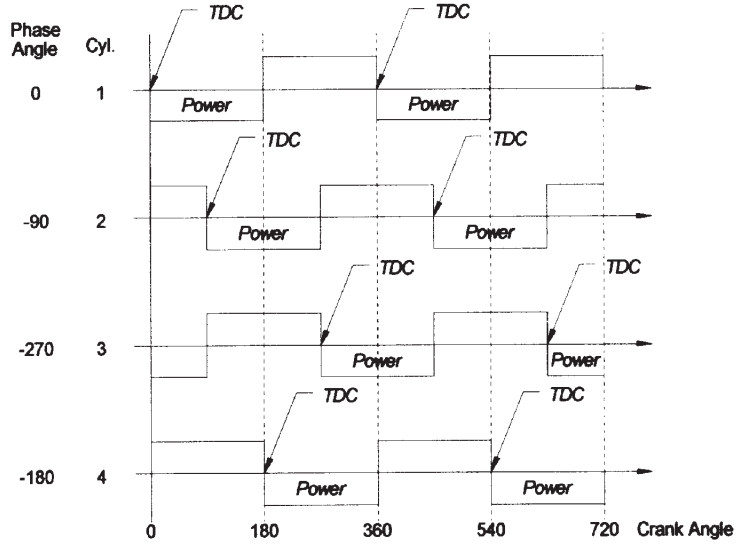
Solution: See Mathcad file P1402.

1. The two-stroke has even firing but even firing is not possible with this four stroke design. The best firing order is 1, 2, 4, 3 for the two-stroke and 1, 4, 3, 2 for the four-stroke.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-3

Statement: Draw a crank phase diagram for a 45-deg vee, four-cylinder engine with a 0, 90, 270, 180-deg crankshaft and determine all possible firing orders for

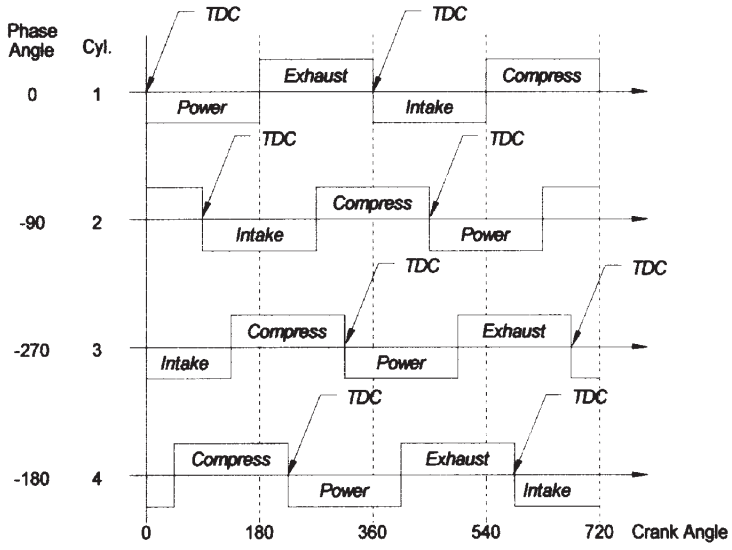
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

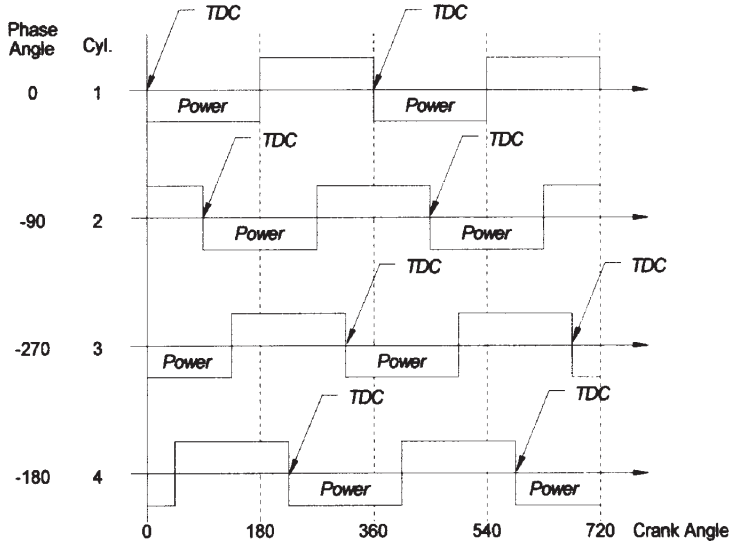
Solution: See Mathcad file P1403.

1. Neither stroke has even firing with this design. The best firing order is 1, 2, 4, 3 for the two-stroke and 1, 4, 3, 2 for the four-stroke.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-4

Statement: Draw a crank phase diagram for a 45-deg vee, two-cylinder engine with a 0, 90-deg crankshaft and determine all possible firing orders for

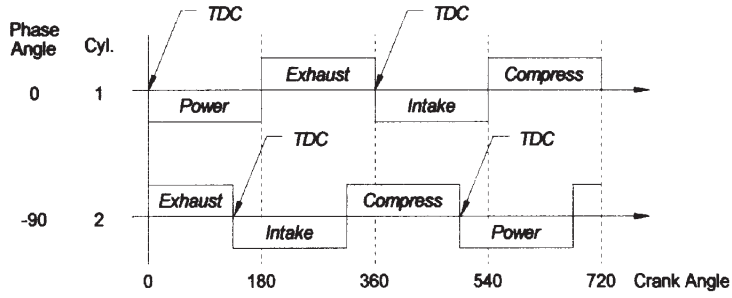
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

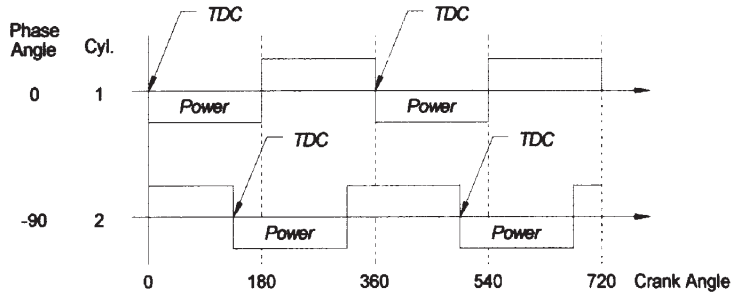
Solution: See Mathcad file P1404.

1. Neither stroke has even firing with this design. The only possible firing order is 1, 2 for either stroke-cycle.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-5

Statement: Draw a crank phase diagram for a 90-deg vee, two-cylinder engine with a 0, 180-deg crankshaft and determine all possible firing orders for

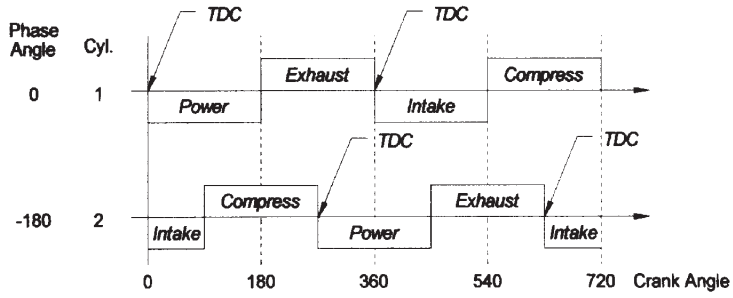
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

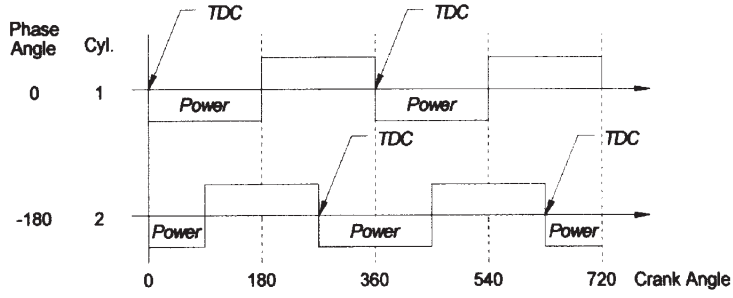
Solution: See Mathcad file P1405.

1. Neither stroke has even firing with this design. The only possible firing order is 1, 2 for either stroke-cycle.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-6

Statement: Draw a crank phase diagram for a 180-deg opposed, two-cylinder engine with a 0, 180-deg crankshaft and determine all possible firing orders for

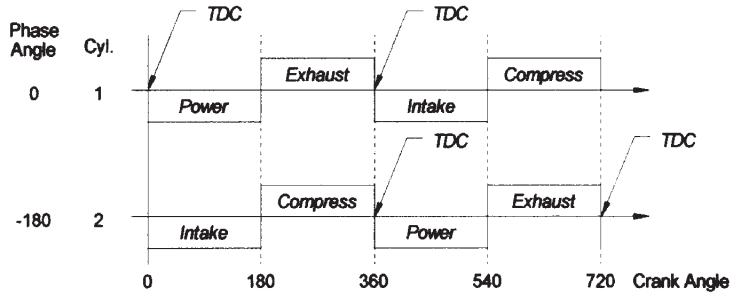
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

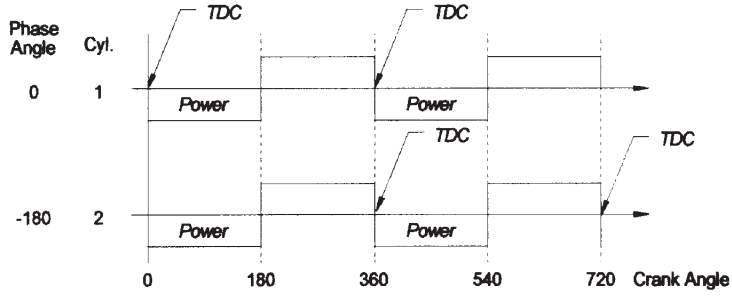
Solution: See Mathcad file P1406.

1. Both stroke-cycles are even firing but the two-stroke looks like a four-stroke in its firing pattern since the second set of firing pulses is on top of the first set. The only possible firing order is 1, 2 for either stroke-cycle.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-7

Statement: Draw a crank phase diagram for a 180-deg opposed, four-cylinder engine with a 0, 180, 180, 0-deg crankshaft and determine all possible firing orders for

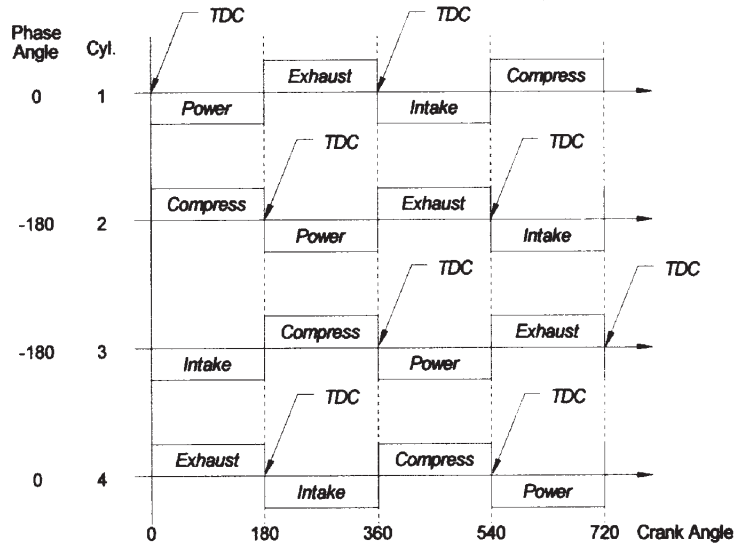
a. Four-stroke cycle.
b. Two-stroke cycle.

Select the best arrangement to give even firing for each stroke cycle.

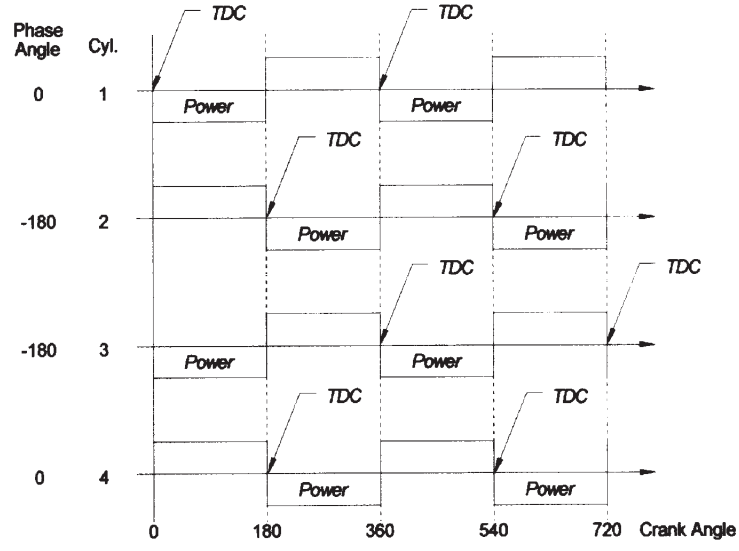
Solution: See Mathcad file P1407.

1. Both stroke-cycles are even firing but the two-stroke looks like a four-stroke in its firing pattern since the second set of firing pulses is on top of the first set. The best firing order is 1, 2, 4, 3 for the two-stroke-cycle and 1, 2, 3, 4 for the four-stroke.

a. Four-stroke cycle



b. Two-stroke cycle



PROBLEM 14-8

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an inline three-cylinder engine with a 0, 120, 240 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14082.eng, P14084.eng, and Mathcad file P1408.mcd.

1. Open file P14082.eng in program ENGINE for the two-stroke cycle or file P14084.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-9

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an inline four-cylinder engine with a 0, 90, 270, 180 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14092.eng, P14094.eng, and Mathcad file P1409.mcd.

1. Open file P14092.eng in program ENGINE for the two-stroke cycle or file P14094.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-10

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an 45-deg vee, four-cylinder engine with a 0, 90, 270, 180 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14102.eng, P14104.eng, and Mathcad file P1410.mcd.

1. Open file P14102.eng in program ENGINE for the two-stroke cycle or file P14104.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-11

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an 45-deg vee, two-cylinder engine with a 0, 90 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14112.eng, P14114.eng, and Mathcad file P1411.mcd.

1. Open file P14112.eng in program ENGINE for the two-stroke cycle or file P14114.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-12

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an 90-deg vee, two-cylinder engine with a 0, 180 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14122.eng, P14124.eng, and Mathcad file P1412.mcd.

1. Open file P14122.eng in program ENGINE for the two-stroke cycle or file P14124.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-13

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an 180-deg opposed, two-cylinder engine with a 0, 180 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14132.eng, P14134.eng, and Mathcad file P1413.mcd.

1. Open file P14132.eng in program ENGINE for the two-stroke cycle or file P14134.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-14

Statement: Calculate the shaking force, torque and moment balance conditions through the second harmonic for an 180-deg opposed, four-cylinder engine with a 0, 180, 180, 0 deg crankshaft.

Assumptions: Use File F14-12.eng for the cylinder data required on the cylinder input screen.

Solution: See program ENGINE files P14142.eng, P14144.eng, and Mathcad file P1414.mcd.

1. Open file P14142.eng in program ENGINE for the two-stroke cycle or file P14144.eng for the four-stroke cycle. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-15

Statement: Derive expressions, in general terms, for the magnitude and angular location with respect to the first crank throw, of the mass-radius products needed on the crankshaft to balance the shaking moment in a 90-deg vee-eight engine with a 0, 90, 270, 180-deg crankshaft.

Solution: No solution is provided to this algebraic exercise.

PROBLEM 14-16

Statement: Derive expressions, in general terms, for the magnitude and angular location with respect to the first crank throw, of the mass-radius products needed on the crankshaft to balance the shaking moment in a 90-deg vee-six engine with a 0, 240, 120-deg crankshaft.

Solution: No solution is provided to this algebraic exercise.

PROBLEM 14-17

Statement: Derive expressions, in general terms, for the magnitude and angular location with respect to the first crank throw, of the mass-radius products needed on the crankshaft to balance the shaking moment in a 90-deg vee-four engine with a 0, 180-deg crankshaft.

Solution: No solution is provided to this algebraic exercise.

PROBLEM 14-18

Statement: Design a pair of Nakamura balance shafts to cancel the shaking force and reduce oscillations in the engine shown in Figure 14-18 (p. 662).

Units: $blob := lbf \cdot sec^2 \cdot in^{-1}$

Given: From Figure 14-18 and file F14-18.eng:

Stroke: $S := 3.537 \cdot in$ L/R ratio: $LoverR := 3.50$

Effective wrist pin mass: $m_B := 0.0116 \cdot blob$

Solution: See Figure 14-18, program ENGINE file F14-18.eng, and Mathcad file P1418.

1. Calculate the crank radius and conrod length.

Crank radius: $r := 0.5 \cdot S$ $r = 1.769\ in$

Conrod length: $l := LoverR \cdot r$ $l = 6.190\ in$

2. Use equation 14.18 to calculate the *mr* product needed for the balance shafts.

$$mr_{bal} := \frac{r}{2 \cdot l} \cdot m_B \cdot r \qquad mr_{bal} = 2.931 \times 10^{-3}\ blob \cdot in$$

$$wr_{bal} := mr_{bal} \cdot g \qquad wr_{bal} = 1.131\ lbf \cdot in$$

3. The specific location of the two balance shafts will depend on the specific geometry of the engine being balanced. The y-dimensions must be symmetric with respect to the engine longitudinal center plane ($y_2 = -y_1$), and the vertical dimensions should be such that $x_1 - x_2 = 0.7\ l$.

PROBLEM 14-19

Statement: Using program ENGINE, data in Table P14-1 and the crank phase diagram from Problem 14-1, determine the maximum force magnitudes on main pin, crank pin, wrist pin, and piston for a 2-stroke engine with even firing. Over balance the crank, if necessary, to bring the balanced shaking force down to at least half of the unbalanced value.

Solution: See program ENGINE file P1419.eng and Mathcad file P1419.mcd.

1. Open file P1419.eng in program ENGINE. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Flywheel* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-20

Statement: Using program ENGINE, data in Table P14-1 and the crank phase diagram from Problem 14-2, determine the maximum force magnitudes on main pin, crank pin, wrist pin, and piston for a 4-stroke engine with even firing. Over balance the crank, if necessary, to bring the balanced shaking force down to at least half of the unbalanced value.

Solution: See program ENGINE file P1420.eng and Mathcad file P1420.mcd.

1. Open file P1420.eng in program ENGINE. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Flywheel* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-21

Statement: Using program ENGINE, data in Table P14-1 and the crank phase diagram from Problem 14-3, determine the maximum force magnitudes on main pin, crank pin, wrist pin, and piston for a 4-stroke engine with even firing. Over balance the crank, if necessary, to bring the balanced shaking force down to at least half of the unbalanced value.

Solution: See program ENGINE file P1421.eng and Mathcad file P1421.mcd.

1. Open file P1421.eng in program ENGINE. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Flywheel* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.

PROBLEM 14-22

Statement: Using program ENGINE, data in Table P14-1 and the crank phase diagram from Problem 14-4, determine the maximum force magnitudes on main pin, crank pin, wrist pin, and piston for a 2-stroke engine with even firing. Over balance the crank, if necessary, to bring the balanced shaking force down to at least half of the unbalanced value.

Solution: See program ENGINE file P1422.eng and Mathcad file P1422.mcd.

1. Open file P1422.eng in program ENGINE. The problem setup data is input from the disk file. Click the *Calculate* button and then the *Done* button, which will return you to the *Home* screen. Click the *Balance* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Assemble* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. Click the *Flywheel* button, accept the values shown and click *Calculate* and then *Done,* which will return you to the *Home* screen. View the calculated results by clicking on the *Charts* drop-down menu, from the main option bar, or use the *Plot* or *Print* buttons on the *Home* screen.