# Math Lab 6 MS 1

# Solving Power Problems for Mechanical Energy Systems

For best results, print this document front-to-back and place it in a three-ring binder. Corresponding teacher and student pages will appear on each opening.

## TEACHING PATH - MATH SKILLS LAB - CLASS M

### RESOURCE MATERIALS

Student Text: Math Skills Lab

### CLASS GOALS

1. Teach your students to recognize common units for measuring or calculating power.
2. Teach your students to solve power problems in mechanical systems by using the formulas $P = W/t$; $P = (F \times D)/T$; $P = F \times v$ or $P = T \times \omega$.

### CLASS ACTIVITIES

1. Take five or ten minutes to go through the Student Exercises. Make sure that your students understand the correct answers.
2. Complete the activities. Students should have read the discussion material and looked at the examples for each activity before coming to this class. You should summarize the main points in each activity, work an example or two, and have the students complete the Practice Exercises for each activity on their own. Supervise student progress. Help students obtain the correct answers.
3. Before the class ends, tell students to read Lab 6M1, "Measuring Linear Mechanical Power," as homework.

# Math Skills Laboratory

Lab 6 MS 1

## *MATH ACTIVITY*

***Solving Power Problems for Mechanical Energy Systems***

## *MATH SKILLS LAB OBJECTIVES*

***When you complete this activity, you should be able to do the following:***

1. ***Work problems that involve units of power in both English and SI units.***
2. ***Solve problems that involve the power formulas:***

$$P = \frac{W}{t}, \; P = \frac{F \times D}{t}, \; P = F \times v, \text{ and } P = T \times \omega.$$

## *LEARNING PATH*

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Work the problems.***

#### *HOW DO TECHNICIANS SOLVE POWER PROBLEMS?*

Industrial technicians monitor and adjust the operation of machines and devices. A large part of a technician's time is spent making measurements and finding how fast a machine gets the work done. In other words, a technician is concerned about the ***rate at which the machine works.***

From the discussion in the mechanical subunit of Unit 6, you've learned that ***power is the rate of doing work.*** In this Math Skills Lab, you'll solve some problems that deal with power. These problems are similar to those that a technician might meet while on the job. But before you work these problems, let's review units.

**ANSWERS TO UNIT REVIEW**

1. $\frac{ft \cdot lb}{sec}$
2. horsepower, (hp)
3. $\frac{N \cdot m}{sec}$, $\frac{J}{sec}$ and watt
4. 1 hp = 746 watts
5. $2 \text{ hp} = 2 \times 550 \frac{ft \cdot lb}{sec} = 1100 \frac{ft \cdot lb}{sec}$
6. 1/4 hp = 1/4 x 746 watts = 186.5 watts

**ANSWERS TO PROBLEMS**

**Problem 1:** F = 300 lb (force applied to lift globe)
D = 18 inches = 1.5 ft (distance globe is raised)
t = 10 sec (time to raise globe 1.5 ft)

a. $P = \frac{W}{t} = \frac{F \times D}{t}$

$P = \frac{300 \text{ lb} \times 1.5 \text{ ft}}{10 \text{ sec}}$

$P = 45 \frac{ft \cdot lb}{sec}$.

b. $P = \frac{1 \text{ hp}}{550 \frac{ft \cdot lb}{sec}} \times 45 \frac{ft \cdot lb}{sec}$

$P = \frac{45 \frac{ft \cdot lb \cdot hp}{sec}}{550 \frac{ft \cdot lb}{sec}} = \frac{45}{550} \left(\frac{\cancel{ft \cdot lb} \cdot hp}{\cancel{sec}} \times \frac{\cancel{sec}}{\cancel{ft \cdot lb}}\right)$

(Invert and multiply denominator; then cancel units.)

P = 0.08 hp.

The cylinder developed 0.08 horsepower.

***LET'S REVIEW UNITS!***

Study Table 6-2. This table was given earlier in the text.

TABLE 6-2. UNITS OF POWER

| System of Units | Units for Work or Energy | Units for Power (based on the formulas P = W/t or P = F × v) | Relationships Between Power Units |
|---|---|---|---|
| **ENGLISH** | foot-pounds (ft·lb) | $\frac{\text{ft·lb}}{\text{sec}}$ | $1 \text{ hp} = 550 \frac{\text{ft·lb}}{\text{sec}}$<br>(1 hp = 746 watts) |
| **SI** | newton-meters (N·m)<br>joules (J)<br>***Note:***<br>1 N·m = 1 J | $\frac{\text{N·m}}{\text{sec}}$<br>$\frac{\text{J}}{\text{sec}}$<br>***Note:***<br>$1 \frac{\text{N·m}}{\text{sec}} = 1 \frac{\text{J}}{\text{sec}}$<br>(also called 1 watt) | $1 \text{ watt} = 1 \frac{\text{N·m}}{\text{sec}} = 1 \frac{\text{J}}{\text{sec}}$<br>(1 watt = 0.00134 hp) |

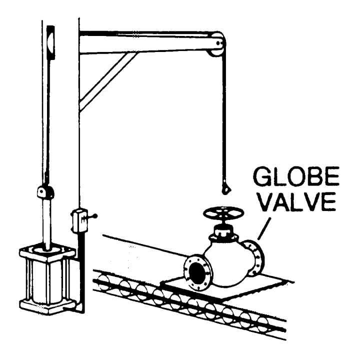
Answer the following questions. Each question is based on data given in Table 6-2.

1. The unit of power in the English system is ______.
2. Another unit for power in the English system, equal to 550 $\frac{\text{ft·lb}}{\text{sec}}$, is ______.
3. There are three equivalent units of power in SI. They are _____, ______ and ______.
4. One horsepower doesn't equal 1 watt. In fact, one horsepower = ______ watts.
5. A certain device is rated at 2 hp. That means its power is equal to ______ $\frac{\text{ft·lb}}{\text{sec}}$.
6. A motor is rated at ¼ horsepower. That means its power in watts is equal to ______ watts.

***ACTIVITY***

## Solving Power Problems for Mechanical Energy Systems

***Problem 1:*** Given: Globe valves often are used to control the flow of fluids in natural gas and water distribution systems. Atlas Valve Company manufactures one type of globe valve that weighs 300 pounds. The shipping department uses an arm hoist, powered by a hydraulic cylinder, to lift the globe valves from an inspection table onto a shipping pallet. The hoist takes 10 seconds to lift the valve 18 inches (straight up) at constant speed.



ANSWERS TO PROBLEMS, Continued

**Problem 2:** a. $F = 37.5 \text{ lb}$ $\quad T = F \times D$

$D = 0.5 \text{ ft}$ $\quad T = 37.5 \text{ lb} \times 0.5 \text{ ft}$

$T = 18.75 \text{ lb}\cdot\text{ft}$

b. $P = \dfrac{T \times \theta}{t}$ ; therefore, $\theta = \dfrac{P \times t}{T}$ .

where: $T = 18.75 \text{ lb}\cdot\text{ft}$

$$P = 0.05 \text{ hp} = 0.05 \times 550 \frac{\text{ft}\cdot\text{lb}}{\text{sec}} = 27.5 \frac{\text{ft}\cdot\text{lb}}{\text{sec}}$$

$$\text{So, } \theta = \frac{P \times t}{T} = \frac{27.5 \frac{\text{ft}\cdot\text{lb}}{\text{sec}} \times 1 \text{ sec}}{18.75 \text{ ft}\cdot\text{lb}} = \frac{27.5 \times 1}{18.75} \left(\frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}} \times \frac{\cancel{\text{sec}}}{1} \times \frac{1}{\cancel{\text{ft}\cdot\text{lb}}}\right)$$

$\theta = 1.47$ rad.

Now, convert to degrees:

$$\theta = 1.47 \text{ rad} \times 57.3 \frac{\text{deg}}{\text{rad}} = 84.2°$$

$\theta \simeq 84°$ (almost full-open).

c. $W = T \times \theta$

$W = 18.75 \text{ lb}\cdot\text{ft} \times 1.47 \text{ rad}$

$W = 27.6 \text{ ft}\cdot\text{lb}$. (Radian is disregarded.)

**NOTE:** The 6-inch-long "control arm" mentioned in the student text is the radius of the geared wheels shown in the illustration.

(See page T-21c for answer to Problem 3.)

**Problem 3:**

$F = 6000 \text{ lb}$

$v = 2 \text{ mph} = 2.93 \text{ ft/sec}$

$$v = \left(2 \frac{\cancel{\text{mi}}}{\cancel{\text{hr}}} \times \frac{44 \text{ ft/sec}}{30 \frac{\cancel{\text{mi}}}{\cancel{\text{hr}}}}\right) = \frac{88}{30} \frac{\text{ft}}{\text{sec}} = 2.93 \frac{\text{ft}}{\text{sec}}$$

a. $P = F \times v = 6000 \text{ lb} \times 2.93 \frac{\text{ft}}{\text{sec}} = 17{,}580 \frac{\text{ft}\cdot\text{lb}}{\text{sec}}$

Convert to horsepower.

$$P = 17{,}580 \frac{\text{ft}\cdot\text{lb}}{\text{sec}} \times \frac{1 \text{ hp}}{550 \frac{\text{ft}\cdot\text{lb}}{\text{sec}}} = \left(\frac{17{,}580 \times 1}{550}\right)\left(\frac{\cancel{\text{ft}\cdot\text{lb}}\cdot\text{hp}}{\cancel{\text{sec}}} \times \frac{\cancel{\text{sec}}}{\cancel{\text{ft}\cdot\text{lb}}}\right)$$

$P = 31.96 \text{ hp}$

$P = 32 \text{ hp}$ (after rounding off).

b. $P = F \times v = 6000 \text{ lb} \times 7.33 \frac{\text{ft}}{\text{sec}} = 43{,}980 \frac{\text{ft}\cdot\text{lb}}{\text{sec}}$

Convert to horsepower.

$$P = 43{,}980 \frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}} \times \frac{1 \text{ hp}}{550 \frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}}}$$

$P = 79.96 \text{ hp}$

$P = 80 \text{ hp}$ (after rounding off).

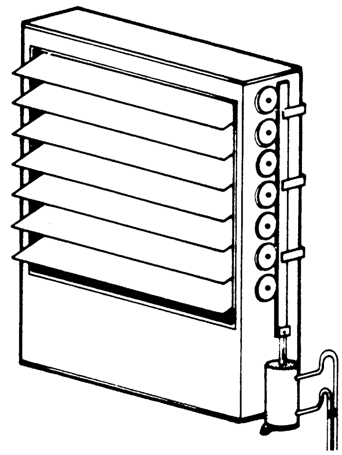
Find: a. The amount of power (in ft·lb/sec) exerted by the cylinder in lifting the valve.

b. The amount of horsepower developed by the cylinder.

(Remember: 1 hp = 550 ft·lb/sec.)

Solution:

***Problem 2:*** Given: Mark works for the Wyatt Tower Hotel as a building systems technician. While inspecting part of the air-conditioning system, he finds an air damper valve that isn't opening and closing correctly. The air damper valve is operated by a control arm 6-inches long . It's powered by a pneumatic cylinder. The cylinder develops 0.05 horsepower while applying 37.5 pounds of force to the control arm. The air damper opens or closes in about 1 second.



Find: a. The amount of torque developed by the control arm.

b. The angle through which the damper shaft rotates.

c. The amount of work done in opening or closing the damper.

Solution:

***Problem 3:*** Given: Growers use many types of agricultural equipment. Many involve a device called a "drawbar." The drawbar connects attachments, such as plows and wagons, to a tractor. When using one type of implement, a tractor exerts 6000 lb of pulling force on the drawbar while traveling at a speed of 2 mph (2.93 ft/sec).

Find: a. The amount of horsepower delivered to the drawbar at a speed of 2 mph (2.93 ft/sec).

b. The amount of horsepower delivered to the drawbar at a speed of 5 mph (7.33 ft/sec).

Solution:

## ANSWERS TO PROBLEMS, Continued

**Problem 4:** a. Use the equation, $P = F \times v$, where:

$F = 20{,}000$ lb

$v = 0.167$ in/sec

$P = F \times v$

$P = 20{,}000 \text{ lb} \times 0.167 \text{ in/sec}$

$$P = (20{,}000 \times 0.167)\ \text{lb} \cdot \frac{\text{in}}{\text{sec}}$$

$$P = 3340\ \frac{\text{in} \cdot \text{lb}}{\text{sec}}$$

We can change to ft•lb/sec as follows:

$$P = 3340\ \frac{\text{in} \cdot \text{lb}}{\text{sec}} \times \left(\frac{1\ \text{ft}}{12\ \text{in}}\right) = \left(\frac{3340}{12}\right)\left(\frac{\cancel{\text{in}} \cdot \text{lb}}{\text{sec}} \times \frac{\text{ft}}{\cancel{\text{in}}}\right)$$

$$P = 278.3\ \frac{\text{ft} \cdot \text{lb}}{\text{sec}}\ .$$

b. $P = F \times v$ where: $F = 88{,}960$; $v = 0.423$ cm/sec

$$P = 88{,}960\ \text{N} \times 0.423\ \frac{\text{cm}}{\text{sec}}$$

$$P = 37{,}630\ \frac{\text{N} \cdot \text{cm}}{\text{sec}}$$

$$P = 37{,}630\ \frac{\text{N} \cdot \text{cm}}{\text{sec}} \times \left(\frac{1\ \text{m}}{100\ \text{cm}}\right)$$ (Convert centimeter to meter.)

$$P = 376.3\ \frac{\text{N} \cdot \text{m}}{\text{sec}}\ .$$

c. The answers to "a" and "b" will be the same if the closing speeds (0.167 in/sec and 0.423 cm/sec) are the same. Everything else in parts "a" and "b" is the same. So, does 0.167 in/sec = 0.423 cm/sec?

Check: $$0.167\ \frac{\text{in}}{\text{sec}} \times \frac{2.54\ \text{cm}}{\text{in}} = (0.167 \times 2.54)\left(\frac{\cancel{\text{in}}}{\text{sec}}\right)\left(\frac{\text{cm}}{\cancel{\text{in}}}\right)$$

$= 0.424$ cm/sec (close enough).

(See page T-22c for answer to Problem 5.)

ANSWERS TO PROBLEMS, Continued

**Problem 5:** $T = 70\ \text{N}\cdot\text{m}$

$$\omega = 418.7\ \frac{\text{rad}}{\text{sec}}$$

a. $P = T \times \omega$

$$P = 70\ \text{N}\cdot\text{m} \times 418.7\ \frac{\text{rad}}{\text{sec}}$$ (Drop rad unit.)

$$P = 29{,}309\ \frac{\text{N}\cdot\text{m}}{\text{sec}}.$$

$P = 29{,}309$ watts. (Recall from Table 6-2 that $1\ \frac{\text{N}\cdot\text{m}}{\text{sec}} = 1$ watt.)

b. $P_{in}$ = 40 hp converted to power units in watts.

One hp = 746 watts

$$P_{in} = 40\ \cancel{\text{hp}} \times \frac{746\ \text{watt}}{\cancel{\text{hp}}}$$

$P_{in} = 29{,}840$ watts

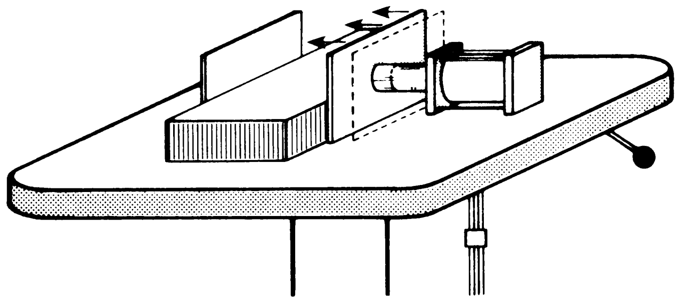
$P_{out} = 29{,}309$ watts

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\text{Efficiency} = \frac{29{,}309\ \cancel{\text{watts}}}{29{,}840\ \cancel{\text{watts}}} \times 100\%$$

$$\text{Efficiency} = 98.2\%.$$

**Problem 4:** Given: Some manufacturers use NC (numerical control) and CNC (computer numerical control) machines for drilling and tapping operations. The parts to be machined are held in place by a precision clamping device. The KURT II is a fluid-operated, vise-type clamp that applies 20,000 lb (88,960 N) of clamping force. The rated power of the vise is determined when the vise is adjusted to close at a speed of 0.167 in./sec with a clamping force of 20,000 lb.



Find:

a. The rated power of the vise, in English units, ft·lb/sec.

b. The power of the vise in N·m/sec if its closing speed is 0.423 cm/sec.

c. Decide whether the answer to "b" is equivalent to the answer to "a."

Solution:

**Problem 5:** Given: Sam's woodworking shop uses a machine called a "planer." A planer mills individual boards to the same thickness. To operate correctly, the planer cutting head must rotate at 418.7 rad/sec (4000 rpm). The planer is powered by a 40-hp electric motor that applies a torque of 70 N·m to the cutter head. A drive belt is used to connect the motor to a pulley on the planer head.

Find:

a. The power produced by the cutter head, in watts.

b. The efficiency of the planer drive-belt system. (***Note:*** 1 hp = 746 watts = 746 N·m/sec.)

Solution:

## ANSWERS TO PROBLEMS, Continued

**Problem 6:** a. Use the equation, $P = F \times v$.

where: $F = 7540$ lb or, $F = 33{,}517$ N

$v = 3.28$ ft/sec $v = 1$ m/sec

$$P = 7540 \text{ lb} \times 3.28 \frac{\text{ft}}{\text{sec}} \qquad P = 33{,}517 \text{ N} \times 1 \frac{\text{m}}{\text{sec}}$$

$$P = 24{,}731 \frac{\text{ft}\cdot\text{lb}}{\text{sec}} \qquad P = 33{,}517 \frac{\text{N}\cdot\text{m}}{\text{sec}}$$

$$P = 24{,}731 \left(\cancel{\frac{\text{ft}\cdot\text{lb}}{\text{sec}}}\right) \times \frac{1 \text{ hp}}{550 \left(\cancel{\frac{\text{ft}\cdot\text{lb}}{\text{sec}}}\right)} \qquad P = 33{,}517 \text{ watts } \left(1 \frac{\text{N}\cdot\text{m}}{\text{sec}} = 1 \text{ watt}\right)$$

$P = 44.87$ hp.

So 44.87 hp, or 33,517 watts, is required to operate the elevator at a safe weight and specified speed.

b. $$\text{Eff} = \frac{P_{out}}{P_{in}}$$

where: Eff = 80%

$P_{in}$ = Shaft horsepower on electric motor

$P_{in}$ = 48.25 hp (given)

$P_{out} = \text{Eff} \times P_{in} = 80\% \times 48.25$ hp

$P_{out} = 0.8 \times 48.25 = 38.6$ hp (power available to operate elevator)

Only 38.6 hp are available at 80% efficiency. But 44.87 hp are needed to operate the elevator. So you may conclude that the motor will not operate the elevator with its current drive system.

***Problem 6:*** Given: Peggy is a service representative for the Hi-Lo Elevator Company. She has been asked to repair an elevator in the Twin Oaks Building. The elevator is powered by an electric motor that appears to be overheating and tripping (opening) its circuit breaker. To help find the cause of the problem, Peggy uses information on the specification plates of the elevator and drive motor to find the amount of power required to operate the elevator.

**SPECIFICATIONS**

| | | | |
|---|---|---|---|
| Hi-Lo Elevator Co | MDL HL 75 | SER # | 000125 |
| Elevator Wt | 2450 N | Hoist Eff. in % | 80 |
| Safe Wt (Elevator + Load) | 33517 N or 7540 lb | At Elevator Speed (Constant) | 1 m/sec or 3.28 ft/sec |

**SPECIFICATIONS**

| | | | | | |
|---|---|---|---|---|---|
| Spark-Em Motor Co. | | Ph./Hz. | 3/60 | | |
| Volts | 240 AC | Amps | 150 A | | |
| Shaft HP | 48.25 | Form No. | 0-00 | Mdl | 1234 |
| | | Code | 0 | Ser # | 12731 |

Find:

a. The amount of power required to operate the elevator while carrying its safe weight at the rated elevator speed of 1 m/sec.

b. Whether the motor will supply the power needed to operate the elevator if the motor's drive system is 80% efficient. Show your work.

Solution: