Math Lab 6 MS 2

Solving Power Problems for Fluid 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 the common units that are used to measure or calculate power.
2. Teach your students to solve problems that involve power in a fluid energy system.

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 already 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 your students complete the Practice Exercises for each activity on their own. Supervise students progress. Help students obtain the correct answers.
3. Before the class ends, ask students to read Laboratory 6F1, "Fluid Power in Hydraulic Systems," as homework.

Math Skills Laboratory

Lab 6 MS 2

MATH ACTIVITY

Solving Power Problems for Fluid Energy Systems

MATH SKILLS LAB OBJECTIVES

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

1. ***Recognize units used to make power measurements in fluid systems. Use the units correctly.***
2. ***Solve problems that involve power in fluid energy systems.***

LEARNING PATH

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

So far, you've learned that ***power*** in fluid systems is the "fluid work done divided by the time it takes to do the work."

Fluid work is done when a pressure difference moves a mass or a volume of fluid. Fluid work also is done when a constant pressure displaces a volume of fluid (ΔV). This means that fluid power is involved when either type of work is done over a given time period.

Technicians often calculate fluid power. That's because many devices used in manufacturing use fluid systems. These fluid systems cause linear and rotational mechanical movement.

There are two unifying equations that can be used to describe power in fluid systems. They are:

$$\text{Fluid Power} = \frac{\text{Work}}{\text{Time}} \text{ or } P = \frac{p \times \Delta V}{t} \text{ or } P = \frac{(\Delta p) \times V}{t} \qquad \textit{Equation 1}$$

and

$$\text{Fluid Power} = \text{"Force"} \times \text{Rate or } P = p \times Q_V \text{ or } P = (\Delta p) \times Q_V \qquad \textit{Equation 2}$$

In this Math Skills Lab, you'll use the equations listed above. You'll also use some equations that you met earlier in the subunit on mechanical power. You'll solve problems like those technicians have on the job. This practice should help you remember these equations. These equations are:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \text{ or } p = F/A \qquad \textit{Equation 3}$$

$$\text{Volume} = \text{Area} \times \text{Height or } V = A \times h \qquad \textit{Equation 4}$$

$$\text{Pressure Difference} = \text{Weight Density} \times \text{Height or } \Delta p = \rho_w \times h \qquad \textit{Equation 5}$$

ANSWERS TO QUESTIONS ON UNIT REVIEW

1. John and Maria are both correct. That's because 1 watt = 1 N•m/sec.

2. $\dfrac{\dfrac{ft \cdot lb}{sec} \times \dfrac{sec}{1}}{lb/ft^2} = \left(\dfrac{ft \cdot \cancel{lb}}{\cancel{sec}}\right)\left(\dfrac{\cancel{sec}}{1}\right)\left(\dfrac{ft^2}{\cancel{lb}}\right) = ft^3$. He gets "cubic feet" for the answer.

3. $\Delta p = 60 \dfrac{lb}{ft^3} \times 2\ ft = (60 \times 2)\left(\dfrac{lb}{ft^{\cancel{3}\,2}} \times \cancel{ft}\right) = 120 \dfrac{lb}{ft^2}$.

4. $\Delta p = 8 \dfrac{N}{m^3} \times 5\ m = (8 \times 5)\left(\dfrac{N}{m^{\cancel{3}\,2}} \times \cancel{m}\right) = 40 \dfrac{N}{m^2}$.

5. Yes. Since 1 watt = $1 \dfrac{J}{sec}$, 1 J = 1 watt x 1 sec.

6. David's motor: 3/4 hp = 0.75 hp = $0.75\ \cancel{hp} \times \dfrac{746\ watt}{\cancel{hp}}$ = 559.5 watts.

   Darrell's motor: 500 watts.
   David's motor has about 60 more watts of power than Darrell's motor.

LET'S REVIEW UNITS!

Here's some good news. Power units are the same in fluid systems and mechanical systems.

Study the units that follow. Then answer the questions. Doing this will help you handle units correctly in the power problems for this Math Skills Lab.

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

1. John and Maria measure the power output of the same fluid motor. John gets an answer of "20 N·m/sec." Maria gets "20 watts." Who is correct? ______
2. Bennie works out a power problem and has the following units to simplify:

$$\frac{\dfrac{\text{ft·lb}}{\text{sec}} \times \text{sec}}{\text{lb/ft}^2}$$

He uses the rule "invert and multiply" for the units in the denominator (lb/ft^2). What should Bennie get for the correct answer?

3. The pressure difference $\Delta p = \rho_w \times h$. If $\rho_w = 60\ \text{lb/ft}^3$, and $h = 2$ ft, what's Δp?
4. The pressure difference $\Delta p = \rho_w \times h$. If $\rho_w = 8\ \text{N/m}^3$, and $h = 5$ m, what's Δp?
5. Nancy says that 1 J = 1 watt × 1 second. Is she correct?
6. David has a motor rated at "¾ hp." Darrell has one rated at 500 watts. Which is more powerful?

ACTIVITY

Solving Power Problems for Fluid Energy Systems

Problem 1: Given: SuAnne works as an equipment maintenance technician for the White Freight Transfer Company. This company uses a shipping dock for loading and unloading cargo from trucks and trailers. The dock is equipped with ramps that can be adjusted to match the height of various trucks and trailers. SuAnne has been asked to find out why one of the ramps rises very slowly compared to the other ramps. She knows the ramp is operated

ANSWERS TO PROBLEMS

Problem 1:

a. Use the formula, $P = p \times \frac{\Delta V}{t}$.

First, find the pressure (p) from data given. Remember: $p = F/A$.

$$p = \frac{1800 \text{ lb}}{10 \text{ in}^2} = 180 \frac{\text{lb}}{\text{in}^2}$$

Next, find the volume of fluid moved (ΔV). Remember: Volume = Area x Height.

$\Delta V = 10 \text{ in}^2 \times 24 \text{ in}$ (h = 2 ft = 24 in)

$\Delta V = 240 \text{ in}^3$

Now substitute in the basic equation, $P = p \times \Delta V/t$.

$$P = p \times \frac{\Delta V}{t}$$

$$P = 180 \frac{\text{lb}}{\cancel{\text{in}^2}} \times \frac{240 \text{ in}^{\cancel{3}}}{30 \text{ sec}} = \left(\frac{180 \times 240}{30}\right)\left(\frac{\text{lb}\cdot\text{in}}{\text{sec}}\right)$$

$$P = 1440 \frac{\text{in}\cdot\text{lb}}{\text{sec}}$$

Convert inches to feet.

$$P = 1440 \frac{\cancel{\text{in}}\cdot\text{lb}}{\text{sec}} \times \frac{1 \text{ ft}}{12 \cancel{\text{in}}}$$

$$P = 120 \frac{\text{ft}\cdot\text{lb}}{\text{sec}} .$$

b. Convert power in ft•lb/sec to power in hp.

$$P = 120 \frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}} \times \frac{1 \text{ hp}}{550 \frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}}}$$ (Cancel units.)

$P = 0.22$ hp.

(Answer to Problem 2 on page T-51c.)

ANSWERS TO PROBLEMS, Continued

Problem 2:

a. $F = p \times A$ (since $p = F/A$)

$$F = 1000 \frac{lb}{\cancel{in^2}} \times 0.8\ \cancel{in^2}$$ (Cancel units.)

$F = 800$ lb (piston force at each front wheel cylinder).

b. $F = p \times A$

$$F = 1000 \frac{lb}{\cancel{in^2}} \times 0.7\ \cancel{in^2}$$ (Cancel units.)

$F = 700$ lb (piston force at each rear wheel cylinder).

c. $$P = \frac{F \times D}{t}$$ where: $F = 800$ lb (from part "a")
$D = 0.150$ in
$t = 1.5$ sec

$$P = \frac{800\ lb \times 0.150\ in}{1.5\ sec}$$

$$P = \left(\frac{800 \times 0.150}{1.5}\right)\left(\frac{lb \cdot in}{sec}\right) = 80\ \frac{in \cdot lb}{sec}$$

$$P = 80\ \frac{\cancel{in} \cdot lb}{sec} \times \frac{1\ ft}{12\ \cancel{in}}$$ (Convert inch to foot.)

$P = 6.67$ ft•lb/sec at each wheel.

Therefore, 6.67 ft•lb/sec x 2 = 13.34 ft•lb/sec of braking power delivered to the front wheels.

d. $$P = \frac{F \times D}{t}$$ where: $F = 700$ lb (from part "b")
$D = 0.150$ in
$t = 1.5$ sec

$$P = \frac{700\ lb \times 0.150\ in}{1.5\ sec}$$

$$P = \left(\frac{700 \times 0.150}{1.5}\right)\left(\frac{lb \cdot in}{sec}\right) = 70\ \frac{in \cdot lb}{sec}$$

$$P = 70\ \frac{\cancel{in} \cdot lb}{sec} \times \frac{1\ ft}{12\ \cancel{in}}$$ (Convert inch to foot.)

$P = 5.83$ ft•lb/sec at each wheel.

Therefore, 5.83 ft•lb/sec x 2 = 11.66 ft•lb/sec of braking power delivered by the rear wheels.

(Answer to Problem 3 on page T-51e.)

Problem 3: $P = p \times \frac{\Delta V}{t}$. Therefore, $\Delta V = \frac{P \times t}{p}$.

$$\Delta V = \frac{P \times t}{p}$$

where: $P = 10{,}000$ ft•lb/sec
$t = 1$ min $= 60$ sec
$p = 6480$ lb/ft^2

$$\Delta V = \frac{10{,}000 \ \frac{\text{ft}\cdot\text{lb}}{\text{sec}} \times 60 \text{ sec}}{6480 \ \frac{\text{lb}}{\text{ft}^2}}$$

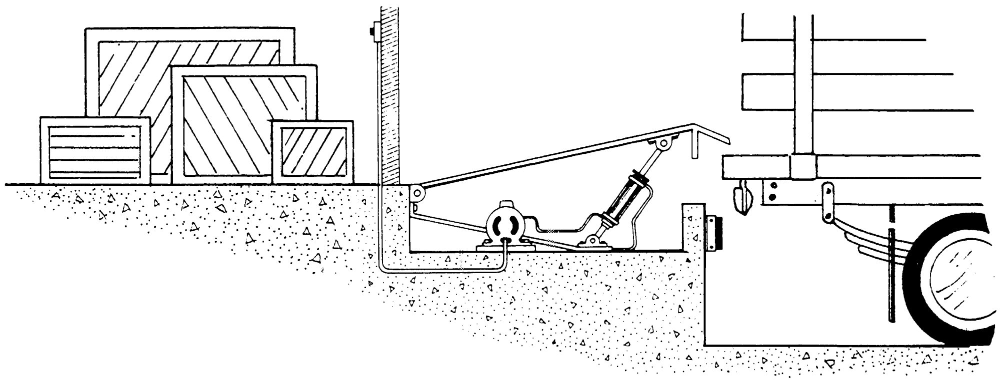
$$\Delta V = \left(\frac{10{,}000 \times 60}{6480}\right)\left(\frac{\text{ft}\cdot\cancel{\text{lb}}}{\cancel{\text{sec}}} \times \frac{\cancel{\text{sec}}}{1} \times \frac{\text{ft}^2}{\cancel{\text{lb}}}\right)$$

(**Note:** We have "inverted and multiplied" the units "lb/ft^2" in the denominator.)

$\Delta V = 92.6$ ft^3.

So 92.6 cubic feet of air flows through the intake manifold in one minute.

by a hydraulic cylinder that has a usable piston surface area of 10 in^2. The ramp weighs 1800 lb and can move a maximum distance of 2 ft.



Find: The amount of horsepower required to raise the ramp 2 feet vertically in 30 seconds.

Solution:

Problem 2: As an automotive service technician, Travis knows there's a weight transfer to the front of an automobile when the brakes are applied. Because of this weight transfer, front brakes must provide more braking force than rear brakes. Suppose that equal forces are applied to the front and rear brakes. The rear brakes can lock up. Lock-up can result in loss of car control. To help prevent lock-up, front brakes are designed to apply more braking force than rear brakes.

Given: Travis installed a pressure gage on the brake system's master cylinder. When the brake pedal is pushed down, the pressure gage reads 1000 lb/in^2. Travis measured each front-wheel cylinder piston and found that each has an effective surface area of 0.8 in^2. He also found that each rear-wheel cylinder piston has a surface area of 0.7 in^2. When the brakes are applied, the piston for each wheel cylinder moves 0.150 inch.

Find:

a. The piston force at each front-wheel cylinder.

(Remember: Force = Pressure × Area; $F = p \times A$.)

b. The piston force at each rear-wheel cylinder.

c. The power, in units of ft·lb/sec, that is passed to the front wheels by the *two* front cylinders during braking that takes 1.5 seconds.

d. The power, in units of ft·lb/sec, that is passed to the rear wheels by the *two* rear cylinders during the same braking action.

(***Hint:*** For parts "c" and "d," use the power equation,

$$P = \frac{F \times D}{t}, \text{ where } F = p \times A.)$$

Solution:

Problem 3: Given: The TDC Engine Company is testing a diesel engine that has a new type of turbocharger. The turbocharger uses the engine exhaust gas to turn a turbine. The turbine shaft causes a fan in the intake manifold to rotate. This forces more air into the combustion cylinders. Suppose the engine is operated at

ANSWERS TO PROBLEMS, Continued

Problem 4: $P = \Delta p \times Q_V$ where: $\Delta p = 12\ \text{lb/in}^2$
$Q_V = 7.5\ \text{ft}^3\text{/sec}$

First, change "Δp" in psi to "lb/ft^2."

$$\Delta p = 12\ \frac{\text{lb}}{\text{in}^2} \times \frac{144\ \text{in}^2}{1\ \text{ft}^2} = (12 \times 144)\left(\frac{\text{lb}}{\cancel{\text{in}^2}} \times \frac{\cancel{\text{in}^2}}{\text{ft}^2}\right) = 1728\ \frac{\text{lb}}{\text{ft}^2}$$

Now substitute in the equation, $P = \Delta p \times Q_V$.

$$P = \Delta p \times Q_V$$

$$P = 1728\ \frac{\text{lb}}{\text{ft}^2} \times 7.5\ \frac{\text{ft}^3}{\text{sec}}$$

$$P = (1728 \times 7.5)\left(\frac{\text{lb}}{\cancel{\text{ft}^2}} \times \frac{\text{ft}^{\cancel{3}}}{\text{sec}}\right) = 12{,}960\ \frac{\text{ft}\cdot\text{lb}}{\text{sec}}\ .$$

Since the turbocharger is only 50% efficient, only half of the available power is used.

$P_{used} = 1/2\ (12{,}960) = 6480\ \text{ft}\cdot\text{lb/sec}.$

In units of horsepower,

$$P_{used} = 6480\ \frac{\text{ft}\cdot\text{lb}}{\text{sec}} \times \frac{1\ \text{hp}}{550\ \frac{\text{ft}\cdot\text{lb}}{\text{sec}}} = \frac{6480}{550}\left(\frac{\cancel{\text{ft}\cdot\text{lb}}}{\cancel{\text{sec}}} \times \frac{\text{hp}}{1} \times \frac{\cancel{\text{sec}}}{\cancel{\text{ft}\cdot\text{lb}}}\right)$$

$P_{used} = 11.8\ \text{hp}.$

So 11.8 hp is extracted from the exhaust gas and used to operate the turbocharger.

(Answer to Problem 5 on page T-52c.)

Problem 5: $P = \frac{(\Delta p) \times t}{t}$. Isolate "t" to get $t = \frac{(\Delta p) \times V}{P}$.

Then, $t = \frac{(\Delta p) \times V}{P}$.

where: $\Delta p = \rho_W \times h = 8 \frac{N}{m^{\cancel{3}\,2}} \times 5\ m = 40 \frac{N}{m^2}$

$V = 2000\ m^3$

$P = 330$ watts (Change watts to N•m/sec; remember, 1 W = 1 N•m/sec.)

$P = 330$ N•m/sec.

Substitute values in the equation, $t = \frac{(\Delta p) \times V}{P}$. Solve for "t."

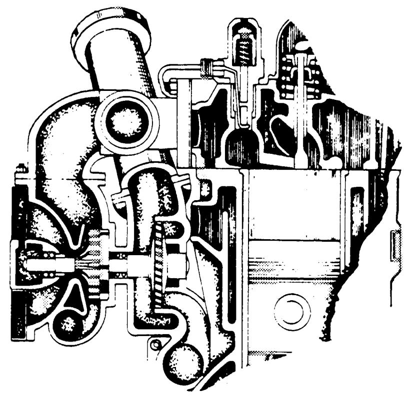
$$t = \frac{(40\ \frac{N}{m^2})(2000\ m^3)}{330\ \frac{N \bullet m}{sec}} = \left(\frac{40 \times 2000}{330}\right)\left(\frac{\cancel{N}}{\cancel{m^2}}\right)\left(\frac{\cancel{m^3}}{1}\right)\left(\frac{sec}{\cancel{N \bullet m}}\right)$$

$t = 242.4$ sec (about 4 minutes).

1800 rpm. The exhaust gas develops 10,000 ft·lb/sec of shaft power in the turbocharger. That power lets the turbocharger develop a pressure of 45 psi (6480 lb/ft^2) in the intake manifold of the engine.

Find: The volume of air that flows through the intake manifold in one minute. Use the formula, $P = \frac{p \times \Delta V}{t}$. Solve for ($\Delta V$).

Solution:



Problem 4: Given: The TDC Engine Company makes large diesel engines. Allen works as a mechanical engineering technician for TDC. He was asked to test a 6-cylinder turbocharged engine to find its exhaust gas pressure and exhaust gas volume-flow rate. His test data showed that when the engine operates at 2000 rpm, exhaust gas pressure is 12 psi. The exhaust gas volume-flow rate is 7.5 ft^3/sec.

Find: The amount of exhaust gas power used by the turbocharger if the turbocharger is 50% efficient and the engine operates at 2000 rpm.

(***Hint:*** Use the formula, $P = (\Delta p) \times Q_V$. Remember that the turbocharger only uses 50% of the exhaust gas power available.)

Solution:

Student Challenge

Problem 5: Natural gas is a fuel that's used by business and industry. When this gas is burned, it can heat buildings, produce steam for use in a steam turbine electric generator, or heat steel. Some companies get an "interrupt gas service rate." With this rate, company representatives agree to let their gas service be cut off when cold weather increases the demand for gas to heat homes. In exchange, these companies are charged a lower rate for the gas they use during "normal" times. (When gas service is interrupted, companies usually use another fuel, such as fuel oil.)

Given: Glenna is a technical service representative for Olympic Oil, Inc. She's helping the Upton Company install a fuel-oil storage tank. The tank's capacity is 2000 m^3. Glenna knows that the tank trucks used to deliver the fuel have pumps that are rated at 330 watts of power. She also knows that the fuel must be raised 5 meters from the truck to the tank. The fuel has a weight density (ρ_w) equal to 8 N/m^3.

Find: How long it will take a tank truck to fill the tank.

(***Hint:*** Use the equation, $P = \frac{(\Delta p) \times V}{t}$, where Δp is given by $\Delta p = \rho_w \times h$.)