2. Gear Ratios and Structures

Henri deVick

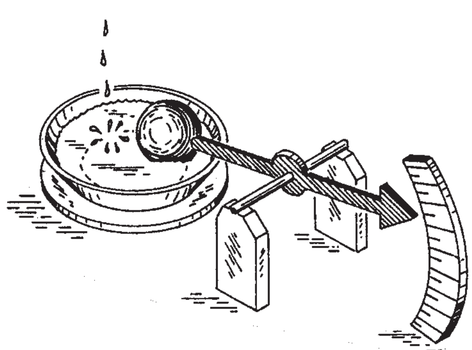
About 1000 years ago, three inventions were made in Europe . . . inventions that changed European civilization. The inventions were: the moldboard plow, horseshoes, and efficient horse harness.

These three devices gradually increased agricultural output beyond what a peasant needed to live.

To sell the excess grain and vegetables, farmers markets developed. Around the markets towns grew. By the 1500's towns and cities had sprung up throughout all of Europe. It was the development of these towns that more than anything else led to the industrial revolution and our modern society.

Peasants don't need clocks. They need only work from sunup to sundown. As towns developed, however, methods of keeping time were needed to regulate hours of trade and to set appointments.

Early clocks worked by letting water drop into a container. The level of water told the time. These water clocks were bulky and awkward to use. What was needed was a mechanical clock.



In 1364 Henri de Vick, under contract to Charles V, King of France, began building one of the world's first mechanical clocks. When finished in 1370 it was about sixteen feet high. It used a hanging weight for power, had an escapement mechanism and balance wheel, and used eight gears.

It was mounted in the Palais de Justice building, and all the churches of Paris were supposed to ring the hour according to its time. De Vick's clock was famous as a mechanical marvel, but it also changed the way people told time. Before his clock the time between sunup and sundown was divided into seven hours, based on the canon of the church. On long summer days hours were long, in winter hours were short. De Vick's clock helped change French timekeeping from the church's variable length hours to the clock's fixed length hours of sixty minutes each.

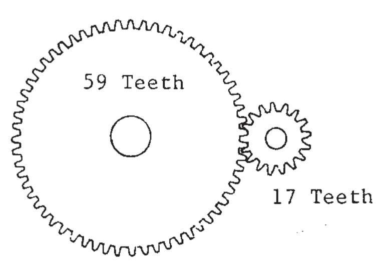
Early clock builders like De Vick spent a lot of time trying to make workable gear trains. Why? Because gears provided transmission of motion in exact speed ratios. A clock builder needs the minute hand to go exactly, not approximately, 12 times faster than the hour hand.

Gear Ratios

When two spur gears (or any other type of gears) are in mesh, the number of teeth in one gear divided by the number of teeth in the other is called the **gear ratio**.

Teeth #1 ÷ Teeth #2 = Gear Ratio

For example, the ratio of this gear set is 59 ÷ 17, or 17 ÷ 59.



In gearing, we usually use a colon (:) instead of a division sign (÷). So 59 teeth and 17 teeth would be 59 : 17 or 17 : 59.

When speaking, the colon represents “to”. So, we say “fifty-nine to seventeen” or “seventeen to fifty-nine”.

Usually, but not always, the big number is given first.

59 : 17 . . . not 17 : 59.

Very often, the ratio is divided out. (Remember a gear ratio is one number divided by another.)

59:17 = 59 ÷ 17 = 3.4706 ÷ 1 = 3.4706:1.

The ratio would be written 3.4706:1, and spoken “three point four seven zero six to one.”

Ratios as Fractions

Another common way of writing gear ratios is as a fraction . . .

$59:17 = \frac{59}{17} = \frac{3.4706}{1}$

$17:59 = \frac{17}{59} = \frac{1}{3.4706}$

Usually, but not always, the big number is on top.

When speaking, start with the top number, and let the fraction line stand for “to”.

$\frac{59}{17}$ is spoken “fifty-nine to seventeen”.

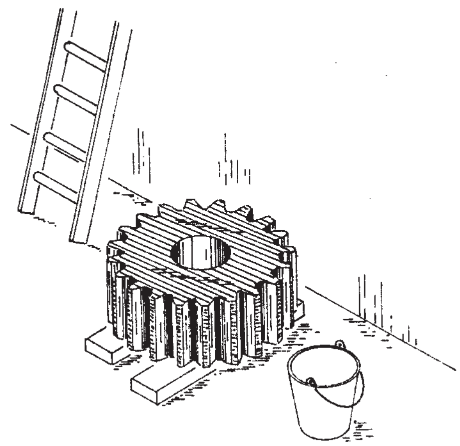
Or, if it’s divided out . . .

$\frac{3.4706}{1}$ is spoken “three point four seven zero six to one”.

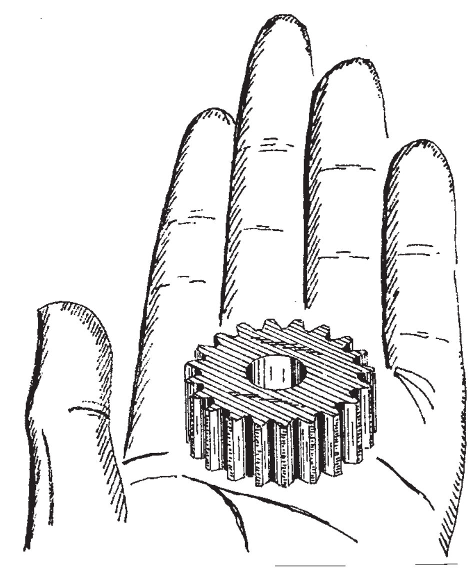
All these ways of writing gear ratios - fractions, colons, and division signs - are equivalent. They all mean the same thing.

A gear with a small number of teeth (under approximately 20 to 25 teeth) is called a **pinion**. (Say pin-yun).

A pinion can be large . . .



Or it can be small . . .



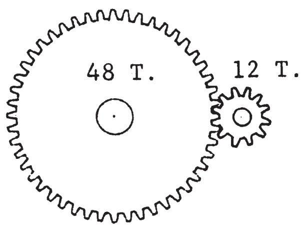
If the teeth are big, the pinion is big. If the teeth are small the pinion is small. In either case, it is called a pinion because it has a small number of teeth.

When a gear with a high number of teeth runs with a gear with a small number of teeth, we call them a "gear and pinion". The big gear is called simply a gear. The small gear is called a pinion.

Self Study Questions

Write your answers in the space allowed after each question. Correct answers follow the questions. Don't peek until you've written your best guess in the blank spaces.

1. What is this gear ratio?



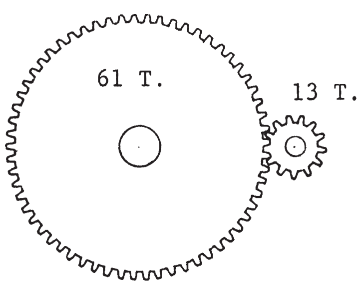
   a. Write it using a colon.

   b. Reduce it to 1.

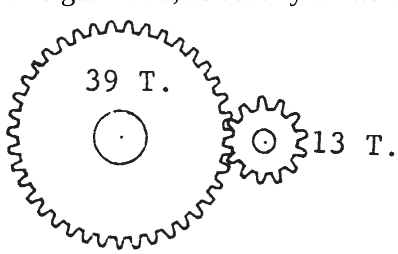
   c. Write it as a fraction.

   d. Write it as a fraction reduced to 1.

2. Which is the pinion and which is the gear?



3. Write this gear ratio, as usually written.



a. With a colon.

b. Colon reduced to 1.

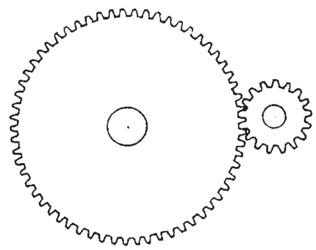
c. As a fraction.

d. Fraction reduced to 1.

e. Write it out as you would speak it.

f. Write it as you would speak it when reduced to 1.

4. Write this gear ratio, as usually written. (Count the teeth).



a. With a colon.

b. Reduced to 1. (You'll save time here if you use a calculator).

c. As a fraction.

d. As a fraction reduced to 1.

e. Write it as it's spoken.

f. Write it as it's spoken when reduced to 1.

Self Study Answers

1. a. 48:12 (or 12:48, but usually written with the big number first.)

   b. 4:1

   c. $\frac{48}{12}$

   d. $\frac{4}{1}$

2. 13 tooth is the pinion.
   61 tooth is the gear

3. a. 39:13

   b. 3:1

   c. $\frac{39}{13}$

   d. $\frac{3}{1}$

   e. "Thirty-nine to thirteen."

   f. "Three to one."

4. a. 61:17

   b. 3.588:1

c. $\frac{61}{17}$

d. $\frac{3.588}{1}$

e. “Sixty-one to seventeen.”

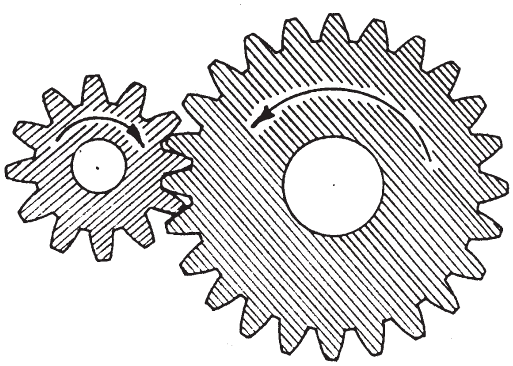
f. “Three point five eight eight to one.”

End of Self Study Questions.

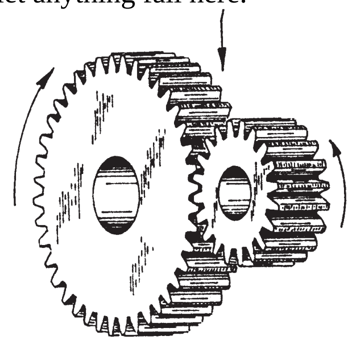
Direction of Rotation

Notice that a gear set reverses direction of rotation, clockwise to counterclockwise, or CCW to CW.

If the pinion turns clockwise, the mating gear will turn counter-clockwise. If the pinion turns counter-clockwise, the mate will turn clockwise.



Never let anything fall here.



Anything falling into the gear mesh will be pulled through the gears and either be crushed, or wreck the gears. A hand or finger will be crushed between the gears. A piece of clothing caught in the gears will pull your body into the gear mesh.

Keep away from rotating gears.

Gears should be enclosed and shielded to keep people and objects from getting caught.

Speed of Rotation, RPM

The spinning or rotational speed of a gear is measured in **Revolutions Per Minute (RPM)**.

If a gear spins completely around exactly 16 times in one minute, it’s going 16 RPM. If it spins exactly 1000.9 times it’s going 1000.9 RPM.

Self Study Questions

Answers follow the questions.

1. What’s the RPM of a gear making 590 revolutions in a minute?

2. What’s the RPM of one turning exactly once around every five minutes?

3. What’s the RPM of one turning exactly seven times in a second?

Self Study Answers

1. 590 RPM.
2. $\frac{1}{5}$ RPM

   Explanation . . . in one minute it will only go one fifth of a complete revolution.

3. 420 RPM

   Explanation . . . there are 60 seconds in a minute. $7 \times 60 = 420$.

End of Self Study Questions.

Speed Ratios

The **speed ratio** of two gears in mesh is the RPM of one divided by the RPM of the other.

RPM #1 ÷ RPM #2 = Speed Ratio

It is usually written using a colon or a fraction (the same as gear ratios).

RPM #1 : RPM #2 = Speed Ratio

or $\frac{\text{RPM \#1}}{\text{RPM \#2}}$ = Speed Ratio

When two gears are in mesh, and you know the gear ratio and the RPM of one gear, you can figure out the RPM of the other gear.

Use these two rules to do it :

Rule 1. When two gears are in mesh, the smaller gear always goes faster, (has the higher RPM).

The larger gear always goes slower, or has a lower RPM than the small gear.

Rule 2. The Speed Ratio is the Gear Ratio turned upside down.

Example :

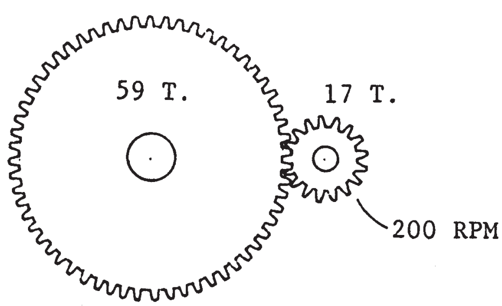
$$\textit{Gear Ratio} = \frac{\textit{Gear}}{\textit{Pinion}} = \frac{\textit{59 Teeth}}{\textit{17 Teeth}}$$

$$\textit{Speed Ratio} = \frac{\textit{Gear}}{\textit{Pinion}} = \frac{\textit{17 RPM}}{\textit{59 RPM}}$$

Mathematically we say speed ratio is the reciprocal of gear ratio.

$$\frac{\textit{Teeth in Gear \#1}}{\textit{Teeth in Gear \#2}} = \frac{\textit{RPM Gear \#2}}{\textit{RPM Gear \#1}}$$

Use two steps to get the answer. For example:



What RPM does the 59 tooth gear go?

Step 1. 59 T. gear is bigger, so it goes slower. Therefore, the answer will be less than 200 RPM.

Step 2. Multiply 200 RPM (pinion speed) by the ratio with small number on top, to get an answer smaller than 200.

$200 \times \frac{17}{59} = 57.63$ RPM (Use a calculator)

Answer is 57.63 RPM.

Fractions

Remember . . . Multiplying any number by a fraction that has a small number on top and a large number on the bottom will give a smaller number for an answer.

$$100 \times \frac{\textit{BIG NUMBER}}{\textit{small number}} = \textit{BIGGER than } 100$$

$$100 \times \frac{\textit{small number}}{\textit{BIG NUMBER}} = \textit{smaller than } 100$$

For example:

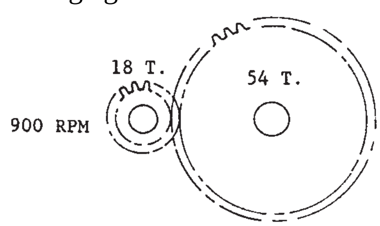
$$365 \times \frac{10}{12} = \text{smaller than } 365$$

$$365 \times \frac{12}{10} = \text{LARGER than } 365$$

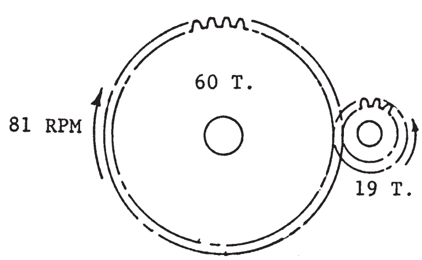
Self Study Questions

Write your answers in the space provided. Correct answers follow the questions.

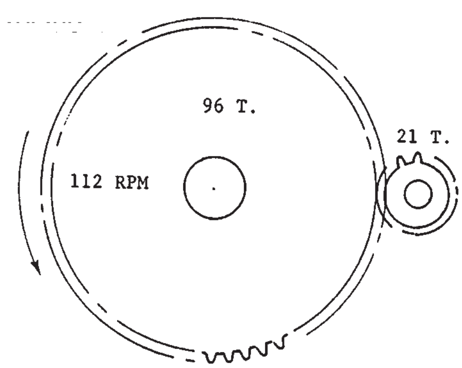
1. What is the RPM of the large gear?



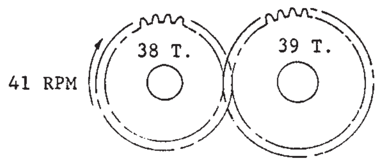
2. What is the RPM of the pinion?



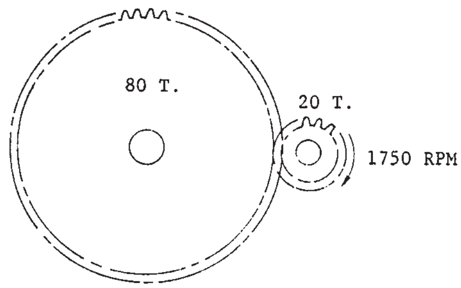
3. What is the RPM of the pinion? Draw an arrow showing direction of pinion rotation.



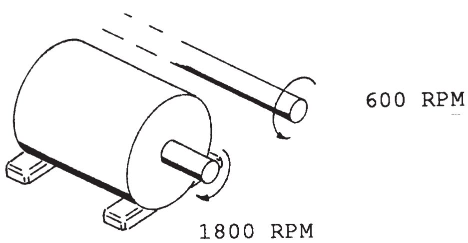
4. What is the RPM of the 39 T. gear?
   Draw an arrow showing direction of 39 T. gear rotation.



5. What is RPM of 80 T. gear? Draw an arrow showing direction of gear rotation.



6. Imagine a motor that turns at 1800 RPM. You want it to drive a shaft at 600 RPM. What gear ratio do you need to connect motor to shaft? Does the big or small gear go on the motor shaft?



7. Refer to the gears in question 6. A good size for a pinion is between 15 T. and 25 T. If you pick a 20 T. pinion, how many teeth must the gear have?

Self Study Answers

1. Answer is 300 RPM.

   Explanation :

   Step 1. 54 T. gear is bigger, so it will go slower.

   Step 2. $900 \times \frac{18}{54} = 300$ RPM

Check answer :

1. 300 is less than 900, so that much is okay.

2. $\textit{Speed Ratio} = \frac{gear}{pinion} = \frac{300}{900} = \frac{1}{3}$

   $\textit{Gear Ratio} = \frac{gear}{pinion} = \frac{54}{18} = \frac{3}{1}$

$\frac{3}{1}$ is the reciprocal of $\frac{1}{3}$ so the answer is correct.

2. Answer is 255.79

Explanation :

Step 1. 19 T. pinion is smaller, so it goes faster. Answer will be bigger than 81 RPM.

Step 2. $81 \times \frac{60}{19} = 255.79$

Check Answer:

1. 255.79 is bigger than 81, so that much is okay.
2. $\frac{60}{19} = 3.158$ $\frac{255.79}{81} = 3.158$

OK

3. Answer is 512 RPM.

Explanation:

Step 1. Pinion is smaller and goes faster, so answer will be bigger than 112.

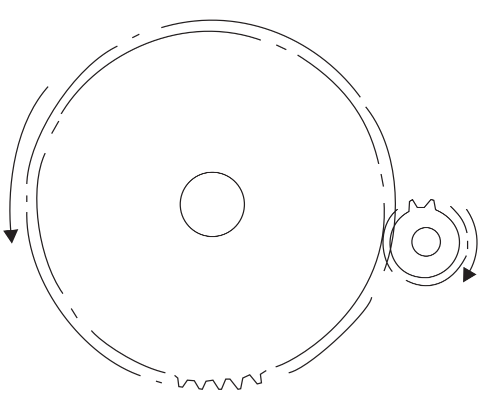
Step 2. $112 \times \frac{96}{21} = 512$ RPM.

Check Answer :

1. 512 is bigger than 112, so that much is okay.
2. $\frac{512}{112} = 4.571$ $\frac{96}{21} = 4.571$

OK

Direction of rotation:



4. Answer is 39.95 RPM

Explanation:

Step 1. 39 T. gear is bigger, so it goes slower. Answer will be less than 41 RPM.

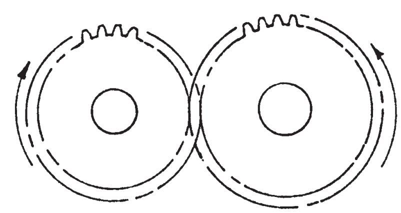
Step 2. $41 \times \frac{38}{39} = 39.95$ RPM

Check answer:

$\frac{41}{39.95} = 1.0263$ $\frac{39}{38} = 1.0263$

OK

Direction of rotation:



5. Answer is 437.5 RPM.

Explanation :

Step 1. 80 T. gear is bigger, so it goes slower. Answer is less than 1750 RPM.

Step 2 . $1750 \times \frac{20}{80} = 437.5$

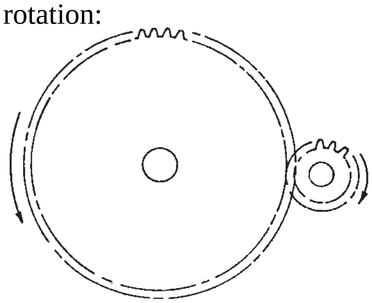
Check answer :

437.5 is less than 1750, so that much is okay.

$\frac{1750}{437.5} = 4$ $\frac{80}{20} = 4$

OK

Direction of rotation:

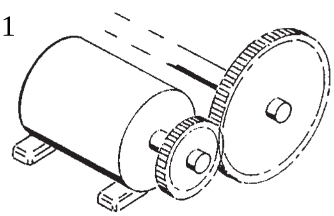


6. Answer is 3:1 ratio with small gear on the motor shaft.

   Explanation:

   Small gear always goes faster.

   $\frac{1800}{600} = \frac{3}{1} = 3{:}1$



7. Answer is 60 teeth.

   Explanation :

   Step 1. Gear is supposed to go slower than pinion, so it will have more teeth.

   Step 2. $20 \times \frac{3}{1} = 60$

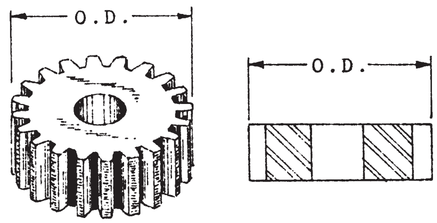
   End of Self Study Questions.

Gear Parts and Structure

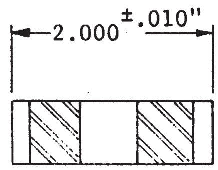
Illustrations below show a picture and often a section view. On engineering drawings you will most often see gears shown in section views.

Outside Diameter

This diameter is called the **outside diameter**, often shortened to **O.D.**

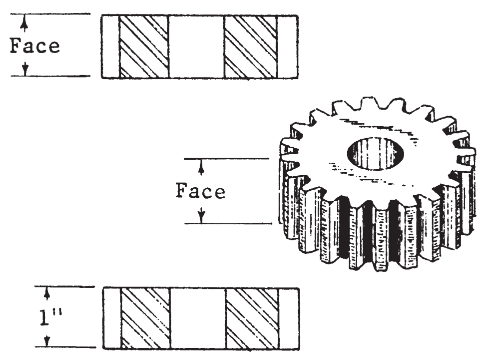


Outside diameter of a gear is shown in millimeters or inches with a fairly loose tolerance.



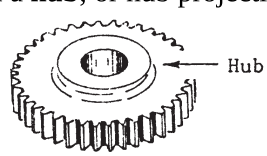
Face

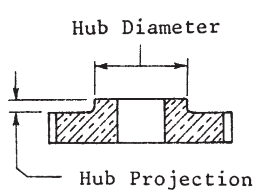
This dimension is called the **face** of the gear, or the **face width**. It's given in millimeters or inches with a loose tolerance.

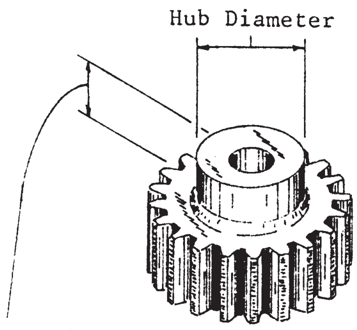


Hub

The lug or shoulder projection found on some gears is called a **hub**, or hub projection.



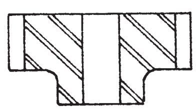




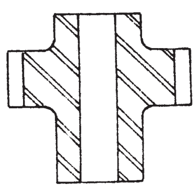
This dimension is called a **hub projection**.

A, B and C Hubs

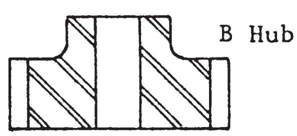
There can be a hub on only one side.



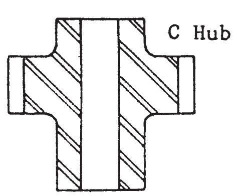
Or on both sides.



A hub one side only is called a “B” hub, or B style hub.



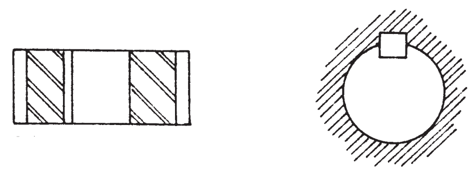
A hub both sides is called a “C” hub, or C style hub.

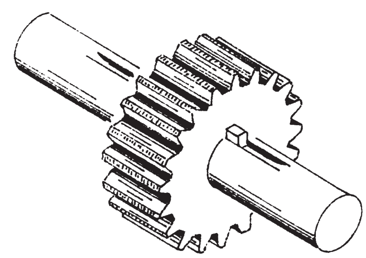


No hubs is called flush hubs, or sometimes “A” style.

Key and Keyway

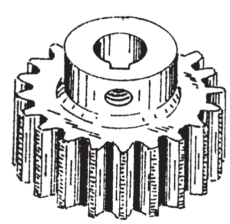
Gears are usually held on a shaft with a key and keyway. Matching slots, called keyways, are cut into the shaft and the gear bore. A square pin, called a key, is put in the slots, half in one slot, half in the other. With the key in place, the gear can’t spin on the shaft. The two are locked together as if they were one piece.

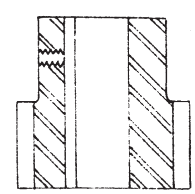




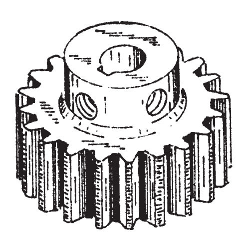
Set Screw

A set screw is used to keep the gear and key from sliding out.





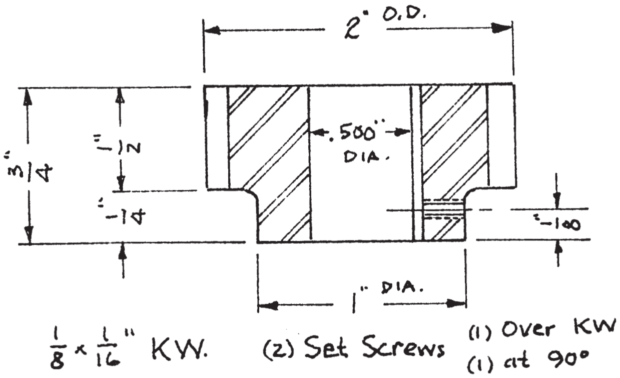
Often two set screws will be used. Usually one will be over the keyway, and one at 90° or 180°.



Dimensions

Here's the way a gear drawing might be dimensioned.

Length through the bore is the total of face width plus hub projection. In this sample it equals 3/4".



Self Study Questions

Draw or write your answers in the space provided after each question, or on the blank line. Correct answers follow the questions.

1. Draw a section view of a steel spur gear with these dimensions. Draw freehand. Drawing does not have to be full size, or to scale. Put dimensions on the drawing.

   3" O.D.
   1" face, 1.000" bore
   1/2" hub projection one side
   1" hub projection other side
   2" hub diameter
   1/4" × 1/8" keyway
   (1) set screw over keyway
   2 1/2" through bore

2. A hub one side only is called a ________________________hub.

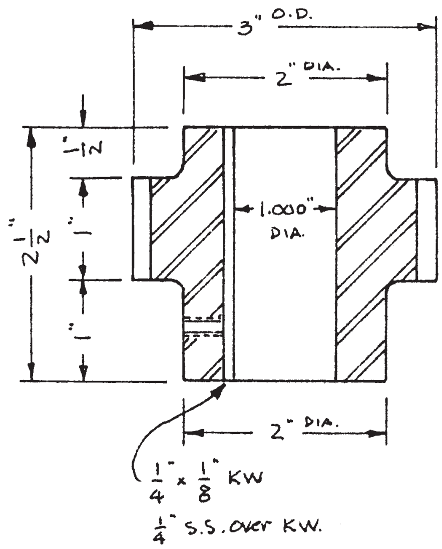
3. A hub both sides is called a _______________________hub.

4. What keeps a gear from spinning on its shaft?

5. What keeps it from sliding end-wise?

Self Study Answers

1. Drawing should look like this.



2. A hub on one side only is called a B style hub.
3. A hub on both sides is called a C style hub.
4. A key keeps the gear from spinning.
5. A set screw keeps it from sliding end-wise.

End of Self Study Questions

Keyway Size

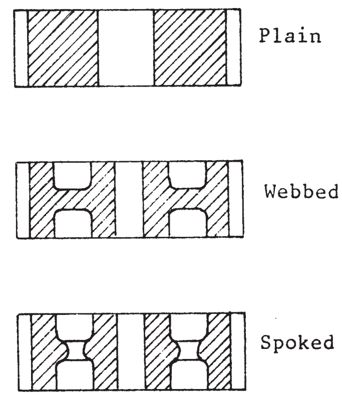
An informal rule of thumb for keyway size is:

$$\text{Keyway width} = \frac{\textit{Bore diameter}}{4} \text{ (approximately)}$$

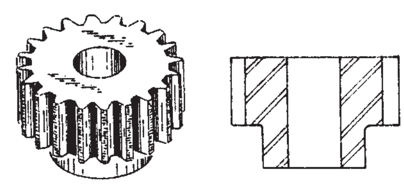
For example, a 1" bore will usually have a 1/4" wide keyway. A 1-1/2" bore has a 3/8" keyway, and so forth. K.W. widths are always even sized . . . 1/4", 1/2", etc., and not odd decimal sizes.

Plain, Webbed and Spoked

There are three types of normal gear structures or construction. Gears can be: Plain, Webbed, or Spoked.

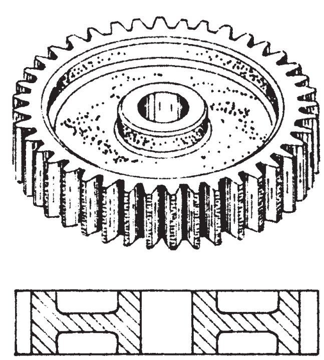


Small gears, and pinions are usually plain construction.

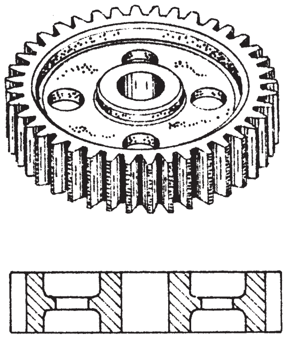


Webbed Gears

Medium sized gears are made webbed in order to reduce the weight. Since steel and iron are purchased by the pound, reducing weight reduces cost.

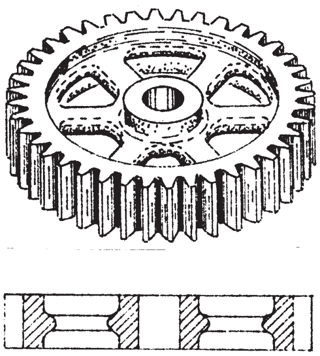


To lighten gear weight even more, holes can be made in the web. These are called lightening holes.



Spokes

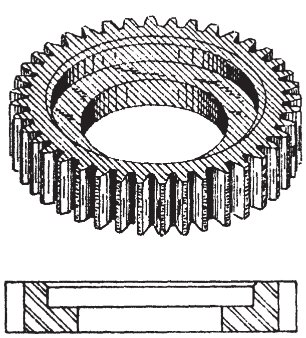
Large gears are made of spoked construction.



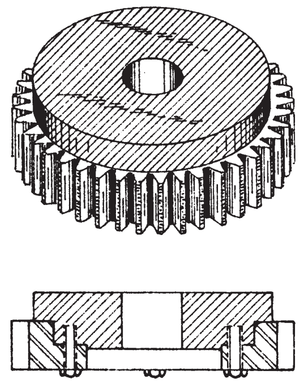
On spoked or webbed construction, hub projections are measured from the rim, not from the web.

Ring Gears

A gear with a very large bore is called a **ring gear**.

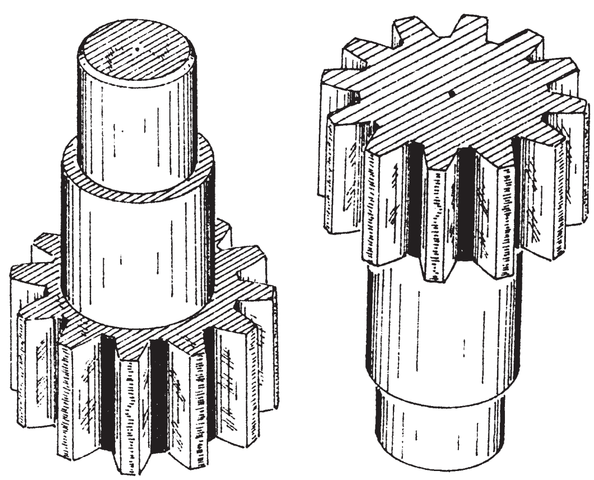


It is usually mounted on a separate hub. The hub is then fastened to a shaft.



Integral Pinions

Spur, helical and bevel pinions are sometimes made integral with their shaft.



This allows the pinion and gear assembly to be made as small in diameter as possible. If you make the pinion diameter small for a given ratio, you can make the gear proportionately small. This allows the whole drive assembly and housing to be small, resulting in lower cost. Integral pinions are often used for this reason.

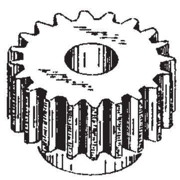
Self Study Questions

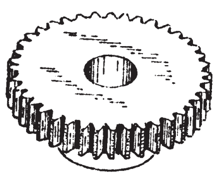
Write or draw your answers in the spaces provided after each question. Correct answers follow. Don't peek until you've actually written your answers down.

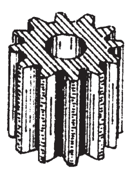
1. Draw a freehand section view of a webbed gear with flush hubs.

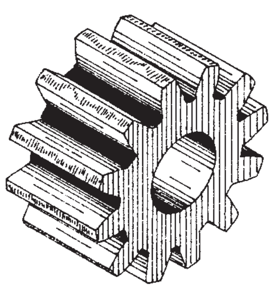
2. What are holes cut in the gear web called?

3. Which of these are pinions:

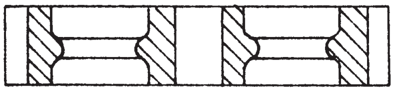
a. 

b. 

c. 

d. 

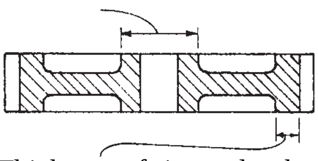
4. Does this section view show a webbed, spoked or plain construction?



Self Study Answers

1. Your sketch should look something like this.

   Hub diameter is usually about twice bore diameter.



   Thickness of rim under the teeth is usually about equal to tooth depth.

   Remember hub projections are measured from the rim. Flush hubs mean flush with the rim.

2. Holes cut in a gear web are called lightening holes.

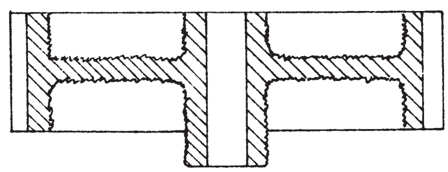
3. a. Is a pinion
   b. Is not a pinion.
   c. Is a pinion.
   d. Is a pinion.

4. This gear is spoked. From the drawing it could be webbed with lightening holes, or spoked. The way the bead is curved slightly makes us think it's spoked.

End of self study questions.

Surface Finish

The sketch below shows a spur gear with surface finish exaggerated. The smooth parts are surfaces finish machined by the gear manufacturer. The rough surfaces are those left in an unfinished state, just as raw material. These unfinished surfaces could be from a sand casting, forging, or rough machined, depending on the raw material used. Plain construction gears are usually finished all over. Webbed and spoked are like this sketch.



Section Summary

In this section you learned what a **pinion** is. You learned what **gear ratios** and speed ratios are, and what **RPM** means. You saw how to calculate speed changes through a set of gears. You learned what **O.D.**, **face**, **hubs**, **keys** and **set screws** are, and how gears are dimensioned on drawings. You saw what **plain**, **webbed** and **spoked** gears look like.

In the next section you'll learn the details of gear teeth. You'll see what the terms pitch diameter and center distance mean, how gear teeth are measured, and how tooth sizes are standardized and specified. You'll learn how gear teeth are proportioned, and what pressure angle, diametral pitch, addendum, and dedendum are. You'll learn what backlash is and its effect.

Proceed to the next section.