



Mechanical Power Trains

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In many machines, power must be transferred from the source to where it is used on the machine. The system of components used to transfer power is called the power train. The component using the power may operate at a different speed and/or rotate in a different direction than the power source. Power trains are used to change the speed and direction of rotation. The four common types of power trains are mechanical, hydraulic, electrical, and pneumatic.

Mechanical Power Trains

Mechanical powertrains have two important principles.

1) The transfer of power is defined by the horsepower equation:

$$Hp = \frac{To \times N}{5252} \quad \text{Equation 1}$$

To = torque (force x lever arm length)

N = speed (rev/min)

5252 = units conversion constant

2) The power output of the system is always less than the power supplied because the efficiency is always less than 100 percent.

Equation 1 shows that when horsepower is fixed, a change in speed must result in a change in torque. If speed is increased the torque must decrease and if the speed is decreased, the torque must increase. This is important to remember when changing speed because the primary factor for determining the size of a shaft is the torque on the shaft.

The following sections describe the function of mechanical power trains.

The types of mechanical power trains include belts and pulleys, chains and sprockets, and gears.

Belts and Pulleys

Belt drives are recommended for power trains that operate at high speeds and drives that have shock loads. Power is transmitted by a flexible belt traveling around two or more pulleys. Standard belts are flat, V, or cog (tooth). Flat belts have limited use in modern machines because the lower amount of friction between the belt and pulley reduces the amount of power that can be transmitted. The use of V-belts increases the power that can be transmitted because of the wedging action between the belt and the pulley, and they can operate at a higher speed.

A cogged belt is used when a belt drive is desired and the components must stay in time.

The Rubber Manufacturing Association, or RMA, identifies belts' drive components in the United States. Other countries use the British, German, or ISO standards. When replacing

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a belt, it is important to know which standard was used when the belt was manufactured.

Chains and Sprockets

In chain drives, power is transmitted by the teeth of the sprocket interlocking with the openings in the chain. Different chain designs are used based upon the amount of power being transmitted and speed of operation. Chains are not designed to operate as fast as belts and shock loads can shorten their life, but they keep components in time. Chains and sprockets are identified by an American National Standards Institute, or ANSI, or ISO number system.

Gears

Gears are primarily used when the shafts in the power trains are close together. For their size, gears are capable of transmitting the greatest amount of power and they can be used at high speeds. Common gear designs are bevel, worm, spur, and helical. Bevel gears are used when a shaft change in direction is desired. They are commonly used when the shafts are 90 degrees apart, but other angles are used. Worm gears require the shafts to be perpendicular and they are used when a large speed reduction is required. Spur gears are mounted on parallel shafts. They are commonly used to change the direction of rotation and/or speed. Helical gears are mounted on parallel shafts like spur gears, but use angled teeth. They operate more smoothly and quietly than spur gears.

Speed Change

A mechanical power train will change the speed whenever there is a difference between the diameter of input and the diameter of the output. When the driver (input) is larger than the driven (output), the speed will increase. When the driver is smaller than the driven, the speed will decrease (Figure 1).

For example: a centrifugal pump needs to operate at 1,500 rpm and is powered by a 540 rpm tractor PTO. In this example, the driver (PTO) must be larger than the driven (pump) because the pump turns faster than the PTO (Figure 2). The difference in the diameter of two pulleys, sprockets, or gears can be expressed as the speed ratio. For this example, the speed ratio, or SR, is calculated by:

$$SR = \frac{\text{Input speed}}{\text{Output speed}} = \frac{540}{1500} = 0.36 \quad \text{Equation 2}$$

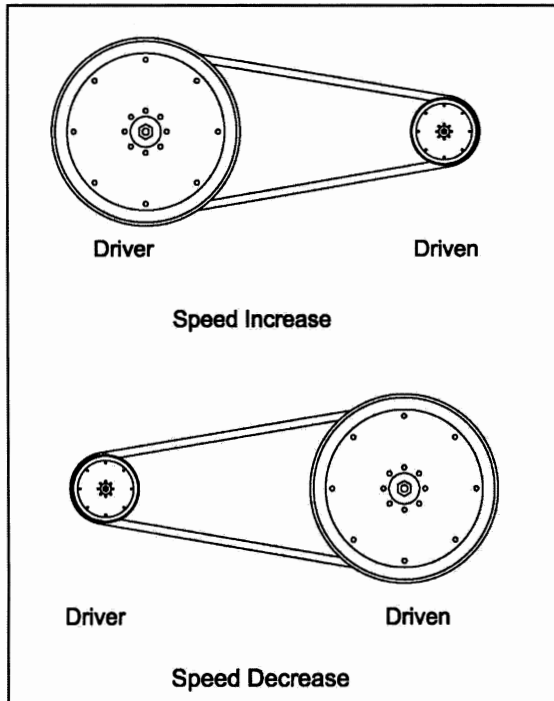


Figure 1.

Belts and Pulleys

The speed ratio of a belt drive is determined by the ratio of the pulley diameters. Therefore, for this example, any combination of pulley diameters that result in a ratio of 0.36 will provide the correct speed.

When determining pulley size, select the smallest diameter first, then use the speed ratio to calculate the diameter of the large pulley. Otherwise, the calculated pulley size could be too small to be practical.

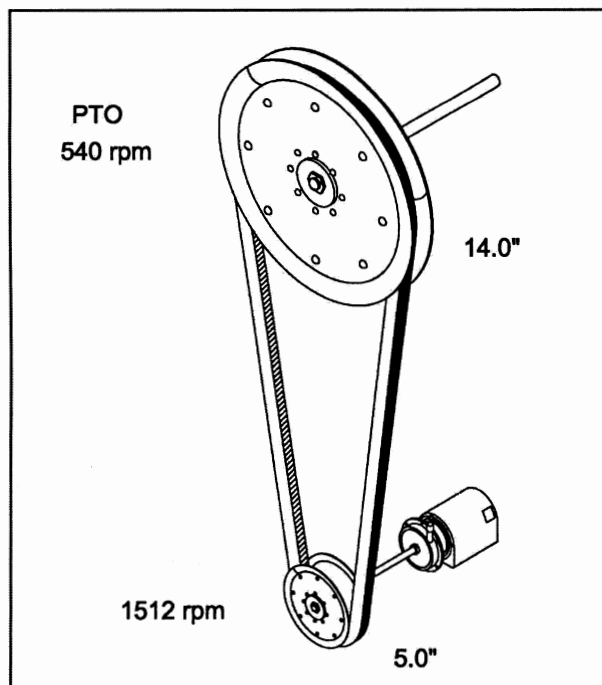


Figure 2.

For the example in Figure 2, assume a 5.0 inch pulley is selected for a pump. Using the speed ratio from Equation 2 the PTO pulley diameter is:

$$\text{Dia.} = \frac{5.0}{0.36} = 13.88 \text{ or } 14 \text{ in.} \quad \text{Equation 3}$$

Note: the speed ratio (0.36) is placed in the denominator of the fraction because the differences in the speed of the two shafts indicates the PTO pulley must be larger than the pump pulley. If a 14.0 inch pulley is used on the tractor PTO, the actual speed of the pump would be:

$$540 \text{ rpm} \times \frac{14}{5} = 1512 \text{ rpm} \quad \text{Equation 4}$$

The extra 12 rpm occurs because the pulley size was rounded up from 13.88 to 14 inches. Rounding down to 13.5 inch pulley will result in a pump speed of less than 1,500 rpm.

In some situations, there may not be enough clearance to mount a 14.0 inch pulley on the tractor. In these situations either a smaller pulley must be used on the pump or an intermediate shaft must be used.

Adding an intermediate shaft can be confusing because there are many different combinations of pulley diameters that will give the desired speed change. For the PTO and pump in Figure 2, assume the largest diameter pulley that can be used on the PTO is seven inches. In this situation another equation is useful:

$$\text{Diameter}_1 \times \text{RPM}_1 = \text{Diameter}_2 \times \text{RPM}_2 \quad \text{Equation 5}$$

To solve this problem, several variables must be arbitrarily chosen. One is the desired speed of the intermediate shaft. In this example, the intermediate shaft speed of 1,020 rpm was selected.

$$\begin{aligned} \text{Diameter}_1 \times \text{RPM}_1 &= \text{Diameter}_2 \times \text{RPM}_2 \\ \text{Diameter}_2 &= \frac{\text{Diameter}_1 \times \text{RPM}_1}{\text{RPM}_2} \\ &= \frac{7.0 \text{ in} \times 540 \text{ RPM}}{1,020 \text{ RPM}} \\ &= 3.705 \text{ or } 4.0 \text{ inches} \end{aligned} \quad \text{Equation 6}$$

Because the pulley diameter was rounded up, the actual speed of the intermediate shaft must be calculated.

$$\begin{aligned} \text{Diameter}_1 \times \text{RPM}_1 &= \text{Diameter}_2 \times \text{RPM}_2 \\ \text{RPM}_2 &= \frac{\text{Diameter}_1 \times \text{RPM}_1}{\text{Diameter}_2} \\ &= \frac{7.0 \text{ in} \times 540 \text{ RPM}}{4.0 \text{ in}} \\ &= 945 \text{ RPM} \end{aligned} \quad \text{Equation 7}$$

The next step is to select the size of the driver pulley on the intermediate shaft. For this example, a 7.0 inch pulley was selected. The pulley size for the pump is:

$$\begin{aligned} \text{Diameter}_1 \times \text{RPM}_1 &= \text{Diameter}_2 \times \text{RPM}_2 \\ \text{Diameter}_2 &= \frac{\text{Diameter}_1 \times \text{RPM}_1}{\text{RPM}_2} \\ &= \frac{7.0 \text{ in} \times 945 \text{ RPM}}{1,500 \text{ RPM}} \\ &= 4.41 \text{ or } 4.5 \text{ in} \end{aligned} \quad \text{Equation 8}$$

Because the pulley size was rounded again, the actual speed of the pump should be calculated.

$$\begin{aligned} \text{Diameter}_1 \times \text{RPM}_1 &= \text{Diameter}_2 \times \text{RPM}_2 \\ \text{RPM}_2 &= \frac{\text{Diameter}_1 \times \text{RPM}_1}{\text{Diameter}_2} \\ &= \frac{7.0 \text{ in} \times 945 \text{ RPM}}{4.5 \text{ in}} \\ &= 1,470 \text{ RPM} \end{aligned} \quad \text{Equation 9}$$

With this mechanism, the pump will operate at 1,470 rpm instead of the desired 1,500 rpm. If this is acceptable, no changes must be made. If the speed is not acceptable, the pulley size on the pump can be reduced one size and the speed recalculated.

Chains and Sprockets

The speed ratio of sprockets and chains is determined by the ratio of the number of teeth on each sprocket. Assume the pump in Figure 2 is a chain drive and the sprocket for the PTO has 25 teeth (Figure 3).

$$\text{No. Teeth} = 25 \text{ teeth} \times 0.36 \quad \text{Equation 10}$$

Note: in this example the number of teeth in the driven sprocket is multiplied by the speed ratio (0.36) because the differences in speed indicates the pump sprocket must be smaller. The pump sprocket would have 9 teeth.

If there is a clearance problem, an intermediate shaft can be used.

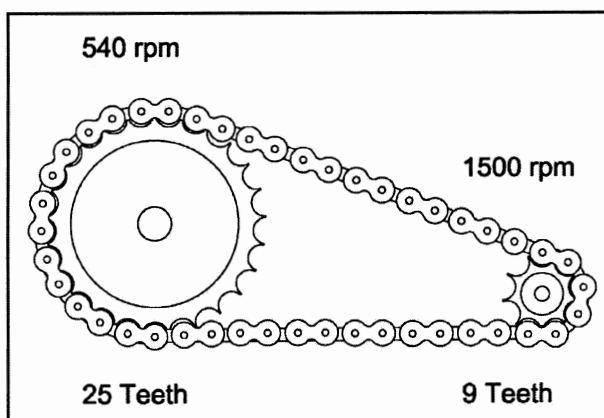


Figure 3.

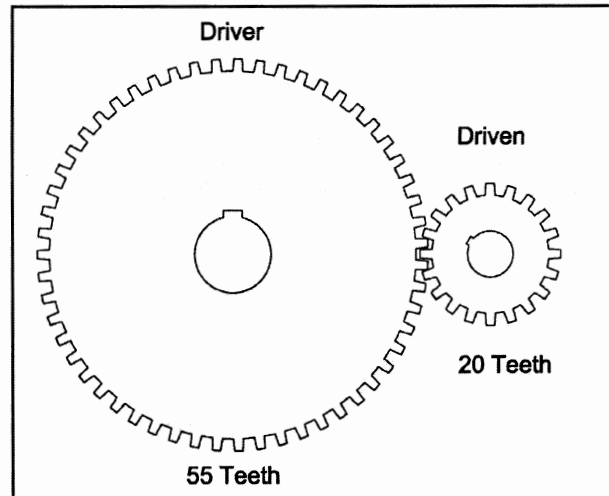


Figure 4.

Gears

The speed change for gears is determined the same way as sprockets—ratio of the number of teeth (Figure 4).

$$\text{Ratio} = \frac{\text{Driver}}{\text{Driven}} = \frac{55 \text{ Teeth}}{20 \text{ Teeth}} = 2.75 \quad \text{Equation 11}$$

Direction of Rotation

It is not unusual for a component on a machine to operate in the opposite direction of rotation than the power source. Changing the direction of rotation can be accomplished with all three types of mechanical power trains.

Belts and Pulleys

Belts and pulleys provide two options for changing directions; twisting the belt and using a third pulley.

When the power train will operate at a slow speed and low torque, the direction of rotation can be changed by twisting the belt on the pulleys (Figure 5). In this arrangement, one

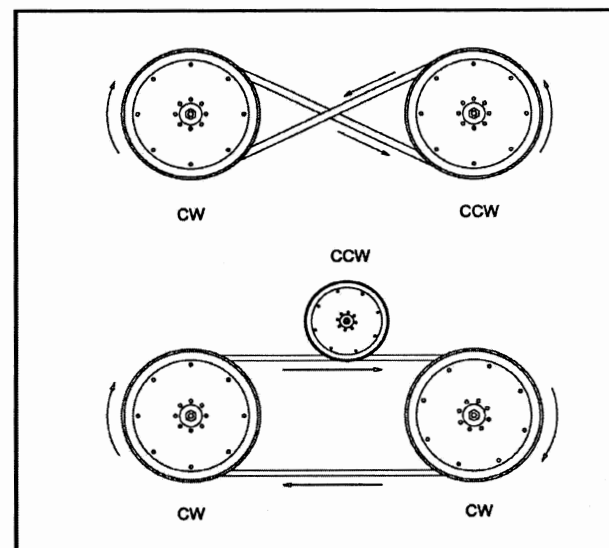


Figure 5.

pulley will be turning clockwise (CW) and the other pulley will be turning counter clockwise (CCW).

For all other applications a third pulley that contacts the backside of the belt must be used (Figure 5). In this arrangement, two pulleys will be turning clockwise and one will be turning counterclockwise. The third pulley will not transmit as much power as the other two unless a six sided V-belt is used.

Note: different diameters can be used to get different speeds simultaneously with changing direction of rotation.

Chains and Sprockets

Changing the direction of rotation when using chains and sprockets is limited to using a third sprocket because a chain cannot be twisted.

The third sprocket will transmit the same amount of power and different speeds can be produced if a different number of teeth are used on the sprockets.

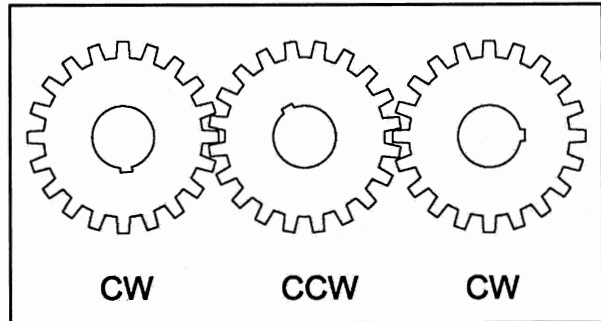


Figure 6.

Gears

Gears are different than belts and chains because each pair of gears changes the direction of rotation. Three gears must be used to transmit power with the same rotation (Figure 6).

Speed changes also can be designed by changing the number of teeth on one or more gear(s).

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