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Converting to linear motion using rack and pinion

How module, circular pitch, rotary motion, and linear travel are related.

As the summer heat builds, we all look forward to the annual family vacation. Whether the trip takes us to the mountains, or to the shore, or to an amusement park, the first part of the vacation is the drive there. Prepping the car for the journey is just the first step in this annual rite of passage. The second is finding suitable entertainment for the children so that you don't have to hear "are we there yet?" repeatedly. Educationally minded parents will try to inject some math learning into this situation by showing the children where they are going on a map and asking them to figure out how long the trip will take if they are traveling 60 miles per hour. This relationship between speed and travel distance also has implications in the world of gearing.

Many gearing applications require converting rotary motion into linear motion. The most common form of this is the use of a pinion attached to a motor that then rests on a gear rack and travels back and forth depending on the direction of the motor shaft rotation. For some applications, the motor is fixed, and the rack is the object that is moving. For either case, there is usually some requirement that the amount of travel of the rack is fixed before reversing direction.

To calculate the amount of travel that the pinion will have across the rack, you need to look at the pinion gear as a circle. The line of action on the pinion is the pitch diameter, so the circumference at this point is the distance that the pinion will travel in one revolution. The formula for circumference is:

$C = \pi * D$; in this case D is the pitch diameter so the formula becomes:

Linear distance = π * Pitch Diameter

As simple as this formula is, it is imperfect in most conditions. Consider the following example:

Module 2.5, 20 Tooth, spur gear; the Pitch Diameter is 50mm

Linear distance = π * 50 = 157.0796mm

Thus, one revolution of the pinion will result in the awkward distance of 157mm of travel. If your requirement was to have 900mm of linear travel, the pinion would need to rotate 5.7295 times to achieve that distance. However, if you were to select a circular pitch for the pinion gear instead of the traditional module, you would end up with a fixed distance for each revolution. For example:

CP 10mm, 20 Tooth spur gear; the Pitch Diameter is 63.66197mm

Linear distance = π * 63.66197 = 200mm

Thus, in this case, one revolution will result in an exact linear travel of 200mm. If this gear system needed to travel 900mm, the pinion would need to rotate exactly 4.5 times to achieve the desired distance.

When considering a rack and pinion for linear motion translation, circular pitch is one way that you can obtain a fixed travel distance without having to use complex calculations to determine the number of rotations needed on the pinion to travel a certain distance. Another advantage for using circular pitch instead of module in these applications is the consideration of backlash in the system. While traveling in one direction, the pinion has continuous engagement with the gear rack. However, once motion is stopped and reversed, there is a small amount of travel that is lost as the pinion reverses and starts to engage the rack in the opposite direction. The gap in transmission is known as the backlash. In most applications, the backlash is a known value and can be compensated for by using an absolute rotary encoder or by adding the measured backlash to the travel requirements.

One of the disadvantages to using circular pitch rack and pinion is that the mounting distance of the pinion in relation to the pitch line of the gear rack, will not be round number. Using our previous examples, the module 2.5, 20 tooth pinion would be set at 25mm above the pitch line of the rack, whereas the CP10, 20 tooth pinion would need to be set at 31.83098mm. Although this initial setup could cause an issue, the resulting known length of travel would most likely offset the headache.

A secondary issue with circular pitch gearing is its relatively infrequent use and the ease at which it is confused with other pitch sizes. The most common accidental interchange is that of CP5 mm and 16DP. These pitch profiles are so similar that many users chose a CP5 pinion but run it against a 16DP rack. This is never a good choice as the rack and pinion will not properly mesh and premature failure due to wear will occur.

Circular pitch sizes are available in both metric and inch standards. For metric applications, the standard sizes are 1mm, 2.5mm, 5mm, 10mm, 15mm, and 20mm. For Inch applications, the standard sizes are 1/10", 1/4", 3/8", 1/2", 3/4", and 1".

For gantry systems, reciprocating motion and other linear motion applications, circular pitch gear racks and pinion are an excellent way to simplify the translation of rotary motion into a fixed linear distance traveled. I look forward to my vacations this year, and I hope you enjoy yours, too. Just remember, it's not the destination. It's the journey that matters.

ABOUT THE AUTHOR

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