EPICYCLICAL GEARING

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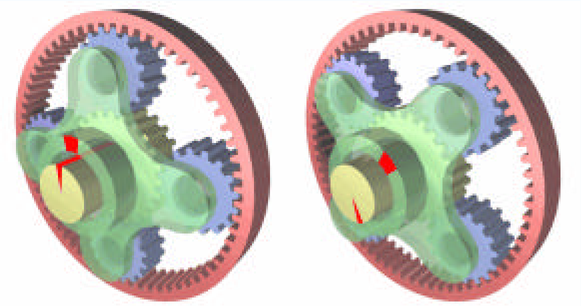
Abstract
Epicyclical gearing is used here to increase output speed. The planet gear carrier (green) is driven by an input torque. The sun gear (yellow) provides the output torque, while the ring gear (red) is fixed. Note the red marks both before and after the input drive is rotated 45° clockwise. Typically, the planet gears are mounted on a movable arm or *carrier* which itself may rotate relative to the sun gear.



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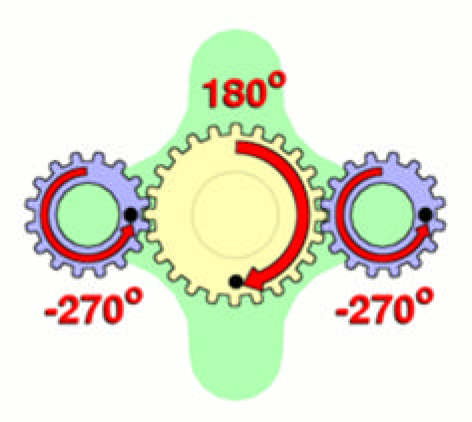
Epicyclical gearing or **planetary gearing** is a gear system that consists of one or more outer gears, or *planet* gears, rotating about a central, or *sun* gear. Typically, the planet gears are mounted on a movable arm or *carrier* which itself may rotate relative to the sun gear. Epicyclical gearing systems may also incorporate the use of an outer ring gear or *annulus*, which meshes with the planet gears.

Gear ratio



The carrier (green) is held stationary while the sun gear (yellow) is used as input. The planet gears (blue) turn in a ratio determined by the number of teeth in each gear. Here, the ratio is -24/16, or -3/2; each planet gear turns at 3/2 the rate of the sun gear, in the opposite direction.

The gear ratio in an epicyclical gearing system is somewhat non-intuitive, particularly because there are several ways in which an input rotation can be converted into an output rotation. The three basic components of the epicyclical gear are:

- *Sun*: The central gear
- *Planet carrier*: Holds one or more peripheral *planet* gears, of the same size,

meshed with the sun gear

- *Annulus*: An outer ring with inward-facing teeth that mesh with the planet gear or gears

In any epicyclical gearing system, one of these three basic components is held stationary; one of the two remaining components is an *input*, providing power to the system, while the last component is an *output*, receiving power from the system. The ratio of input rotation to output rotation is dependent upon the number of teeth in each gear, and upon which component is held stationary.

One situation is when the planetary carrier is held stationary, and the sun gear is used as input. In this case, the planetary gears simply rotate about their own axes at a rate determined by the number of teeth in each gear. If the sun gear has *S* teeth, and each planet gear has *P* teeth, then the ratio is equal to -*S*/*P*. For instance, if the sun gear has 24 teeth, and each planet has 16 teeth, then the ratio is -24/16, or -3/2; this means that one clockwise turn of the sun gear produces 1.5 *counterclockwise* turns of the planet gears.

This rotation of the planet gears can in turn drive the annulus, in a corresponding ratio. If the annulus has *A* teeth, then the annulus will rotate by *P*/*A* turns for each turn of the planet gears. For instance, if the annulus has 64 teeth, and the planets 16, one clockwise turn of a planet gear results in 16/64, or 1/4 clockwise turns of the annulus. Extending this case from the one above:

- **One turn of the sun gear results in *S*/*P* turns of the planets**
- **One turn of a planet gear results in *P*/*A* turns of the annulus**

So, with the planetary carrier locked, one turn of the sun gear results in -*S*/*A* turns of the annulus.

The annulus may also be held fixed, with input provided to the planetary gear carrier; output rotation is then produced from the sun gear. This configuration will produce an increase in gear ratio, equal to 1+*A*/*S*.

These are all described by the equation:

$$(2+n)\omega_a + n\omega_s - 2(1+n)\omega_c = 0 \quad (1)$$

where n is the form factor of the planetary gear, defined by:

$$n = \frac{N_s}{N_p} \quad (2)$$

If the annulus is held stationary and the sun gear is used as the input, the planet carrier will be the output. The gear ratio in this case will be 1/(1+*A*/*S*). This is the lowest gear ratio attainable with an epicyclical gear train. This type of gearing is sometimes used in tractors and construction equipment to provide high torque to the drive wheels.

More planet and sun gear units can be placed in series in the same ring gear housing (where the output shaft of the first stage becomes the input shaft of the next stage) providing a larger (or smaller) gear ratio. This is the way some automatic transmissions work.

During World War II, a special variation of epicyclical gearing was developed for portable radar gear, where a very high reduction ratio in a small package was needed. This had two outer annular gears, each half the thickness of the other gears. One of these two annular gears was held fixed and had one fewer teeth than did the other. Therefore, several turns of the "sun" gear made the "planet" gears complete a single revolution, which in turn made the rotating annular gear rotate by a single tooth.

A simpler way to calculate the output RPM from the input RPM

It is first drawn simplified as the sun, a single planet, the ring, and an arm holding the planet. Any gear can be the input or output, including the arm.

Now, simply plug in the known values and solve for w_{out}:

$$\frac{N_{in}}{N_{out}} = \frac{w_{out} - w_{arm}}{w_{in} - w_{arm}} \quad (3)$$

where N is the number of teeth, w is rpm.

One caveat: if the arm is the input or output, say the ring is the output/input instead and reverse the direction (since if the arm moves a certain speed relative to the ring, the ring moves that same speed the other way relative to the arm, and obviously the arm doesn't have a tooth count to plug in)

If you want to derive this, just imagine the arm is locked, and calculate the gear ratio $w_{out} : w_{in} = N_{in} : N_{out}$. Then unlock the arm. From the arms reference frame the ratio is always N_{in}/N_{out}, but from your frame all the speeds are increased by the angular velocity of the arm. So to write this relative relationship, you arrive at the equation from above.

Also, make sure $N_{sun}+2N_{planet}=N_{ring}$ where N is the number of teeth. This simply says that the gears will fit, since N is directly proportional to diameter.

References:
1. Aron, I., s.a., *Angrenaje conice cu dinti curbi*. Editura Casa Cartii de Stiinta, Cluj-Napoca, 1999;
2. Jula, A., s.a., *Proiectarea angrenajelor evolventice*. Editura Scrisul Românesc, Craiova 1989;
3. Minciu, C., *Precizia si controlul angrenajelor*, Editura Tehnica, Bucuresti, 1984;
6. *** - www.thegearworks.com/tools
7. *** - www.metalwebnews.com
8. *** - www.ameritoolindustries.com