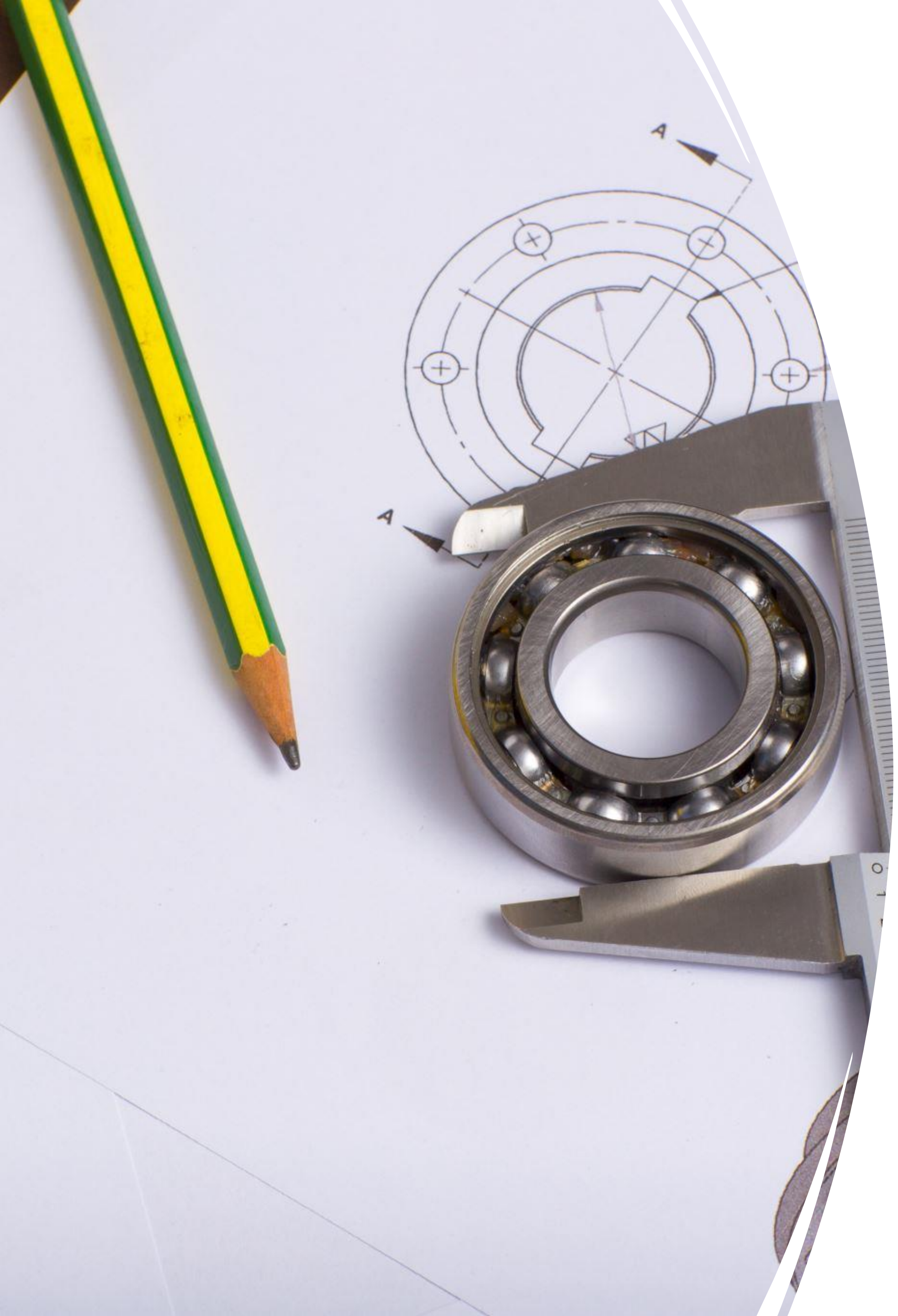
Planetary Gear Trains – Part #2

Analysis by the Formula & Tabular Methods.



Learning Outcomes for Part #2

- Introduction to Planetary Gear Trains.
- Identifying kinematics relations for the analysis of the Planetary Gear Trains motion.
- Defining the method of superposition used to "step through" the planetary gear movements.

Planetary Gear Trains

- Planetary gear trains are one family of the simple *epicyclic gear train family*.
- They are often used when space and weight are an issue, but a large amount of speed reduction and torque are needed.
- A planetary gear train has a central *sun gear* which meshes with and is surrounded by *planet gears.* The outermost gear is called the *ring gear*, which mates with each of the planet gears as shown in Figure (8-17) in the next slide:

Note: The term "epicyclic" comes from the Greek words epi, meaning "upon" or "above," and kyklos, meaning "circle" or "wheel," indicating the orbiting motion of gears within the system.

Planetary Gear Trains

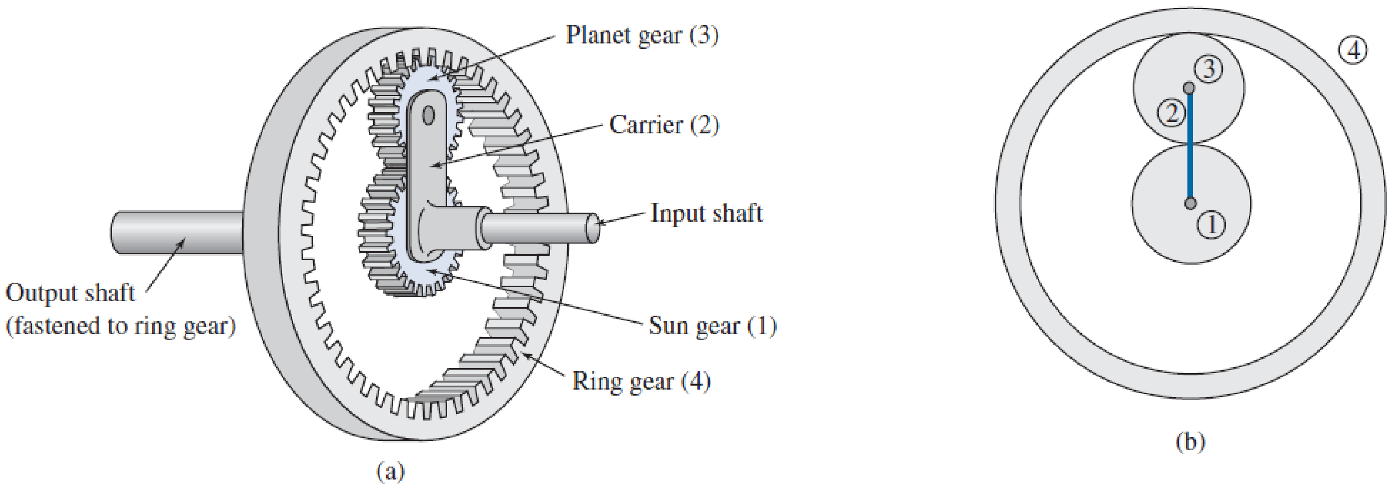
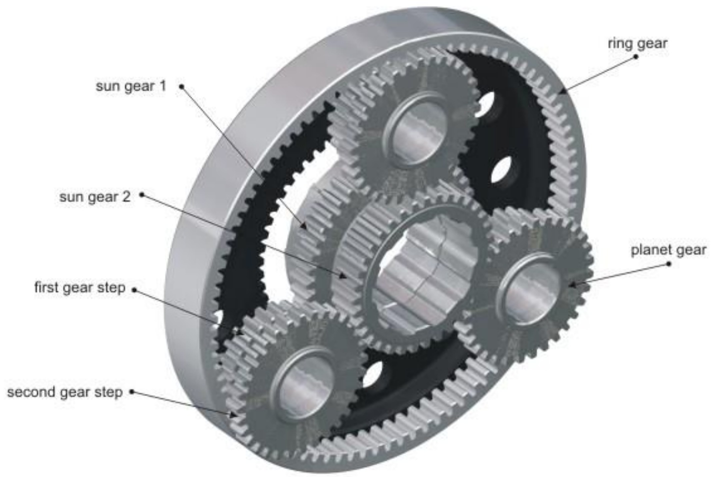


Figure 8-17 A Planetary Gear Train. Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Types of Planetary Gear Trains

- The three main types of simple epicyclic gears are:
  - *planetary,*
  - *star*
  - *solar*



- ***Note:*** These three types differ only in arrangement. This means that they have the same kinematics relations for analyzing the motion.

Planetary Gear Trains – Advantages & Disadvantages

- *Advantages* to using a planetary gear train as opposed to a parallel gear train:
  - ✓Planetary gear trains take up less space and have a lighter weight and have smaller and stiffer components which lead to reduced noise and vibration while increasing efficiency.
  - ✓The input and output shafts of planetary gear trains are concentric, so, no bending moments or torques are created from radial forces that develop from the change of the force's line of action.
  - ✓The input and output shafts of planetary gear trains are concentric so driver and driven equipment can be mounted in line, providing additional space savings.

Planetary Gear Trains – Advantages & Disadvantages

- ✓The reduced size of planetary components often offsets the cost of additional parts, especially when manufacturing many gear trains.
- ✓In very high horsepower units, the components of parallel shaft designs become so bulky that planetary trains gain a further economical gain.

- *Disadvantages:*
  - Complexity.
  - Assembly of gear trains is limited to specific teeth per gear ratios.
  - Efficiency calculations are difficult.
  - Driver and driven equipment must be in line to avoid additional gearing.

Planetary Gear Trains

- There are two approaches to implement the superposition method for the analysis of the motion of a planetary gear train. These are the *Tabular Method*, and *Formula Method*.

- The *Tabular Method* of superposition is best illustrated with an example problem.

Analysis of a Planetary Gear Train Motion - Method of Superposition

- In general, the *method of superposition* is used to analyze the motion of a planetary gear train. The three steps are:
  1. Temporarily assume that the carrier is locked and relax the constraint on the fixed link. Then, turn the previously fixed gear one revolution and calculate the effect on the entire train.
  2. Free all constraints and record the movement of rotating each link one revolution in the opposite direction of the rotation in step one. As this motion is combined with the motion in the first step, the superimposed motion of the fixed gear equals zero. The motion of all links is determined by combining the rotations from the first two steps.
  3. Finally, the velocities are proportional to the rotational movements. Stated in general terms, this method seems complex. However, it is rather straightforward.

Tabular Method - An Example

- *Example 8-2.* A planetary gear train is illustrated in Figure 8-18. The carrier (link 2) serves as the input to the train. The sun (gear 1) is the fixed gear and has 30 teeth. The planet gear (gear 3) has 35 teeth. The ring gear serves as the output from the train and has 100 teeth.
- Determine:
  - the rotational velocity of all members of planetary gear train when the input shaft rotates at 1200 rpm clockwise.

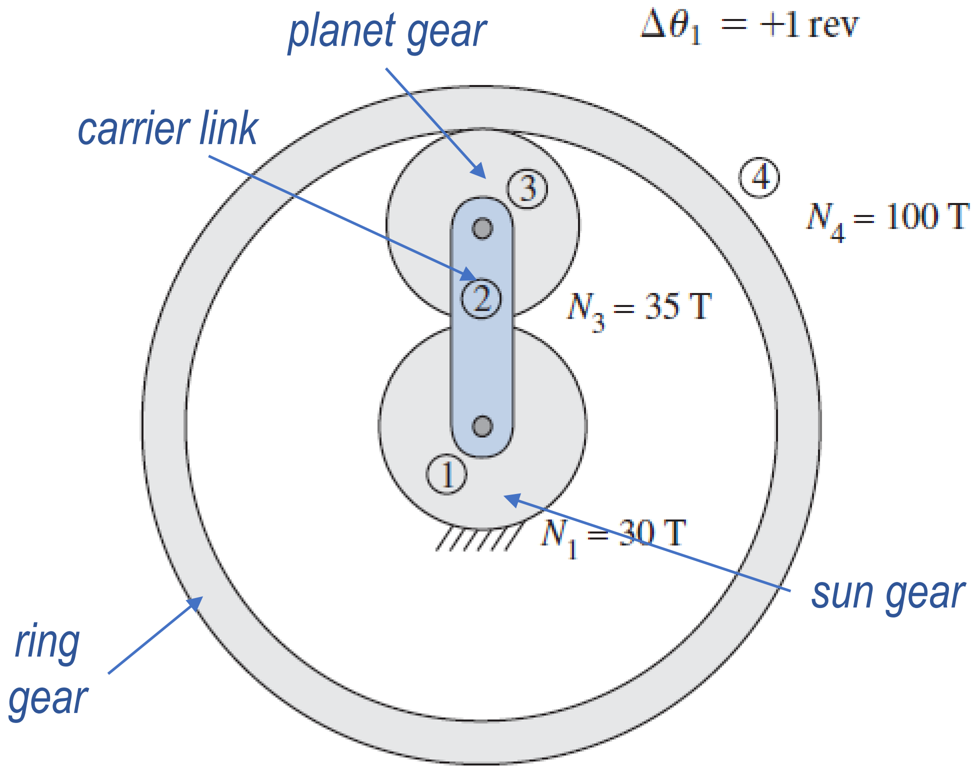


Figure 8-18 Planetary Gear Train for Problem 8-2.

Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Tabular Method - An Example

- *Solution.* Following the three steps for the analysis:
- The first step is to temporarily fix the carrier then calculate the motions of all gears as the previously fixed gear rotates one revolution:

Gear 1 rotates one revolution.

Gear 3 rotates (VR_{1-3}) as much as gear 1. Therefore:

$$\Delta\theta_3 = (VR_{1-3})(\Delta\theta_1) = \left(-\frac{30}{35}\right)(+1\ rev) = -0.857\ rev$$

Gear 4 rotates (VR_{3-4}) as much as gear 3. Then, $\Delta\theta_4$ becomes:

$$\Delta\theta_4 = (VR_{3-4})(\Delta\theta_3) = (VR_{3-4})(VR_{1-3})(\Delta\theta_1) = \left(\frac{+35}{100}\right)\left(-\frac{30}{35}\right)(+1\ rev)$$
$$= -0.3\ rev$$

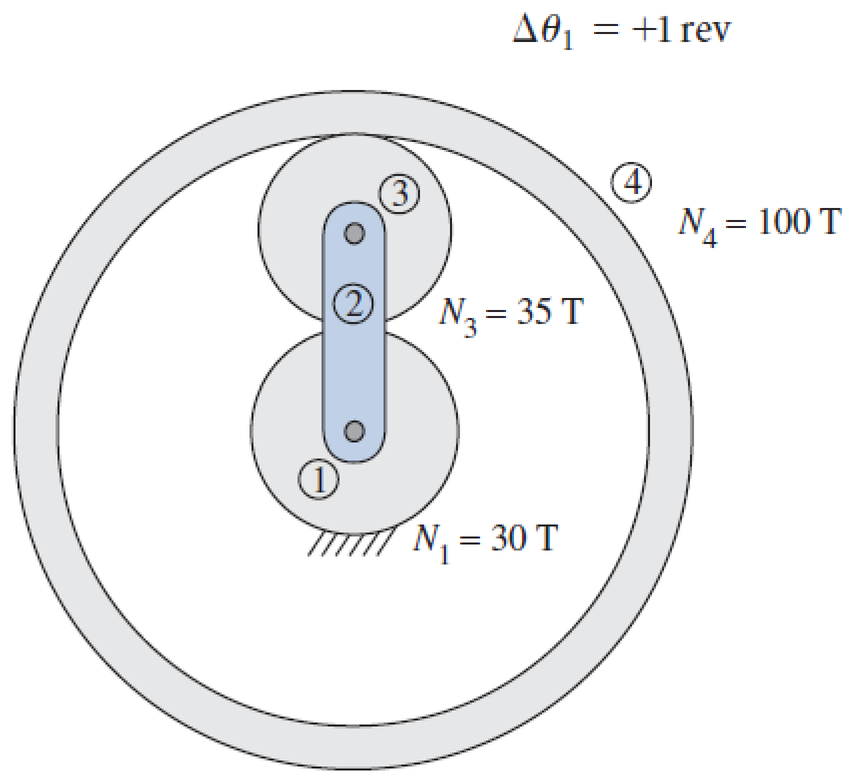


Figure 8-18 Planetary Gear Train for Problem 8-2.

Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Tabular Method - An Example

- *Solution (cont.).*
- The second step rotates all links –1 revolution. This returns the sun gear to its original position, yielding a net movement of zero.
- The method of superposition involves combining these two motions, resulting in the actual planetary gear train motion.
- Therefore, the rotations from both steps are algebraically added together. The two steps are summarized in Table 8-1 (next slide).

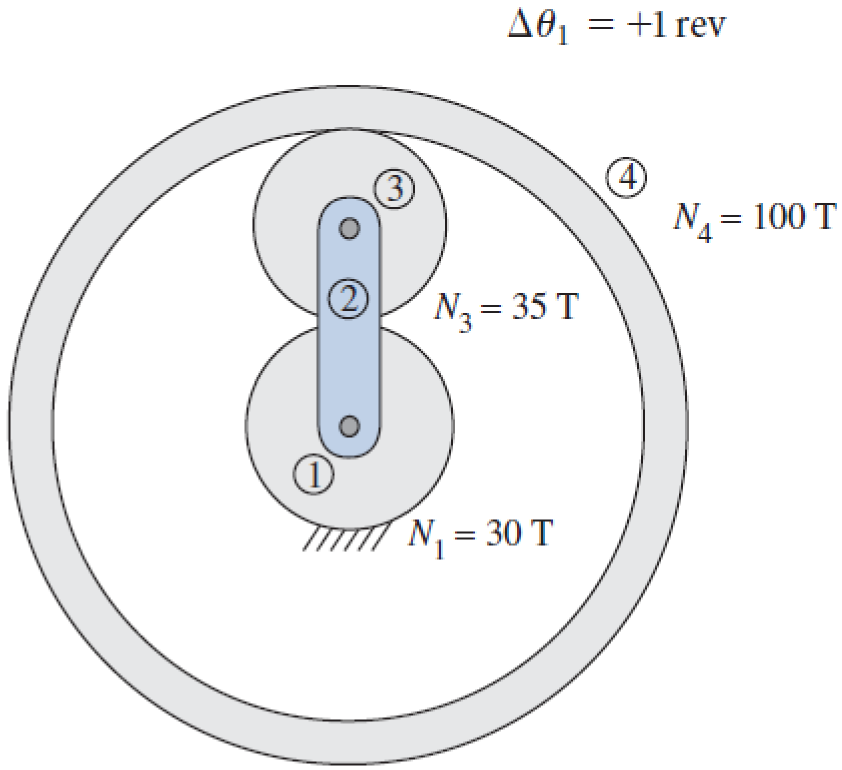


Figure 8-18 Planetary Gear Train for Problem 8-2.

Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Tabular Method - An Example

- *Solution (cont.).*

Table #8-1 Tabulating Planetary Gear Analysis for the Example 8-2.				
Link	Sun	Planet	Ring	Carrier
Step 1: Rotate with fixed carrier	$+1$	-0.857	-0.3	0
Step 2: Rotate all links	-1	-1	-1	-1
Step 3: Total rotations	0	-1.857	-1.3	-1

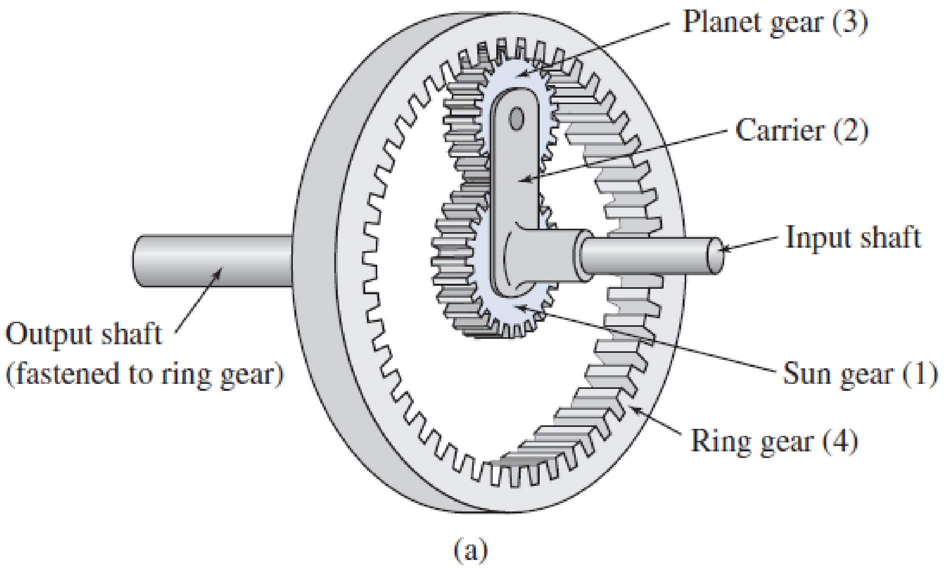


Figure 8-17 A Planetary Gear Train.
Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Tabular Method - An Example

- *Solution (cont.).*
- The third step is to determine velocities of all links. The velocities can be determined by using the ratios of angular displacements as:

$$\omega_{sun} = \left(\frac{\Delta\theta_{sun}}{\Delta\theta_{carrier}}\right)\omega_{carrier} = \left(\frac{0}{-1}\right)(1200\,rpm) = 0\,rpm$$

$$\omega_{planet} = \left(\frac{-1.857}{-1}\right)\omega_{carrier} = (+1.857)(1200\,rpm) = +2228\,rpm, cw$$

$$\omega_{ring} = \left(\frac{-1.3}{-1}\right)\omega_{carrier} = (+1.3)(1200\,rpm) = +1560\,rpm, cw$$

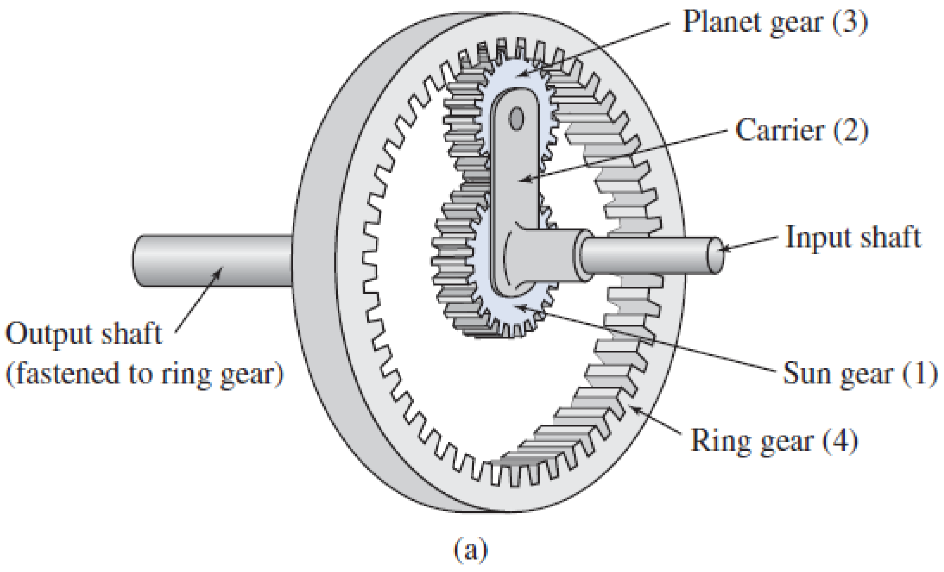


Figure 8-17 A Planetary Gear Train.
Source: Myszka, D.H. Machines and Mech. Applied Kinematic Analysis. Prentice Hall. 4th Edition. USA.

Formula Method

- To develop the formula method procedure, the motion of the mating gears is examined relative to the carrier. Follow these steps:
  1. View the gear train as if the carrier were fixed.
  2. One gear on the end of the gear train is designated as first gear. The gear on the opposite end of the gear train is designated as last gear.
  3. The first gear is designated as a driver gear and the last gear is a driven gear.
  4. The intermediate gears are appropriately identified depending on whether they drive or are driven.
  5. Calculate the ratio for each pair. ***Note***: The ratio is negative for mating external gears and positive for gears having an internal mesh.
  6. Calculate the velocities. The first gear has an angular velocity designated ω_F and the last gear has an angular velocity designated ω_L. The carrier has an angular velocity $\omega_{carrier}$. The relationship between the angular velocities and number of teeth in the train is given as follows (next slide):

Formula Method

$$\frac{\omega_{L/carrier}}{\omega_{F/carrier}} = \pm \frac{\text{product of number of teeth on driver gears}}{\text{product of number of teeth on driven gears}} = \frac{\omega_L - \omega_{carrier}}{\omega_F - \omega_{carrier}} \quad \text{Eq. (8-9)}$$

- *Example 8-3.* A planetary gear train was illustrated in Figure 8-18. The carrier (link 2) serves as the input to the train. The sun (gear 1) is the fixed gear and has 30 teeth. The planet gear (gear 3) has 35 teeth. The ring gear serves as the output from the train and has 100 teeth.
- In Example 8-2, the rotational velocity of the ring gear was determined to be 1560 rpm clockwise, as the input shaft rotates at 1200 rpm clockwise. Use the formula method to verify this result.

Formula Method – An Example

- *Solution:*

1. *Specify the first and last gear:*

   The sun (gear 1) will be designated the first gear. Being on the other end of the train, the ring gear (gear 4) will be designated as the last gear as shown in Figure 8-18.

2. *Substitute Gear Ratios into the Planetary Train Formula:*

   Gear 1 (first) mates with gear 3, which in turn mates with gear 4 (last). Substituting into Eq. (8-7), we get:

$$\left(-\frac{N_1}{N_3}\right)\left(+\frac{N_3}{N_4}\right) = \frac{\omega_L - \omega_{carrier}}{\omega_F - \omega_{carrier}} \qquad \text{Eq. (8-10)}$$

Formula Approach – An Example

- *Solution (cont.)*

3. *Identify the Angular Velocity Terms:*

The sun is fixed, giving $\omega_F = 0$. The carrier rotates at 1200 rpm clockwise. Taking clockwise to be a negative direction, $\omega_{carrier} = 1200$ rpm. So, the ring gear ω_L must be determined. Substituting in Eq. (8-10), we have:

$$\left(-\frac{30}{35}\right)\left(+\frac{35}{100}\right) = \frac{\omega_L - (-1200)}{0 - (-1200)}$$

Solving for ω_L, we get:

$$\omega_L = 1200\left(-\frac{30}{35}\right)\left(+\frac{35}{100}\right) - 1200$$

$$= 1560\ rpm, cw$$

End of Planetary Gear Trains – Part #2.