Design and Use of Epicyclic Gear Systems

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Introduction

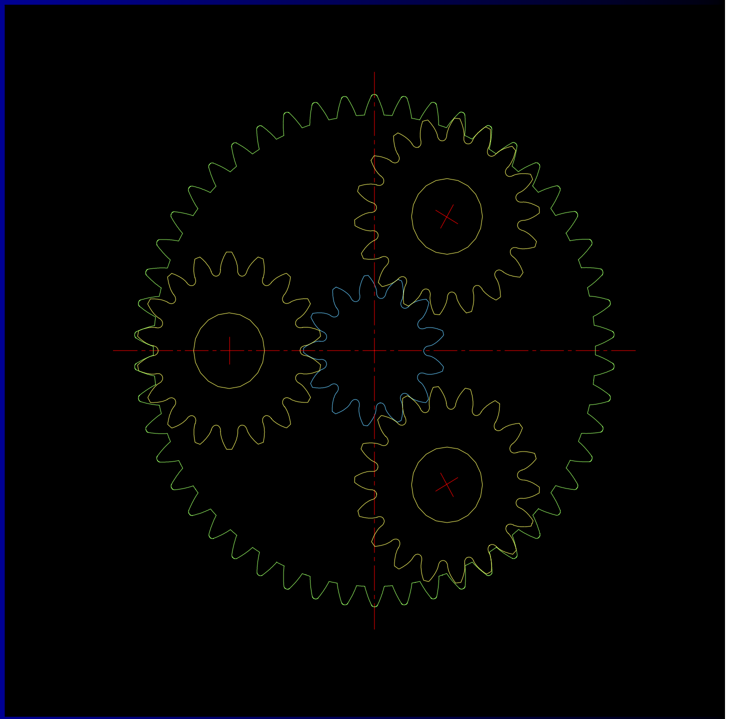
- Jim Marsch
- Gear Product Manager Universal Technical Systems
- Previous Affiliations
  - Allis-Chalmers Corp.– 12 Yr.
  - Harnischfeger Corp. – 18 Yr.
  - Morris Material Handling – 3 Yr.

Presentation Objectives

- Define Types & Arrangements
- Show Why Epicyclic Sets are Used
- Show What is Unique to Epicyclic Design
- List Do’s and Don’ts
- Share Design Tips / Pitfalls

Terminology

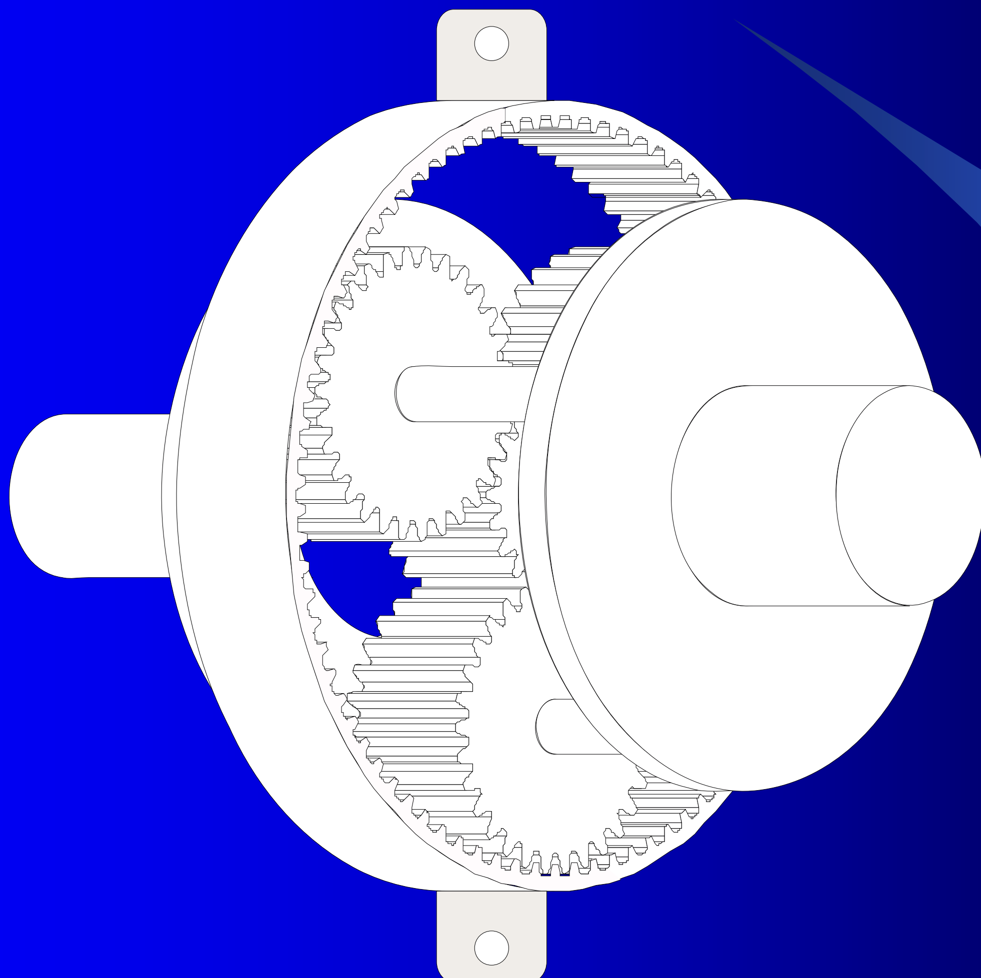
- Sun – Center Gear Meshing with Planets
- Carrier – Houses Planet Gear Shafts
- Planets
  - Orbit Sun as Carrier Rotates
  - Rotate on Planet Gear Shafts
- Ring – Internal Gear Meshing with Planets



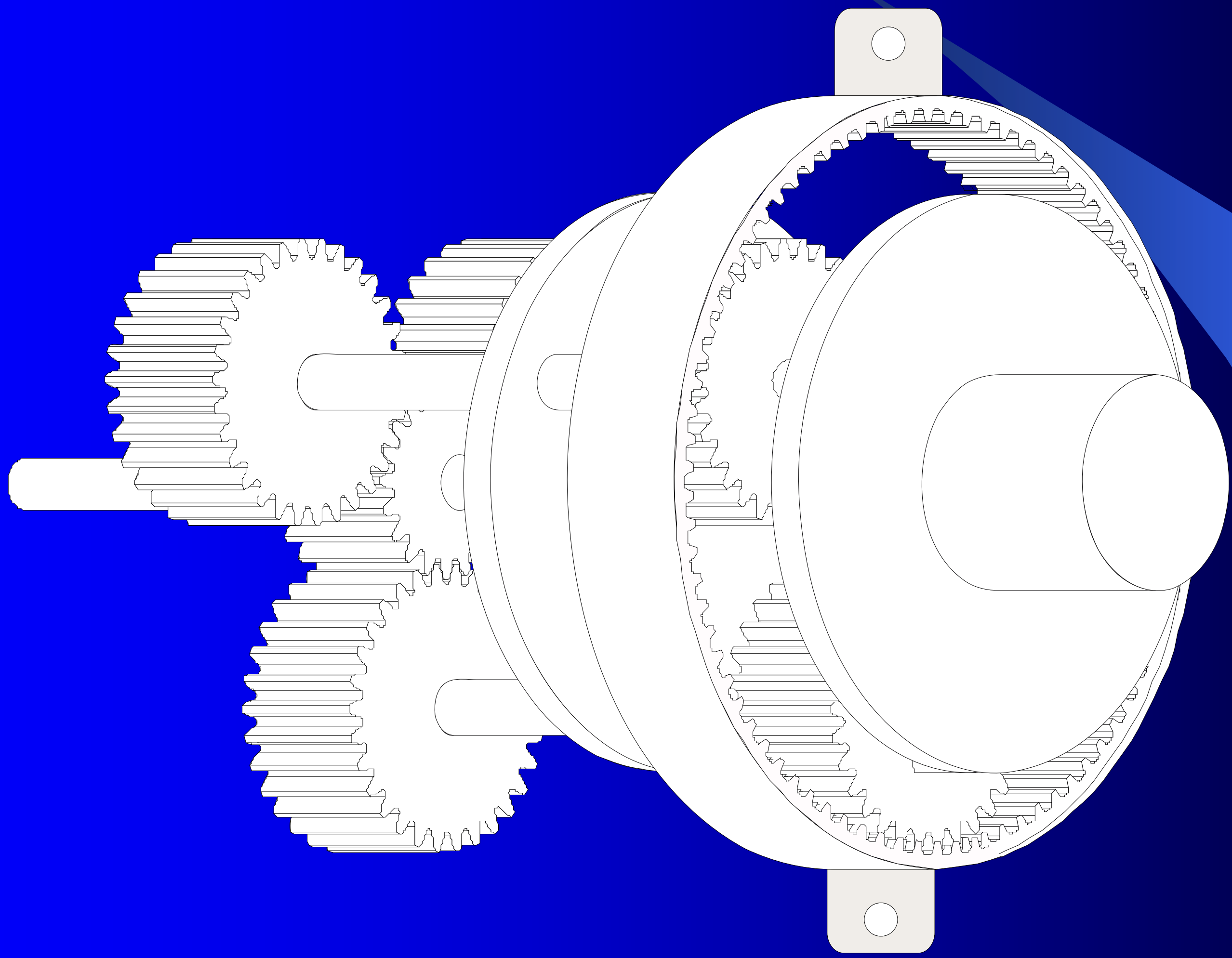
Epicyclic Gear Systems

- Most Common Types
  - Simple
  - Compound
  - Coupled

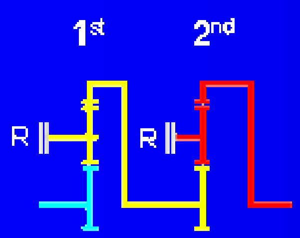
Simple Planetary Epicyclic



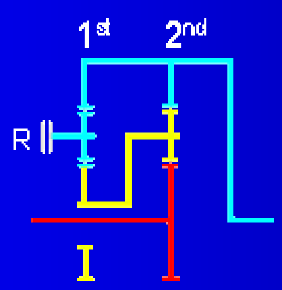
Compound Epicyclic



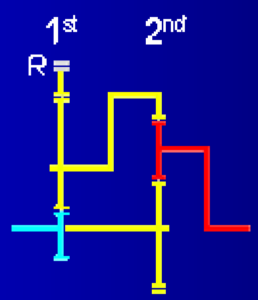
Coupled Epicyclic Sets



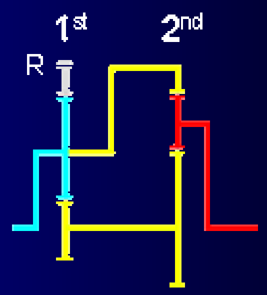
Series
Ratios of:
5.1 to 121



Split Power
Ratios of:
-4.1 to -120



Split Power
Ratios of:
2.0 to 5.8

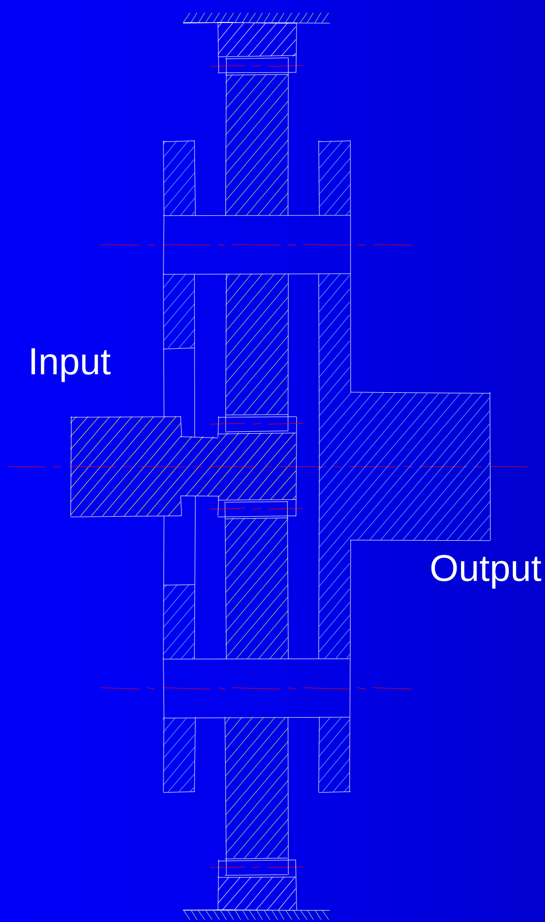


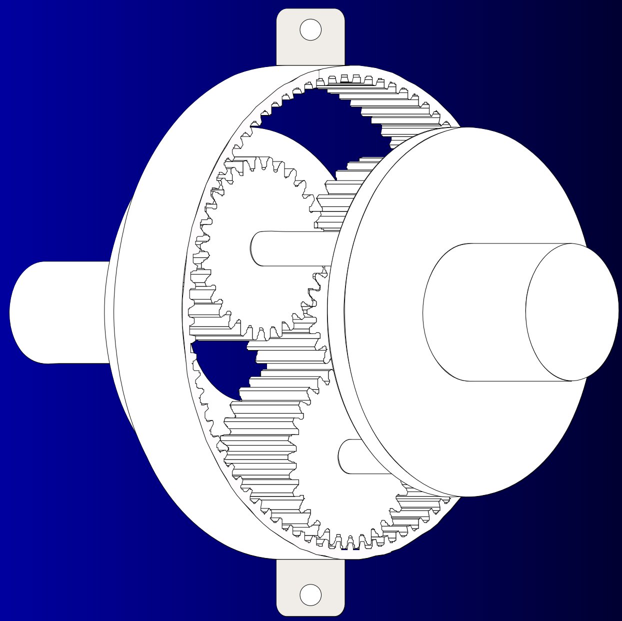
Split Power
Ratios of:
1.1 to 5.4

Epicyclic Arrangements

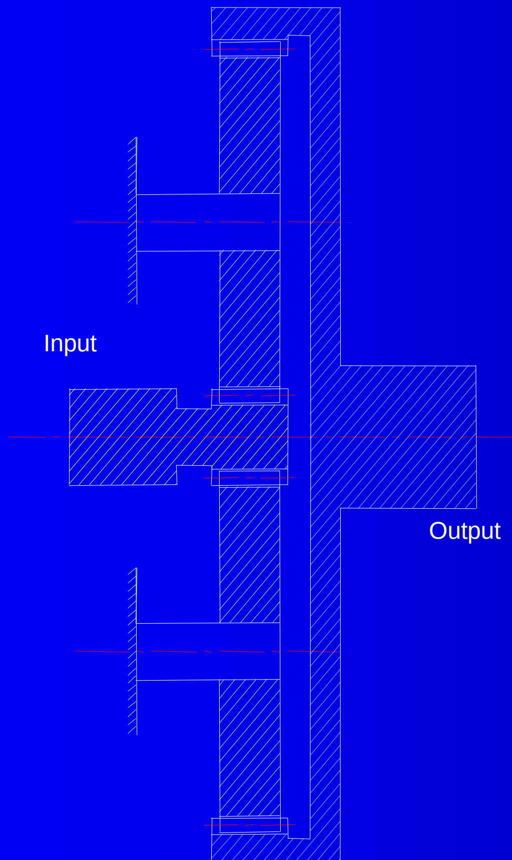
- Planetary – Ratios Between 3:1 and 12:1
- Star – Ratios Between -2:1 and -11:1
- Solar – Ratios Between 1.2:1 and 1.7:1

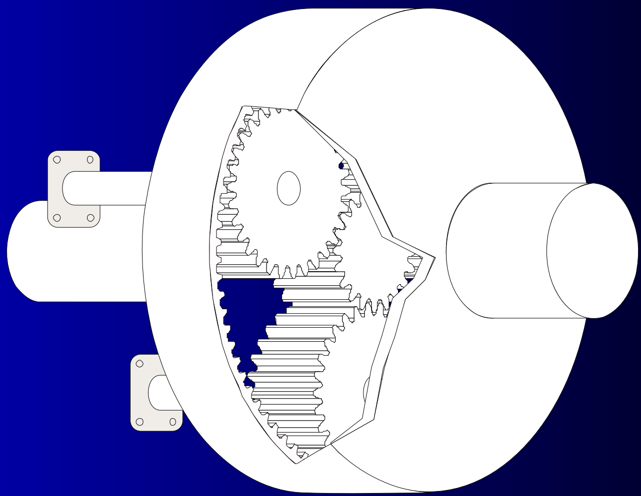
Planetary Arrangement



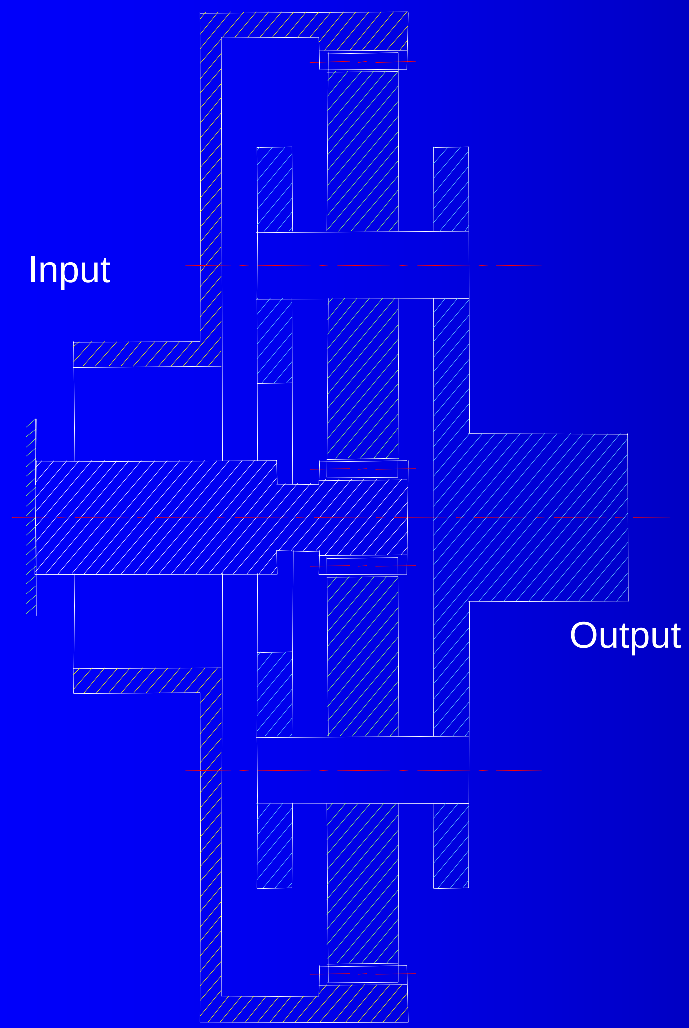


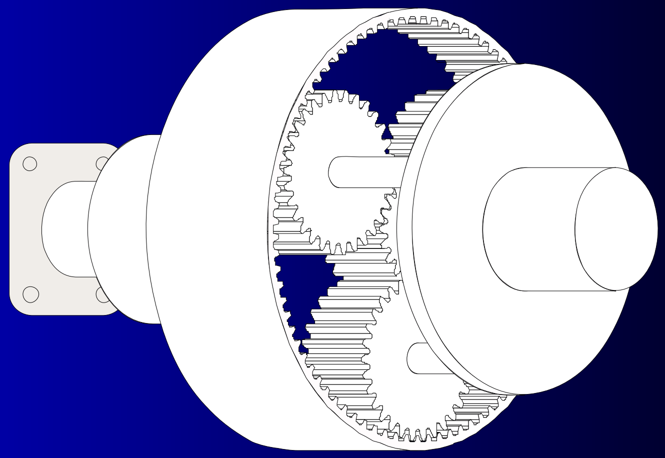
Star Arrangement





Solar Arrangement





Why Use Epicyclic Gearing?

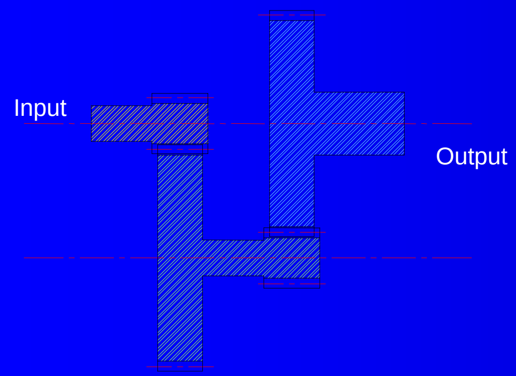
- Tooled properly, they are less expensive.
- Epicyclic gear sets will be smaller than offset gear sets.
- Epicyclic gear boxes will be lighter and more compact than countershaft gear boxes.
- In most cases they will be more efficient.

Application Example

- A high speed gear box is to be designed to satisfy the following requirements:
  - A turbine delivers 6,000 horsepower at 16,000 rpm to the input shaft.
  - The output from the gear box must drive a generator at 900 rpm.
  - The design life is 10,000 hours.

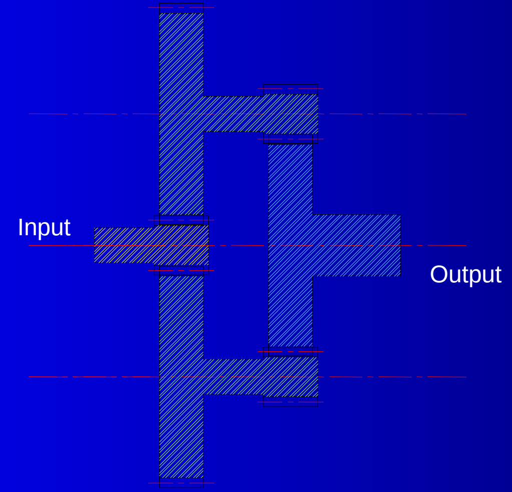
Three Possible Design Solutions

Single Branch
Two-Stage



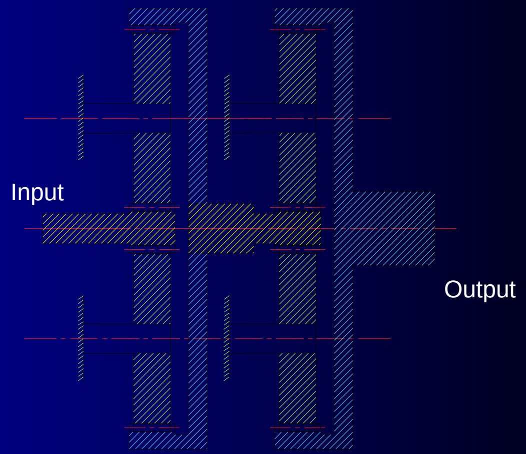
Ratio 1 = 4.216
Ratio 2 = 4.216
Weight = 5,293#

Double Branch
Two-Stage



Ratio 1 = 3.925
Ratio 2 = 4.536
Weight = 3,228#

Star Epicyclic
Two Stage



Ratio 1 = 4.865
Ratio 2 = 3.655
Weight = 2,422#

Unique Design Characteristics

- Relative Speeds
- Torque Splits
- Multiple Meshes
- Mesh Losses
  - Pitch Line Velocity
  - Tangential Load

Relative Speeds

- In a star arrangement
  – The carrier is fixed.
  – The sun and planet relative speeds are determined by the numbers of teeth in each gear.

Relative Speeds

- In a planetary arrangement
  - The ring gear is fixed.
  - The planets orbit the sun while rotating on the planet shaft.
  - The sun and planet relative speeds are determined by the numbers of teeth in each gear <u>and</u> the speed of the carrier.

Relative Speeds in Coupled Set

- In a coupled epicyclic, relative speeds may not be intuitive.
- Always calculate the speed of sun, planet and ring relative to the carrier.
- Even in a solar arrangement where the sun is fixed, the sun has a speed relationship with the planet…it is not zero rpm at the mesh.

Torque Splits

- Torque is divided among the planets equally.
- Member support and number of planets determine the “effective” number of planets to use for the torque division.
  - The “effective” number of planets in epicyclic sets with two or three planets may be equal to the number of planets.
  - When more than three planets are used, the effective number of planets is always less than the number of planets.

Torque Splits – Fixed Support

- All members supported in bearings
  - Centers of sun, ring and carrier will not be coincident due to manufacturing tolerances.
  - Fewer planets are simultaneously in mesh, resulting in a lower "effective" number of planets sharing the load.

Torque Splits – Floating Support

- One or two members are allowed a small amount of radial freedom or float. This could be as little as .002 inch.
  - The float allows for the centers of sun, ring and carrier to be coincident.
  - Three planets will always be in mesh, resulting in a higher “effective” number of planets sharing the load.

Multiple Mesh Considerations

- Cycles are multiplied on some members.
- Torque gets divided.
- Assembly of planets is complicated.

Cycles

- Given the speed of sun gear relative to the carrier.
- Sun gear cycles per sun rpm are equal to the relative speed to the carrier multiplied by the number of planets.
- Planet gear cycles per sun rpm are equal to the relative speed of the sun divided by the ratio between sun and planet. <u>The planet is an idler.</u>
- Ring gear cycles per sun rpm are equal to the sun gear cycles divided by the ratio between the sun and the ring.

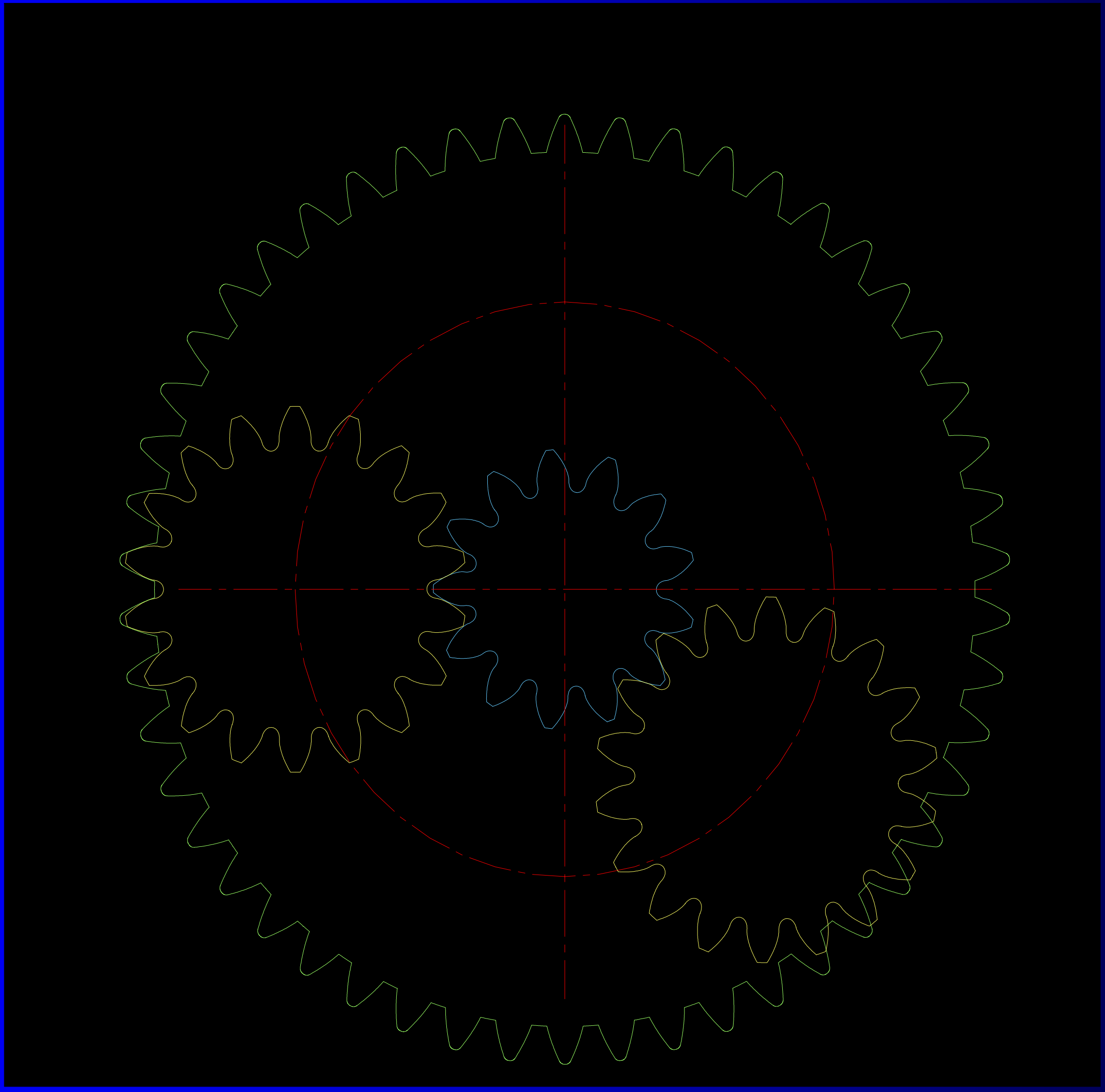
Torque

- Torque for each mesh cycle on the sun is equal to the sun gear torque divided by the effective number of planets.
- Torque for each mesh cycle on the planet is equal to the torque per mesh on the sun multiplied by the ratio between sun and planet.
- Torque for each mesh cycle on the ring is equal to the torque per mesh on the sun multiplied by the ratio between sun and ring.

Assembly Complications

- Placing one planet in position between sun and ring fixes the angular position of one to the other.
- The next planets can now be assembled only in discreet locations where sun and ring can be engaged.

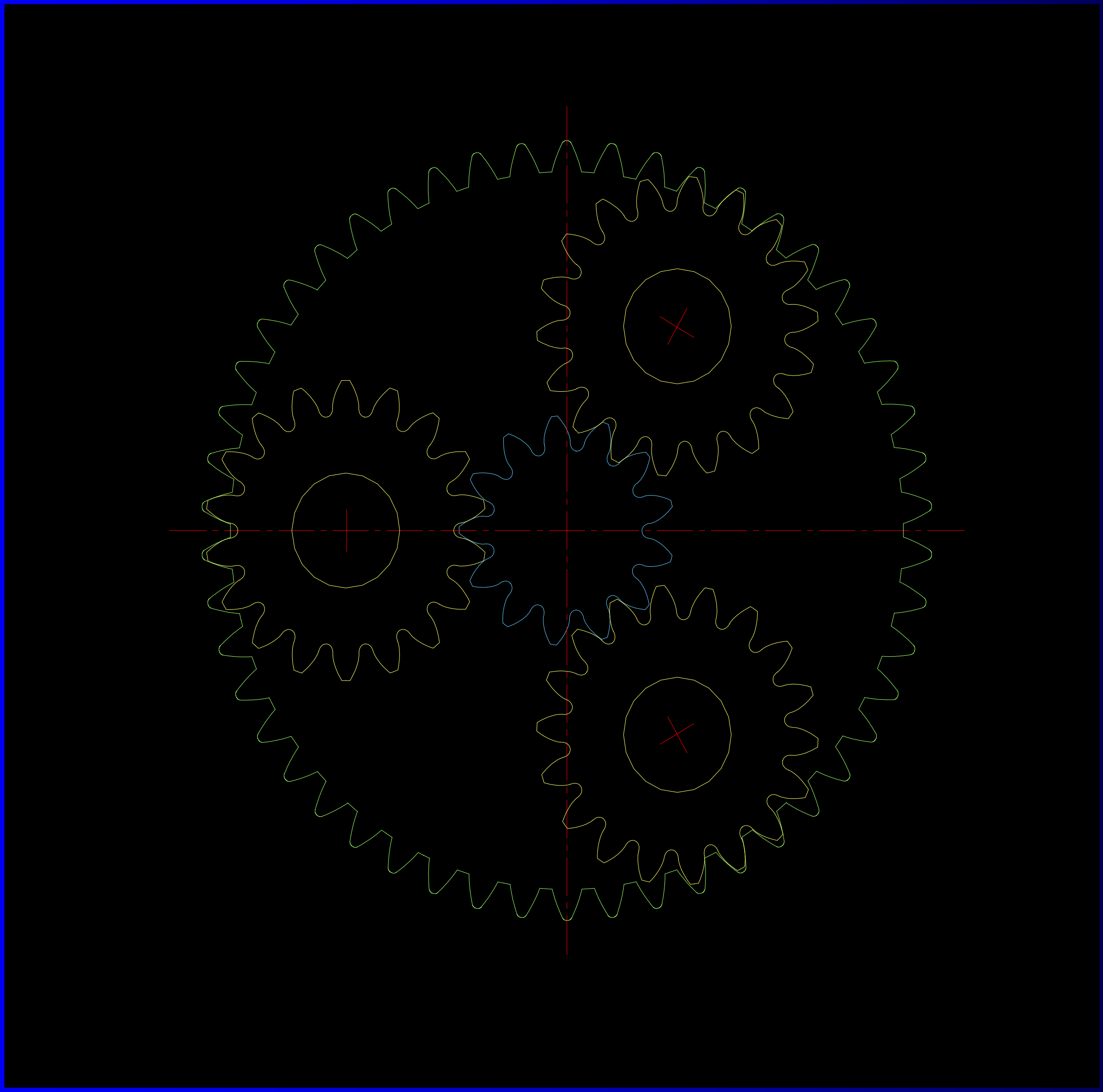
Planets Do Not Mesh Anywhere



Planet Spacing

- In a simple epicyclic, planets may be spaced equally when the sum of the numbers of teeth in the sun and ring are divisible by the number of planets to an integer.
- In a compound epicyclic planet spacing is more complex and may require match marking of teeth.

Equally Spaced Planets



Mesh Losses & Efficiency

- Power transmitted at each mesh, not input power, must be used to compute power loss.
  - For simple epicyclic sets, total power transmitted through sun-planet mesh and ring-planet mesh may be less than input power.
  - For certain coupled epicyclic sets, total power transmitted internally through each mesh may be greater than input power.

Power at the Mesh

- Simple & Compound Epicyclic Sets
  - Calculate power using planet torque and planet relative speed.
- Coupled Epicyclic Sets
  - Calculate tangential load at each mesh using a free-body diagram on the system.
  - Calculate power using tangential load and velocity at each mesh.

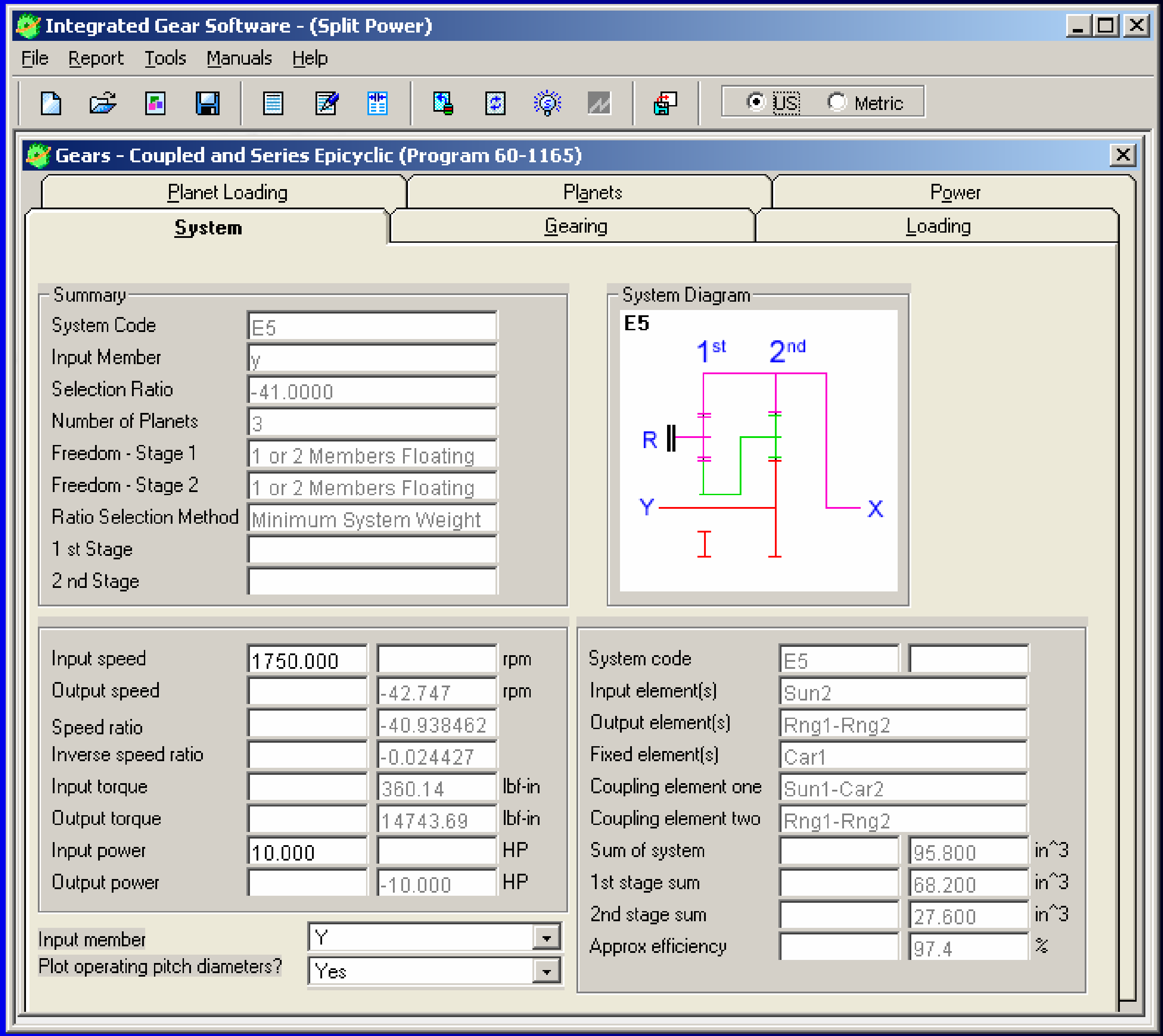
Coupled Epicyclic Sets

- Elements of two epicyclic sets can be coupled 36 different ways using one input, one output and one reaction.
  - Some split the power.
  - Some have internal recirculation of power.
- Elements of two epicyclic sets can be coupled 9 different ways in series using one input, one output and two reactions.

Split-Power Coupled Set

Ratio = -40.9

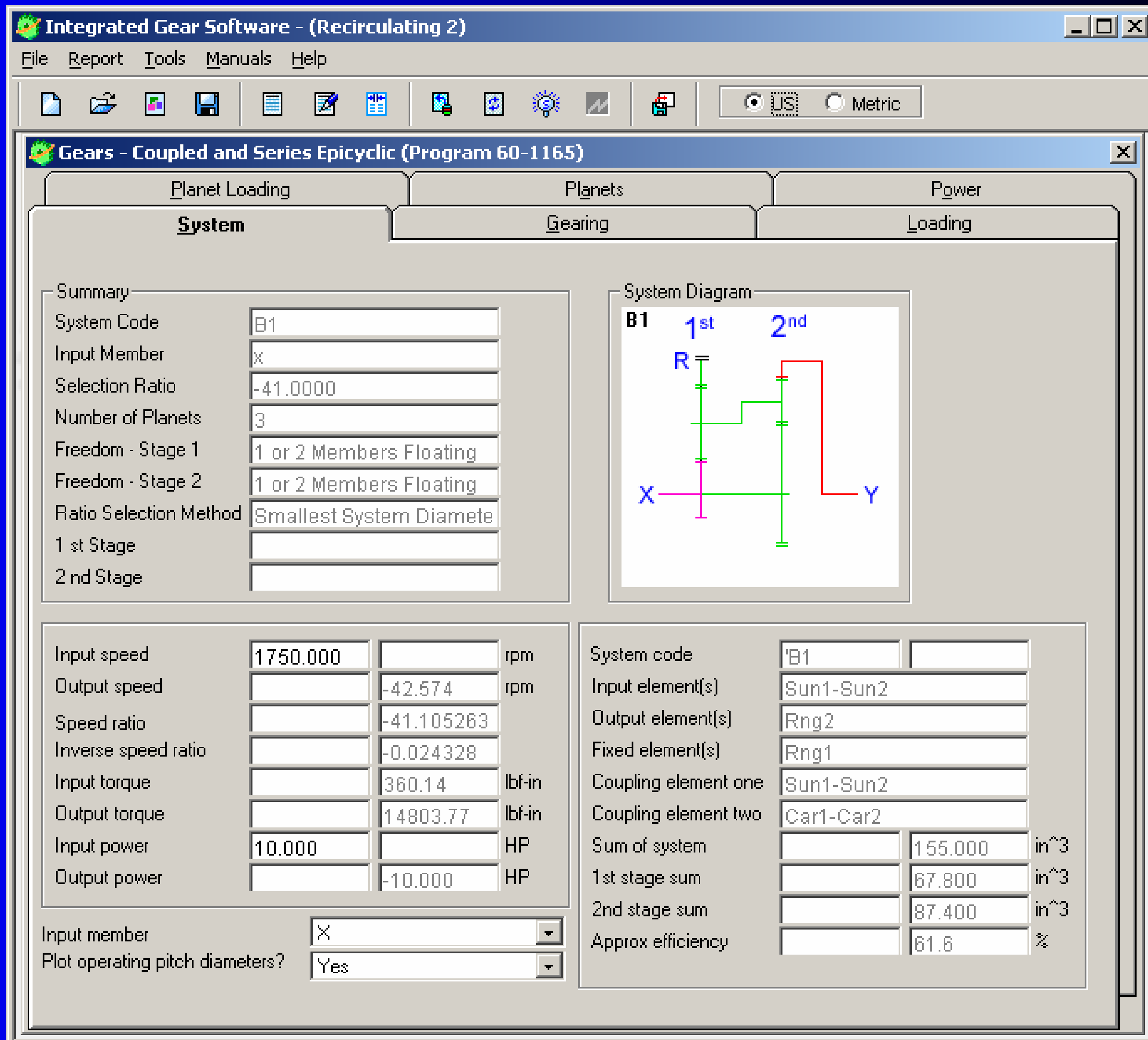
Efficiency = 97.4 %



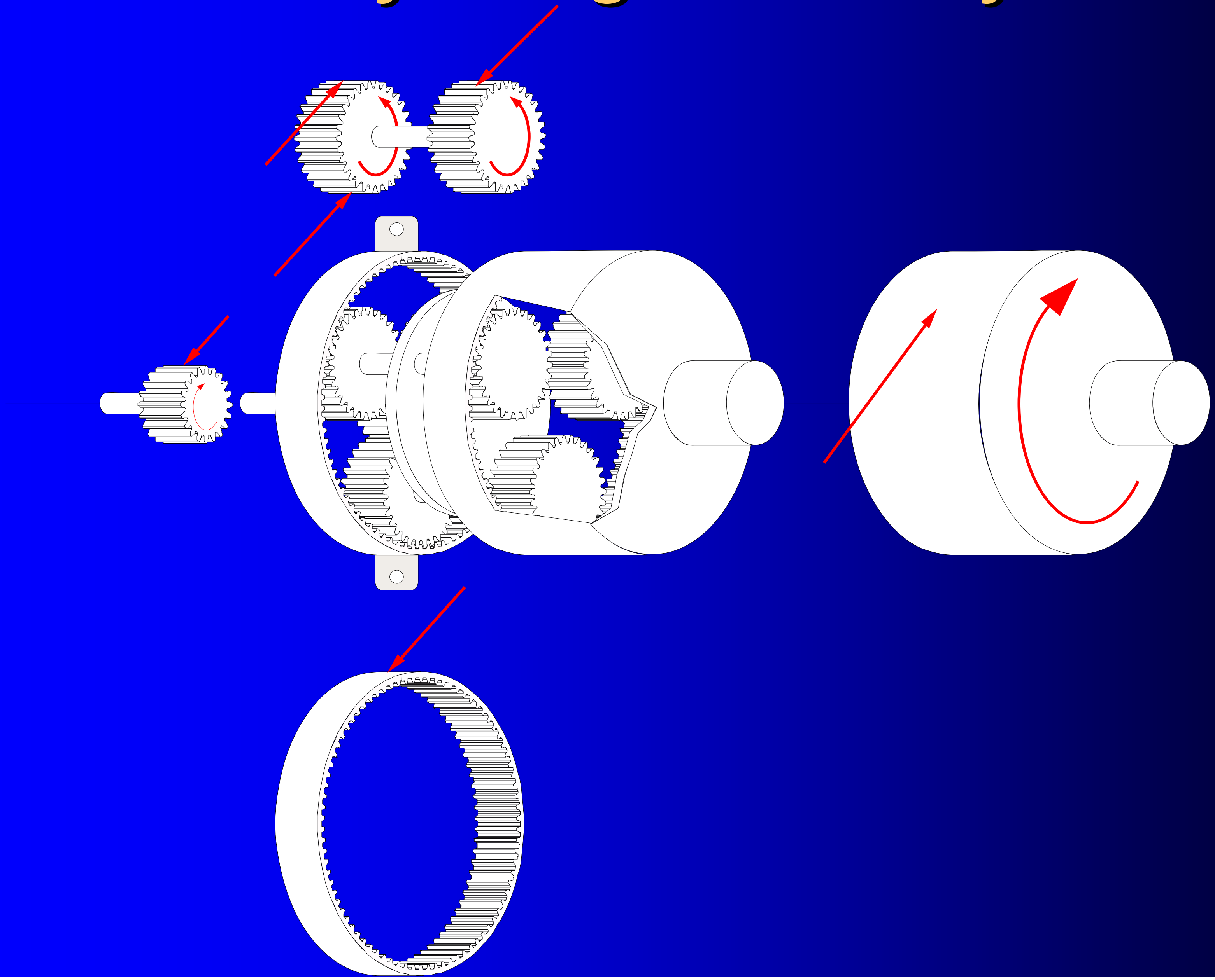
Set with Power Recirculation

Ratio = 41.1

Efficiency = 61.6 %



Free-Body Diagram of System



Do's and Don'ts

- Do
  - Calculate planet locations
  - Define assembly match marks on drawing.
  - Use relative speeds
  - Divide torques correctly
  - Analyze planets as idlers in simple epicyclic sets
  - Check planets for O.D. interference
  - Use free-body diagrams
- Don't
  - Rigidly fix all members unless application requires it
  - Assume power splits
  - Use coupled sets that have internal power recirculation
  - Forget centrifugal loads on planet bearings

Design Tips / Pitfalls

- Designing on standard centers will result in higher specific sliding and lower efficiency.
- Removing one tooth from the planet gear will enhance both sun and ring meshes.
- Allow “float” or specify very tight location and run-out tolerances or load sharing will be less than anticipated.
- Use tangential loads and pitch line velocities to determine mesh power transmission.

Where to Get More Information

- ANSI/AGMA 6023-A88
- ASME Paper 68-MECH-45 by P.W. Jensen
- UTS Gear Training
- UTS Software
- www.uts.com