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Design and development of planetary gearbox for variable performance

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ABTRACT

In the commercial cars, the generally conventional gearbox is used, but in an all-terrain vehicle and military combat vehicle automatic transmission is used, where Continuous Variable Transmission (CVT) is coupled with the epicyclic gearbox or generally recognized by the planetary gearbox. In this type of gearbox, we are establishing a gear train with high torque in a compact and light package. Here we are designing single stage planetary gearbox with co-axial alignment. Epicyclic gearing arrangements are comprised of four different elements that produce a wide range of speed ratios in a compact layout. These elements are: (1) Sun gear, an externally toothed ring gear co-axial with the gear train; (2) Annulus, an internally toothed ring gear co-axial with the gear train; (3) Planets, externally toothed gears which mesh with the sun and annulus; and (4) Planet Carrier, a support structure for the planets, co-axial with the train. The name "epicyclic" is derived from the curve traced by a point on the circumference of a circle as it rolls on the circumference of a second fixed circle.

Keywords*— Planetary gearbox, Planetary gear trains, Planet gears, Epicycloid curve*

1. INTRODUCTION

In epicyclic gearbox, internal teeth gear (ring gear), external teeth sun gear and two more gears are used. In which sun gear is at the centre of the ring gear and two more gears are mounted between the sun gear and ring gear and these gears are free to rotate about its own axis and about centre gear, like planet rotate about the sun and its own axis also. This arrangement of gears known as epicyclic gear train or planetary gear train, which gives variable speed. Epicyclic gearboxes are used in the automatic gear transmission system in an automobile.

Most modern gearboxes are used to increase torque while reducing the speed of a prime mover output shaft (e.g. a motor crankshaft). This means that the output shaft of a gearbox rotates at a slower rate than the input shaft, and this reduction in speed produces a mechanical advantage, increasing torque.

By fixing one of the co-axial members and using the remaining two for input and output, three types of simple single-stage epicyclic gearing are possible. Generally, these are called planetary, star, and solar arrangements. This investigation is primarily concerned with planetary gear drives which have a fixed annulus with the planet carrier rotating in the same direction as the sun gear. [5]

The two-wheel planetary gear stage consists of four parts.
(a) Sun gear (center) S
(b) Planetary gears (the two gears rotating around the Sun gear)
(c) Planetary carrier (holds the planetary gears in place so the gear doesn't jam) C
(d) Ring wheel (the outer gear rim) R [5]

By locking the rotation of different components in the gear, four ratios and two rotational directions can be achieved. By changing the input and output axes even more ratios are available. [2]

2. WORKING PRINCIPLE

(a) An epicyclic gear train consists of two gears mounted so that the center of one gear revolves around the center of the other. A carrier connects the centers of the two gears and rotates to carry one gear, called the planet gear, around the other, called the sun gear. The planet and sun gears mesh so that their pitch circles roll without slip. A point on the pitch circle of the planet gear traces an epicycloid curve. In this simplified case, the sun gear is fixed and the planetary gear(s) roll around the sun gear.
(b) An epicyclic gear train can be assembled so the planet gear rolls on the inside of the pitch circle of a fixed outer gear ring, which is called an annulus gear. In this case, the curve traced by a point on the pitch circle of the planet is a hypocycloid.

(c) The combination of epicycle gear trains with a planet engaging both a sun gear and an annular gear is called planetary gear train. In this case, the annular gear is usually fixed and the sun gear is the driver.

(d) Epicyclic gears get their name from their earliest application, which was the modeling of the movements of the planets in the heavens. Believing the planets, as everything in the heavens, to be perfect, they could only travel in perfect circles, but their motions as viewed from Earth could not be reconciled with a circular motion. At around 500 BC, the Greeks invented the idea of epicycles, of circles traveling on the circular orbits. With this theory, claudius ptolomy in the almagest in 148 AD was able to predict planetary orbital paths. The antykythera mechanism, circa 80 BC, had gearing which was able to approximate the moon's elliptical path through the heavens, and even to correct for the nine-year precession of that path.[2]

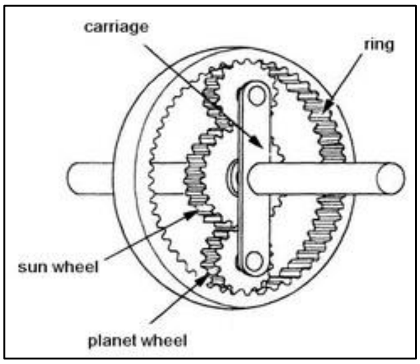

Fig. 1: Basic Layout of Planetary Gearbox

3. DESCRIPTION OF MAJOR COMPONENTS

3.1 Sun Gear

It is the central gear of the epicyclic gear train, the output shaft is connected to the sun gear. When it rotates planet gears also rotates and it connects to the input shaft and the output shaft efficiency is more. This gear meshes with and is surrounded by planet gears. The epicyclic gear train family, in general, has a central sun gear which meshes with and is surrounded by planet gears. In this case, the gear ratio is simply given by (S+A)/A where S is the number of teeth on the sun and A is the number of teeth on the annulus. The number of planet teeth is irrelevant. [2]

3.2 Planet Gear

Holds one or more peripheral planet gears, all of the same size, meshed with the sun gear. When the sun gear rotates all planet gears rotate at a circular area. In these planet gears, carrier is connected from that carrier a shaft takenout. The outermost gear, the ring gear, meshes with each of the planet gears. The more planet gears in the system, the greater the load ability and the higher the torque density. The planetary gearing arrangement also creates greater stability (it's a balanced system) and increased rotational stiffness. From these planet gears, carrier is connected and the input is given. Power transmission is done through these gears. Because through carrier connected to planets is given as input. [2]

3.3 Annulus Gear

An outer ring with inward-facing teeth that mesh with the planet gear. It is stationary it will not move.all planet gears are meshes with this annulus gear. If the annulus is held stationary and the sun gear is used as the output, the planet carrier will be the input. The gear ratio, in this case, will be 1/(1+A/S). This is the lowest gear ratio attainable with an epicyclic gear train. This type of gearing is sometimes used in tractors and construction equipment to provide high torque to the drive wheels. Three planet gears are meshes and rotated in this annulus gears. [2]

3.4 Carrier

The planet gears are held to a cage or carrier that fixes the planets in there orbit relative to each other. In the epicyclic gearing system, the planet gears are surrounded around the central gear. Those planet gears are connected to the carrier. The input shaft is given to it. In these gearing system, three planet gears are connected by the carrier that carrier is connected through three shafts to the planet gears. [2]

3.5 Bearings

The guidance and support of a rotating shaft require at least two bearings arranged at a certain distance from each other. For a bearing arrangement in a planetary gear, only one bearing is used depending on the application. The floating bearing arrangement is a simple and economical design solution for supporting planetary gears. In this type of bearing arrangement, the planetary gear can be displaced relative to the planetary gear carrier by the axial clearance “s”.

3.6 Casing

The casing encloses completely different sets of spur gears, bearings to support the shafts. The casing could be a part of the gear box, it provides support to the shaft, bearing and thence the gear loading. Using static analysis we the overall quantity of stresses and displacement is in the permissible limit, therefore the structure is safe. The static analysis has helped in developing an optimum design of gearbox casing.

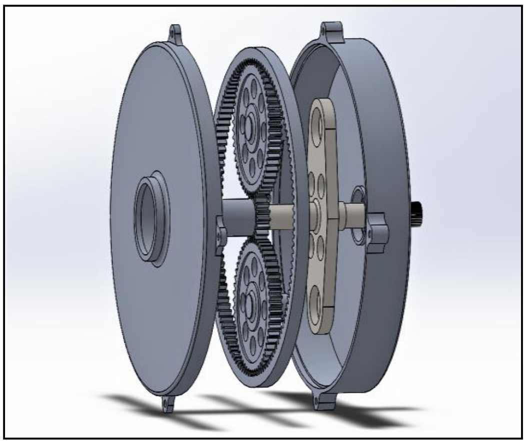

Fig. 2: Exploded view of Epicyclic GearBox

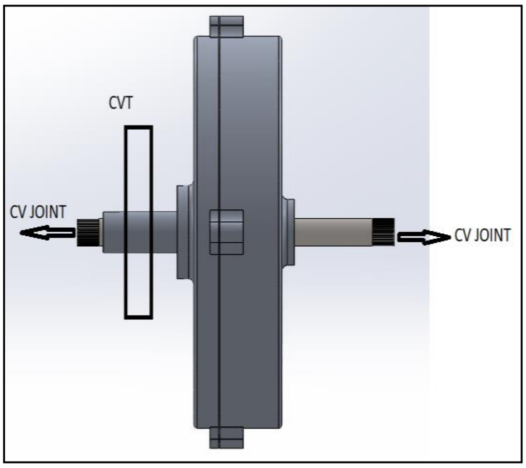

Fig. 3: Block diagram of transmission

4. DESIGN METHODOLOGY

The design of planetary gear trains consists of the following steps:

(a) Determination of reduction ratio
(b) Calculation of number teeth of sun, planets and ring gear.
(c) Force analysis
(d) Calculations of shaft diameter and bearing
(e) Calculation of shear and bending stress of Gears.
(f) Material and heat treatment Selection. [2]

4.1 Determination of Reduction Ratio

The reduction ratio in the planetary gear train is determined as below:-

$$Ratio = (PCD\ of\ Ring\ Gear + PCD\ of\ Sun\ Gear)/PCD\ of\ Sun\ Gear$$

Consider, Z_1, Z_2, Z_3 are Number of teeth of Sun Gear, Planet Gear and Ring Gear. [2]

$$Ratio = (Z1 + Z3)/Z1$$

4.2 Calculation of Number Teeth of Sun, Planets and Ring Gear

Consider, Z_1, Z_2, Z_3 are Number of teeth of Sun Gear, Planet Gear and Ring Gear.
Minimum no. of teeth for spur gear,

$$Zm = 2/sin^2\Phi$$

$$Zm = 2/[sin(20)\ ^2]$$

$$Zm = 17.09$$

$$Zm \approx 18\ teeth$$

Then, Sun Gear,

Assume No. of teeth for Sun Gear and Module to achieve our ratio and requirements;
Number of Sun Gear Teeth(z)= 26
Module =1.5 mm
Pitch circle diameter of sun gear = m*z

$$D = 1.5 * 26$$

D= 39mm and r = 19.5mm

Ring gear calculations,

$$G.R = (Ts + Tr)/Ts$$

Our reduction gear ratio is 6 to achieve the requirement

$$6 = (26 + Tr)/26$$

Tr = 130 teeth

Then Ring Gear Diameter,

$$D = m * Tr$$

$$D = 1.5 * 130$$

D= 195mm and R= 97.5mm

Planet Gear Calculations

$$Tr = Ts + 2 * Tp$$

$$130 = 26 + 2 * Tp$$

Tp = 52 teeth

Then Diameter of planet gear,

$$D = m * Tp$$

$$D = 1.5 * 52$$

D = 78mm and R= 39mm

We select the 20 full depth involute system,

$$Pressure\ angle = \Phi = 20\ \ and\ \ ha = 1m$$

5. APPLICATION

(a) It is used in military combat vehicles.
(b) It is used in muscle cars.
(c) It is used in the Antikythera Mechanisms.
(d) It is used in astronomical clocks.
(e) It is also used in book stand for proper orientation of books.
(f) It is used in commercial vehicles and tractors.

6. ADVANTAGES

(a) Compactness.
(b) High power density.
(c) Multiple kinematic combinations.
(d) Pure torsional reactions.
(e) Co axial shafting.
(f) Increased rotational stiffness.
(g) Equal distribution of load.
(h) Greater stability.
(i) Increased torque capability.
(j) Outstanding power transmission efficiencies

7. CONCLUSION

The main objective of this work was to redesign the planetary gear box which will be suitable for all-terrain vehicle has been designed with the targeted reduction ratio with the high torque. In the modified gear box, we have optimised space and we aligned both input and output co-axially. Hence it is seen that the optimization of gear box for high reduction ratio and space reduction is satisfied.

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