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Compatibility of Various High Ratio Gear Technologies to Fit in a Small Volume – A Review

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ABSTRACT:

In past few decades, the technological advancements have been high. Many technologies have been invented, designed and checked for working and safety. In the last three decades many scientists and scholars have contributed a lot, especially in the field of gear transmissions. In this research oriented paper, various technologies (Cycloid Drive, Harmonic Drive) available in gear transmission drives that can work efficiently when designed for high gear ratios and smaller diameters are compared to the conventional gear systems. The result of the study is a high ratio (greater than 100) gearbox with smaller diameters (less than 5 cm), high efficiency and dense transmission torque. This paper compares the present day technologies of the gearbox, the results of their calculated efficiencies.

INTRODUCTION:

In this competitive era, most of the machines are commercial. Usually in commercial machines, higher output is expected with lower input. Also, there are a few constraints on the weight, size and shape of the machines. Hence, many applications call for the need of lighter mechanical components example UAVs, aerospace vehicles, kitchen Aid equipment, house hold machines, etc. Apart from these applications, the reduction of size of gear box results in lower payload of aerospace vehicles, such as rockets, drones, aircrafts, etc.While considering weight reduction from a machine, the reduction of weight contributed by gears will be a huge contribution. Present day technologies available for gear transmission are: conventional gear drives (spur gear, helical gear etc), Harmonic Drive, 2- stage Hypocycloid Drive, single-stage cycloid drive.

THEORY:
Conventional gear system:

In conventional gear systems the multiplication of torque or reduction of speed is possible by employing two or more gears. A schematic view of a gear box using conventional gears is shown in Figure 1. The gears used in conventional gear boxes may be spur gears, helical gears, herringbone gear, face gears, bevel gears etc. As they employ external contact, the space occupied by them is also high.In a sun –planet model, (as shown in Figure 2) internal contact of gears is employed. It requires at least a sun gear, a planet gear and two pinion gears. When compared to the drives these weigh more. While designing, when the factor of safety is fixed to be 2 and the outer diameter of the largest gear is fixed to be 50 mm, then these tend to have higher thickness (higher face width). Higher face widths as compared to their diameter may pose serious problems such as bending of the gear. Hence the search for alternative technologies was essential.

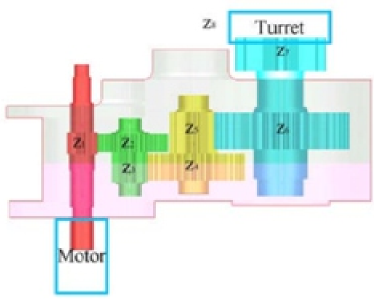

Figure 1 Schematic view of gear box with conventional gears

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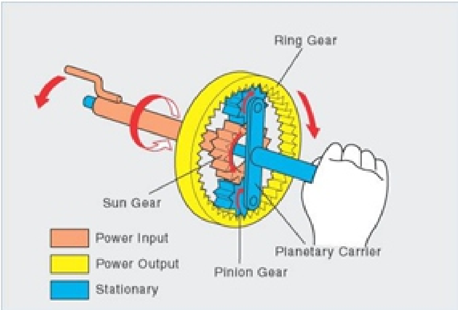

Figure 2 Sun-Planet gearing system

Various applications call for various gearboxes commercially available today. Among the ones available, widely used drives are: single stage cycloidal drive, 2-stage cycloidal drive, harmonic drive

Single stage cycloidal drive:

A single-stage cycloid disk in a cycloid drive has Z1 lobes and its housing is made of Z2 rollers, where Z2 is an integer higher than Z1. The output/input torque gear ratio is:

i= (Z_2-Z_1)/Z_1

Where,

i = Reduction rate

Z1 = number of teeth (lobes) on the cycloid disc

Z2= number of roller pins in the housing.

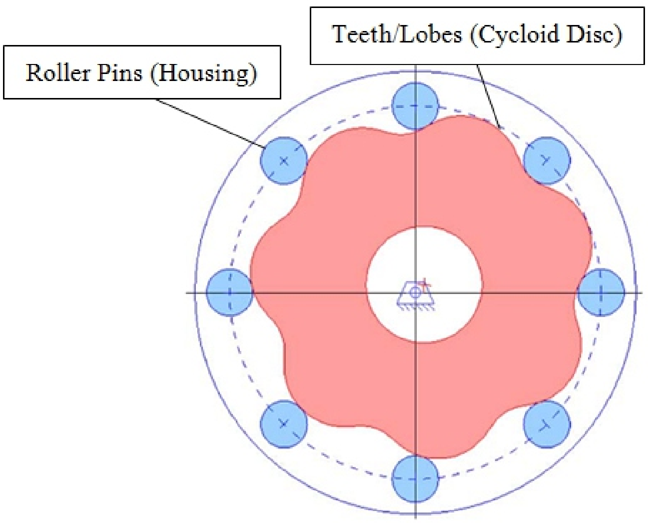

Figure 3 Shape of cycloidal drive

As the difference in number of teeth (lobes and pins) is only 1, the disc rotates in the housing with a small eccentricity. The roller pins of the housing act as cams, guiding the cycloidal discs motion. Normal reduction ratio range of the cycloidal drive is around 60:1 to 190:1. The cycloidal drive allows for relatively low effective input inertia owing to the single step reduction. However, this adds to the complexity in design. While typical cycloidal drives are claimed to provide for high load-carrying capacity, quiet operation, and shock load resistance, they suffer from relatively heavy weight and high stiction due to many contact elements and bearings, when designed for sizes higher than 40 cm. The value of backlash in these systems is nearly zero. Also this system does not have any serious vibration issues. Here, a major advantage of cycloidal drive is that its diameter (and/or module) can be selected depending on the application. But in conventional gearing systems independent selection of module is not possible.

2-stage cycloidal drive:

In 2 stage cycloidal drives, there is flexibility in choosing eccentricity, outer diameters, no of lobes and pins for housing independently.

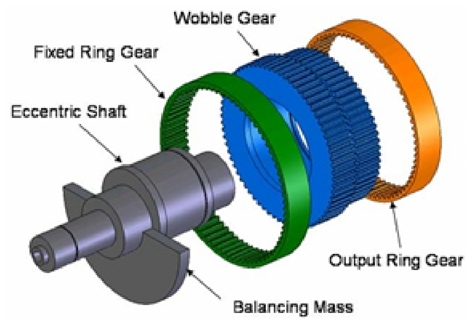

Figure 4 2-stage cycloidal drive

Figure 4 shows an expanded view of a typical 2-stage cycloidal drive assembly. It is basically composed of an eccentric shaft with balancing mass, wobble gear, stationary internal gear (shown as fixed ring gear), and output internal gear (shown as output ring gear).The operating principle is as follows. The eccentric shaft is connected to the motor input and drives the wobble gear against the stationary internal gear. The small eccentricity (e) of the shaft makes the wobble gear generate the hypocycloidal motion; the wobble gear rotates not only about its own axis but also about the axis of the gear train inside the two internal gears.

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This motion causes tooth number differencing between the two internal gears and thus relative motion. The simplicity in design and minimal number of parts make the 2-stage cycloidal drive easy to assemble and reduces the negative effects on gear contact due to the stack up of manufacturing errors.

The configuration of the HGT inherently allows for the widest range of reduction ratio, i.e., from 50:1 to 6500:1, and exceptional torque density (torque to weight/volume ratio). In combination with carefully designed tooth profiles, the 2-stage cycloidal drive is designed to provide high stiffness, low power loss, nearly zero backlash and lost motion, and smooth and quiet operation.

Harmonic drive:

The harmonic drive is composed of three main parts; wave generator, flexspline, and circular spline (Figure 5). Wave Generator: The wave generator is an oval-shaped cam with a thin ball bearing placed around the outer circumference of the oval cam. The wave generator is mounted onto the motor shaft.

Flex Spline: The flex spline is a thin, cup-shaped component made of elastic metal, with teeth formed along the outer circumference of the cup's opening.The gear's output shaft is attached to the bottom of the flex spline. Circular Spline:

The circular spline is a rigid internal gear with teeth formed along its inner circumference. These teeth are the same size as those of the flex spline, but the circular spline has two more teeth than the flex spline. The circular spline is attached to the gearbox along its outer circumference.

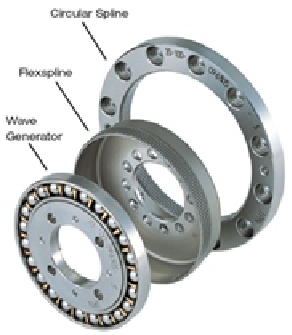

Figure 5 Components of harmonic drive.

The wave generator is connected to the prime mover input, and its elliptical shape causes elastic deflection of the flexspline as it rotates. Through two external-internal tooth meshes that are 180° apart, the flexspline drives the circular spline which is connected to the output load.

It is designed to provide for multiple tooth engagement (minimum of two at no load) at any given time resulting in nearly zero backlash (less than one arc-min). Its reduction ratio range is reasonably wide (approximately 50:1 to 200:1).

For these reasons, harmonic drives are widely used in applications requiring precision positioning, especially in robotics and semiconductor industries. Other advantages are simplicity in configuration, small number of parts, and good torque density.

Advantages of cycloidal and harmonic drive over conventional drives are

- Since power is transmitted through multiple teeth engagement harmonic gear drive offers high output torque capacity than conventional planetary gear drive having nearly twice its size and thrice its weight.
- High speed - reduction ratios from 50: 1 to 6500: 1 can be achieved using these drives.
- Cycloidal and Harmonic drive operates with zero backlash.
- The input and output shafts are coaxial hence drive becomes compact compared to other high ratio, high torque drives.
- These drives can also be used as reversible drives.

Before concluding, the above drives for their applications to smaller sizes let us compare their other parameters.

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Table 1 Comparison of various drives

Parameter	Cycloidal	2-stage cycloidal drive	Harmonic
Reduction Ratio	1	1	2
Volume/Weight	2	1	1
Load Capacity	2	1	2
Shock Resistance	1	2	1
Stiffness	3	1	3
Effective Inertia	1	2	1
Efficiency	1	1	2
Noise/Vibration	1	1	2
Backlash/Lost Motion	2	1	1

1 = Excellent, 2 = Good and 3 = Average

RESULTS AND DISCUSSIONS:

The above drives have been designed to check the compatibility of the current project. The design outcomes and comparisons are discussed in this section.

As discussed above, each drive can be designed independently for various applications. Hence freezing a few factors helps us in better understanding of the analysis.

The frozen design specifications of these drives are:

- Gear ratio = 100
- OD = 50 mm
- FS = 2
- Material : steel

The design of a gear train using the conventional gears was made. This involved 3 stages of power transmission when designed for spur gearing, i.e., it involves 3 sets of gears - pinion pairs. For a torque transmission of 100 Nm (output) and gear ratio 100, the face width of the largest member was 27 mm. And its efficiency was nearly 72 %.

In The crucial factor is the face width. Face width of various drives obtained are

- Cycloidal drive: 4.7 mm
- 2 stage cycloidal drive: 8.4 mm (combined face width of the rotor of both the stages)
- Harmonic drive: 13.5 mm

The second factor is the efficiency. The efficiencies are calculated by evaluating the power losses by first principles. The power losses in the gear transmission in general consist of sliding power losses (tooth friction losses), bearing power losses, rolling power losses, churning power losses, and windage power losses. Efficiencies of various drives obtained are

- Cycloidal drive: 91.1 %
- 2 stage cycloidal drive: 92.7 %
- Harmonic drive: 87.5 %

CONCLUSION:

From the above theory and results, we see that compared to the conventional drives, the drives studied in this paper are highly efficient when compared to the conventional drives when designed for a diameter of 50 mm. As the inertia is quiet less in the initial stages of torque transmission, the efficiency will definitely be high.

Using cycloid and harmonic drives, the gear reduction ratios of upto 1:6500 (max.) are attainable. Introduction of these compact drives help in reduction of power input to be supplied to the gear system. Thus, reducing the overall cost.

Neither cycloid nor harmonic drives are universally superior for all applications and conditions. However, cycloid drives should be considered for applications in robots and aerospace applications, where the need for precision and applications of back drivability are important. The harmonic drives especially can be recommended for those applications in which size, inertia, and efficiency take precedence over backlash and torque ripple.

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