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Comparison of Cycloidal, Heliocentric & Conventional Drive

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ABSTRACT: Conventional gear drives like helical, bevel, etc., require more than one stage when the ratio is higher which eventually increases the size of the gearbox. Cycloid drives are compact devices that offer great reduction ratios. In comparison with conventional gear drives, like helical, bevel etc., it can achieve much higher reduction ratios within the compact space or stage. In this paper, a comparison is made between Cycloidal drive, Heliocentric drive and Conventional drive.

KEYWORDS: Cycloidal Drive, Conventional Gear Drive, Heliocentric Drive, High reduction ratio.

I. INTRODUCTION

Conventional gearboxes like Spur, Worm, and Helical higher ratios can be achieved by adding additional stages of gearing as needed. With each additional stage of gearing, a backlash is created which decreases the precision of the gearbox. However, Helio and cycloid drives offer higher reduction ratios in a single stage with high precision.

Depending on the application, gear size can be a critical factor in deciding the type of drive required. The conventional drive has a shorter radial length and a longer axial length, while the cycloid or heliocentric drive has a longer radial length and a shorter axial length.

Cycloidal Drive

A cycloidal drive is comprised of four components: 1) the high-speed (low torque) input shaft, 2) a cycloidal disc (single or compound), 3) eccentric shaft (eccentric bearing), and 4) a slow speed (high torque) output shaft.

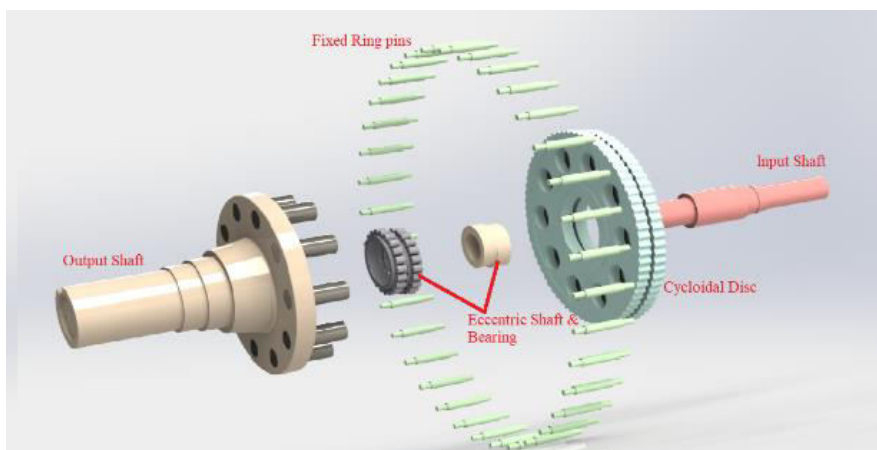


Fig.(a) Exploded view of Cycloidal drive

An eccentric cam (drive shaft) is used to drive a cycloidal cam or disc. There are fixed ring pins arranged around the eccentric shaft in a circle, and a cycloidal disc engages with those ring pins. The eccentric motion causes the cycloidal disc to rotate around the axis of symmetry due to its motion around these pins.

In contrast to the eccentric shaft, the cycloidal disc has holes that rotate clockwise. The output shaft engages these holes with roller pins. The output shaft which is coaxial with the input shaft and is driven by the cycloidal disc in this manner is attached to the centrally mounted output shaft.

Heliocentric Drive

Heliocentric Drive is comprised of two components: 1) an input shaft carrying a centrally located eccentric, and 2) a plunger holder coupled to an output shaft that rotates within a fixed rack at a rate of one tooth for each rotation of the input shaft and eccentric. Plunger holders are radially slotted to support a series of reciprocating plungers.

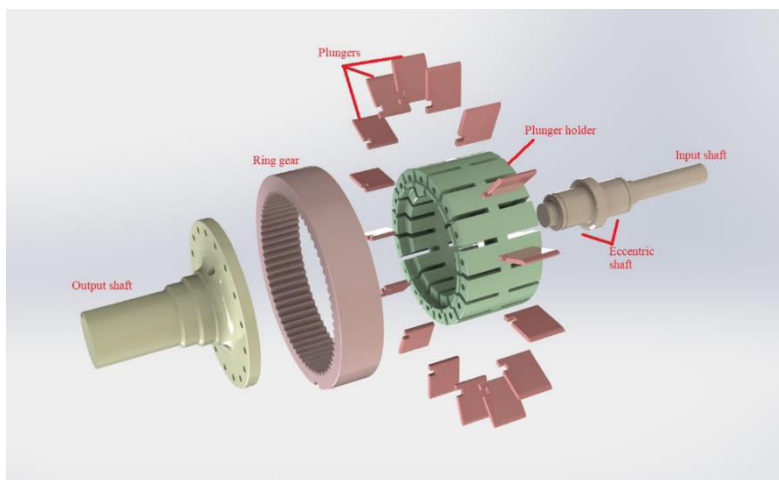


Fig.(b) Exploded view of Heliocentric drive

The shape of the rack teeth imposes a consistent motion on the plungers as they are forced outward and into the stationary rack by the eccentric on the input shaft. The output shaft is rigidly connected to the plunger holder, which causes a smooth, uniform rotation as the plungers gradually come into contact. When each reaches its stroke limit, it is retracted by a retaining ring that operates simultaneously with the eccentric. Heliocentric relies on this conversion of the series of plungers to slow rotational motion of the output shaft by engaging the plunger with ring gear or stationary rack.

Conventional Gear Drive

A conventional gear drive is comprised of four components: 1) the high-speed (low torque) input shaft, 2) a driving or pinion gear, 3) the driven gear, and 4) a slow speed (high torque) output shaft.

In many conventional gear drives, the input shaft and driving gear act as a single component which is called as Pinion shaft. The pinion shaft or driving gear then rotates the driven gear. i.e.) Gear is connected to the output shaft either using key or shrink fit.

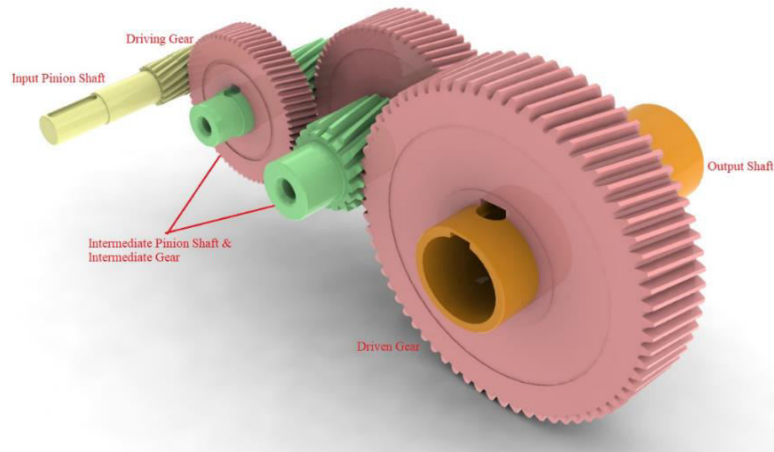


Fig.(c)Conventional gear drive

II. COMPUTATIONAL COMPARISON FOR CYCLOIDAL, HELIO AND CONVENTIONAL DRIVE

Methodology of Design

The key of the cycloid drive is cycloid disc. Its geometry plays a major role in the kinematics of the transmission. The profile of such a disc can be traced back to a cycloid. That's why the gearbox is called a cycloidal drive.

Calculation for Cycloidal

Cycloidal disc profile is generated using Solid Works software by using equation-driven curve method.

$$X = (m/2) * ((Z2 * \sin(t) - 0.7 * \sin(Z2 * t)) + ((2 * (0.7 * \sin(Z2 * t) - \sin(t)))) / (\text{sqrt}(1 - (1.4 * \cos(Z1 * t)) + x)))$$

$$Y = (m/2) * ((Z2 * \cos(t) - 0.7 * \cos(Z2 * t)) + ((2 * (0.7 * \cos(Z2 * t) - \cos(t)))) / (\text{sqrt}(1 - (1.4 * \cos(Z1 * t)) + x)))$$

Where,

m = module

Z2 = number of pins in roller

Z1 = number of lobes

x = coefficient of modification

The transmission ratio of the cycloidal drive can be determined by using the number of lobes Z1 and the number of pins Z2 on the cycloidal disc as follows:

$$\text{Ratio} = Z1/(Z2-Z1)$$

eg.) If the Number of lobes is 43, then the number of pins in the roller is 44. Therefore, the ratio is:

$$\text{Ratio} = 43/ (44-43)$$

$$= 43:1$$

The Number of lobes in Cycloidal Disc is always equal to the ratio of the gearbox.

Calculation for Heliocentric Drive

In Heliocentric, instead of a cycloidal disc, the teeth themselves are made in the rack and the plunger acts like a disc.

The transmission ratio of a Heliocentric drive can be determined as follows based on a number of teeth Z_h in the rack plus one.

$$\text{Ratio} = Z_h + 1$$

eg.) If Number of teeth in the rack is 42, therefore, the ratio is

$$\begin{aligned}\text{Ratio} &= 42 + 1 \\ &= 43:1\end{aligned}$$

Calculation for Conventional Gear Drive

In Conventional gear drive, instead of a disc or plunger, gears are used to transmit the power which is either spur, helical, bevel, or worm, etc.,

The transmission ratio of the conventional gear drive can be determined by using the number of teeth in driving gear Z_1 and the number of teeth in driven gear Z_2 .

$$\text{Ratio} = Z_2 / Z_1$$

eg.) If the number of teeth in driving gear is 18 and number of teeth in driven gear is 54 Therefore, the ratio is:

$$\begin{aligned}\text{Ratio} &= 54 / 18 \\ &= 3:1\end{aligned}$$

Complexity in Design

Unless like conventional gear drives like Helical, Spur, Worm arrangements, in Cycloidal, and Heliocentric drives don't require any gears for power transmission instead Cycloidal drive uses a disc and Helio drives use a plunger.

In assembly point of view, the cycloidal drive assembly is easier than the conventional gear drive since they use discs.

In Cycloidal, the ratio determines the number of lobes and pins for multiplying torque, whereas in Helio ratio determines the number of teeth in the rack.

Manufacturing

Conventional gear drives like Helical, Spur, Bevel, and Worm arrangements have gears and shafts need to be manufactured. In many conventional gear drives, the input shaft act as a driving gear. Also, gears manufacture by hobbing, shaping and requires profile grinding after heat treatment.

In Cycloidal drive, disc, shafts and ring gear need to be manufactured whereas, in Heliocentric drive, the plunger, ring gear, plunger holder and then shafts need to be manufactured.

The plunger concept in Heliocentric drive is much more complex to manufacture and assemble than conventional gears and cycloidal discs.

Cost of Manufacturing

Regardless on the increase of the ratio, Cycloidal or Helio drives attain the ratio within single stage.



If the ratio is increased in conventional gear drives, more stages are required and gears needed to manufacture will increase which increases the cost.

In Cycloidal drive, the manufacturing cost of the disc is less than the manufacturing cost of the gear. Even though the ratio increases, it can be achieved within the single stage than conventional gear drive.

Whereas in Heliocentric drive, the manufacturing cost is more than cycloidal drive because of the plunger. If the ratio is increased, it can be achieved within the single stage like cycloidal drive. But the number of plungers required to manufacture is also increased so, that the cost is also considerably more than cycloidal drive.

III. CASE STUDY

One of the Conveyor application gearboxes uses a heliocentric drive of Power 8 kW with an input speed of 1000 rpm and an output speed of 14 rpm. The Gearbox in this application must be compact, have high torque density, be permanently lubricated, and be quiet to operate. Initially it is planned to manufacture by using one of the conventional gear drive mechanisms called planetary system. But, it requires more than one stage to achieve the required ratio so, a cycloidal drive mechanism is approached for this application. Here are the detailed calculations:

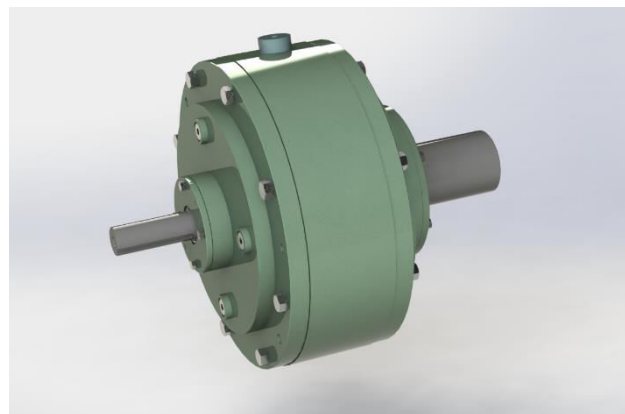
$$R = \text{Input RPM} / \text{Output RPM}$$

$$= 1000 / 14 = 71.42:1$$

Overall reduction ratio $R = 71.42$, convertible to cycloidal gear $R = 71:1$ ratio. In contrast to conventional gear drives, the conversion can be done in one step.

Hence, $R = 71$, Therefore $Z1 = 71$

If $Z1 = 71$, we get $Z2 = 72$.



Fig(d). Cycloidal gearbox

In conventional gear drive, it requires minimum two stages to achieve it, making it a more robust model than the cycloid drive.

or one of the conventional gear drives system called planetary which mostly uses spur gears, the reduction ratio $R = 71$ can be divided into the ratios $r1$ and $r2$. where $r1 = 1^{st}$ stage reduction ratio and $r2 = 2^{nd}$ stage reduction ratio.

Then, total reduction ratio $R = r1 * r2$

Assume, $Z1 = 17$, we get $Z3 = 133$, $Z2 = 58$, reduction ratio, $r1 = (Z3 + Z1) / Z1$.

Assume, $Z1 = 16$, we get $Z3 = 112$, $Z2 = 48$, reduction ratio, $r2 = (Z3 + Z1) / Z1$.

Therefore, overall ratio is determined by

$$r1 = (133+17) / 17 = 8.82:1$$



$$r2 = (112+16) + 16 = 8:1$$

$$R = 8.82 * 8 = 70.56:1$$

IV. RESULTS AND DISCUSSION

From the case study, it is obvious that a conventional gear drive requires a minimum of two stages to achieve the required ratio whereas Cycloidal drive achieves the ratio within a single stage. Both Heliocentric and Cycloidal Drives achieve this ratio by Single stage. However, the heliocentric drive requires a more complex design than the cycloidal drive, and the cycloidal drive is also a modified version of the heliocentric drive. The results obtained in the case study are compared based on conventional gear drives and cycloidal drives.

Table (1): Comparison table of conventional gear, cycloidal and heliocentric drive

S.No.	Conventional Gear drive	Cycloidal Drive	Heliocentric Drive
Accuracy	If positioning accuracy and lost motion are not a concern, conventional gear drives are good.	When application requires high positioning accuracy and a minimum lost motion work, cycloidal drives are best.	Same as Cycloidal drive.
Ratio	Conventional gear drive work on small ratio. It requires additional stage for higher ratio.	Cycloidal drive works well on a high ratio without additional stage.	Heliocentric drive also works well on a high ratio without additional stage but more components added than cycloidal drive.
Size	Depends on ratio, size of the gearbox increased.	It is compact compared to Conventional gear drive because of elimination an additional stage when ratio is increased.	Compact in size compared to conventional but slightly increased than cycloidal drive.
Backlash	Conventional drives are subjected to backlash errors	Nearly Zero backlash.	Nearly Zero Backlash.
Speed	Conventional gear drive works well on high-speed application.	Efficiency of the cycloidal drive decrease on high speed application.	Efficiency of the Heliocentric drive decrease on high-speed application but comparatively more on cycloidal drive.
Maintenance	Conventional gear drive require maintenance more often than cycloidal drive.	Doesn't require more maintenance and also have more life than conventional gear drive because of gearless design.	Require more maintenance than Cycloidal drive because of the plungers. If breakdown occurs, repairing time also increased.

V. CONCLUSION

1) Reduction ratio of 71:1 is achieved in a single stage on Cycloidal drive or Heliocentric which can be achieved in two or more stages with Conventional gear drives like Spur, Helical, Bevel, etc.

2) Achieving this ratio with heliocentric gear requires a more complex design and more cost, but it's require simpler design in cycloidal drive and also compact in size compared to conventional gear drives.

3) Cyloidal and Helio drives are suitable for inline application. If application like parallel axis, intersecting axis, non-parallel & non-intersecting axis, additional conventional drives like spur, helical, bevel need to be added with Cycloidal and Heliocentric drives.



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