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PRECISION GEARHEADS

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USING GEARHEADS IN MOTION CONTROL

Precision Planetary vs. Harmonic/Cycloidal drives

INTRODUCTION

When selecting a gear drive to build into demanding servo and stepper motor applications such as robotics, machine tools, and injection molding machines, there are many choices. Trying to achieve higher performance characteristics like high torque, speed and load ratings, while maintaining low backlash, is the desired goal for any gearhead manufacturer. The main objective is to achieve a long lasting, high performance product which will save the end-user money. A gear drive allows a customer to downsize the motor and amplifier needed in a system, and will result in reduced overall system cost.

This technical paper will compare state-of-the-art planetary gearheads to other common types of drives in use today. It will give a description of the harmonic and cycloidal drive styles, and compare the features and benefits of the planetary to these two different types of gear drives in terms of technology and performance.

PRECISION PLANETARY GEAR DRIVE

BAYSIDE PLANETARY GEARHEAD

Planetary gearheads can often be used in place of other styles of gear drives in a variety of applications, such as robotic painting applications, where precise motion is absolutely necessary. Precision planetary gearheads are high torque, low backlash gearheads which are designed for use in high performance applications. Their advantages are that they allow:

- **high input speeds - exceeding 5000 RPM with peak input speeds of up to 10,000 RPM.**
- **low backlash - less than 3 arc minutes.**
- **compact design to accommodate applications where space is a limiting factor.**
- **less than 68db, while still offering exceptionally high torque-carrying capabilities.**

Today's planetary gearheads achieve much quieter operational levels than ever before

The planetary drive also allows ratios of, 3:1 through 100:1, (and sometimes higher) while harmonic and cycloidal drives cannot offer low ratio options; typically below 50:1.

There are many different types of planetary gearheads. The hybrid planetary has a high-torque planetary stage adjacent to the gearhead's output, and a high-speed input spur gear stage adjacent to the motor. The simple planetary has a spur gear planetary section adjacent to the output, directly driven by the input drive gear. The latest technolgy, the helical planetary, uses all-helical planetary stages to increase torque and stiffness (30% over the simple planetary) while running up to 10 db quieter.

Today's planetary gearbox, in contrast to when the technology was first introduced (the age of Henry Ford and the Model T transmission), has seen improvements which have led to longer lasting gearboxes. The output shaft and the planet carrier section are made of one-piece steel construction which increases load carrying capacity. Planetary sections previously were made of two or more separate parts, often welded or staked together. New heat treating processes, such as Plasma Nitriding, have provided a new way to further increase the life and strength of the planetary gear. Plasma Nitriding will harden the gear surface to 66Rc while keeping the core duc-

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tile. This allows the planetary gear to resist wear and stand up to high shock loads found in severe duty applications.

Planetary Technology

A planetary section works as follows: Power is transmitted from the motor to the sun gear (the input gear of the planetary section), either directly or through an internal spur gear cluster adjacent to the sun gear. The sun gear drives three planet gears which are uniformly spaced and rotating around the sun gear. The planetary gears are contained within an internal tooth ring gear, held stationary by the planetary housing. With new technology, the ring gear is machined right into the inside of the housing, keeping the gears from disengaging under heavy loads. The planet carrier, which is part of the output, supports the planet gears. The planet gear and carrier rotate, so the output shaft automatically rotates inside the stationary ring gear as the sun gear drives it. The number of teeth in the sun gear and the number of teeth in the ring gear determine the reduction ratio of the planetary carrier section only. The equation for this is as follows:

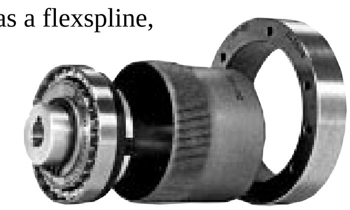
$$\text{Ratio} = 1 + \frac{N_{Ring}}{N_{Sun}}$$

N = the number of teeth

In order to offer a range of ratios, you have to combine the planetary carrier section with a spur gear input section in a hybrid planetary, or multiple stages in a simple planetary. Due to load sharing among the planet gears, the torque carrying capacity of the planetary is high, leading to extremely high reliability and life. The transmitted power through the gear drive is not only higher in torque than what was input, but lower in speed (the gear drive can also be used as a speed increaser/torque decreaser).

HARMONIC GEAR DRIVE

The harmonic gear drive is an epicycloidic design featuring a flexible cylinder, known as a flexspline, which allows this drive to achieve near-zero backlash (less than 1 arc minute). It is made up of three parts:



- **Circular Spline** - a solid, thick walled ring with internal teeth.

- **Flexspline** - a thin walled, flexible steel cylinder with external teeth machined on the outside. It is slightly smaller than the circular spline. The number of teeth on the flexspline is less than the number of teeth on the circular spline. (generally 1 to 2 fewer teeth).

- **Wave Generator** - is an elliptical cam enclosed in a bearing assembly. When inserted within the flexspline, it transfers its elliptical shape, leading to the engagement of the external teeth of the flexspline with the internal teeth of the circular spline. This occurs at two points: 180 degrees apart, between the flexspline and the circular spline.

The constant tooth contact achieved by having the teeth mesh at two different points allows the Harmonic Drive to achieve less than 1 arc minute backlash. The number of teeth on the inside of the circular spline and on the outside of the flexspline determines the reduction ratio to be achieved. The equation for this is as follows:

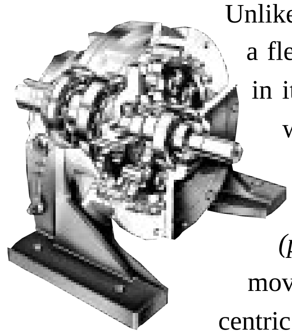
$$GR = \frac{FS}{CS - FS}$$

where: **GR** = **Gear Ratio**
FS = **Number of teeth on the flexspline**
CS = **Number of teeth on the circular spline**

Due to its inherent low torsional stiffness, distinct speed/torque ripple, and low efficiency, the harmonic drive can be a problem for certain precision applications (e.g. painting applications in automotive plants). The following section on gear drive comparisons will describe in greater detail, the planetary's advantages in many different areas.

CYCLOIDAL (PLANOCENTRIC) GEAR DRIVE

The cycloidal (planocentric) drive is a design which employs eccentric motion to achieve its speed reduction. It uses non-circular or eccentric motion to convert input rotation into a wobbly cycloidal motion. This motion is then converted back into a circular output rotation. During this process, speed reduction occurs.



CYCLOIDAL REDUCER

Unlike Harmonic drives, which employ a flexible cylinder that doesn't move in its entirety, but stretches to mesh with the internal circular spline gear to achieve a type of cycloidal motion, the cycloidal *(planocentric)* drives will actually move the entire internal gear in an eccentric motion. This design has achieved redution ratios as high as 200:1, in a small package.

However, like the harmonic drive, the cycloidal also has some deficiencies such as low torsional stiffness, and low efficiency compared to the planetary (which will be addressed in the comparison section.)

THE ADVANTAGE COMPARISON

As we have seen, each gear drive has an advantage that makes it desirable for a particular type of application, such as robotics requiring precise motion. This section will compare the planetary gear drive with the harmonic and cycloidal (planocentric) gear drives on the topics of lost motion, ratios, speed and torque ripples, gear drive preload, and efficiency/ life.

LOST MOTION

Lost motion is defined as total system backlash. It is a combination of tooth backlash, torsional stiffness, and hysteresis, which all add up to some lost motion in the gear drive system. Lost motion is a key measurement in motion control applications and provides a more complete picture of gearhead accuracy. Backlash is the most commonly used gauge of lost motion, but the drawback to using this measurement alone is that it only tells the system designer about the lost motion between gear teeth. When taking into account the factors of torsional stiffness and hysteresis, we can determine how the gear drive will perform within systems requiring heavy loads and high positional accuracy.

Harmonic and cycloidal (planocentric-type) drives, as mentioned before, have less than 1 arc minute backlash. Today's planetaries can achieve less than 3 arc minutes of backlash, considering some spacing is required to allow for lubrication and expansion of the gears. The near-zero capability of harmonic and cycloidal is offset by their inherently low torsional stiffness, and greater hysteresis as compared to a planetary gearhead. The cycloidal has a higher torsional stiffness than the harmonic, but not as high as the planetary. From the previous descriptions of harmonic and cycloidal drives, we saw that there was flexibility and wobbly motion. This lack of torsional stiffness often negates the advantages of near-zero backlash. Positional accuracy is extremely important in most motion control applications, such as robotics and machine tools, and the high stiffness of a planetary gear drive is required. Out of these three technologies, planetary gearheads exhibit the least amount of lost motion.

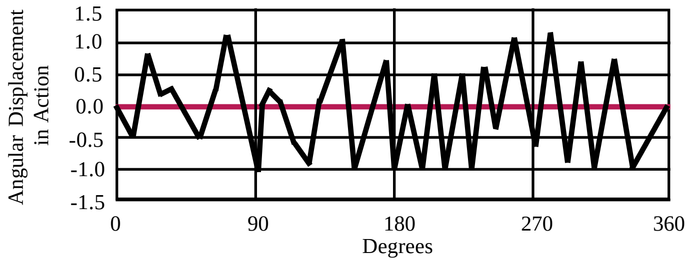
RATIOS

Harmonic and cycloidal drives are able to achieve ratios as high as 200:1 within a single stage, while maintaining moderate efficiencies. The disadvantage is that it leaves out low ratio applications which require ratios sometimes as low as 3:1. These technologies do not achieve ratios below 50:1 effectively. The planetary can achieve high ratios, generally 100:1, with very high efficiencies. They can also go as low as 3:1, making the planetary more suitable to a wider range of applications. This large range of ratios is achieved within the same size package by changing the carrier section, or changing some of the internal spur gear clusters used in a hybrid planetary. The dimensions for the input, output, or the pinion gear will not change when different ratios are chosen. Higher ratios can be achieved with some modifications, if necessary.

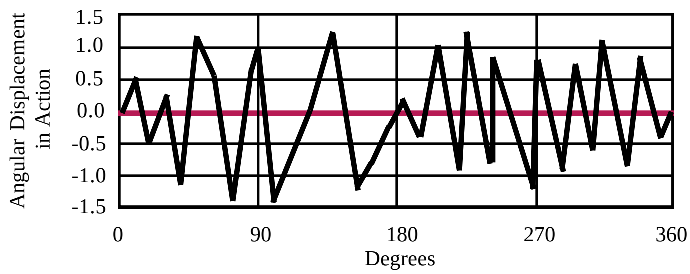
SPEED AND TORQUE RIPPLES

Harmonic and cycloidal type drives will exhibit speed and torque ripples because of their methods of transmitting motion. The inherent eccentric motions inside of these drives translate into the ripple (non-linear speed and torque output), and are especially evident at slow speeds. This can be problematic in industries where smooth motion is an absolute necessity, (i.e. automotive painting, gluing, and plasma or laser cutting applications.) High precision planetary gearheads, (which are essentially gears rolling against each other), provide almost perfect linear speed and torque outputs. This is true at all speeds and loads imposed on the planetary gear drive.

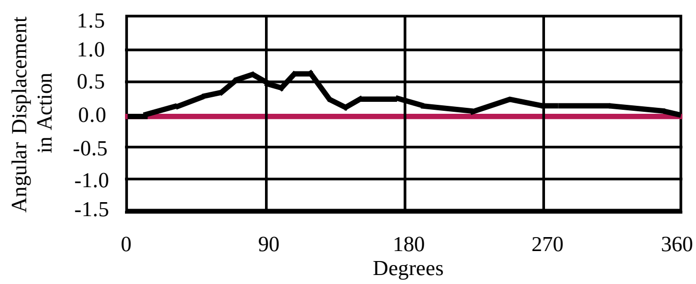
(see charts on next page for comparison of smooth planetary motion versus eccentric cycloidic and harmonic motion)



RIPPLE FOUND AT THE OUTPUT OF THE CYCLOIDAL DRIVE DURING OPERATION.



RIPPLE FOUND AT THE OUTPUT OF THE HARMONIC DRIVE DURING OPERATION.



RIPPLE FOUND AT THE OUTPUT OF THE PLANETARY DRIVE DURING OPERATION.

GEAR DRIVE PRELOAD

Harmonic drives must have sufficient preload on the flexspline and bearings to achieve less than 1 arc minute backlash. This will significantly decrease the effective life and efficiency of the unit. Planetary gear drives do not have flexible parts that require a preload. If the planetary gear drive capabilities are utilized within their specifications 50,000+ hours of life can be realized.

EFFICIENCY/LIFE

Planetary gear drives have the advantage of longer life and reliability compared to harmonic and cycloidal drive technologies. Generally, gearing that follows a rolling action (planetary), as opposed to total or partial sliding action, (harmonic and cycloidal), will generally be of a higher efficiency and longer life. Planetary drives have an efficiency of above 90% while harmonic and cycloidal drives average 80% and 70% efficiency, respectively.

FEATURE SUMMARY

	Harmonic	Cycloidal	Planetary
Backlash	< 1 arcminute	< 1 arcminute	< 3 arcminute
Stiffness	Low	Moderate	High
Efficiency	80%	70%	92%
Input Speed	3000 RPM	3000 RPM	5000 RPM

CONCLUSION

Today's motion control applications have become more demanding and will require that gear drives keep up the pace. New designs in servomotors require that gearheads handle higher input speeds and greater torques while exhibiting quieter operation. Today's planetary gearhead will be able to step up to these new challenges with peak input speeds up to 10,000 rpm and with operation noise below 65db. Additionally, state of the art technology has allowed higher torque and increased life through new helical planetary gear designs and heat treatment processes.

The many advantages of planetary gearheads that have been mentioned such as; no speed or torque ripples, no need for preloading, and the two of three components of lost motion, (torsional stiffness and hysteresis), that outweigh the advantage of near-zero backlash in harmonic and cycloidal drives, make the planetary a very attractive option in many of today's demanding applications; such as robotics, webs, and precision machine tools.

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