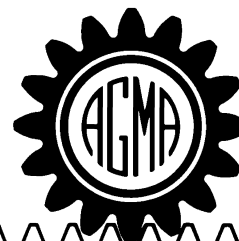


Precision Planetary Servo Gearheads

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American Gear Manufacturers Association



TECHNICAL PAPER

Precision Planetary Servo Gearheads

Gerhard G. Antony, Neugart USA LP and Arthur Pantelides, mG miniGears North America

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Modern automated machineries are increasingly using flexible high dynamic servomotors because of their ability to speed up and flexibly automate complex motions these machineries need to perform. Planetary gearheads are used frequently in conjunction with servomotors to match the inertias, lower the motor speed, boost the torque, and at the same time provide a sturdy mechanical interface for pulleys, cams, drums and other mechanical components.

This paper addressing following topics:

- main reasons why the planetary (epicyclical gear systems) are the preferred choice for "servo applications" (applications using servo motors);
- what influencing the positioning accuracy repeatability of a planetary servo gear;
- helical gears in planetary systems;
- the rating practices establishing a transparent "comparability" of different torque listings;
- introduction of a simple reliable method to the required gearbox torque rating for a servo-application based on the selected motor torque data.

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Precision Planetary Servo Gearheads

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Because of their versatility as well as their ability to speed-up and automate a wide-range of highly-complex motion sequence programs required in many of today's industries, computer-controlled, programmable, highly dynamic-capable servo motors are increasingly being used in modern machinery required in complex automation applications. Precision planetary gearheads are frequently used in conjunction with such servo motors in order to: balance inertial loading conditions seen during frequent speed cycling sequences, decrease motor speeds, and boost torque, while at the same time, provide a robust mechanical interface for pulleys, cams, drums, and other mechanical transmission components.

This paper shall present a foundation and fundamental approach for understanding why the planetary system is the preferred design choice for servo gearheads; clear up some misconceptions about planetary servo gearheads; compare rating practices by establishing a transparent comparability of different torque listings; and introduce a simple and reliable method of determining the required gearbox torque rating for a selected servo motor/gearbox application.

Main topics covered in the paper shall be:

- The planetary (epicyclic) gear system as the "system of choice" for servo gearheads;
- The best "balanced" planetary ratio from a torque density point of view;
- The gearhead design influence on positioning-accuracy and repeatability;
- Typical dynamic servo applications and servo gearhead torque ratings;
- How to establish comparative torque ratings;
- Sizing/selection of servo gearheads for matching AC servo motors in automation applications.

1. The Planetary (Epicyclic) Gear System as the "System of Choice" for Servo Gearheads

Frequent misconceptions regarding planetary gears systems involve backlash: *planetary systems are used for servo gearheads because of their inherent low backlash; low backlash is the main characteristic requirement for a servo gearboxes; backlash is a measure of the precision of the planetary gearbox.*

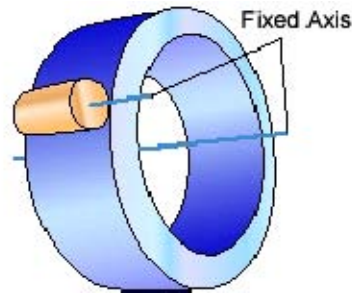
The fact is, fixed-axis, standard, "spur" gear arrangement systems can be designed and built just as easily for low backlash requirements. Furthermore, low backlash is not an absolute requirement for servo-based automation applications. A *moderately*-low backlash is advisable (in applications with very high start/stop, forward/reverse cycles) to avoid internal shock loads in the gear mesh. That said, with today's high-resolution motor-feedback devices and associated motion controllers it is easy to compensate for backlash anytime there is a change in the rotation or torque-load direction.

If, for the moment, we discount backlash, then what are the reasons for selecting a more expensive, seemingly more complex planetary systems for servo gearheads? What advantages do planetary gears offer?

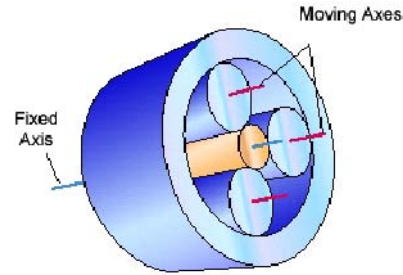
High Torque Density - Compact Design

An important requirement for automation applications is high torque capability in a compact and light package. This high torque density requirement (a high torque/volume or torque/weight ratio) is important for automation applications with changing high dynamic loads in order to avoid additional system inertia.

Depending upon the number of planets, planetary systems distribute the transferred torque through multiple gear mesh points. This means a planetary gear with say three planets can transfer three times the torque of a similar sized fixed-axis "standard" spur gear system. Reference Figure 1.



Fixed axis "standard" gear



Planetary "Epicyclical" gear system

Figure 1.

Rotational Stiffness/Elasticity

High rotational stiffness, or minimal elastic windup, is important for applications with elevated positioning accuracy and repeatability requirements; especially under fluctuating loading conditions. The load distribution unto multiple gear mesh points means the load is supported by N contacts (where N = number of planet gears) increasing the torsional stiffness of the gearbox by factor N . This means it considerably lowers the lost motion compared to a similar size standard gearbox; and this is what is desired.

Low Inertia

Added inertia results in an additional torque/energy requirement for both acceleration and deceleration. The smaller gears in planetary system result in lower inertia. Compared to a same torque rating standard gearbox, it is a fair approximation to say that the planetary gearbox inertia is smaller by the square of the number of planets. Again, this advantage is rooted in the distribution or "branching" of the load into multiple gear mesh locations.

High Speeds

Servomotors run at high rpm, hence a servo gearbox must also operate in a reliable manner at high input speeds. For servomotors 3,000 rpm is practically the standard and in fact speeds are constantly increasing in order to optimize more and more complex application requirements. Servomotors running at speeds in excess of 10,000 rpm are not uncommon. From a rating point of view with increased speed the power density of the motor increases proportionally without any real size increase of the motor or electronic drive. Thus Amp rating stays about the same while only the Voltage must be increased.

An additional, important factor is in regards to lubrication and operating speed. Fixed-axis spur gears will exhibit lubrication "starvation" and quickly fail if running at high speeds because the lubricant is slung away. Only special means such as expensive pressurized forced lubrication systems can solve this problem. On the other hand, grease lubrication is impractical because of its "tunneling effect," in which the grease, over time, is pushed away and cannot flow back into the mesh.

In planetary systems the lubricant *cannot escape* — it is continuously redistributed, "*pushed and pulled*" or "*mixed*" into the gear contacts, ensuring safe lubrication practically in any mounting position and at any speed. Furthermore, planetary gearboxes can be grease lubricated. This feature is inherent in planetary gearing because of the relative motion between the different gears making up the arrangement.

2. The Best "Balanced" Planetary Ratio from a Torque Density Point of View

For easier computation it is preferred that the planetary gearbox ratio is an exact integer (3, 4, 6 ...). Since we are so used to the decimal system, we tend to use 10:1 even though this has no practical advantage for the computer/servo/motion controller. Actually, as we will see, 10:1 or higher ratios are the weakest, using the least "balanced" size gears and hence have the lowest torque rating.

This paper addresses "simple planetary" gear arrangements, meaning all gears are engaging in the same plane. The vast majority of the epicyclical gears used in servo applications are of this "simple planetary" design. Figure 2a illustrates a cross-section of such a planetary gear arrangement with its central sun gear, multiple planets (3), and the