

Design of a High Ratio, Ultra Safe, High Contact Ratio, Double Helical Compound Planetary Transmission for Helicopter Applications

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American Gear Manufacturers Association



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[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

An ultra-safe, high ratio compound planetary transmission, for application as a helicopter main rotor drive, has been designed under the sponsorship of the National Rotorcraft Technology Center- Rotorcraft Industry Technology Association (NRTC/RITA). It is anticipated that this new planetary transmission offers improvements relative to the current state-of-the-art including, reduced weight, reduced transmitted noise and improved fail-safety. This paper discusses the analysis and design results for the subject planetary transmission. Fabrication and testing of the transmission will be conducted in subsequent phases of the project.

Typically, the final stage in helicopter main rotor drives consists of one or two simple planetary stages which themselves are composed of a sun gear, multiple planet gears (typically between 3 and 6) and an internal gear which is generally the fixed member of this epicyclic system. The main rotor transmission is the most critical and usually the heaviest assembly in the drive system for any rotary wing aircraft, be it a single or tandem rotor helicopter or a tilt rotor vehicle.

The new ultra-safe, high ratio planetary transmission design utilizes a compound planetary configuration with a 17.5:1 reduction ratio which would replace a conventional two stage simple planetary transmission. The new design uses ultra-safe principles such as split-torque paths and high combined contact ratio gearing. Double helical gears in the planet/ ring meshes balance axial tooth forces so that axial bearing reactions are not required. The spur gear sun/planet meshes are staggered to achieve a compact spatial arrangement.

In order to provide major, simultaneous improvements in weight, noise, power density, and reliability, a paradigm shift must occur in the basic design of the gear system in this component. This program brings together a large number of individual gear system innovations which, taken together, are expected to yield a large improvement in noise and performance combined with improved reliability and fail safety.

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Introduction

Currently, the final gear reduction stages in virtually all helicopter main rotor drives consist of one or two simple spur planetary stages. These simple planetaries are composed of a sun gear, multiple planet gears (typically between 3 and 6) and an internal gear that is generally the fixed member of this epicyclic system. While this proven concept provides relatively good power transmission efficiency, it has a tendency to generate high noise levels due to the limited contact ratio of the individual gears and the multiple, often simultaneous, tooth contacts of the several planet gears.

The simple planetary drives often used in helicopter main transmissions are subject to several technical limitations. Load capacity is limited as a function of the number of planets that can be accommodated within the internal gear that is, itself sized by the combination of ratio requirements and allowable stress limits. The planet bearings, which are generally mounted in the bore of each planet gear, must be sized to carry the applied loads and to allow a minimum rim thickness under the planet gear teeth. This requires the planet gear and bearing to be optimized as a unit. In addition, more planets improve load capacity but as the reduction ratio is increased, the number of planets that will fit in the annulus between the sun and ring decreases. Practical reduction ratios, which can be obtained from one-stage simple planetary systems, are limited by geometry to approximately 5:1. Because of this limitation, two stages (or more) are often required to obtain higher reduction ratios.

Because the simple planetary system is densely packed, a gear tooth failure is generally very destructive as the high power density and very limited space among the

gears prove to be a vulnerable configuration. While it might seem, on the surface at least, that the use of multiple planets would provide parallel load paths, which might offer some redundancy, quite the opposite is true. In a conventional design, the planets themselves provide little in the way of fail-safety; rather the dense package almost assures consequential damage will occur. Another consideration is that when a planet gear loses load-transmitting capability, the internal load balance of the planets is compromised so that radial mesh loads are no longer balanced on both the sun and internal ring gears.

Technical Approach

Despite the limitations cited above, the planetary gear system, in a general sense, is far from obsolete. Many still serve quite well in applications flying all over the world. One aircraft which utilizes a two-stage simple planetary design is the CH-47D Chinook helicopter. While this transmission system was designed in the late 1970's, it continues to be a reliable and efficient gearbox to this day. However, improvements are necessary for the next generation of rotorcraft transmissions. Rather than scrapping the entire concept, an improved planetary concept has been investigated that retains that which is good about the simple planetary and adds specific features or design enhancements. These features are directed at increasing load capacity, improving system safety and the ability to withstand single tooth faults, while decreasing the generated noise level and reducing weight.

To circumvent the limitations of current planetary designs and to investigate improved gear arrangements for helicopter main rotor drives, a high ratio, Ultra-Safe,

high contact ratio, staggered and intermeshed planet, double-helical compound epicyclic gear system concept was developed. This gearbox arrangement is intended to provide simultaneous improvements in load capacity, noise level, and system safety.

A technical effort, under the sponsorship of the National Rotorcraft Technology Center-Rotorcraft Industry Technology Association (NRTC/RITA), with the following objectives is currently being conducted to address this improved planetary speed reducer design:

1. Develop the concept configuration and basic gear system design for an improved planetary gear system – with the following technical goals:
 - Reduce planetary subsystem weight by 25% compared to the CH-47D baseline planetary
 - Reduce transmitted noise at planetary operating frequencies by 10 dB compared to the CH-47D baseline planetary
 - Improve tolerance for defects and damage
2. Produce detailed designs for all components and test configuration hardware
3. Fabricate the improved planetary, including the sun, planet, and internal gears and the supporting carrier
4. Test the improved planetary transmission in a full-scale (CH47D) test configuration to simulate operational characteristics and verify the concept.
5. Demonstrate, via test, the weight and noise reduction achieved relative to the baseline planetary subsystem.

As of this writing, items 1 and 2 are complete. Item 3, test component fabrication, is currently underway. Testing and evaluation is scheduled for completion

in 2005. There are basically three major milestones in this program – design, manufacture, and test. Of course, each of these major accomplishments is based on the successful completion of a number of interrelated tasks.

Design Approach

The CH-47D Chinook rotor transmission planetary drive was selected as the baseline application for the design study. Currently, this transmission utilizes a two-stage conventional spur gear planetary design with fixed internal ring gears. Torque is supplied to the first stage sun gear that, in turn, meshes with four planet gears. First stage output is via a planet carrier that drives the second stage sun gear. The second stage sun meshes with six planets and the second stage carrier drives the helicopter rotor shaft to turn the helicopter main rotor blades. This two-stage planetary provides a reduction ratio of 17.47-to-one. The planetary gears are designed for continuous operation at 4,500 horsepower at 225 RPM output.

From initial concept studies, a planetary configuration emerged that can potentially meet the performance goals of an improved planetary design in the CH47D main rotor drive application. A compound planetary configuration, with unconventional features, has the potential to improve a simple planetary drive. Compound planetary designs are not new. They are used in automotive, off-road, and gas turbine applications and, more recently, in helicopter main rotor transmissions.

In their traditional arrangement, compound planetary reducers encounter some of the same limitations as simple planetary drives. However, enhancements to the basic compound epicyclic drive arrangement allow an increase in load capacity, reduction in weight and envelope, reduction in noise, and improved damage tolerance through fail-safety. We will examine each of these aspects as they pertain to the CH-47D transmission design.

A load capacity limiting factor of the simple planetary arrangement is the number of