

Fabrication, Assembly and Test of a High Ratio, Ultra Safe, High Contact Ratio, Double Helical Planetary Transmission for Helicopter Applications

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American Gear Manufacturers Association



TECHNICAL PAPER

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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 planetary transmission, for application as a helicopter main rotor drive, has been designed, fabricated and tested under the sponsorship of NRTC-RITA. The anticipated improvements offered by this new planetary transmission are reduced weight, reduced transmitted noise and improved fail-safety. This paper discusses the fabrication assembly and test results for the subject planetary transmission. The design and analysis of this transmission system have been discussed in a previous paper presented at the AGMA FTM in 2004.

The 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.

Fabrication and assembly of the components for this transmission are complicated by their configuration. The grinding process for the helical gears must use small diameter wheels due to the proximity of the adjacent helix, since most the gears in this configuration are integrated designs. Assembly procedures also require special consideration because of the integrated design and helical gears. Test results are presented to support the goals of this project, including, concept verification, weight reduction, noise reduction and determination of the operating characteristics of the test transmission.

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Fabrication, Assembly and Test of a High Ratio, Ultra-Safe, High Contact Ratio, Double Helical Compound Planetary Transmission for Helicopter Applications

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Introduction

An ultra-safe, high ratio planetary transmission, for application as a helicopter main rotor final drive, has been designed, fabricated and tested under the sponsorship of National Rotorcraft Technology Center – Rotorcraft Industry Technology Association (NRTC/RITA). The improvements offered by this new planetary transmission are reduced weight, reduced noise and improved fail-safety and efficiency. This paper discusses the fabrication, assembly and testing of the improved planetary transmission. The design and analysis of this transmission system have been discussed in a previous paper presented at the AGMA FTM in 2004 [1].

An existing helicopter rotor transmission planetary drive served as the baseline for comparison to the improved transmission design. The existing CH47 system 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 the 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-1.

The new double helical planetary (DHP) system design uses a compound planetary arrangement with innovations such as staggered planets and high combined contact ratio gearing in a unique configuration. Double helical gears in the planet/ ring meshes balance axial tooth forces so that axial planet bearing reactions are not required. The spur gear sun/planet meshes are staggered to achieve a compact spatial arrangement. The sun gear is fully floating. 'Proof-of-Concept' or demonstration testing of a full scale prototype DHP transmission has recently been completed. This testing has demonstrated successful operation of the DHP transmis-

sion. Preliminary evaluation of the data recorded in the test suggests that reduced weight and improved efficiency have been achieved. These parameters will be investigated in further testing.

Description - Double Helical Planetary

To transcend the limitations of current planetary designs [1], 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. The improved transmission is configured as a single stage compound planetary with an axially staggered, intermeshed, spur gear input mesh and double helical output mesh with an overall ratio of 17.5-to-1. This ratio is approximately equivalent to the existing baseline transmission, which has a two-stage simple planetary system described above. The DHP gears were sized for the same power and speed operating conditions as the baseline design, 4500 HP at 225 RPM (output). The core DHP transmission configuration is shown in Figure 1.

The unique features of this planetary system are the use of double helical gears for the final mesh and the axially staggered, intermeshed spur gear configuration, which permits the use of six planets rather than three, for greater power density. The overall spatial arrangement is slightly larger than the baseline two-stage planetary system; however the weight of the system is less.

A capacity limiting factor of the simple planetary arrangement is the number of planets that can be accommodated within the internal ring gear diameter. Note that the sun-planet mesh in a compound planetary is not restricted to fit within the internal ring gear diameter. This means that the sun-planet envelope may be radially larger than in a simple planetary design. With the compound planetary, "staggering" the planets can circumvent another limitation and substantially increase capacity. In a

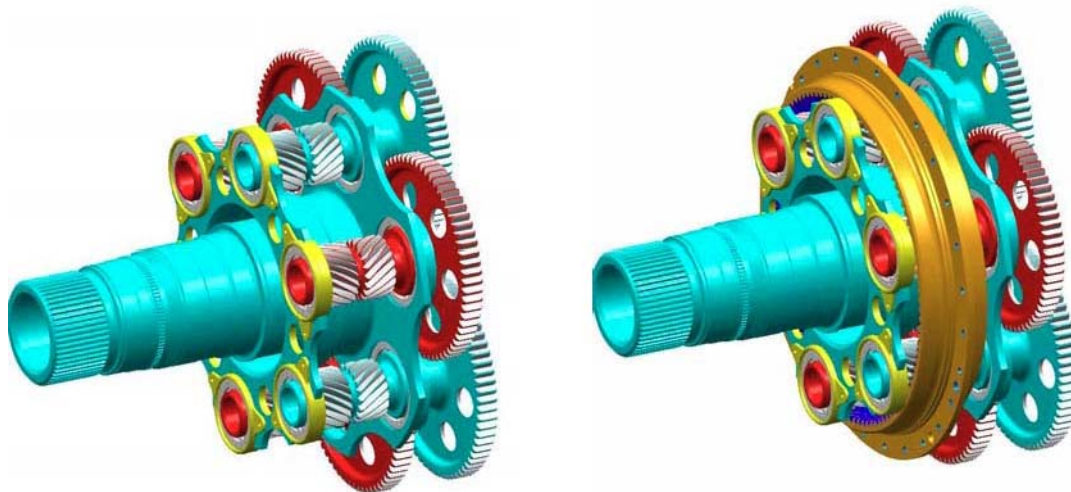


Figure 1. Compound planetary transmission configuration
(with and without ring gear installed)

staggered arrangement, the sun gear is lengthened to allow it to mesh with staggered planetary gears. This nearly doubles the number of planet gears which can fit within the compound planetary, resulting in significantly higher capacity and power density for a given gearbox envelope. A fully floating sun gear design was used to aid in uniform load-sharing among the planet gears.

The use of double helical gears in a compound planetary arrangement is another unique feature of this drive. Double helical gears are used extensively in heavy industry – like mill drives. One benefit of the double helical arrangement is increased total contact ratio due to the action of the helix angles in the double helical gears. The increased contact ratio results in higher mesh load capacity and reduces mesh-generated noise. Since the thrust loads developed on each helix within the double helical gear are oriented in opposing directions, the net axial load from a double helical mesh is zero. This permits a simpler support bearing arrangement where large axial load capacity is not required.

Component weights for the DHP configuration were

determined and compared with the existing baseline planetary. A weight saving of 90 lbs was identified for the DHP when compared to the baseline two-stage simple planetary components as shown in Table 1. This is a 12.7% weight reduction for the DHP components compared to the baseline design. This represents a substantial improvement in power density which is due only to the DHP configuration, independent of other technology improvements. It should be noted that the incorporation of technologies to improve gear tooth load capacity would have additive effects on the power density improvements. Weight reduction technologies applied to non-gear components, such as ceramic rolling elements in the planet and shaft support bearings, would also further reduce the weight. It should also be noted that the weight comparison is based on the weight of the prototype test components. These test components were not fully optimized for minimum weight due to the limited scope and budget of this project. It may be possible, with additional optimization effort, to further increase the weight reduction realized with the DHP design.

Table 1. Weight comparison of baseline and DHP design planetary components

Design	Baseline Planetary	DHP
Weight of planetary components	708 lb	618 lb
Weight reduction for DHP design	--	90 lb
Percent weight reduction for DHP design	--	12.7 %

Gearbox Fabrication

Fabrication of the components for the prototype DHP gearbox involved many challenges. All main power gears were fabricated using aerospace practice. Gears were fabricated from aerospace quality 9310 alloy steel. Gear teeth were carburized, hardened and ground. Standard aerospace post-grinding processes, such as shotpeening and NDT inspections, were employed. Gear teeth were manufactured to tolerances equivalent to AGMA Quality 12, with tip and root modifications appropriate for the expected load conditions. Other technical challenges encountered with the fabrication of the gearbox components included:

Complexity of the one piece planet carrier/ shaft component required significant amount of machining time on a relatively large component. Innovative fixtures and machining processes were required to produce this part. The existing baseline transmission uses an integral rotor shaft / planet carrier, and therefore, a similar design approach was selected for the DHP design. This part could be designed as a two-piece splined assembly thereby avoiding some of the complexity associated with the one-piece design.

Grinding operations were complicated by the double helical configuration, as expected, and the space between opposing helices on the double helical gears limited grinding wheel size and tool life. The aisle width between the helices on the internal ring gear was 0.6 inch and between the helices on the planet it was 0.55 inch. For final grinding of these gears, 1.9 inch diameter aluminum oxide wheels were selected, as illustrated in Figure 2. The grinding wheel was mounted on a belt driven spindle and it was noted that this was not the ideal solution for grinding these components in a production environment. Improvements can be made to this approach, including more robust tooling, larger spacing between opposing helices, or possibly as an alternative, joined or welded helical gears

Greater than anticipated distortions during carburization and heat treatment required additional stock removal from ring gear. Alternate heat treat methods, development of specific (for the application) quench process tooling, heat treatment simulation and analysis, are a few approaches that could

be utilized to deal more effectively with this issue in future products.

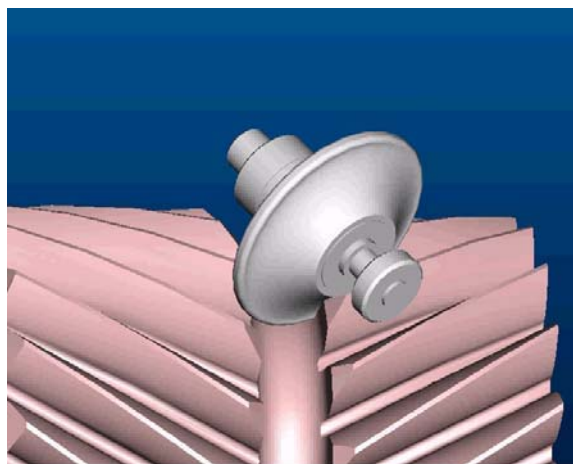


Figure 2. Grinding wheel clearance for staggered double helical tooth arrangement

Manufacturing tolerances and structural deflections of the gears and shafts can have a significant effect on the effective load sharing among planet gears. Accordingly, an additional tolerance requirement was established for the angular indexing relationship of the planet gear teeth. This index tolerance controlled the location of the planet spur gear teeth relative to a datum established by the helical gear teeth. The tolerance allotted for gear tooth indexing was considered very tight by the fabricators. Additionally, the long and short planet shafts were designed to have the same torsional “wind-up” under load so that the gear teeth would share load equally between the long and short planets.

Photographs of some parts during fabrication are shown in Figures 3 through 5.



Figure 3. Sun gears early in fabrication process