

Executive Summary

This document constitutes a technical opinion regarding the Counter-Rotation Drive (CRD[®]™ patented). The CRD[®]™ is an innovative mechanism that allows for counter-rotation of inline shafts with reduction ratios. That is to say that the rpm of the input shaft need not remain constant but can be increased or decreased depending on the application. This invention has gone far beyond the drawing board; US patent has been granted, and a PCT (Patent Cooperation Treaty) application is in the final stages ensuring worldwide intellectual property protection. A demonstrator model is available, and work was recently completed on testing a working model for a large, medium-range helicopter.

This invention represents a step in technology in the field of rotating machinery with significant benefits to the aerospace propulsion industry in terms of fuel efficiency and weight reduction. Additional benefits exist in the field of turbo propellers, and all applications that employ reduction gearboxes.

Background

The inception of the Gas Turbine Engine, and its application to the aerospace industry, revolutionized transportation of people and goods across great distances, effectively shrinking the modern world as we know it. With the increased reliance on aircrafts as a major instrument of facilitating the daily conveniences of most, if not all of, humanity, it has become necessary to closely monitor, with the intent to reduce, fuel consumption. Fuel shortage is viewed by all as the single biggest threat to the aerospace transportation industry. This has prompted the industry, particularly engine manufacturers, to invest heavily in technology and innovations related to fuel efficiency. Paramount among the focus areas is weight reduction and increased performance of critical engine components such as the fan/compressor. However, progress seems to have stagnated beyond the multi-spool configuration; a technology introduced in the 1950's. Incrementalism, rather than innovation, has been the underlying foundation of most improvements. The result is obvious; aside from the size difference, today's engines look remarkably similar to engines from the 1960's and 1970's.

While the gas turbine engine cycle remains the most effective cycle for jet propulsion, continued research has shown that counter-rotation, within the compressor component, offers the single biggest step in technology since the introduction of the engine itself. Recently, the General Electric Company introduced the mammoth GE-90 High-Bypass Turbofan, with counter-rotation in the compressor component. That is to say, the high-pressure compressor (HPC) component rotates in the opposite direction as the fan and intermediate-pressure compressor (IPC, or booster). This is accomplished by having the low-pressure turbine (LPT) rotation reversed with respect to the high-pressure turbine (HPT) component. And since the LPT is directly connected to the IPC/fan, rotation reversal is achieved. The price paid for this innovation was high; complexity in the aerodynamic and mechanical turbine designs, as well as the demand placed on the bearings is not small. When viewed in light of the small gains achieved – counter-rotation is accomplished in only a single stage within the entire compression system – it is easy to place a value on what counter-rotation means to the engine manufacturers and their respective customers. Experts further agree that the ultimate compressor will not only have counter-rotation, but also each stage will be allotted its own optimized rotation speed, or rpm. So far, this fictitious configuration has been the dream of every engine designer with no realistic, feasible mechanism to achieve it.

This apparent and desperate need prompted Mr. Marko Ivankovic to invent the Counter-Rotation Drive (CRD[®]™ patented). The CRD[®]™ can be described as a **mechanism for enabling sequential inline counter-rotation with [increasing or decreasing] real reduction ratios**. This brilliant invention is not a gear, but a mechanism that employs a series of plates aligned to generate counter-rotation of inline shafts, co-rotation is also available as an optional feature. The precise geometric shapes of the plates are described by a series of complex trigonometric relations and further facilitate increasing or decreasing



reduction ratios. Additionally, this invention can and will enable inline sequential counter-rotation of axial compressor stages, with different rpm per stage, all from a single [turbine] drive shaft. A brief description follows.

Brief Description of the CRD

The Counter-Rotation Drive (CRD[®]™ patented) is fully described in a US patent. The following is a summary and brief discussion of key features disclosed in the patent application.

The CRD[®]™ can be described as a mechanism for enabling sequential inline counter-rotation with [increasing or decreasing] real reduction ratios. The mechanism is comprised of a series of plates housed in a support-housing. The plates are of moderate thickness and have their outer perimeters described by a series of complex trigonometric relations. Variations of key parameters in those relations produce plates of different perimeter shapes and contribute directly to the reduction ratios. Counter-rotation is achieved by eccentricities in the drive shaft coupled with a certain arrangement of pins which restrict the motion of the plates causing them to rotate in the opposite direction as the input torque. An additional feature exists by which co-rotation is also available.

The below figures (not to scale) illustrate three different embodiments (configurations) of this invention.

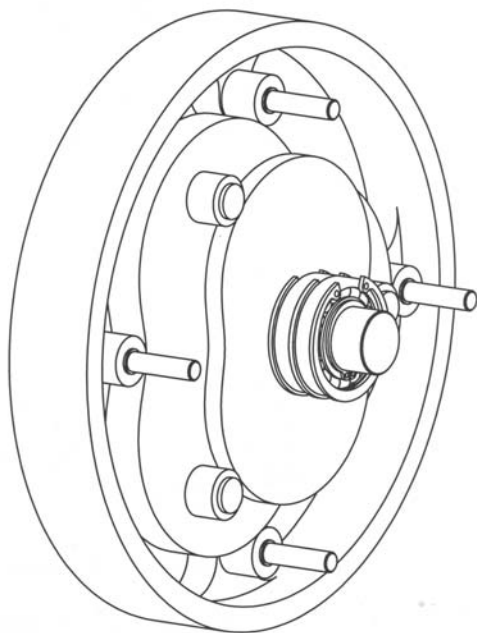


Figure 1

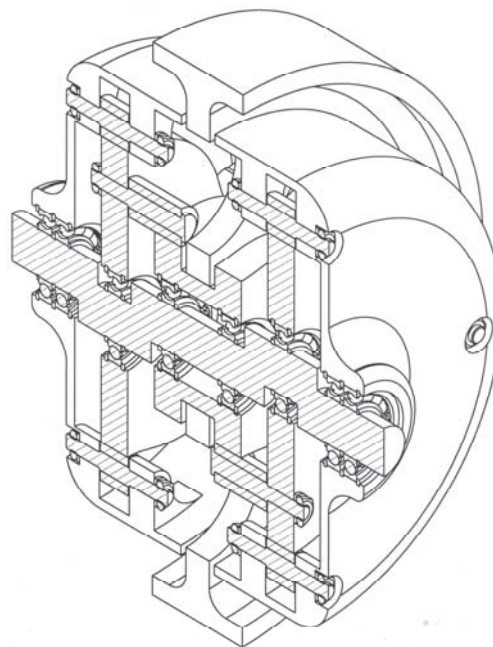


Figure 2

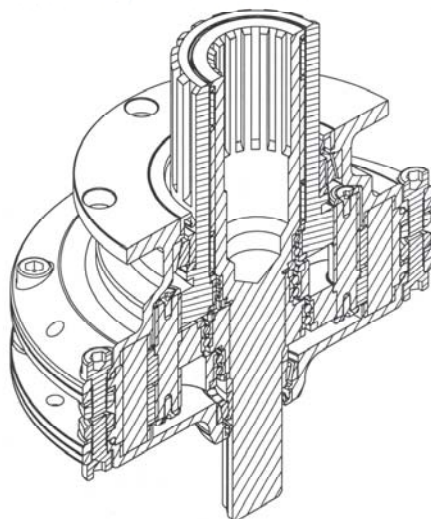


Figure 3

Figure 1 illustrates the simplest form of this invention (CRD[®]™ patented) having a 1:1 reduction ratio. Figure 2 is a double-plated configuration where the outermost portion of the housing rotates at the desired reduced rpm in a direction opposite to the direction of the input shaft. This embodiment is particularly suited to sequential counter-rotation and is designed to minimize shaft vibrations. Figure 3 illustrates a shaft-within-shaft embodiment. In this configuration, the input shaft is maintained throughout the entire assembly. Additionally, the output shaft, having counter-rotation and the desired reduction ratio is in very-close proximity to the input shaft. This configuration, Fig. 3, is ideal for counter-rotation of shafts in close proximity such as counter-rotating propellers, including for helicopter applications.

A more detailed description of this invention, several embodiments, and key features can be found in the US patent application.

Technological Innovation

The technological innovations in this invention and their respective impacts are many. Only a few are discussed below.

- **Counter-Rotation** is achieved by a simple, yet ingenious, eccentricity in the input shaft. This is a very robust feature with virtually no chance of deterioration of any kind, fatigue, or decrease in part life as would be the case in most, if not all, current engine rotating components.
- **Reduction Ratio** is accomplished by the modification of the perimeter shapes of the plates. No gears are involved. Real reduction ratios, increasing or decreasing, are possible with ease, for example 4.2:1 or 1:6.78. Furthermore, the plates are in continuous contact with the pins (see patent application). This guarantees smooth and precise motion. The continuous contact contributes to minimizing the wear on the parts, and eliminates any lag time such as that present in some geared applications.

- **Inline Shafts** are the main focus of this invention. Many geared applications are of nonaligned shafts. Re-alignment requires the use of more gears which make the device bulky, heavy, expensive, and riddled with manufacturing, life, and service problems. Counter-rotation of inline shafts is at the heart of this invention.
- **Size and Weight** of this device are remarkably smaller than devices with similar HP/Lb capabilities. It is estimated, for example, that a gearbox for a medium turboshaft weighing roughly 600 lbs and being 40-45 inches in length can be replaced by a CRD[®]™ weighing less than 200 lbs and being 12-14 inches in length.
- **Precise Motion** of the moving parts of the CRD[®]™ patented is one of its key features. This is accomplished by the plates and pins features and the strictly guided motion of the plates. The design contributes to the sustainability of part life and the virtual elimination of wear and tear via continuous contact or moving parts, and the continuous contact also reduces noise emission considerably; a feature that was well measured and documented during recent tests. Additionally, rotation speeds upward of 100,000 rpm were achieved with ease.
- **Sequential Counter-Rotation** is perhaps the most significant consequence of applying this invention. Its remarkably small size and weight, precise motion, and compact design allow for “stacked” CRD’s with ease. This “stacked” configuration is at the heart of counter-rotating compressors for high pressure ratio.

Example Applications

The first and foremost application is in axial compressors and fans for commercial [high-bypass] and military [low-bypass] turbofans. **The potential for this technology is a reduction in the compressor component, the largest and most complex of the three main components [compressor, combustor, and turbine], length and weight by as much as 60%.** Furthermore, an accompanying simplification in the turbine component is also credited to the CRD[®]™; multi-spool configurations, and related complexities and risks, are no longer needed.

The second application is in the field of counter-rotating propellers, including helicopter applications, as outlined by the shaft-within-shaft configuration, Fig. 3. Thirdly, the light weight and reduced complexity of the CRD[®]™ make it ideal for replacing most, if not all, gear boxes on turboprop applications. For the average turboprop application, the gearbox can make up to 35% of the engine size and weight. The planetary gears, necessary for the significant reduction ratios in turboshaft engines, are expensive, bulky, heavy, and problem-laden. The entire gearbox would be replaced by a CRD[®]™ at a fraction of the size and weight. Additionally, due to the precise motion of the plates, there would be virtually no lag time between the turboshaft and the propeller.

In summary, applications are many and all of them present a significant improvement over the current state-of-the-art. The future of this technology is limitless.

Notice and Disclosures

¹The information provided in this document refers to the Counter-Rotation Drive (CRD[®]™), an invention that is protected by a US patent. The figures enclosed are also protected by the same patent, and are published with permission of the inventor. All information contained herein is considered proprietary and is not to be used for purposes other than evaluation purposes only.

²The information provided in this document constitutes a technical opinion and implies in no way a guarantee of performance.

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