Solving the Gearbox Reliability Problem

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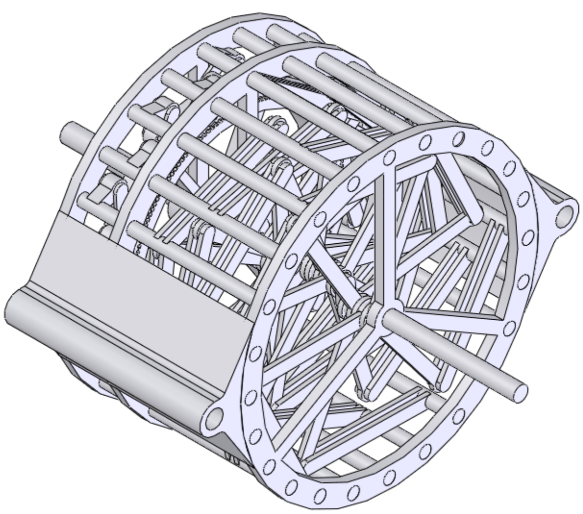
Abstract

Wind turbine gearbox reliability is a well-documented industry-wide concern. The Eclipse Gearbox is a high-reliability, novel gear set that can significantly reduce reliability problems. The gear set embodies a speed ratio of up to 300 to 1 in a single stage, which is achieved through an original configuration of gears: One gear rotates and provides a circular path for another gear. A rotational gear is attached a high torque shaft. Another gear is engaged with the rotational gear and translates on a circular path. The second gear is connected with linkages to a low torque shaft that resembles a crankshaft.



Eclipse Gearbox

Introduction

Premature gearbox failures present major issues in the wind energy industry. Gearbox unreliability and high repair costs combine to result in critical negative effects on the cost of wind energy production. Lost revenues result from (1) long down-times when energy cannot be produced, (2) the substantial expense of the large crane needed to lift a replacement gearbox into place and (3) the cost of the gearbox itself (**Fig. 1**).

Fig. 1-Wind Turbine Gearbox Installation

The gearbox is the critical component prone to failure in the load path between the turbine and the generator. Traditional wind turbine gearboxes utilize an indirect path through a multi-stage planetary system. Introduced here is a gearbox that features a shortened load path through a single pair of gears combined with linkages and a crankshaft (**Fig. 2**).

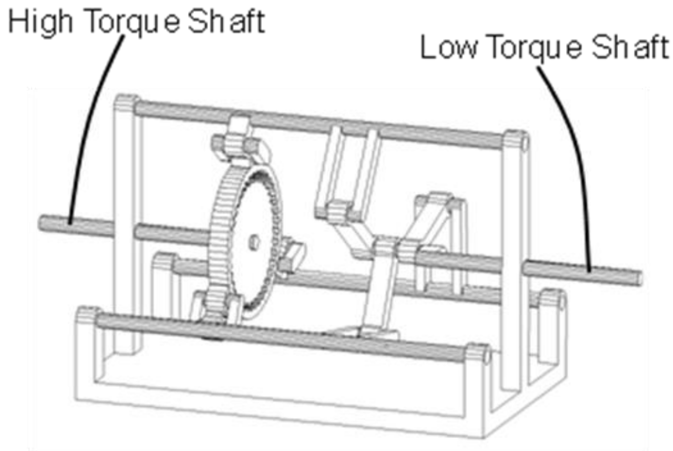


Fig. 2-Eclipse Gearbox (Simplified illustration)

Traditional wind turbine gearboxes utilize a two-stage planetary gear with a one-stage parallel shaft (**Fig. 3**). The substantial ring gear forces are distributed to the sun gear through the planetary gears, where the ring gear and sun gear forces are equal in magnitude. The planet gear bearing forces are the sum of the ring gear and sun gear forces. The combination of large forces and limited bearing size create a critical failure point. Advanced lubrication systems and other planetary gear improvements have not resulted in increased service life. As such, the physical limits of planetary gear sets have been reached. Traditional designs have a finite space for the bearings required to carry the loads of the planetary gears (**Fig. 4**).

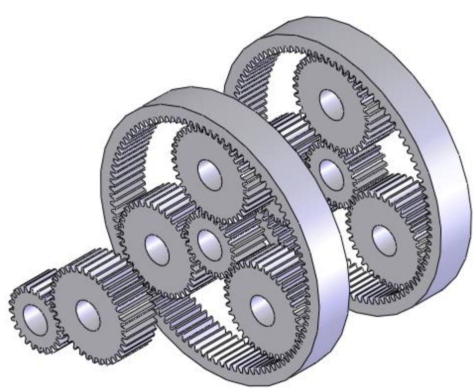


Fig. 3-Traditional Wind Turbine Gearbox

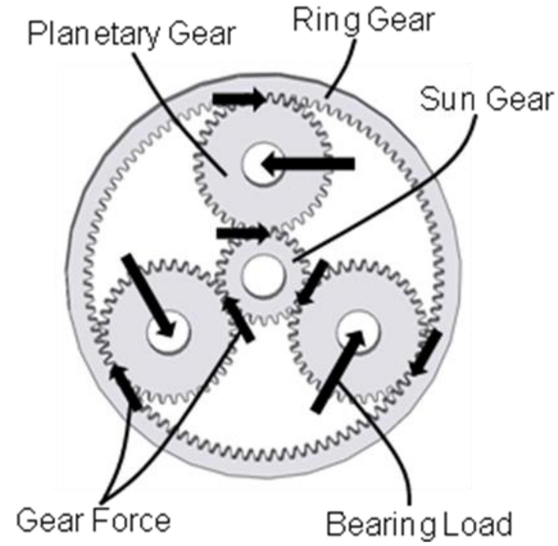


Fig. 4-Planetary Gear Set Loads

The Eclipse Gearbox overcomes the limitations of the planetary gear set and offers a practical, high-reliability gearbox for 200 kW to 20 MW wind turbines. It is a single-stage gearbox that can distribute the loads through multiple linkages.

Mechanics

A simplified version of the Eclipse Gearbox is illustrated in **Fig. 2**. One gear rotates and provides a circular path for another gear. The second gear translates on a circular path. The second gear is connected with linkages to the output crankshaft.

The load path begins with the high torque shaft and ends with the low torque shaft. Components of the gearbox are shown in **Figs. 5** through **11** relative to the load and torque paths.

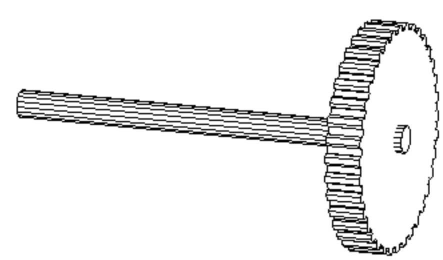


Fig. 5-High Torque Shaft and Spur Gear

The high torque shaft and spur gear (**Fig. 5**) are directly connected to the wind turbine and rotate about the central axis of the high torque shaft. The spur gear drives the translational gear (**Fig. 6**) about a circular path.

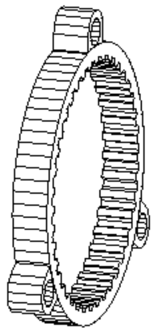


Fig. 6-Translating Gear

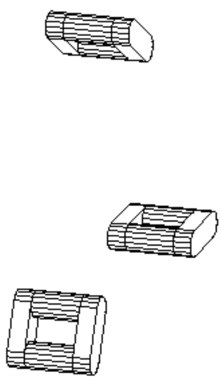


Fig. 7-Short Links

The motion of translational gear is only translational. It does not rotate. Through the short links (**Fig. 7**), the energy is transferred from the translational gear to the short rocker-arm. The short rocker-arm, rocker-shaft and long rocker-arm (**Fig. 8**) are fixed together as a single part and rotate back and forth about 15 degrees.

Through the long links (**Fig. 9**), the energy is transferred from the long rocker-arm to the crankshaft and the low torque shaft (**Fig. 10**). The frame (**Fig. 11**) is the support structure.

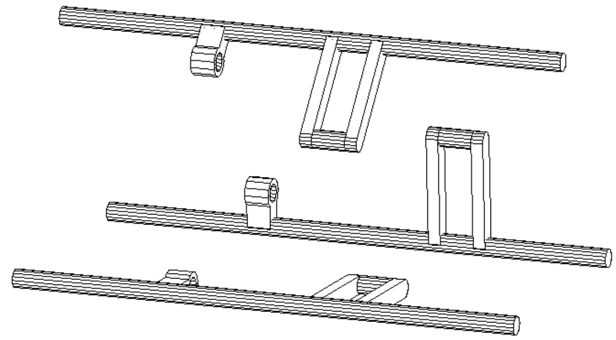


Fig. 8-Short Rocker-Arm, Rocker-Shaft and Long Rocker-Arm

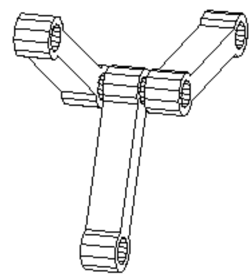


Fig. 9-Long Links

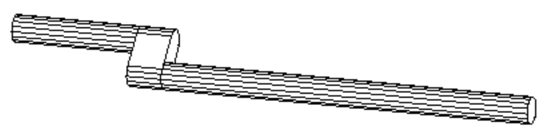


Fig. 10-Crank Shaft and Low Torque Shaft

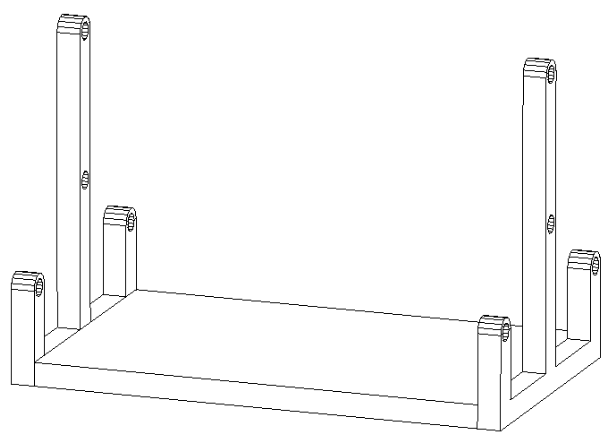


Fig. 11-Frame

The crankshaft and a minimum of three linkages are required to control the translational motion of the translational gear. Additional linkages are used to distribute the translational gear reaction loads.

The Eclipse accommodates speed ratios up to 150 to 1 in a single stage. This speed ratio limit is based on the practical limit to the gear tooth size.

Speed ratio: $\frac{-N_S}{N_T - N_S}$ to 1

Where N_S is the number of teeth on the spur gear and N_T is the number of teeth of the translating gear.

1.6 MW Eclipse Gearbox

The 1.6MW Eclipse Gearbox is equivalent to the size of a traditional gearbox but with half the weight, (**Figs. 12** through **19**). The estimated weight is 15,000 pounds and the estimated service life exceeds 50 years when using industry standard materials and assembly techniques.

There is no magic in the high torque and long service life capacity of the Eclipse Gearbox. The endurance life and power rating of the Eclipse Gearbox are dependent on the number of linkages and the sizing of the bearings and gears. In comparison, for traditional gearboxes to be sized for successful operation in high power wind turbines, their cost, weight and size would be prohibitive.

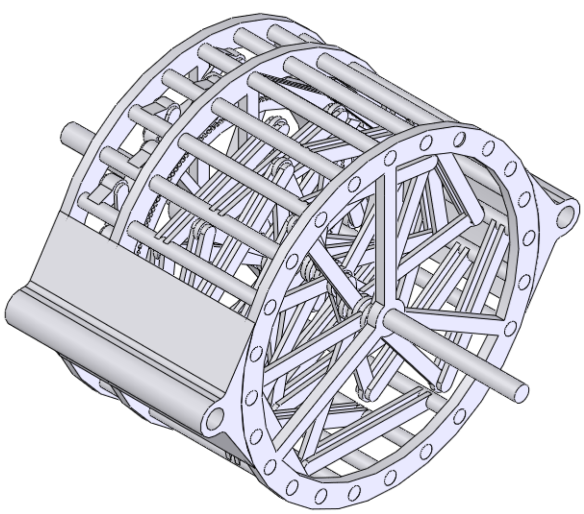


Fig. 12-1.6 MW Eclipse Gearbox

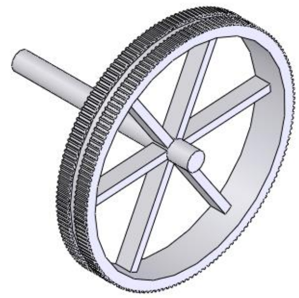


Fig. 13-High Torque Shaft and Two Spur Gears

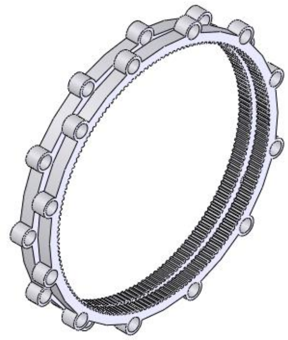


Fig. 14-Two Translating Gears

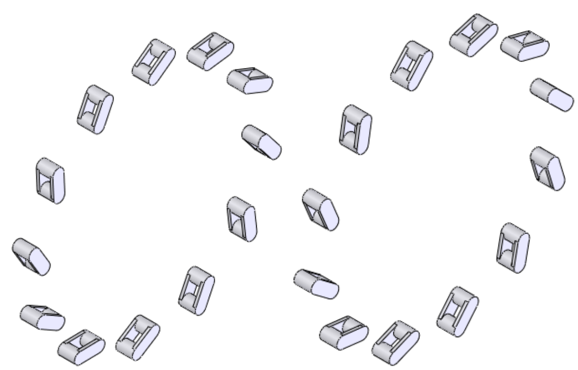


Fig. 15-Short Links

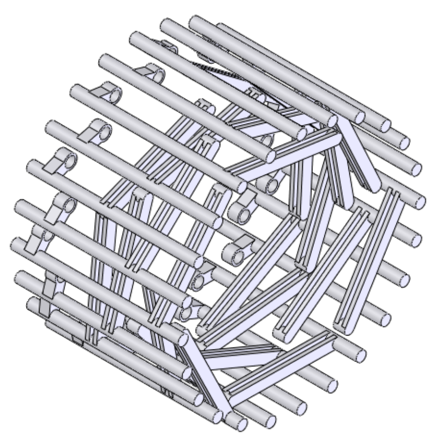


Fig. 16-Short Rocker-Arm, Rocker-Shaft and Long Rocker-Arm

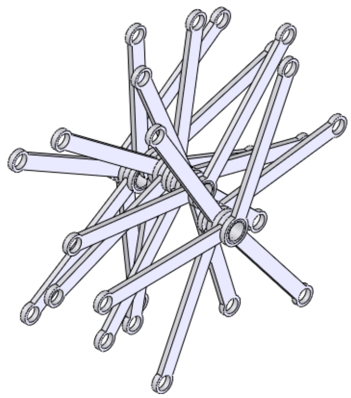


Fig. 17-Long Links

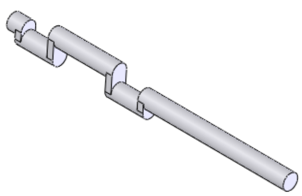


Fig. 18-Crank Shaft and Low Torque Shaft

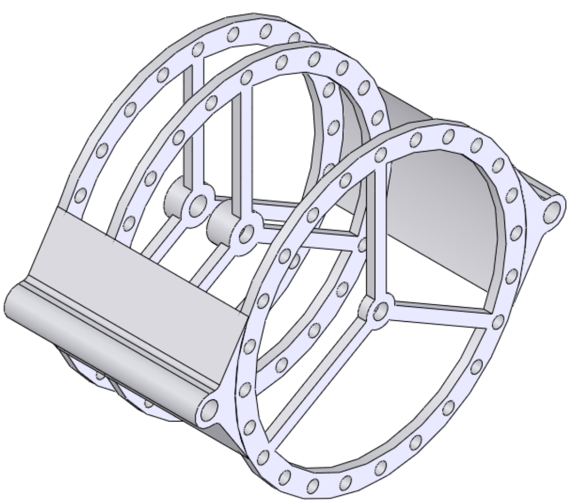


Fig. 19-Frame

The link load cycle for a 1.6 MW gearbox is illustrated to show the distributed load through several linkages in **Figs. 20** and **21,** depicting an input torque of 600,000 lb-ft. The summation of the linkage loads are equal to 75 percent of the bearing forces in the planetary gears of a traditional planetary gear set.

Fig. 20-Short Link Forces for One of the Two Translating Gears

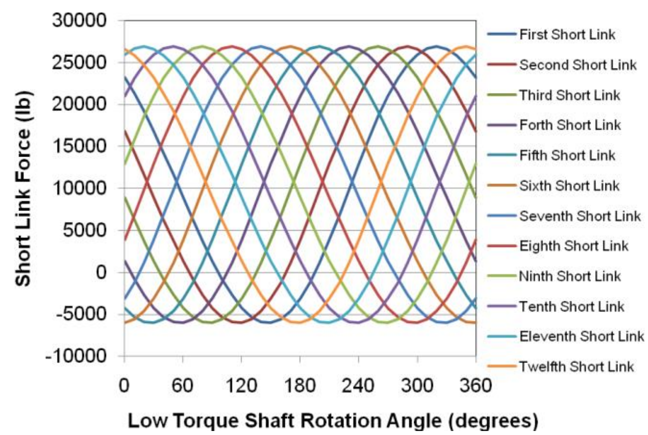


Fig. 21-Short Link Forces for One Rotation of the Low Torque Shaft

The linkages are designed with respect to manufacturing tolerances, joint free play and stiffness to maintain evenly distributed linkage loads throughout the Eclipse system, regardless of the loads applied to the windmill blades. The linkages act in parallel to distribute the translational gear loads. The gear loads are distributed over multiple bearings. The bearings in the linkages rotate back and forth about 15 degrees.

Only the bearings on the crankshaft and the alignment bearings for the high and low torque shafts rotate a complete 360 degrees.

The amplitude of the gear tooth stresses are substantially reduced due to the loads being distributed over a greater number of teeth, (**Fig. 22**). The lower gear tooth stresses substantially increase the fatigue life of the gears.

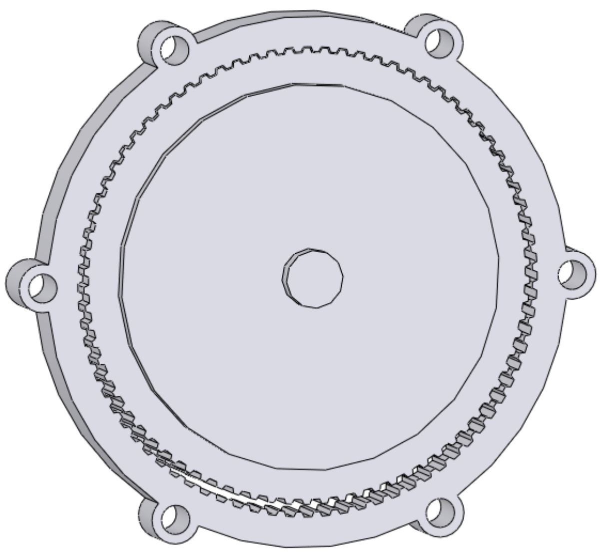


Fig. 22-Torque Distributed Over Several Gear Teeth

Efficiency

The mechanical design efficiency of the Eclipse Gearbox results in significantly greater efficiency than traditional planetary gearboxes, due to the reduced number of energy-dissipating components and to the fact that energy travels though only one set of gears and bearings.

There are two primary components that dissipate energy in a gearbox system: the gear tooth contact and the bearing contact. A basic rule of thumb in gearbox design for energy loss through gear tooth contact is approximately one half of one percent (1/2 of 1%) for every stage of gear interaction that the energy passes through.

Bearing contacts contribute energy loss through rolling motion. The linkage bearings in the Eclipse are small in size in relation to traditional gearbox bearings and rotate back and forth about 15 degrees, producing only minimal energy losses. Only the crankshaft bearings rotate a complete 360 degrees and are similarly relatively small in size.

Traditional gearbox systems routinely suffer energy losses amounting to four to five percent (4-5%) due to multiple stage planetary gear sets and massive bearings.

The Eclipse gearbox will operate with a total mechanical efficiency of approximately 99 percent. Until this claim is validated by testing, a conservative estimate would be a mechanical efficiency no less than 98 percent.

Endurance Life, Size and Weight

The long endurance life, small size and light weight are the primary strengths of the Eclipse Gearbox. Its size is equivalent to a traditional gearbox with half the weight. Even with half the weight, the Eclipse Gearbox handles greater torque loads with gears and bearings selected to handle all the requirements of the most challenging wind turbine applications, while maintaining endurance over a greater length of time.

Gear tooth contact stress is substantially lower due the increase in the number of gear teeth that are simultaneously engaged. The decreased tooth contact stress directly increases the endurance life and torque capacity of the gears.

Gear Alignment

Gear alignment is a critical factor for endurance life. Small misalignments quickly and severely reduce the endurance of gears. Another enhancement of the Eclipse Gearbox is a gear self-alignment capability between the spur and translating gears, which is accomplished through alignment guides on the spur and translating gears. The centrifugal forces acting on the translating gears keep the alignment guides together.

Conclusion

The Eclipse gearbox is scalable for 200 kW to 20 MW wind turbines with speed ratios up to 300 to 1. Retrofitting existing structures is possible. The weight of the Eclipse amounts to approximately 10,000 pounds per MW with a service life in excess of 50 years. Manufacturing costs are substantially reduced due to replacing traditionally high-cost machined components with smaller, less expensive parts. All of these advantages, combined with long endurance life and optimal efficiency, dramatically lower wind turbine operating expenses and solve the gearbox reliability problem.

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