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Design, Development and Testing of Eclipse Drive Train for Wind Turbine

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ABSTRACT

A wind energy conversion system consists of a number of components to transform the wind energy to electrical energy. The rotor is one of the component of wind turbine that extracts energy from the wind. One of the major component, Gearbox is used for transfer high torque generated by rotor to low torque required for generator. Gearbox Un-reliability and high repair costs combine to result in critical negative effects on the cost of wind energy production. The Eclipse Gearbox is suggested in this paper that can significantly reduce reliability problems occurred in traditional gearbox. The features of Eclipse gearbox is a shortened load path through a single pair of gears combined with linkages and a crankshaft. Multi-stage planetary system of traditional gearbox is reduced to single stage eclipse gearbox, helps to increase speed ratio, long endurance life, small size and light weight. Its size is identical to a traditional gearbox weight reduced to half. Contact stress of gear tooth is substantially lower due the increase in the number of gear teeth that are simultaneously engaged. The minimum tooth contact stress eventually increases the endurance life and torque capacity of the gears.

Keywords— Eclipse Gearbox, Reliability, Speed Ratio, Traditional Gearbox, Wind Turbine

1. INTRODUCTION

A wind energy conversion system consists of a number of components to transform the wind energy to electrical energy. A wind turbine operating regime is divided into three regions. Region 1 (wind speed up to 4m/s) is the low wind speed region for which the turbine does not produce any power, the turbine is disconnected from the grid. If the turbine will be connected to the grid at low wind speeds, the generator will start working as a motor.

The region 2 (wind speed 4 to 14m/s), is the region in which turbine starts to operate (V_w ;cut:in) and the wind speed at which maximum power is produced (V_w ;rated). This is the region for which maximizing energy capture, but limitation of dynamic loads also becomes more important. In region 2 operation

accounts for more than 50% of the annual energy capture. This indicates the importance of efficient operation in this regime. In region 3 (wind speed 14 to 25m/s), which is the region from the rated wind speed to the wind speed at which the turbine is stopped to prevent damage (V_w ;cut:out). In region 3, energy capture is limited such that the turbine and generator are not overloaded and dynamic loads do not result in mechanical failure. The limitation in energy capture is generally controlled by pitching the rotor blades, by suitable methods. Because of blade pitching, less energy is extracted from the wind results in decreasing the efficiency.

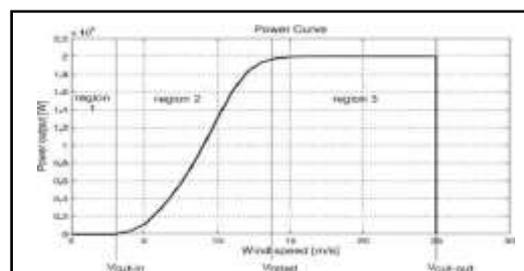


Fig. 1: Power o/p Vs Wind speed

2. PRESENT THEORIES AND PRACTICES Power Electronics

The generator results in the production of current with a variable frequency. The frequency of the produced current is noted by the electrical angular speed of the generator. The frequency and phase of all power generating units must remain synchronous within narrow limits. If the frequency of the generator varies too much (2 Hz), circuit breakers cause the generator to disconnect from the system, prevent damage to the grid. Small deviations in the generator frequency can indicate instability in the grid.

Power electronics is a technology that is develop rapidly. High current and voltage ratings are available, efficiency maximizes and costs minimizes. Therefore, power converters are largely used in the wind turbine industry to increase the performance of wind turbines. However, there are lots of disadvantages of using power electronics.

Disadvantages of Power Electronics

The largest disadvantage of power electronics is reliability. Mechanical components expose wear & tear and therefore any failures in these components can be predicted, maintenance can be scheduled before failure occurs. Power electronics do not show signs of degrading; hence failures cannot be predicted and these sudden failures are very expensive to repair. Combine with high failure costs, power electronics tend to fail quite rapidly because they are very sensitive to voltage spikes. In the wind energy industry about 25% of all failures is due to the power electronics. Traditional gearbox failures present major issues in the wind energy industry. Gearbox Un-reliability and high repair costs [3]. combine to result in critical negative effects on the cost of wind energy production

Lost revenues result from

- High down-times when energy cannot be produced,
- The substantial expense of the large crane needed to lift a replacement gearbox into place

Eclipse Gearbox Introduction

The gearbox is the critical component prone to failure in the load path between the turbine and the generator. Traditional wind turbine gearboxes commute 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.

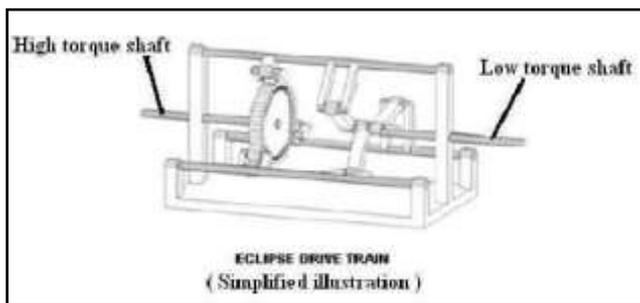


Fig. 2: Eclipse Gearbox

The Eclipse Gearbox overcomes the limitations of the planetary gear set and offers a practical, high-reliability gearbox. A simplified version of the Eclipse Gearbox is illustrated in figure above. One gear rotates and provides a circular path for another gear. The second gear oscillates on a circular path, gear is connected with linkages to the output crankshaft. The load path gets with the high torque shaft and ends with the low torque shaft [2].

Functionality and operation of the eclipse drive train

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 is based on the practical limit to the gear tooth size.

$$\text{Speed ratio} = -N_s / N_T - N_s \text{ to } 1$$

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

The endurance life and power rating of the Eclipse Drive Train are dependent on the number of linkages and the sizing of the bearings and gears. In comparing, for traditional gearboxes to be sized for successful operation in high power wind turbines, their

cost, weight and size would be preventive. The link load cycle for a 1.6 MW gearbox is illustrated to show the distributed load through different linkages depicting an input torque of 600,000 lb-ft. The addition of the linkage loads are equal to 75 percent of the bearing forces in the planetary gears of a traditional planetary gear set.

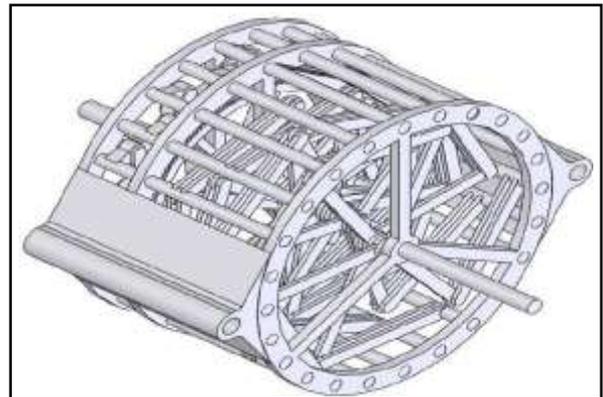


Fig. 3: 1.6 MW Eclipse Gearbox

The linkages are designed with respect to fabrication tolerances, joint free play and stiffness to maintain evenly distributed linkage loads throughout the Eclipse system, irrespective 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 revolve back and forth about 15 degrees. The high and low torque shafts rotate a complete 360 degrees. The gear tooth stresses are substantially reduced due to the loads being distributed over a greater number of teeth. The lower gear tooth stresses substantially increase the fatigue life of the gears. The mechanical design efficiency of the Eclipse Drive train results in significantly greater efficiency than traditional planetary gearboxes, due to the decreased number of energy dissipating components and to the fact that energy travels through only one set of gears and bearings [1].

3. METHODOLOGY

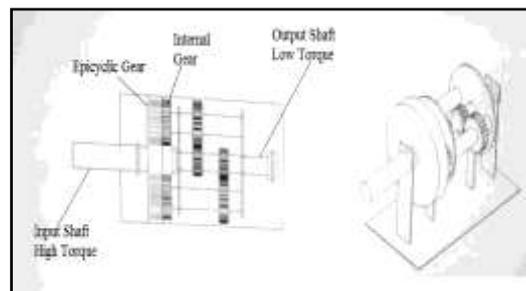


Fig. 4 Layout of Eclipse Gear Box

Epicyclic gear is connected to the input shaft (high torque). Two internal gears are connected to the epicyclic gear through two linkages and linkages are connected to output shaft (low torque) through gears. Motion delivered by epicyclic to internal gear in 360-degree rotation of input shaft (by one pinion) is only during forward state due to one way clutch. During 0-degree-180-degree one pinion in forward transmission is continuous.

Output is mainly depends on: Number of linkages, Linkages dimensions, Gear ratio of epicyclic gear and internal gear, at the same time other pinion will be in reverse state, during next phase of 180 degree -360 degree condition reverse so motion gear.

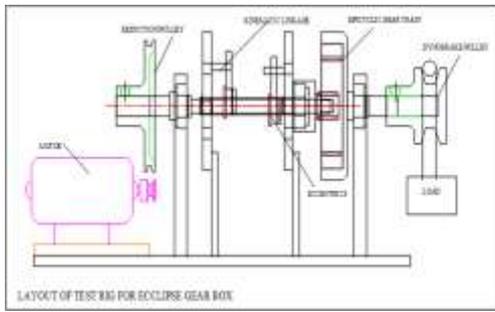


Fig. 5 Layout of Test Rig for Eclipse Gear Box

A standard internal gear and pinion are meshed without tooth interference. On the driving shaft A is mounted an eccentric, the axis of the driving gear follows the motion of eccentric, but is kept from revolve about its own axis by pin, which works in the slot. Linkage is actuated by the eccentric, which constantly maintains slot in a perpendicular position through the action of parallel links, pivoted on studs. Since the axis of gear follows the motion of Eccentric and the gear does not rotate about its own axis, the motion imparted to the driven gear will be uniform. For testing purpose, we take low torque shaft as i/p shaft by using motor and belt input motion is given. Two linkages are in motion through gear and epicyclic gear rotates high torque means output shaft at high torque, various loads are applied and change in rpm is noted. Design and analysis of internal gear ring and external wobble gear

To Calculate Input Torque

Input data - Motor is an Single phase AC motor, Power 50watt, Speed is continuously variable from 0 to 6000 rpm. Assuming operation speed = 800 rpm.

$$Power = \frac{2\pi NT}{60}$$

$$T = \frac{60 \times P}{2 \times \pi \times N}$$

$$T = \frac{60 \times 50}{2 \times \pi \times 600}$$

$$T = 0.5968 \text{ N.m.}$$

Assuming 100% overload.

$$T_{design} = 2 \times T$$

$$= 2 \times 0.5968 \times 10^3$$

$$= 1.19 \times 10^3 \text{ Nmm}$$

$$T - design = 1.19 \text{ N - m}$$

Internal Gear Data:

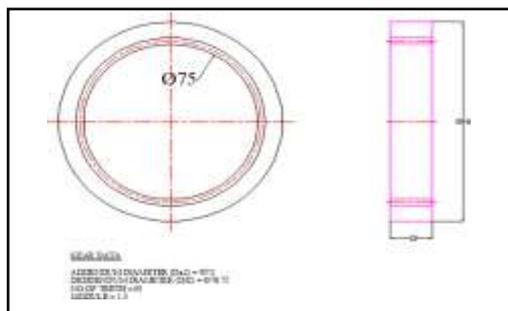


Fig. 6 Internal Gear

$$Addendum Diameter (D_{a^2}) = 96 \text{ mm}$$

$$Dedendum Diameter (D_{f^2}) = 78.75 \text{ mm}$$

$$No. of Teeth = 50$$

$$Module = 1.5$$

Design of Internal Gear - Theoretical method

Table 1: Material selection for internal gear

Designation	Ultimate Tensile strength N/mm ²	Yield strength N/mm ²
EN 24	800	680

As Per ASME Code;

$$f_s_{max} = 108 \text{ N/mm}^2$$

Check for torsional shear failure:

$$T = \frac{\pi f_s_{act}}{16} \times \left(\frac{D_o^4 - D_i^4}{D_o} \right)$$

$$1.19 \times 10^3 = \frac{\pi f_s_{act}}{16} \times \left(\frac{69^4 - 32^4}{69} \right)$$

$$f_s_{act} = 0.01 \text{ N/mm}^2 \text{As}; \quad f_s_{act} < f_s_{all}$$

Gear is safe under torsional load

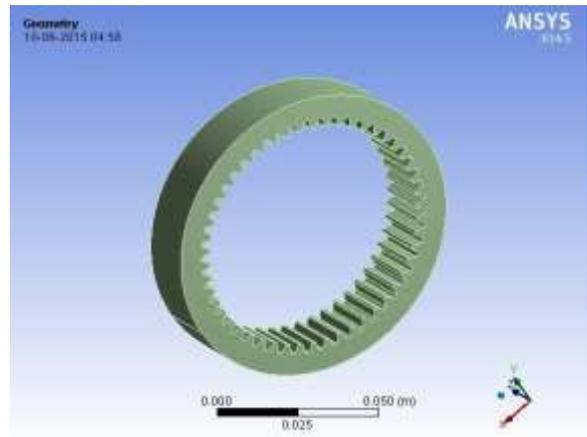


Fig. 7 Geometry of Internal gear

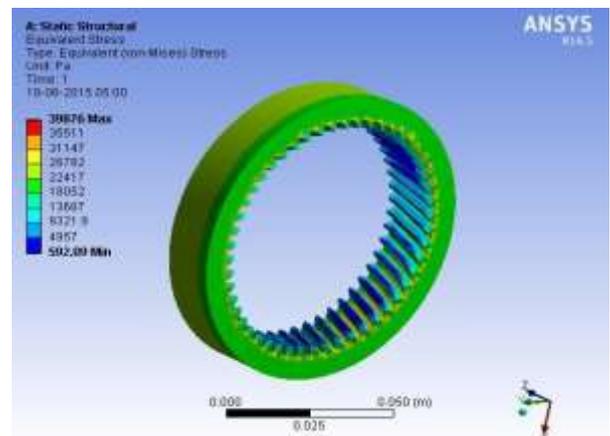


Fig. 8 Equivalent stresses in Internal gear

Maximum stress by analytical methods is well below the allowable limit of 108 N/mm² hence the internal gear is safe.

External Gear Data -

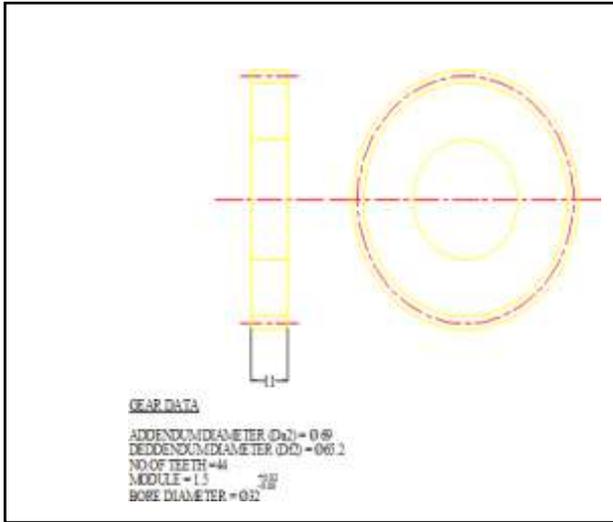


Fig. 9 External Gear

Addendum Diameter(Da2) = 69 mm Deddendum Diameter(Df2) = 65.2 mm No. of Teeth = 44

Module = 1.5

Bore Diameter = 32 mm

Design of External gear - Theoretical method

Table 2: Material selection for external gear

Designation	Ultimate Tensile strength N/mm ²	Yield strength N/mm ²
EN 24	800	680

As Per ASME Code;

$$fs_{max} = 108 \text{ N/mm}^2$$

Check for torsional shear failure:-

$$fs_{act} = 0.02 \text{ N/mm}^2$$

$$As; fs_{act} < fs_{all}$$

Gear is safe under torsional load

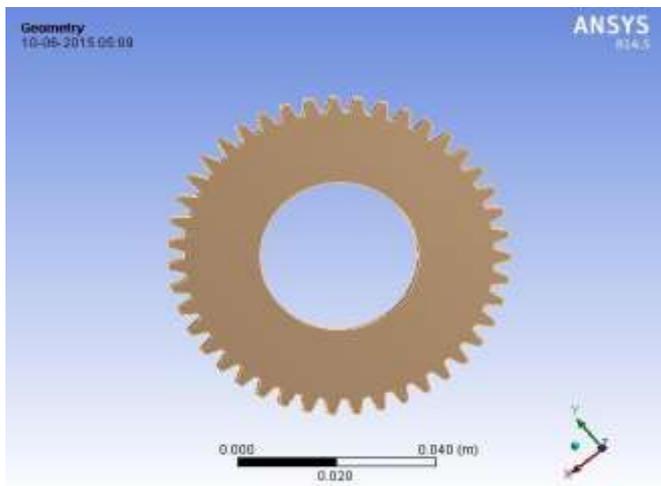


Fig. 10 Geometry of External gear

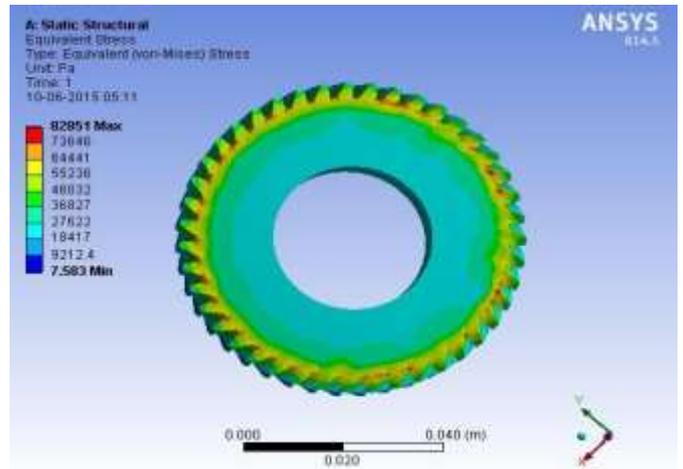


Fig. 11 Equivalent stresses in External gear

Maximum stress by analytical methods is well below the allowable limit of 108 N/mm² hence the external gear is safe.

TESTING

The testing is conducted three various set with changes in electric motor speed by regulator and note down changes in speed at output shaft using tachometer as follows,

Table 3: Result table

Parameter	N _{mean} (rpm)	Torque(O/P) (N-m)	Power (O/P) (watt)
Weight (kg)			
2.0	76	0.7848	6.24
2.1	74.5	0.824	6.42
2.2	73	0.8632	6.59
2.3	72	0.9025	6.80
2.4	71	0.9418	7.01
2.5	70	0.981	7.19

4. RESULT AND DISCUSSION

At high torque shaft various loads are applied and change in rpm is noted for that we consider following graphs of Torque and Power v/s Speed.

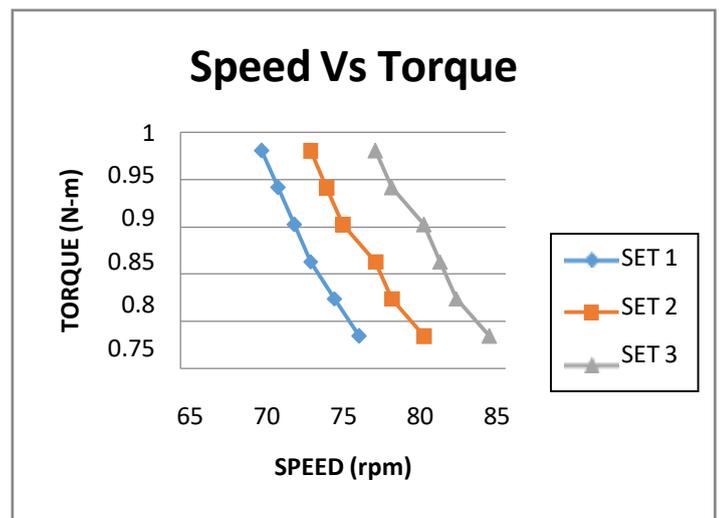


Fig. 12 - Graph of speed i/p vs. Torque o/p for Sets 1, 2 & 3.

For three successive incremental input speed the output speed (N_{mean}) obtained was observed. The output speed (N_{mean}) was observed for different Weight parameter (W) varying from 2.0 to 2.5 kg at the same input speed. The observation taken from eclipse gearbox performance based on above mentioned different

sets testing observation are noted, with increase in load the torque obtained improves for all three input speeds. It is also noted that, for same weight equal Torque is obtained for all three input speeds. The output speed (N_{mean}) is reducing with increasing in weight parameter (W) for all three successive incremental inputs.

The first region in wind turbine, the wind speed is not sufficient to rotate the rotor of the wind turbine and it does not produce power because of high torque but from the speed vs. torque graph shows the torque is same for the three different sets results in improving the speed of rotor of wind turbine.

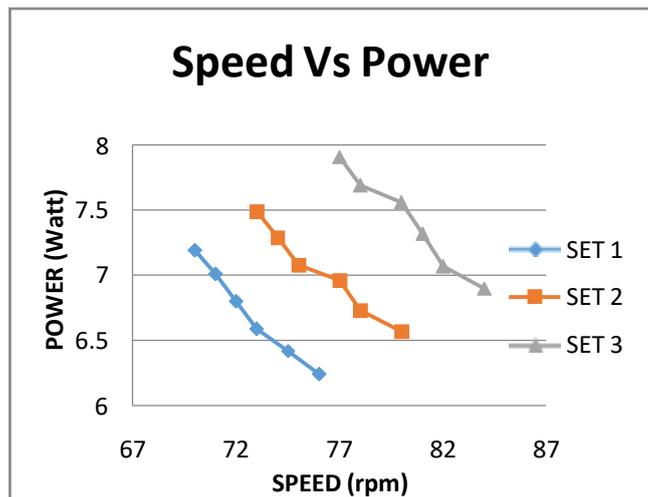


Fig. 13 - Graph of o/p speed vs. Power o/p for Sets 1, 2 and 3.

The performance observed from above experimental analysis on eclipse gearbox with two linkages it is quite clear that, with increase in weight parameter (w) at output pulley the output speed (N_{mean}) reduces and helps in improving torque. The improvement in torque due to reduction in output speed (N_{mean}) ultimately results in improving power. The power is depending on the output speed and output power, the output speed increases when increase the motor speed rpm but the testing gearbox is speed reduction gearbox. Hence for the testing purpose parameter is weight and speed from this different reading sets are note down and calculate the output toque.

5. CONCLUSIONS

- From the experimental analysis it was found that the speed ratio of eclipse gearbox is mainly function of number of linkages, Eccentricity of cam, variation in geometry of linkages, Gear ratio of external and internal gear.
- The speed ratio obtained at various speed and loads for fabricated model of eclipse gearbox is 26:1.
- The speed ratio can be improved by increasing number of linkages and cam eccentricity.
- The variation of input speed has small effect on the output speed which helps in increasing the region one and two of traditional gearbox.
- The rated output speed is achieved faster hence energy is produced only when the rotor rotates at a minimum speed.
- The eclipse gearbox achieves a higher velocity ratio than the existing. The service life for the proposed gear box will be marginally higher as compared to the existing.

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