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# Analysis of Eclipse Gearbox of Wind Turbine for Torque Optimization

Mr. Waghmare R.M., Prof. Kathale S.S., and Prof. Shitole J.S.
*Department of Mechanical Engineering DGOI, FOE, Swami-Chincholi*

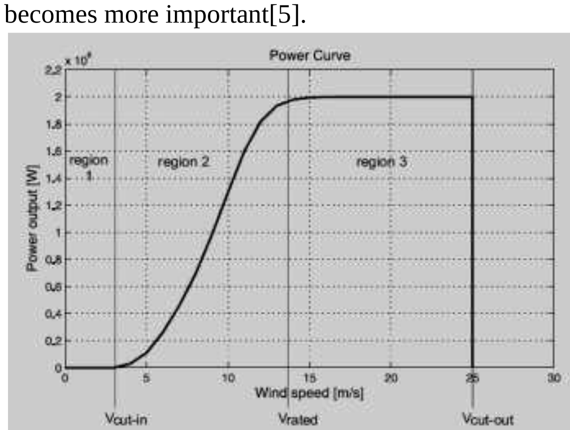
***Abstract*—A wind energy conversion system consists of a number of components to transform the energy in the wind to electrical energy. One of these components is the rotor, which is the component that extracts energy from the wind. Energy transferred to rotor by gearbox hence it is one of the most important component of wind energy conversion system. The gearbox is the critical component prone to failure in the load path between the turbine and the generator. Introduced here is a gearbox that features a shortened load path through a pairs of gears combined with linkages and a crankshaft. The Eclipse Gearbox is a high-reliability gear set that can significantly reduce reliability problems.**

***Index Terms- Wind Turbine, Traditional Wind Turbine Gearbox, Eclipse gear box.***

## I. INTRODUCTION

The fastest growing renewable energy source is wind power. Wind power is currently responsible for about 1:5% of the world's electricity use. Because of this high interest in wind energy, it becomes more and more important to increase the efficiency of wind energy conversion systems (WECS), also called wind turbines. The complete system required to convert the energy in the wind to electricity is called a wind energy conversion system (WECS). Such a system consists of a rotor to capture the energy in the wind, a gearbox configuration to speed up the rotational speed of the shaft and a generator to convert the mechanical energy into electrical energy. The efficiency of the total system is not only determined by the efficiencies of the gearbox and generator, but also by the amount of energy that can be extracted from the wind [1].

I. A wind energy conversion system consists of a number of components to transform the energy in the wind to electrical energy. One of these components is the rotor, which is the component that extracts energy from the wind. The operating regime of a wind turbine 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 rotor is standing still and the turbine is disconnected from the grid. When the turbine would be connected to the grid at these low wind speeds, the generator would start working as a motor, driving the turbine. The turbine would then actually be working as a huge fan, consuming energy instead of producing. The second region, region 2(wind speed 4 to 14m/s), is the region between the wind speed at which the turbine starts to operate (Vw;cut¡in) and the wind speed at which maximum power is produced (Vw;rated). This is the region for which maximizing energy capture is very important, but limitation of dynamic loads also becomes more important[5].




In a typical wind turbine, region 2 operation accounts for more than 50% of the annual energy capture. This indicates the importance of efficient operation in this regime. Finally there is 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 (Vw;cut¡out). In this region, 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 control methods. Blade pitch control is used to control the aerodynamic power captured from the wind. By pitching the rotor blades along their longitudinal axis, the aerodynamic efficiency of the rotor is changed. A disadvantage of using blade pitching below rated speed is that less energy is extracted from the wind, decreasing the efficiency.

## II. CURRENT PRACTICES

The literature review points out that research have been done on transmission of power in wind turbine by using various transmission drives but still, there is scope to improve the design of a gearbox that features a shortened load path through a single pair of gears combined with linkages and a crank shaft.

• Jelena Stefanovic-Marinovic [2] have Worked In Selection Of CVT Transmission Construction Design For Usage In Low Power Wind Turbine, In That Necessity of multiplicator application as a component of wind turbine is implication of incompatible number of rpm of rotor and number of rpm of generator. Currently approach (method) connecting turbine with permanent convertible number of rpm and generator with constant number of rpm by multiplicators with constant transmission ratio came out non- effectively.

Miltenivic [3] discussed regarding new concept of wind turbine power transmission, which instead of multiplicators with constant transmission ratio, uses variable transmission ratio (CVT) is increasing. In order to exceed multiplicators with constant transmission ratio disadvantages, new concept of wind turbine power transmission anticipates differential power transmission and power transmitters with variable transmission ratio (CVT) instead of multiplicators with constant transmission ratio. It is used for adjusting turbine impeller work with generator work. The capacity of power generation increase in wind turbines but generated many technical problems. Many of those problems are related to power transmission. Actual transmission types in wind turbines include planetary differential transmitters. Differential planetary transmitters have significant function in those concepts

Dipl. Ing. ETH Hanspeter Dinner, [4] have worked in The overall trends in wind turbines and their drive trains are opposing: multi unit offshore installations vs. local single units in local grids, small wind turbines vs. multi megawatt turbines, classical drive trains vs. regulated CVT drive trains, medium vs. high speed gearboxes and so on. While the need for smaller gearboxes leads to the requirement for low cost yet noise optimized gears, the need for large gearboxes leads to technological challenges in gearing, large bearings and highly stressed structural members like planetary carriers.

• M.J. Verdonschot, [5] worked in Modeling and Control of wind turbines using a Continuously Variable Transmission. In that, Conventional variable speed wind turbines obtain their variable speed operation by a controlling the generator torque. This control uses the power electronics that connect the generator to the electrical grid. The range of variable speed in these systems is limited and the power electronics are one of the main sources of failure in wind turbines. Therefore, the possibility of using a continuously variable transmission for the control of a wind turbine is investigated.

• Frank et al [6] worked on wind turbine systems using CVT & various controls. A wind turbine system is disclosed comparing a plurality of turbine blades; a continuous variable transmission coupled to said plurality of turbine blades; a generator coupled to said continuous variable transmission; wherein said generator generates electricity & outputs said electricity to a load/grid; and controller providing control signal as a filtered function of power to said a continuous variable transmission. The controller of said wind turbine system may also continuously maintain the parameter dP/dR substantially zero where P is power & R is the ratio of transmission.

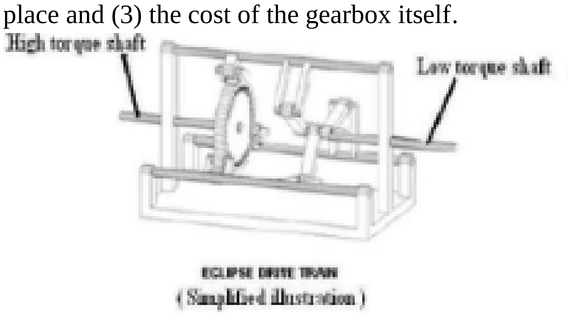
• Gold, A [9] discussed regarding CVT History, Categories, Efficiency, Positive Engagement CVT: Problem correction class, problem elimination class, tooth conforming family.

• Terry Lester [7] discussed about Wind turbine gearbox reliability, 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 long down-times when energy cannot be produced, the substantial expense of the large crane needed to lift a replacement gearbox into place and the cost of the gearbox itself. 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.

• P. C. Sen [8] discussed regarding Power Electronics as a solution of reliability problem in that variable speed operation of the generator results in the production of current with a variable frequency. The frequency of the produced current is determined by the electrical angular speed of the generator. When the frequency of the generator varies too much, in the order of 2 Hz, circuit breakers cause the generator to disconnect from the system, preventing damage to the grid. Power electronics is a technology that is developing rapidly. Higher current and voltage ratings are available, efficiency increases and costs decrease. Therefore, power converters are widely used in the wind turbine industry to improve the performance of wind turbines. However, there are also a number of disadvantages of using power electronics The biggest disadvantage of power electronics is reliability. Mechanical components show wear & tear and therefore any failures in these components can be predicted, maintenance can be scheduled before failure occurs. Unfortunately power electronics do not show signs of degrading, therefore failures cannot be predicted and these sudden failures are very expensive to repair.

## III. 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.




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.

Traditional wind turbine gearboxes utilize a two- stage planetary gear with a one-stage parallel shaft.

Fig 4a -Traditional Wind Turbine Gearbox

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.

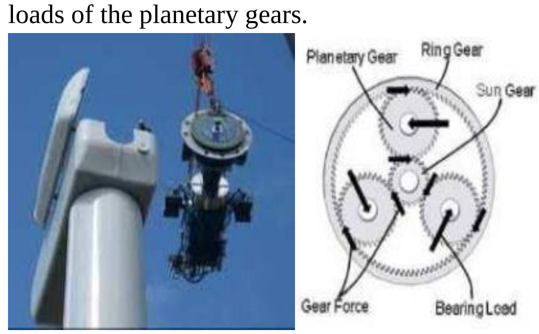



Fig 4b.-Planetary Gear Set Loads

The Eclipse Gearbox overcomes the limitations of the planetary gear set and offers a practical, high-reliability gearbox for 200 kW to 10 MW wind turbines. It is a single-stage gearbox that can distribute the loads through multiple linkages.

## IV. MECHANISM OF ECLIPSE DRIVE TRAIN

Basic of eclipse drive train is depends on four bar linkage mechanism. In our eclipse model when input shaft rotate through one revolution ($360^0$) then connecting link rotate through $24^0$ in two linkages, this motion is combination of forward and reverse motion i.e.($12^0$ forward + $12^0$ reverse) this mechanism drawing is shown below In case of our model we used following data Eccentricity of cam = 3.5 mm Connecting rod small end to big end length = 32 mm Connecting link small end to big end length = 25mm Distance between input to intermediate shaft = 27mm Angle of Oscillation of intermediate shaft = 120 No of teeth of internal gear= 50 No of teeth of pinion= 12 No of cranks= 2, Hence phase angle is $360^0/2 = 180^0$ Gear ratio of internal gear to pinion = 50/12 = 4.16: 1

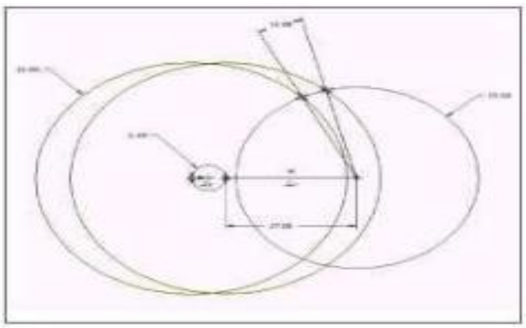
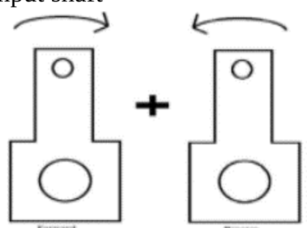


Fig 5 mechanism of eclipse drive train

Case – I consider one intermediate shaft During 3600 rotation of input shaft



I. $0^0$-$180^0$: in that case connecting link performs 120 forward motion.

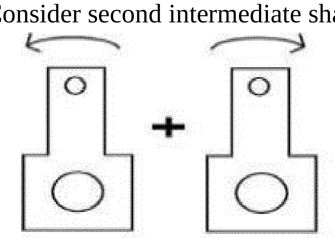
II. $180^0$-$360^0$: in that case connecting link performs 120 reverse motion.

Therefore,

Total motion in one revolution of input shaft = forward motion + reverse motion $=12^0+12^0=24^0$

Speed ratio = $360^0$ / $24^0$ = 15

Case –II Consider second intermediate shaft



I. $0^0$-$180^0$: in that case connecting link performs reverse 120 motion.

II. $180^0$-$360^0$: in that case connecting link performs 120 forward motion

Therefore,

Total motion in one revolution of input shaft = forward motion + reverse motion

$=12^0+12^0=24^0$

Speed ratio = $360^0$ / $24^0$ = 15

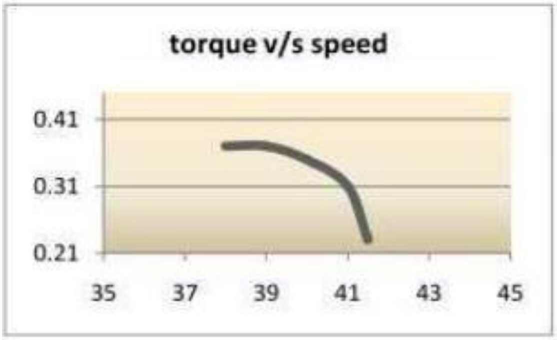
Motion delivered by pinion to internal gear in 3600 rotation of input shaft (by one pinion) is only during forward state due to one way clutch. During 00-1800 one pinion in forward state at the same time other pinion will be in reverse state, during next phase of 1800-3600 condition reverse so motion transmission is continuous. With minimum variation in the dimensions of linkages and eccentricity of cam output can be increased. Output is mainly depends on Number of linkages, Eccentricity of cam, Phase angle of crank, Linkages dimensions, Gear ratio of pinion and internal gear. Fabricated model is shown in fig.

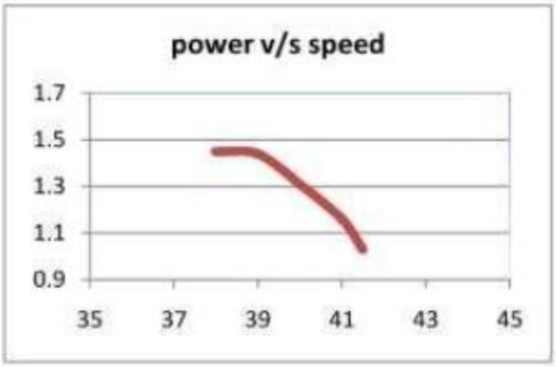
Fig 6 Fabricated Eclipse Gear Box Model With Two Linkages

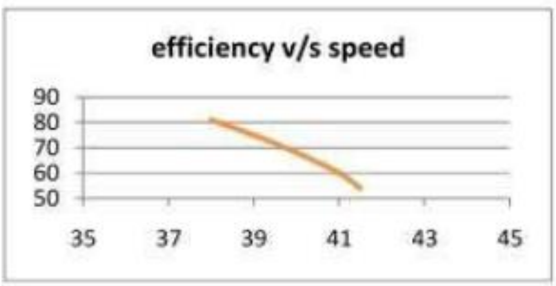
| Part no | Component | Part no | Component |
|---|---|---|---|
| 1 | Low Torque Shaft | 7 | Connecting Rod |
| 2 | Bearing Housing | 8 | Connecting Link |
| 3 | Internal Gear | 9 | Crank |
| 4 | Clutch Housing | 10 | High Torque Shaft |
| 5 | INT Shaft Holder | 11 | Pinion |
| 6 | Intermediate Shaft | 12 | Frame |

Table: List of component

For testing purpose we take low torque shaft as i/p shaft then by using motor and belt input motion is given. At other end i.e. at high torque shaft various loads are applied and change in rpm is noted for that we consider following data Graphs of Torque, Power, Efficiency v/s Speed




5 1.6 MW ECLIPSE GEARBOX

The 1.6MW Eclipse Gearbox is equivalent to the size of a traditional gearbox but with half the weight, 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.

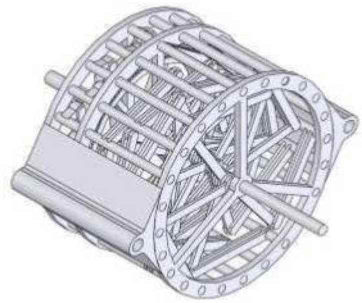


Fig 9 -1.6 MW Eclipse Gearbox

The link load cycle for a 1.6 MW gearbox is illustrated to show the distributed load through several linkages depicting an input torque of 600,000 lb-ft. The summation of the linkage loads is equal to 75 percent of the bearing forces in the planetary gears of a traditional planetary gear set. 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.8). The lower gear tooth stresses substantially increase the fatigue life of the gears.

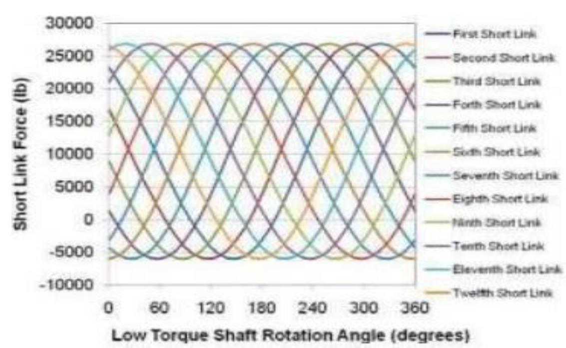



Fig 7 -Short Link Forces for One Rotation of the Low Torque Shaft

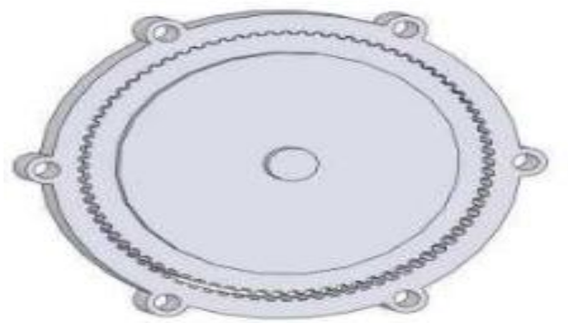


Fig 8 -Torque Distributed Over Several Gear Teeth

## V. 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
95percent. Until this claim is validated by testing, a conservative estimate would be a mechanical efficiency no less than 85 percent.

## 7. ENDURANCE LIFE, SIZE AND WEIGHT

The long endurance life, small size and lightweight 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 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.

## 8. 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.

## 9. CONCLUSION

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. 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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