Review Paper on Horizontal Axis Wind Turbine (HAWT) Gearbox Design and Analysis

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Abstract*- Horizontal Axis Wind Turbine(HAWT) is one of the most renewable energy sources. In this paper we are designing, analysing and manufacturing HAWT gear box. In this paper we are designing gearbox according to Brendan Speechleys methodology. Analysis is static analysis. As we cannot manufacture original product due to high cost more time required we are manufacturing prototype of gearbox. Gear box will be planetary gearbox and gears used are spur or helical. Overall gearbox ratio is 100:1. Output speed of gearbox is 1500 rpm. Application of horizontal axis wind turbine is industrial or residential. By determining gearbox geometry and all parameters we will make the ANSYS model. And then we will analyze this model in ANSYS software. In this paper objectives are to minimize size and weight of gearbox, to increase reliability and to reduce vibration.*

Keywords- Planetary gearbox, design, analysis, manufacturing.

I. INTRODUCTION

In this research paper, we are worked on renewable energy source. We are considering about expanding the wind farm capacity with the establishment of a 140 MW. For this facility the client has approached organization to undertake the detailed design of locally-made gearboxes.

This paper outlines the design process of the gearbox, including relevant arguments, sketches and calculations made, supported by an accurate, operational solid works model. The gearbox has been designed using the British Standards Gear Design Standard BS436 (1940), unless otherwise stated. The gearbox design has been taken to the stage where all important decisions have been made.

Major areas of investigation include the following:

- Overall layout of gearbox,
- Gear design, including materials and dimensions,
- Shafts, including stresses, fatigue life, deflections,
- Vibration characteristics of the gearbox and gearing, and
- Ease of manufacture and assembly

The theoretical efficiency formulas were derived for the full working range, and further verified by experimental data [1]. Planetary gears have only planet, rotational and translational mode critical speeds. Divergence instability is possible at speeds adjacent to critical speeds, and whether or not it occurs is determined using a perturbation method [2]. The wind energy sector is still far too expensive to be profitable, especially the strong growing offshore branch [3]. Absence of friction and constant angular speeds, it is shown that gyroscopic torques do not enter into power flow analysis [4]. High effective contact ratio and the low noise can be achieved by arranging the tooth surface modifications with the higher-order transmission error [5]. Gearbox field performance, characterized by reliability, availability and maintainability (RAM) has been a major driver in the research domain due to challenges the industry has faced in gearbox design, operations and maintenance [6]. A Variable Ratio Gearbox (VRG) can be used in the drivetrain of a small to medium-size wind turbine to improve aerodynamic efficiency [7]. Alternatively, a Variable-Ratio Gearbox (VRG) can be integrated into the fixed-speed wind turbine to facilitate operation with a discrete set of variable speeds that boost efficiency [8]. It was possible to extract most of this information from the vibration signal itself in the case of a wind turbine gearbox with one planetary and two helical parallel stages [9]. The gears and bearings are graded based on their fatigue damage and a maintenance map is developed to focus on those components with higher probability of fatigue failure and lower level of reliability [10]. Taking gravity, tooth separation, backside contact and bedplate tilt angle into consideration, a rotational-translational-axial dynamic model of the spur planetary gear is developed [14].

II. RESEARCH ELABORATION

By varying the gear ratios, one can determine the effect this has on the power curve. Lower gear ratios correspond to an increase in the amplitude of the power curve. Moreover, with the exception of the low speed region less than 10 m/s, each lower gear ratio curve envelops those that have higher ratios. For example, the gear ratio of 14.71 makes a 'shell' that surrounds all the higher gear ratios. The lowest gear ratio of 14.71 intersects the maximum power line at a lower wind speed than any other curves, which means it will harness the most energy [3].

The growing factor of global climate change has helped the importance of renewable energy become on first number. The wind industry, in particular, has seen an unbreakable demand as a result, and the need for reliable and affordable wind turbines now is all the more visible. Unfortunately, recurrent drivetrain failures have characterized the industry and have prevented the turbines from achieving their intended 20-year design life [6]. The component most responsible for downtime is the gearbox. Gearbox replacement and lubrication account for 38% of the parts cost for the entire turbine system. This situation calls for the implementation of new and advanced simulation techniques to be integrated into the gearbox-design process so that this component can meet its intended design life. The drivetrain has the important task of transforming the rotational energy of the rotor into electrical power. The drivetrain is composed of several elements, each of which contributes to a specific task. Except for the direct drivetrain, all drivetrains have a gearbox [7]. The gearbox is responsible for increasing the angular velocity transmitted from the rotor to the generator, to satisfy the velocity required by the generator. It is the component of greatest mechanical complexity in the drivetrain and, as noted, is responsible for most wind turbine operational downtime and for increased costs [11].

With the increase of wind turbine size gravity becomes an important non-torque excitation source. Gravity disrupts the cyclic symmetry of the planetary gear and causes unequal load-sharing. Because of the specific operation conditions, the bedplate will tilt and lead to the offset of the gear plane and vertical plane. Taking gravity, tooth separation, backside contact and bedplate tilt angle into consideration, a rotational-translational-axial dynamic model of the spur planetary gear is developed. With two different load-sharing factor models, the load-sharing characteristics of the planetary gear in horizontal axis wind turbines are numerically investigated. The effects of gravity, ring support stiffness and bedplate tilt angle on load-sharing characteristics are systematically examined. When planets move to certain positions, severe unequal load-sharing and backside contact are more likely to happen. Load-sharing characteristics change with the bedplate tilt angle and the ring support stiffness, and the variation trend is closely related to the occurrence of tooth separation and backside contact [14].

Brendan Speechley and Chi Sun Wong (2012) have studied the life time of gearbox in his paper. The growing factor of global climate change has helped the importance of renewable energy become on first number. The wind industry, in particular, has seen an unbreakable demand as a result, and the need for reliable and affordable wind turbines now is all the more visible. Unfortunately, recurrent drivetrain failures have characterized the industry and have prevented the turbines from achieving their intended 20- year design life The component most responsible for downtime is the gearbox. Gearbox replacement and lubrication account for 38% of the parts cost for the entire turbine system. This situation calls for the implementation of new and advanced simulation techniques to be integrated into the gearbox -design process so that this component can meet its intended design life.The drivetrain has the important task of transforming the rotational energy of the rotor into electrical power. The drivetrain is composed of several elements, each of which contributes to a specific task. Except for the direct drivetrain, all drivetrains have a gearbox. The gearbox is responsible for increasing the angular velocity transmitted from the rotor to the generator, to satisfy the velocity required by the generator. It is the component of greatest mechanical complexity in the drivetrain and, as noted, is responsible for most wind turbine operational downtime and for increased costs.

Joel I. and Kazem A. (2015) Performance assessment of wind turbine gear boxes using in-service data. The evolution of the wind industry in the last decade has seen growth in the installed capacity of turbines and innovation within the industry and has also seen an increase in research activities in this domain. Gearbox field performance, characterized by reliability, availability and maintainability (RAM), has been a major driver in the research domain due to challenges the industry has faced in gearbox design and operations and maintenance. This paper presents a systematic literature review of the current approaches of performance assessment, such as reliability and maintainability analysis of wind turbine gearboxes with a focus on the use of in-service data. The state-of-the-art in literature are discussed and classified according to key research themes, whilst identifying possible gaps due to lack of literature in specific areas. Also, the future trends in gearbox field performance assessment research are explored. In an attempt to close the gaps in one of the areas not covered in literature, an approach for the estimation of gear box maintainability was presented. Furthermore, a case study on how preventive maintenance of gear box bearings which can be applied in practice was carried out to demonstrate the importance of the techniques discussed in this article towards meeting industry's needs. For wind turbine (WT) gearboxes compared to other subassemblies are known to have high down time per failure. This is largely due to the complexity of their repair and maintenance procedures, particularly in offshore applications. Also, WT gearboxes historically suffered from early failures caused by underestimation of design and operating loads. In reaction to this, WT manufacturers have tended to add large increase to sales prices so as to cover warranty issues. That may arise from early gearbox failures and the resulting down- time with making gearboxes one of the most expensive WT subassemblies. This high sales price, combined with those attributed to failure and downtime of gearboxes during operation, contribute to a higher cost of energy, hence affecting the economic viability of wind farms (WFs) especially in offshore applications.

Pedro M.T., Marques and Raquel Camacho (2015) Efficiency of a planetary multiplier gearbox: Influence of operating conditions and gear oil formulation. In a three stage gearbox used in a 1 MW wind turbine an improvement of 0.33% per gear stage leads to an overall efficiency improvement of 1% which gives an energy gain of 10kW.The average house hold energy consumption worldwide for 2011 was 3338 kW _ h, representing 0.93 kW per household .This means that such a slight improvement as 0.33% would allow each wind turbine to supply at least 10 extra households. As little as it may seem, taking into account all the already existent wind farms with wind turbines usually with a capacity ranging 1.5–3 MW, these light improvements on at efficiency of a gearbox should not be neglected. PAGD lead to the highest operating temperatures and power loss. The no-load loss promoted by PAGD was now measured and it was shown that it is quite high comparing to the other oils, which justifies some of the findings previously described in. PAOR leads to the lowest values of stabilization temperature. PAOR appears to be a quite solid gear oil for wind turbine applications if power loss is one of the main concerns. MINR leads to the highest stabilization temperatures, except for the test at 100 rpm. PAGD achieved the lowest values for the coefficient of friction while MINR had the highest. The numerical results indicate that PAGD had the lowest load dependent power loss. The reduction of the friction in the gears was not high enough to overcome the increase in the no- load losses relatively to the other lubricants.

Xinghui Q. and Qinkai H. (2015) have studied Load-sharing characteristics of planetary gear transmission in horizontal axis wind turbines. With the increase of wind turbine size gravity becomes an important non-torque excitation source. Gravity disrupts the cyclic symmetry of the planetary gear and causes unequal load-sharing. Because of the specific operation conditions, the bedplate will tilt and lead to the offset of the gear plane and vertical plane. Taking gravity, tooth separation, backside contact and bedplate tilt angle into consideration, a rotational-translational-axial dynamic model of the spur planetary gear is developed. With two different load-sharing factor models, the load-sharing characteristics of the planetary gear in horizontal axis wind turbines are numerically investigated. The effects of gravity, ring support stiffness and bedplate tilt angle on load-sharing characteristics are systematically examined. When planets move to certain positions, severe unequal load-sharing and backside contact are more likely to happen. Load-sharing characteristics change with the bedplate tilt angle and the ring support stiffness, and the variation trend is closely related to the occurrence of tooth separation and backside contact.

Germano D. and Ettore P. (2013) have studied Kinematic and power-flow analysis of bevel gears planetary gear trains with gyroscopic complexity. In this paper a method for the kinematic and power -flow analysis of bevel epicyclic gear trains with gyroscopic complexity. By gyroscopic complexity, we mean the possibility of the gear carrier to be a floating link as, for instance, in robotic gear wrists. Thanks to the new formulas herein deduced, the methods based on the graph representation of planetary spur gear trains have been extended to bevel gear trains. In particular, the well known Willis equation has been modified to maintain its validity for bevel gears. The modified Willis equation was then embodied in new power ratio expressions. Under our simplifying hypotheses of absence of friction and constant angular speeds, it is shown that gyroscopic torques do not enter into power flow analysis. Two numerical examples are discussed. A fundamental step in mechanical efficiency analysis is the ascertainment of the amount of power flow through the meshing gears. Although not self evident, due to power circulation, some meshing gears may sustain a power higher than the input one. Power circulation, that usually occurs with very low transmission ratio , must be detected at the early design stages in order to dimension properly meshing gears and lubricating methods. Most of the contributions are related to spur gear trains. In this case the kinematics can be studied with the classic scalar Willis equation.1 The relationship between the absolute angular speeds of bevel gear trains is not scalar and this complicates the analysis. This paper focuses on kinematic and power flow analysis of planetary trains with bevel gears. It can be considered as an attempt to extend the modus operandi of the analysis methods devised for spur gear trains to bevel gear trains.

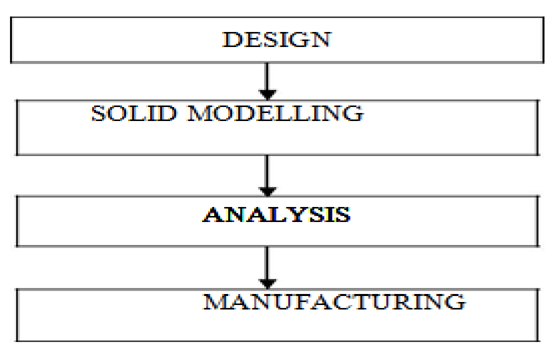
Zhang G.(2012) have studied Load allocation and equilibrium for planetary gear reducers of earth-pressure-balance shield machine. To optimize the 3-stages planetary gear reducer (PGR) in the Earth -Pressure-Balance Shield Machine (EPBSM), it is necessary to firstly define the EPBSM environment. The needed torque of the cutter-head, therefore, is analyzed when the EPBSM cutting the earth body. The load of any PGR is allocated according to the equivalent principle in the size between the force and its response one and the distributing uniformity of the PGRs around the main axle gear. Because the structure of the main drive system is equal to a huge planet-gear reducer made of 8 planetary gears, for the main axle connected with it gear, one side is connected with a bidentate coupling, the other is connected with an elastic shaft to realize the dual connection floatability of the main axle gear and support the whole main axle gear so that the relative displacement can be compensated to high degree among the PGRs resulting from the uneven force when the cutter-head cuts earth body. Because the motive power of the EPBSM cutter-head originates from the output torque of the PGRs, while the needed torque of the cutter-head decides on the structures of the PGRs, therefore, besides grasping the basic principle of the EPBSM, we still analyze its force to guide the whole optimization for the high power and 3-stages PGRs in the EPBSM. The cutter head of the shield machine, which is the object driven by the output torque of PGR, is analyzed from the torque, then the load is assigned for every PGR, the uneven ones among PGRs are balanced by means of the dual connection floatability mechanism and an elastic shaft to define the environment of EPBSM for optimizing PGR, therefore, the high-power 3-stages PGR can be optimized and its innovative work can be developed.

Jiang J. and Fang Z. (2015) have studied Design and analysis of modified cylindrical gears with a higher -order transmission error. A design of tooth surface modifications for cylindrical gears that are provided with a controllable higher order polynomial function of transmission error (H-TE) are proposed to reduce vibration and noise, and the procedures for creating mathematical models of the tooth surfaces are described. Firstly, the polynomial coefficients of H-TE curve as well as processing parameters for rack generating pinion tooth surface can be individually determined based on TCA and LTCA by optimizing the aim of minimum amplitude of loaded transmission error (ALTE) of drive gears by using the particle swarm optimization (PSO). Secondly, the deviations of pinion tooth surface with H -TE from the theoretical one are derived according to the rack movement parameters. Thirdly, a numerical simulation of example based on spur gears and helical gears with different order transmission error are performed, which prove that the actual contact ratio and the effective contact ratios are the valid indices and the gear drive with H -TE has the lowest ALTE. The proposed gear drives are proved numerically to be able to reproduce the H-TE function and the effective contact ratios are the valid indices of LTE.The main goals are achieved by the application of an approach based on the following ideas: Firstly, a predesigned sixth order polynomial function of transmission error (H-TE) is assigned to the gear drive, one (gear) of which is theoretical involute tooth, and the other (pinion) are modified tooth surfaces. The modified tooth surfaces are determined by a sixth order polynomial function of the additional rotation of the pinion based on theory of rack -cutter generated involute tooth surfaces. Secondly, the derivation of the coefficient of H-TE is based on LTCA program. Thirdly, a reverse TCA model is used for the derivation of coefficients of additional rotation of the pinion, and the deviations of pinion tooth surface from the theoretical one are derived according to the coefficients.

John F. and Christine A. (2012) Wind energy conversion with a variable-ratio gearbox: design and analysis. Variable Ratio Gearbox (VRG) can be used in the drivetrain of a small to medium-size wind turbine to improve aerodynamic efficiency. Currently, all commercially-available wind turbines operate using a fixed-gear ratio between the turbine rotor and electrical generator. A VRG allows wind turbines, with a constant-speed generator, to discretely vary rotor speed and to achieve greater aerodynamic efficiency. The authors' previous results demonstrate the viability of the VRG design. This research quantifies the gain in efficiency for a VRG-enabled wind turbine based on wind data from representing all seven wind classifications. A method is also presented to identify turbine sites that provide the VRG with the greatest opportunities to increase production. The overall findings suggest that the VRG can benefit all wind turbines, irrespective of wind class, with some wind profiles in the study experiencing gains greater than 10%. In planetary gear transmissions, multiple planet gears are used to form the power split, which allows the load to be shared by the planets. This makes planetary gears with compact structure and large torque-to-weight ratio. Planetary gear is widely used in modern wind turbines and has become one of the focuses in wind turbine researches. In horizontal axis wind turbines, planetary gears with three equally spaced planets are widely used. In the ideal situation, the planetary gear can achieve good load -sharing effect. But in practice, because of the influence of the flexible support and manufacturing and assembly errors, unequal load-sharing phenomenon is remarkable and leads to failures. Therefore, it is an important issue to investigate the load-sharing characteristics of the planetary gear.

III. METHODOLOGY

Methodology of HAWT gearbox is as per following steps:



IV. AKNOWLEDGEMENT

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V. CONCLUSION

This paper is about the design and analysis of gearbox for a Horizontal Axis Wind Turbine. The gearbox have 3 stages, the first two stages are using a compound epicylic planetary gear. And third stage is of parallel shaft helical gear. The input and output shafts were not coaxially aligned. In first stage there are four planets and in second stage there are five planets. The overall gear ratio for gearbox is 1:100.

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