博士論文（要約）

Fatigue prediction of wind turbine main shaft bearing based on field measurement and three dimensional drivetrain model

（現地観測と３次元ドライブトレインモデルを利用した風車主軸軸受の疲労予測に関する研究）

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Main shaft bearing is one of most important components in drivetrain that causes long downtime and has high cost of replacement. Main shaft bearing in three-point mounting (TPM) drivetrain system (DTS) are found having high failure rate worldwide. A surveyed in U.S. shows 20% failure rates mostly within 6 years, and for Tomamae wind farm in Japan the failure rate of main shaft bearing reaches 65%. Thus, the fatigue life of main shaft bearings in TPM drivetrain should be studied.

TPM drivetrain has one main shaft bearing support at front and two torque arm supports at rear. Firstly, previous study uses a 1D rigid model to study the drivetrain behavior, so the standard deviation of shaft bending moment is overestimated. Since the two side torque arms are not considered in 1D model, torque arm motions cannot be evaluated by the previous model either. Secondly, pounding loads, which commonly exist in bearings industrial applications, are evaluated with empirical load factor based on the operation environment. However, load factor applied in wind turbine main shaft bearing is not determined, and numerical model is not proposed for numerical simulation. A pounding model applied in the bridge engineering is described and the applicability for main shaft bearing needs to be investigated. Thirdly, the bearing fatigue life is predicted with the conventional method in ISO 281-2007 and the predicted life is around 141 years, which does not explain the high failure rates on site. Two additional parameters of life ratio due to internal clearance and the load factor due to pounding needs to be applied. Determination of their values for wind turbine main bearing is necessary. In this research, the fatigue loads and fatigue life are predicted with a three-dimensional elastic drivetrain model, a bearing pounding model, and operating parameters based on field measurements.

In Chapter 1, backgrounds of wind turbine, drivetrain system, and bearing fatigue prediction theory are introduced. Objectives of this research are proposed, and outline of thesis is presented.

In Chapter 2, field measurement on wind condition and wind induced turbine response are described, survey on main bearing is also explained. The objective wind farm and wind turbine are described for establishment of wind turbine model. Wind conditions around the wind farm are measured to determine the input wind for the model. Wind induced dynamic responses of wind turbine and drivetrain are measured to validate the wind turbine and drivetrain models. Survey on main shaft bearings are conducted to determine the operating parameters for bearing fatigue prediction.

In Chapter 3, an active stall-controlled wind turbine model with split pitch control algorithm is built up to simulate the wind loads and is validated by tower base moment measurements. The wind turbine model is established with the wind turbine characteristics and the measured wind condition. Split pitch control algorithm is applied to simulate the control system. The optimized offset angles are identified by the power spectra density of tower base moment, and the divergence of tower vibration without applying split pitch control is suppressed. The predicted tower base moments agree well with the measurement, which indicates the wind turbine model is validated.

In Chapter 4, a three-dimensional elastic drivetrain model is proposed to evaluate shaft bending moments and torque arm motions. The stiffness of elastic supports of main shaft bearing and torque arm are determined from literature review and measurement identification. The predicted shaft moments by the proposed model improves the overestimation by 1D rigid model. Variant behaviors of torque arm in three directions at two sides are clarified that Z is symmetric, Y is the same, and X is asymmetric, while torque arm motions in 1D rigid model cannot evaluate those values.

In Chapter 5, a numerical model for the pounding simulation of wind turbine main shaft bearing for evaluating the load factor is described. A pounding spring model including rollers, inner/outer rings, and internal clearance is considered for main shaft bearing. For the initial stage of bearing without internal clearance, the bearing is modeled as linear. As the bearing wear occurs with longer service life, internal clearance appears, and the bearing is modelled with pounding spring model. Load factors at variant wind speeds are evaluated with the described model while main shaft bearing has normal operating clearance. The estimated load factors can be applied for bearing fatigue life prediction

In Chapter 6, parameters of life ratio and load factor are applied to predict main shaft bearing rating life. For the observed records of rating life, statistics of main shaft bearings fatigue life at Tomamae wind farm is conducted. Based on the curve fitting of Weibull distribution, the rating life L_{10} of main shaft bearing with 90% reliability is around 7.7 years. Conventional method in ISO predicts bearing rating life as 141 years, which show 18 times overestimation on the observation. With considering those two parameters of life ratio and load factor, the predicted rating life is close to observed records.

In Chapter 7, conclusions of this study are summarized.

The contents in Chapter 4, 5, and 6 are scheduled to be published as a journal paper within 5 years.