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Meta-Modeling of Transmission Error for Spur Gear in Wind Turbine Applications

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Abstract. The foreseen oil crisis has diverted the focus of energy policies towards renewable technologies. Wind Turbine technology is a key source of cleaner energy. In order to efficiently determine the transmission error of gear boxes, meta-modeling technique based on regression analysis is applied at an eccentricity, shaft bending, torque and speed, and at particular gear parameters for wind turbine applications. Abaqus 6.12-1 is used for the development of meta-models. Upon evaluating the results, it is concluded that meta-modeling technique can be an efficient way of predicting the transmission error.

Keywords: Transmission error, wind turbine, meta-models, abaqus, spur gear, regression analysis.

1. Introduction

The oil crisis in the mid-seventies diverted the energy policies towards renewable energy resources. Since then wind turbine technology has received increasing attention as a renewable energy resource to produce electricity without emission of greenhouse gases during operation. According to the annual report of American Wind Energy Association the total U.S. utility-scale wind power capacity would be 60,007 MW after the completion of 43 MW till 4th quarter of 2012. The cost efficiency of wind turbine may increase with longer service life of gear boxes. Better models for the drive train dynamics are demanded, particularly with respect to transmission error arising in indirect drive systems. Since turbine certification requires thousands of different analyses, these models should be efficient to evaluate. Torque and rotational speed of the drive train system determine the designing power capacity of wind turbine. A common indirect drive train design consists of a multiple stage gearbox, coupling, break and generator. For current utility-scale wind turbine, mechanical power is transmitted from 12-30 rpm of turbines rotor to 1200-1800 rpm of generators rotor via two or more than stages of planetary gears [1].

In order to avoid unexpected gear box failure it is important to understand the effect of different parameters in gear contact analysis. With particular geometry parameters of gears on different issues have been conducted: in [2] for pin stiffness and misalignment, in [3], [4] and [2] dynamic analysis for tooth wedging and bearing clearance nonlinearities, transient regime, and eccentricities respectively. Sankar and Nataraj studied transmission error (TE) [5]. Robert and Parker examined how gear efficiency could be improved [6]. Finite element and analytical models techniques together were used in [7]. Similarly, particular gear parameters to generate 3D gear were chosen for the work of [8]-[11]. In this work the effect of different gear parameters will be analyzed on transmission error. Raul Tharmakulasingam examined effects of tooth profile modifications on gear pair [12]. In this work eccentricity (radial misalignment) and shaft bending (angular misalignment) are also examined in addition to gear parameters. This analysis will be done by meta-

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modeling through regression analysis because dynamic simulation of gears contact can be easily evaluated through this meta-modeling.

"*The deviation in position of the driven gear (for any given position of the driving gear), relative to the position that the driven gear would occupy if both gears were geometrically perfect and un-deformed* [13]."

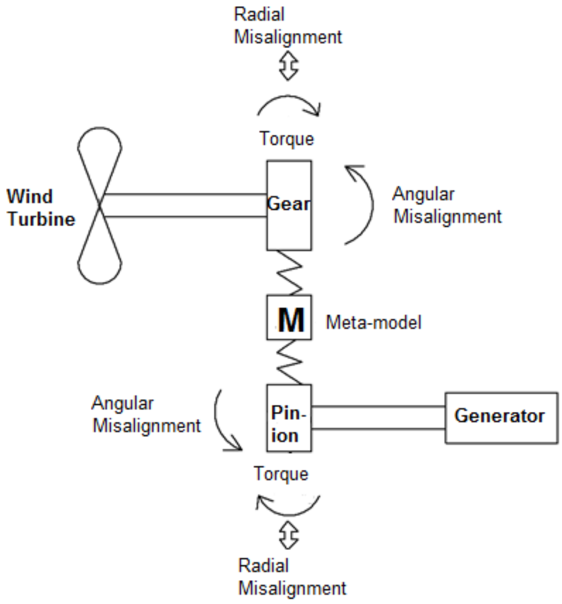

Fig. 1: Introduction of dynamic variables to gear contact.

Fig. 1 reflects how the dynamic variables (radial misalignment, angular misalignment and torque) will be introduced to gear contact analysis. Meta-model will determine transmission error at different values of the dynamic variables.

2. Spur Gear Modeling

The is simulation of spur gear rotation through Abaqus is accomplished by different modules including part, material, assembly, steps, interaction, mesh, load, and boundary. A convergence test is studied to ensure reasonable results at a reasonable computational effort.

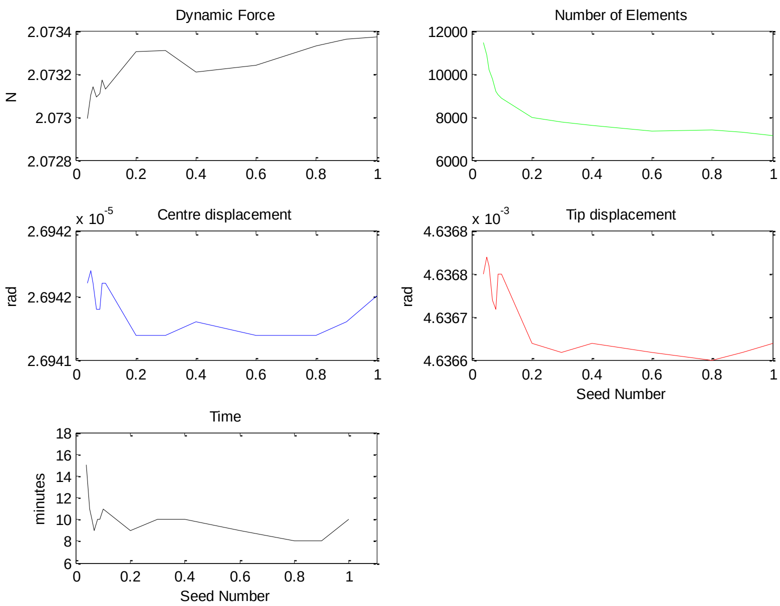

Fig. 2: Dynamic force, number of elements, displacement at centre and tip, and time at seed number 0 to 01.

It is shown from Fig. 2 that there is not much variation for dynamic force and displacement of gears. But variation for number of elements and time is higher comparatively. Seed number 0.5 is assigned to all over the teeth. Seed number over whole gear body is 01 because it will not severely affect the results.

3. Meta-Modeling

The regression analysis is a statistical process for estimating the relationships among variables. It consists of techniques for modeling and analyzing several variables, especially when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. A mathematical expression of transmission error was developed to estimate the transmission error (TE) in the drive train analysis. A mathematical model through the regression analysis is developed between independent input variables and dependent output variables. Input variables can also be classified into two different types of variables. One type is referred to dynamic variables as these expect to be varied during running with applied torque, misalignment and shaft bending. Second type is static variables with gear ratio, pressure angle and addendum. Once gear is manufactured, its geometric parameters cannot be changed. Misalignment, shaft bending, applied torque, gear ratio; pressure angle and addendum are considered as input independent variables while transmission error is considered as output dependent variable.

4. Results and Discussion

The different parameters are studied by developing the meta-models. The flow of stresses at teeth contact is higher when radial misalignment increases and stresses are higher for smaller contact area when angular misalignment increases.

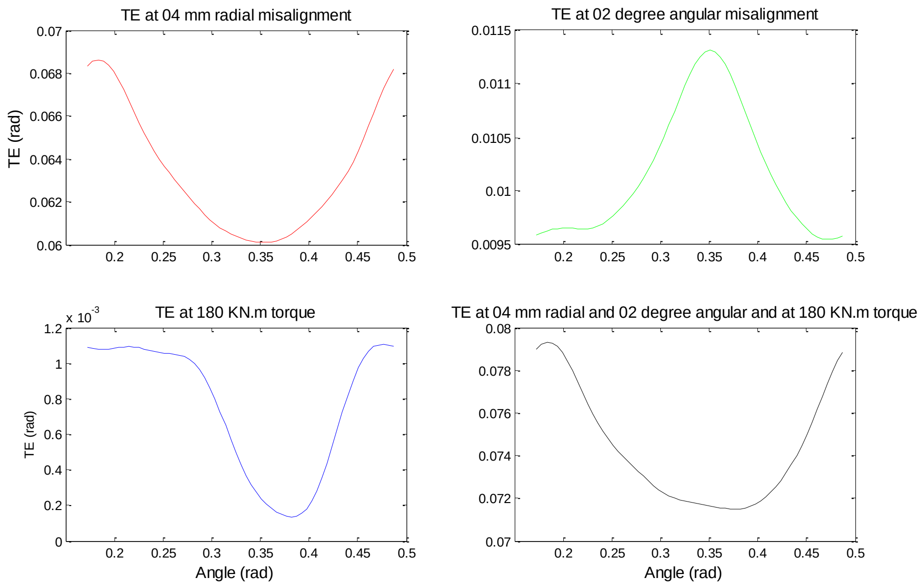

Fig. 3: Dynamic Combine effect of radial and angular misalignment and torque.

Fig. 3 shows TE at radial misalignment, angular misalignment and torque. Radial misalignment contributes more to TE than angular misalignment and torque. Radial misalignment tries to increase TE whereas angular misalignment and increasing torque try to decrease TE.

5. Evaluation of Transmission Error

Let us consider that the two teeth are in contact at initial position when next two teeth comes at the same contact position that angle of rotation accounts for one period of transmission error. This kind of error cannot be accounted for the validity of the meta-models. All meta-models are developed only for one period so it is not sure that starting points and ending points of the results of simulations for evaluation will match with each other.

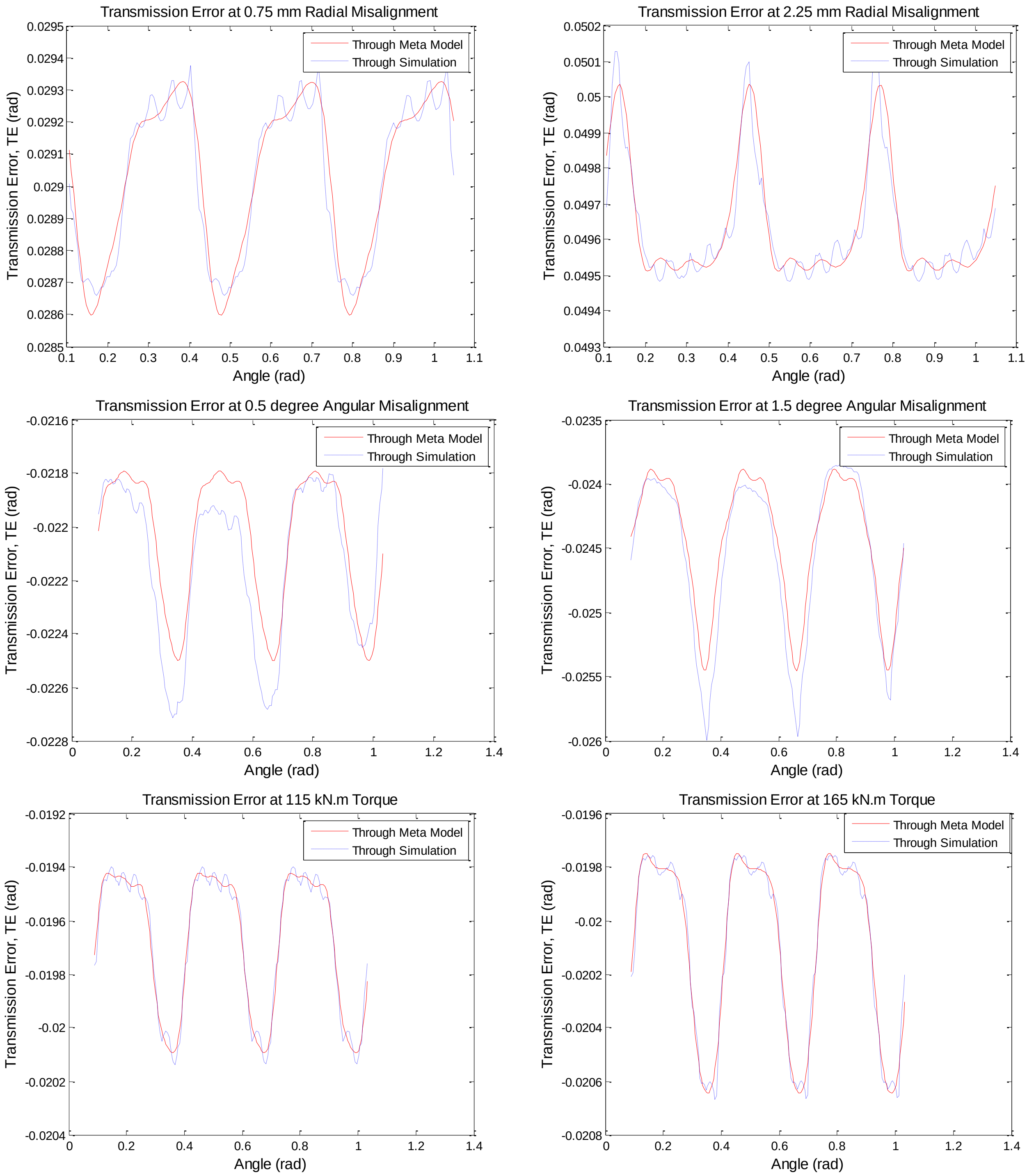

Fig. 4: TE because radial misalignment, Angular misalignment and Torque from meta-model and simulation

As shown in Fig. 4, meta-model's TE can predict sinusoidal behavior of simulation's TE but it cannot follow variations efficiently within crest and trough. It can be noted that TE lines of meta-models are higher than the simulation's TE lines. This kind of variation is due to the wrong position of the coordinate system. Especially for the angular misalignment of helical gears it is hard to exactly define the centre of coordinate system to run simulation on Abaqus. The same kind of errors is found for the development of meta-models and also it is checked that these errors cannot contribute to the accuracy of meta-models. It is shown that prediction of torque meta-model for TE is a close approximation than the prediction of meta-models for radial and angular misalignments. This efficient prediction is due to less simulation errors for the development of torque meta-models.

6. Conclusion

It can successfully be concluded that calculating Transmission Error from meta-models can be a computationally attainable method compared to calculating the Transmission Error from complex Finite Element-models of the gear geometry. Meta-models for the dynamic parameters (radial and angular misalignments and torque) are developed at particular values of static parameters (gear ratio, pressure angle, and addendum). Lack of fit of the meta-model is most likely because of the simulation errors. Meta-models predictions of Transmission Error for the dynamic parameters are more reliable than predictions of Transmission Error for the static parameters.

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