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Predicting contact characteristics for helical gear using support vector machine

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ABSTRACT

Friction force and friction torque are important factor in dynamics characteristics of transmission system. But, it is very difficult to measure friction force and friction torque. Numerical method is very complex to consult the mathematic model and take more time to calculate. A method was proposed, numerical algorithm and support vector machines were combined to predict the friction force and the friction torque of helical gear. First, numerical method was constructed to calculate contact characteristics. Then the results were adopted as inputs for support vector machines to predict friction force and friction torque. The conclusion shows the results are direct utilization which came from the output of support vector machines. Since the results are available directly from the output of the numerical method. The proposed method provides the possibility to predict friction force and friction torque in Engineering.

1. Introduction

Gear is the important component that widely used in mechanical equipment. The detection of noise and vibration for gear has been extensively studied [1]. Some important excitation sources of noise and vibration exist in gear transmission systems. The contact line varies with time and causes time-varying friction forces [2,3], which is very important excitation source of vibration and noise. By the study of instantaneous friction forces of a spur or a helical gear, tooth friction force is crucial for force transmission system. It is pointed by Vaishya and Singh [4] that the fluctuation of friction force is the important reason for dynamic response in gear transmission system. Lundvall et al. [5] have got two conclusions. One is that the input and output torque have changed with time-varying friction; another is that friction force cause dynamic transmission error in mechanical system.

The different mathematical models were used to compute tooth friction forces in recent research. Vaishya and Singh [6] predicted friction forces by combine a contact algorithm and a time-step integration scheme. The results showed friction force has important effect on torsional fluctuation. Velex and Sainsot [7] have done a number of work in calculating frictional force and friction torque. Lubrication varies between thin film boundary lubrication and full elasto hydrodynamics, so instantaneous friction forces is very difficult to measure [8]. In [9] have found that friction force and friction torque cause large transmission force during low speed operation.

Recently, the method of process monitoring processes has been considerably studied in industrial [10,11] or network [12] such as Data-Driven [13–15] and Intelligent Particle Filter [16]. As we know, while the transmission system is running, there are so many friction force and friction torque among various components. The friction force and friction torque of helical gear are very difficult to measure in practice. Numerical calculation need to construct complex mathematical model [17]. In [18] concerned model reduction for linear time-invariant system. There are not so many training samples, which can be used. Big data contain so many information, special characteristics need to distinguish from data [19].Therefore it is necessary to establish a new method to predict the friction force and friction torque.

In recent years, some promising methods were adopted for transmission system. such as Kernel Principal Component Analysis [20], Bayesian Inference-based Finite Gaussian Mixture Models [21], Partial Least Squares [22,23] and Multiway Gaussian Mixture Models [24]. Performance monitoring was used in vehicle suspension system [25]. Data-based techniques is very good approach under different operating condition, which provide efficient solutions [26]. Support Vector Machine (SVM) approach was used to diagnosis rolling bearings. The important advantage is that the simulation data can be used as training data [27]. Lotfi Saidi [28] adopted the higher order spectra analysis and SVM to diagnose the bearing. In [29], adaptive fuzzy control was used in unmodeled dynamics for nonlinear time-delay systems. Recently, the support vector machine has been used to gear fault classification, the

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method based on the training parameters of SVM [30,31]. SVM is rare as a tool to condition monitoring among available method [32]. But the SVM can be seen a higher accuracy method for fault detection [33,34].

Support Vector Machines are adopted, which is a relatively new algotiyhm. SVM has some advantages, the algorithm does not need so many training samples. SVM can solve complicated problem, even there are small number of training samples. On the other hand, SVM has higher accuracy which is very important reason in this paper. The paper adopted support vector machines to predict friction force and friction torque. The remainder of the article is constructed as follows. The numerical algorithms of friction force and friction torque were discussed in Section 2. Section 3 descripts SVM theory. Section 4 uses support vector machines to predict friction force and friction torque. The discussion and conclusion were given in Section 5.

2. Developed refinement algorithm of tooth surface friction and friction torque for helical gear

Based on the length of the time-varying contact line, the algorithm of tooth friction and friction torque were constructed with considering the relation between contact line and pitch circle. The algorithm has some advantages such as simple, rapid and convenient. Fig. 1 shows relationship between contact line and tooth friction force. In order to calculate friction force, the helical gear was divided into n slices, every slice can be seen a spur gear. Fig. 2 shows a flow chart of contact lines and friction force in contact zone. It can be used to calculate the friction force and the friction torque of helical gear. The results were obtained in the form of four matrices. The first column was used to calculate the length of contact line. The second column was used to calculate friction force. The third and fourth columns were used to calculate friction torque. Friction force is positive when the contact line located outside of cylinder section, adversely it is negative. Friction force varies with the contact line in meshing period.

The expression can be obtained as follow [35]:

$$F_{fij}(t_k) = -\mu_{ij}(t_k)\frac{F}{\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} L_{ij}(t_k)}\Delta L_{ij}(t_k) \quad i=1\ldots n_1 \quad j=1\ldots n_2$$
$$k=1\ldots n \tag{1}$$

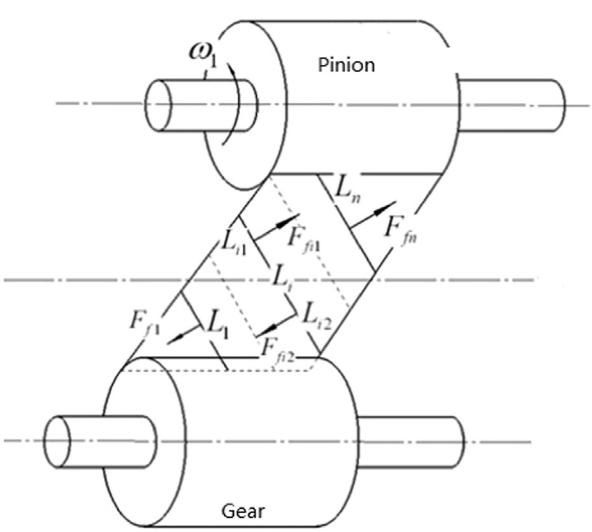

Fig. 1. Friction forces act on contact line in contact zone of helical gear.

Friction coefficient of elastohydro dynamic lubrication as follows [36]:

$$\mu = e^{f(sr,p_k,\eta_0,\sigma)} p_h^{b_2} \left|sr\right|^{b_3} v_e^{b_6} \cdot \eta_0^{b_7} R^{b_8} (f_{EHL}(T_{min},\sigma))^{0.2}$$

$$f(sr,p_h,\eta_0,\sigma) = b_1 + b_4|sr|p_h \log_{10}^{\eta_0} + b_5 e^{-|sr|p_k \log_{10}^{\eta_0}} + b_9 e^{\sigma}$$

Where $f_{EHL}(T_{min},\sigma)$ is load coefficient. T_{min} is the thickness of oil film. sr is sliding-rolling ratio. p_h is normal pressure. v_e is relative sliding velocity.

The value of b_1 to b_9 as follows:

$$\begin{cases} b_1 = -8.9, & b_2 = 1.1 \\ b_3 = 1.0, & b_4 = -0.3 \\ b_5 = 2.8, & b_6 = -0.1 \\ b_7 = -0.7, & b_8 = -0.4 \\ b_9 = -0.6 \end{cases}$$

where F is normal force (N); $\mu_{ij}(t_k)$ is friction coefficient at moment t_k of the jth contact line of the ith slice; $L_{ij}(t_k)$ is length of contact line at moment t_k of the jth contact line of the ith slice; $\Delta L_{ij}(t_k)$ is Length difference at moment t_k of the jth contact line of the ith slice.

The total tooth surface friction expression:

$$F_f(t) = \sum_{k=1}^{n}\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} F_{fij}(t_k) \tag{2}$$

The gear tooth surface friction torque is positive when it helps rotation, on the contrary it is negative. Tooth surface friction torque expression is given:

$$T_{fij}(t_k) = \mu_{ij}(t_k)\frac{F}{\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} L_{ij}(t_k)} L_{ij2}(t_k)\left(L_{AC} - l_{ij2}(t_k)\right) - \mu_{ij}(t_k)\frac{F}{\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} L_{ij}(t_k)} L_{ij1}(t_k)\left(L_{AC} - l_{ij1}(t_k)\right) \tag{3}$$

where $L_{ij1}(t_k)$ is the length of right segment line at moment t_k of the jth contact line of the ith slice; $L_{ij2}(t_k)$ is the length of left segment line at moment t_k of the jth contact line of the ith slice; $l_{ij1}(t_k)$ is the distance from midpoint of right line to right side at moment t_k of the jth contact line of the ith slice; $l_{ij2}(t_k)$ is the distance from midpoint of left line to right side at moment t_k of the jth contact line of the ith slice.

$$L_{AC} = \sqrt{r_a^2 - (r\ \cos\ \alpha_t)^2}$$

The total tooth surface friction torque formula as follow:

$$T_f(t) = \sum_{k=1}^{n}\sum_{i=1}^{n_1}\sum_{j=1}^{n_2} T_{fij}(t_k) \tag{4}$$

3. Support vector machines

The SVM is used to analyze recognize patterns and data, which is a set of related supervised learning methods. The original SVM algorithm was developed. Vapnik and Cortes [37] proposed the current standard incarnation. The basic idea of SVM is put the signal data into higher dimensional feature space. The algorithms pave the way for numerical practical applications, in which the data are separated by support vector. The simple principle as Fig. 3.

The support vector can be considered to create a hyperplane between two classes. The linear boundary was attempted to place