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A Novel Method to Improve Crack Detection Ability in Helical Gear

Mohsen Rezaei[1], Shahram Hadian Jazi[2],
Mehrdad Poursina[3], Farhad Haji Aboutalebi[4]

1. Introduction

Helical gear systems have some distinctions such as more precision, long life and more applications in the industry, and less vibration, noise and transmission error compared to spur gear systems. One of the damages that can affect the operation of these systems is the gear tooth root crack. So, crack detection in its early stages of growth and development is very important. The residual signal method is one of the most common methods to extract the effect of crack from the system vibration signal. Since the residual signal calculation requires the information of the vibration response of the healthy state or the system initial parameters, providing a method to extract the effect of crack from the vibrating response without any more information is very helpful. In this research, at first the calculation of the helical gear pair mesh stiffness is explained and also the effect of tooth root crack is also described. Then, a single-stage helical gear system, with the motor and the load, is modeled and solved numerically to achieve the system dynamic response. Then, the effect of the present method on the vibration signal obtained from the dynamic simulation of a system with a small crack is shown and discussed. Finally, the proposed method is applied to the dynamic response signal of a system presented in one of the previous researches, and its efficiency is illustrated.

2. Analytical Calculation of Mesh Stiffness

The first step in the process of evaluating a gear system is determining the mesh stiffness of the two involved gears. When two teeth of two involved gears come into contact, the gears become strained due to the force they bring to each other and their elastic behavior. The ratio of the force applied between the two teeth and the displacement that occurs due to this force is called the mesh stiffness. To calculate the mesh stiffness, the stiffness of a pair of teeth is first investigated and then assembled together using the contact ratio of the gears.

In this method, the helical tooth is divided into thin slices, which can be assumed to be a spur tooth approximately. As it is known, the stiffness of the original helical tooth can be obtained from the stiffness of the spur slices by considering their angular distance. In order to model the crack effect, its area is considered as a dead area and is not considered in calculating tooth stiffness. The only variables that change in this method are the tooth cross-section area and its second moment of area.

3. Helical Gear System Dynamic Model

The Lumped Mass Model is used to model the single-stage helical gear system. In this type of model, system is modeled as components with concentrated masses that are connected to each other by springs and dampers. The springs' stiffness is related to the stiffness of system components such as bearings, axles, and gear mesh stiffness. An 8 DOF model of the helical gear system is shown in Figure 1.

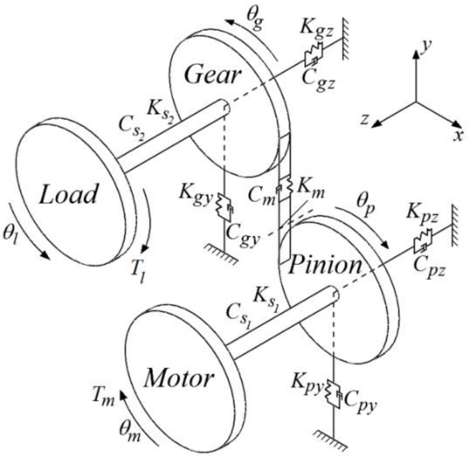

Figure 1. 8 DOF Dynamic Model of Helical Gear System

4. Sum of symmetric neighbors multiplication

In this article, the sum of symmetric neighbors multiplication method is proposed to highlight the local variations of a signal.

In this method, the amplitude of a certain number of neighboring points of each point of the original signal are symmetrically multiplied into each other and the sum of these multiplications is assigned to that point.

In fact, the difference between healthy and defective areas comes from multiplying neighboring values, which shows the large changes due to small changes in a region of the original signal. For a discrete signal $x[n]$, the sum of symmetric neighbors multiplication is defined as:

$$SSNM_x[n,d] = \sum_{k=1}^{d} x[n+k]x[n-k]$$

where d represents the size of the neighborhood.

5. Results and Discussion

The transmission error obtained by dynamic simulation of the system with a crack of 10% length and depth of tooth length and thickness in the pinion 14th tooth is shown in Figure 2 (a). The difference between the geometric location of a point on the base circle of the gear and its line of action, in the actual and theoretical cases is called the transmission error of a gear pair.

Due to the small size of the crack, its effect on the system transmission error is very small and not easily distinguishable in the figure. The amount of transmission error in the area where the cracked tooth (14th tooth) is

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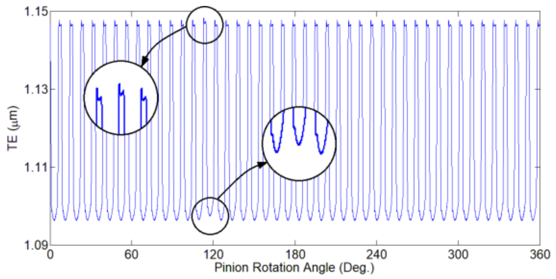
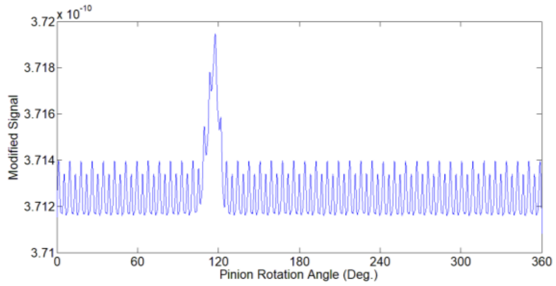
[1] *Ph. D. in Mechanical Engineering, University of Isfahan.*
[2] *Corresponding Author: Assistant Professor, University of Isfahan. s.hadian@eng.ui.ac.ir*
[3] *Associate Professor, University of Isfahan.*
[4] *Assistant Professor, University of Isfahan.*

involved (about 120 degrees of rotation of the pinion) is greater than the corresponding values in the other teeth. Figure 2 (b) shows the sum of symmetric neighbors multiplication with a neighborhood size equal to one mesh cycle. As observed, the operation was quite effective in highlighting the effect of the crack and showing its location.



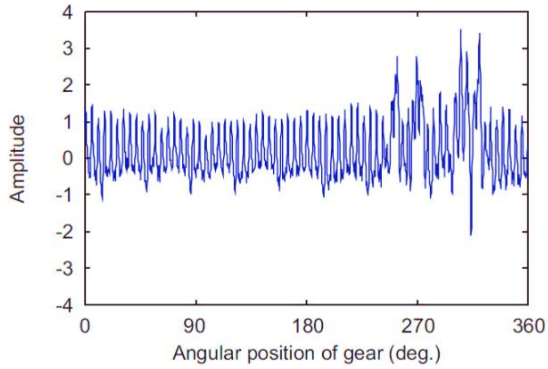
(a)



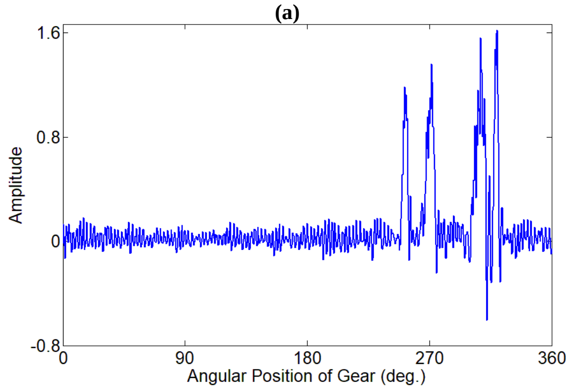
(b)

Figure 2. (a) Vibration signal obtained by dynamic simulation of the system. (b) The sum of the symmetric neighbors of this signal

Figure 3 (a) shows the vibration signal of a gear system with 71 pinion teeth and four cracked teeth presented by Wang and Wong. As can be seen from Figure 3 (a), the local changes occur in the region between the pinion rotation angles from 240 to 340 degrees. As observed, it is not possible to accurately identify faulty teeth. Figure 3 (b) shows the sum of symmetric neighbors multiplication with the neighborhood size of a mesh cycle. As observed, the four distinct areas have been clearly identified.



(a)



(b)

Figure 3. (a) Vibration signal of the gear system provided by Wang and Wong. (b) The sum of symmetric neighbors multiplication of this signal

6. Conclusion

In this study, the sum of symmetric neighbors multiplication method is introduced to highlight the effect of defects in a vibration signal. The results show, by applying the proposed method, small local changes on the vibration signal amplitude, caused by a small tooth root crack, increase approximately three times with respect to the original signal. The capability of the newly proposed method is also assessed in a multi-crack case. The results indicate that the proposed method can highlight the effect of each crack. That is, the proposed method not only can highlight the effect of defects but also can locate these defects with reasonable accuracy.