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A windowing and mapping strategy for gear tooth fault detection of a planetary gearbox

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ABSTRACT

When there is a single cracked tooth in a planet gear, the cracked tooth is enmeshed for very short time duration in comparison to the total time of a full revolution of the planet gear. The fault symptom generated by the single cracked tooth may be very weak. This study aims to develop a windowing and mapping strategy to interpret the vibration signal of a planetary gear at the tooth level. The fault symptoms generated by a single cracked tooth of the planet gear of interest can be extracted. The health condition of the planet gear can be assessed by comparing the differences among the signals of all teeth of the planet gear. The proposed windowing and mapping strategy is tested with both simulated vibration signals and experimental vibration signals. The tooth signals can be successfully decomposed and a single tooth fault on a planet gear can be effectively detected.

1. Introduction

A planetary gear set typically consists of a sun gear, a ring gear and several planet gears as shown in Fig. 1 [1]. There are several sun-planet gear pairs and several ring-planet gear pairs meshing simultaneously. Therefore, there are multiple vibration sources inside a planetary gearbox. In addition, with the rotation of the carrier, the distance between a planet gear and a transducer fixed on the top of the housing varies all the time. The time varying distance will induce the effect of transmission path which attenuates the vibration signals generated from the vibration source far from the transducer. Multiple vibration sources and the effect of the transmission path lead to the complexity of fault detection of a planetary gearbox [2].

To understand the vibration properties of a planetary gearbox, model based methods have been widely used to simulate the vibration signals of a planetary gearbox. Several studies [3–6] simulated and investigated the vibration signals of the sun gear or a planet gear of a planetary gear set. However, transducers were generally installed on the housing of a gearbox or the housing of a bearing to acquire the vibration signals of the whole gearbox rather than the signals of a specific gear. Therefore, it is more helpful for fault detection to model and investigate the vibration signals of a planetary gear set rather than a single gear. Refs. [2,7–10] modeled the vibration signals of a planetary gear set by incorporating the effect of transmission path with the assumption that as planet n approached the transducer location, its influence would increase, reaching its maximum when planet n was the closest to the transducer location, then, its influence would decrease gradually as the planet travelled away from the transducer. In this paper, the method reported in [2] will be used directly to model the vibration signals of a planetary gear set in the healthy condition and in the faulty condition. The simulated signals will be

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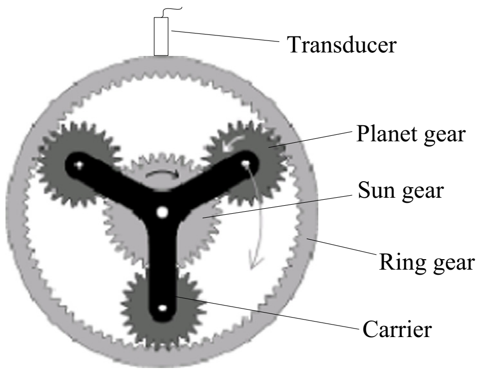

Fig. 1. The structure of a planetary gear set.

used to test the effectiveness of the proposed fault detection method.

Many vibration analysis techniques have been developed to detect the gear fault of a planetary gearbox [11–14]. McFadden [15] proposed a windowing and mapping strategy to obtain the vibration of individual planet gears and of the sun gear in a planetary gearbox. In his method, a window function is applied to sample the vibration signals when a specific planet gear is passing by the transducer and then the samples are mapped to the corresponding meshing teeth of the sun gear or the planet gear to form the vibration signals of the sun gear or the planet gear. Many additional studies attempted to improve the performance of the method reported in [15]. Refs. [16–19] investigated the techniques to index the positions of each planet gear, which were used to find the best location of putting the windows. Ref. [17,18,20–22] tried to find the best window type and window length for the sampling. The performances of rectangular window, Hanning window, Turkey window and cosine window were investigated in [15–22]. All these efforts were trying to decompose the vibration signal of a planetary gearbox while focusing on the vibration signal of the sun gear or the planet gear of interest. The decomposed signal can reduce the interference from the vibration of other gears and consequently emphasize the fault symptoms of the gear of interest.

In this paper, a new windowing and mapping strategy is proposed to generate the vibration signal of each tooth of a planet gear. The decomposed vibration signal can reduce the interference from the vibrations of other teeth of the planet gear of interest. Examining the signals of all the teeth of a planet gear, the health differences of the teeth can be measured. To apply the proposed windowing and mapping strategy, an important issue to be addressed is to determine where to apply the windows. A numerical optimization algorithm is developed to find the optimal positions of windows given a vibration signal of a planetary gearbox with a single tooth fault in a planet gear. The proposed method is numerically and experimentally demonstrated to be able to detect a cracked tooth in a planet gear.

The organization of this paper is as follows: firstly, the vibration properties of a planetary gearbox are examined; then, a windowing and mapping strategy will be proposed to generate the vibration signal of each tooth; lastly, the proposed method is assessed numerically and experimentally for detection of a tooth crack in a planet gear.

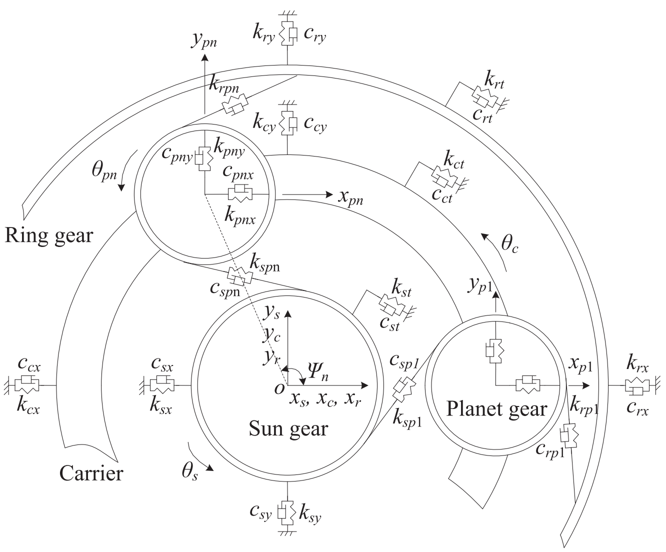

Fig. 2. Dynamic model of a planetary gear set [2].