Feature extraction for gear diagnostics based on EEMD in different crack size

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ABSTRACT

In these days, diagnostics techniques enabling the condition based maintenance are being paid great attention in many industry fields to achieve increased reliability of the system as well as the reduction of operating cost. The techniques are particularly useful to the system that costs a tremendous amount for the maintenance or leads to the catastrophic results when failure occurs. In such systems, the gearbox is usually employed to deliver the power under extreme loading conditions which are expensive to maintain and replace when failure occurs. Among the many gear faults, crack is the most critical in the sense that it grows suddenly to the tooth breakage, resulting in the whole system loss. To diagnose tooth cracks, many authors have conducted studies using gear vibration signals. Choi and Li estimated gear tooth transverse crack size using vibration signals by fusing selected gear condition indices [1]. G.R proposed vibration signature to estimate fault size [2]. This study classifies features of fault signal in different crack size using TE. In the previous study [4], authors have conducted a fault classification study of spall and crack, in which a pair of gears are operated in a testbed, faults are imbedded to the gear, and features are extracted based on the Ensemble Empirical Mode Decomposition (EEMD) technique using the transmission error (TE) signals [3-4]. Types of the fault are then identified based on the finite element analysis (FEA) of the faulted gears. In this study, further progress is made with the goal to evaluate the severity of the crack faults from the signal. To this end, gears with different crack size are prepared. The FEAs are conducted and compared with the measured signals, from which the critical size is identified that requires maintenance action. Since the measured crack signals include various noise and uncertainties, study on the statistical significance is also made to check whether the signal can be large enough to detect the fault. Once successful, the technique can be applied to estimate not only the size of the crack fault but also its severity against the critical level, using the measured TE signals of the gears in operation.

1. INTRODUCTION

Gears are critical component of many machinery equipment. As it takes much part of the costs when failure occurs, the fault detection and diagnosis is the important part of the gear maintenance. Gear faults are largely divided in crack and spall. Crack is attributed to the repetitive bending stress and prone to the failure by tooth breakage. If the crack size can be identified, the severity of the fault can be estimated and efficient maintenance is possible. Toward this objective, gears with different crack sizes are prepared, for which the finite elements analyses (FEA) are conducted, testbed is operated by the gears with the crack, and the features from the measured signals are compared with the FEA results. As in the previous study, EEMD method is used for feature extraction, which was found useful for classifying the spall and crack from the normal ones [3]. The EEMD is further applied to categorize the crack size and classify the severity of the fault. Finally, the method is validated by running a gear with arbitrary crack and estimating the severity in a probabilistic way.

2. SIMULATION

To identify signals of different crack size, FEA is conducted. The problem is given in Fig. 1, in which the upper driving gear is rotated by applying the torque of 450 Nm while the lower gear is fixed at its hub. The crack is made in the pinion gear. For the different crack sizes, the FEA carries out the static analysis to determine the teeth deformation in contact. The transmission error, which is the discrepancy of rotation angle between the ideal and real value due to the finite gear stiffness is computed from the result, which is obtained by Eq.

1 where the theta1, theta2, R1 and R2 represent the angular displacements and radii of the gear and pinion, respectively.

$$TE = \theta_2^{ideal} - \theta_2 = \frac{R_1}{R_2}\theta_1 - \theta_2 \tag{1}$$

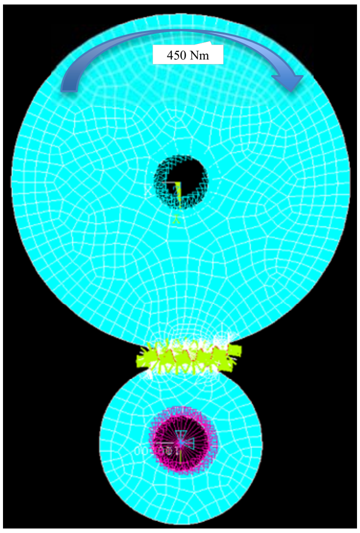

Fig. 1 System model of gear

The analysis is repeated over a single pitch by increasing the angle in contact with a small amount. The obtained TE's from the FEA are shown in Fig. 2 with the crack sizes from 0 mm to 5 mm with the increment in 1 mm. The maximum TE values are also given in Fig. 2. In Fig. 3, it is found that the TE value increases as the crack size gets longer, which is expected due to the smaller stiffness of the tooth.

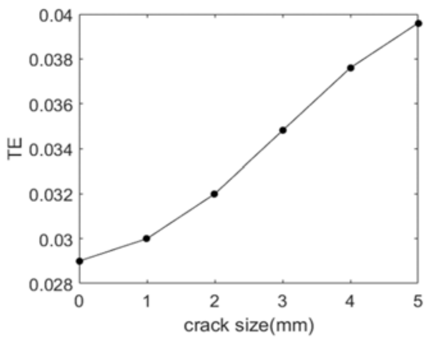

Fig. 2 TE value of each crack size

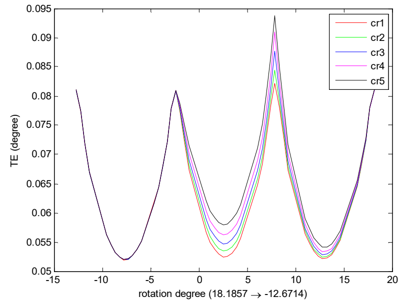

Fig. 3 TE obtained from FEA in different crack size

3. ENSEMBLE EMPIRICAL MODE DECOMPOSITION

EEMD is improved method of EMD which decompose the original signal by different mode. Intrinsic Mode Function (IMF) is obtained from shifting process of the original signal. Shifting process is described as follows. First, determine local extrema and connect each upper and lower extremum by interpolation. Second, calculate the local mean of each envelope. Third, subtract the local from the signal to obtain the residual signal. If the residual signal satisfies the definition of IMF, subtraction function is defined as the IMF. Otherwise it is repeated until the IMF is obtained. This shifting is repeated over the residual signal to get the series of the IMF until no more IMF can be made.

EMD has a problem named 'mode mixing', which is that each mode is not decomposed well. To improve this, EEMD is proposed, which adds white noise to the original signal [5-6]. v Rest is the same as the EMD. In the previous study, the spall and crack have been classified using the EEMD. In this study, the same EEMD is attempted to estimate the severity of crack fault with the aid of the FEA for different crack sizes.

4. EXPERIMENT

In the experiment, a simple test-bed is installed as shown in Fig. 4, which consists of motor, powder brake, a pair of spur gears with 35 and 70 teeth and encoder. Faults of crack with differing size are artificially imbedded at the tooth of a gear as shown in Fig 5. During the operation, TE is obtained from the measurement of rotation angle from the two encoders [7].

Table. 1 Test-bed specification

Component	Specification
Gear ratio	2:1 (number of teeth70:35)
Module	4mm, spur gear
Servo motor	2.9kW
Gearbox ratio	50:1
Powder brake	40kgf m
Rotary encoder	8192ppr

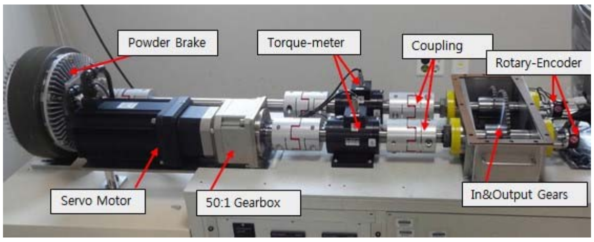

Fig. 4 Test-bed

Fig. 5 Crack imbedded at tooth of a gear

To reduce the influence of noise from the raw signals, signal processing is made to obtain the Residual Transmission error (RTE), which includes the time synchronous averaging (TSA) and notch filtering around the gear mesh frequency. The RTE, as shown in Fig. 6, is further processed by applying the EEMD to obtain the unique feature that is representative of the crack size.

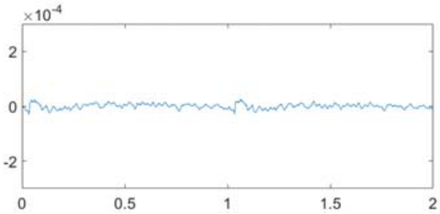

Fig. 5 Residual transmission error

5. CONCLUSION

In this study, simulation and experiments are conducted to diagnose the crack severity of a pair of spur gears in operation. The TE measured from the encoder is used as the signal. After reducing the noise by TSA and notch filtering, feature is extracted using the EEMD technique. The crack severity is then estimated based on the relation established for the feature and the FEA simulation results. Finally, the method is validated by operating the gear with an arbitrary crack, estimating its severity and check the validity.

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