Fault Feature Extraction and Degradation State Identification for Piezoelectric Ceramics Cracking in Ultrasonic Motor Based on Multi-Scale Morphological Gradient

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Piezoelectric ceramics cracking is one of the main faults of the ultrasonic motor. According to the morphological mathematics and information entropy, a method based on multi-scale morphological gradient was proposed for ceramics fault feature extraction and degradation state identification. To solve the problem that traditional multi-scale morphology spectral (MMS) entropy cannot exactly describe the performance degradation of the piezoelectric ceramics, multi-scale morphology gradient difference (MMGD) entropy was proposed to improve the sensitivity to the fault. Furthermore, multi-scale morphology gradient singular (MMGS) entropy was presented to reduce the system noise interference to the useful fault information. The disturbance analysis of temperature, load, and noise for MMGD entropy and MMGS entropy was also given in this paper. Combining the advantages of the above two entropies, a standard degradation mode matrix was built to distinguish the degradation state via the grey correlation analysis. The analysis of actual test samples demonstrated that this method is feasible and effective to extract the fault feature and indicate the degradation of piezoelectric cracking in ultrasonic motor.

1. INTRODUCTION

Ultrasonic motors have been widely used in the areas such as aerospace, medical equipment, optical instruments, robots, and new military equipment, due to some advantages of high torque, quick response, no electromagnetic, and auto-locking. Piezoelectric ceramics is a key part of the ultrasonic motor. But this material is brittle, and it is prone to crack due to high frequency excitation for a long-time operation. The propagation of crack would result in the failure of the piezoelectric ceramics. It is needed to pay considerable attention to the fault feature extraction and degradation state identification for the piezoelectric ceramics cracking in ultrasonic motor. Unlike other mechanical devices, the ultrasonic motor comes with a monitor electrode used to reflect the vibration state of stator. Therefore, the monitor electrode voltage generated by the positive piezoelectric effect can be used for fault information extraction. But the rotor is driven by the frictional forces between the friction material and metal elastomer particles whose trajectory is ellipse. It seems hard to effectively extract the fault information due to the effects of other mechanical system noises. Consequently, an effective signal processing method is required.

Recently, many studies have been performed on the fault feature extraction of mechanical device. The typical methods are the wavelet transform and empirical mode decomposition (EMD). In the aspect of wavelet transform, Li Y. et al. used tunable Q-factor wavelet transform to separate the transient impact component related to early fault information of rolling bearing. Pan et al. introduced the empirical wavelet transform to extract inherent modulation mechanical fault information by decomposing signal into mono-components. Singh et al. used methodology based on over-complete rational dilation wavelet transform to enable the proposed indicator be sensitive to fault severity. Wang D. et al. proposed Gauss-Hermite integration-based Bayesian inference method to estimate the posterior distribution of wavelet parameters, then an optimal wavelet filtering was conducted to extract bearing fault features. In the aspect of EMD, Xue X. et al. utilized an adaptive fast ensemble EMD to solve the problems of residue noise in the signal reconstruction and the parameters selection and extracted the fault feature of bearing with high computational ef-