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Automatic classification of magnetic tiles internal defects based on acoustic resonance analysis

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ABSTRACT

A novel signal processing method using wavelet packet transform (WPT), linear discriminant analysis (LDA) and support vector machine (SVM) is presented for detecting internal defects in magnetic tile. In this methodology, the acoustic signal obtained by a mechanical system based on acoustic resonance is analyzed. WPT is applied to extract the normalized features of the signal. The internal defects are identified by SVM based on the extracted features optimized by LDA and a constraint algorithm. The experimental results demonstrate that the presented approach can be employed for a promising application of automatic detection of internal defects in magnetic tile.

1. Introduction

Magnetic tile is a curved component made of magnetic materials, and it is widely used to generate the magnetic field of permanent magnet motor. The performance and life circle of the motor could be significantly affected by the product quality of magnetic tile. However, the surface and internal defects are unavoidable during the manufacturing process, especially the cracks. These defects can directly alter the physical properties and mechanical integrity of a magnetic tile, which will result in the performance degradation of the motor. Thus, the defect detection is significant and necessary to insure the quality of magnetic tiles.

The manufacturing process of magnetic tile is so massive and continuous that inspection speed and accuracy are demanded. Currently, some successful investigations on the basis of computer vision have been utilized to test the surface crack defects on magnetic tile [1]. However, the internal defects in magnetic tile are invisible, random and complicated. There are few effective researches that can be used directly. At present, the internal defects of magnetic tile are mostly detected by manual work, the accuracy of which depends on the acute human hearing and long-term experience of laborer. In practice, the presence or absence of internal defects can be determined using manual recognition of the sound generated by tapping a metal with magnetic tile. Manual inspection is lack of efficiency and precision. Therefore, it is necessary to develop a reliable approach to detect internal defects in magnetic tile automatically.

Various non-destructive testing technologies, such as X-rays, ultrasound, infrared, laser-ultrasonic, acoustic emission, etc., have the ability to test the structural defects. Considering the inspection requirements, the acoustic resonance method

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is more conducive to implement the simple, convenient and low-cost detection [2–8]. The principle of this method is established based on the analysis of acoustic signal obtained from the collision of magnetic tile with metal. Consequently, the main task of this work is defects identification based on the acoustic signal characteristics. However, this signal is generally non-stationary, non-Gaussian, and non-linear. The conventional analyses are difficult to achieve valid feature extraction.

With the development of signal processing technology, it has obvious advantage to extract features from non-stationary signal with WPT [9–11]. The main features of wavelet packet coefficients (WPC) obtained by WPT, for instance, energy and entropy, can reflect the characteristics of signal in particular [12–14]. Moreover, in recent relevant studies, certain statistical data of WPC, for example, variance, skewness, kurtosis, root mean square [15,16], etc., are declared as significant features. The eigenvectors associated with the WPT features are usually high-dimensional data that can increase the difficulty of defects identification. Therefore, in order to simplify and optimize the data, the dimension reduction is frequently performed prior to feature classification. The common dimension reduction algorithms include principal component analysis (PCA) [17], LDA, independent component analysis (ICA) [18], and locally linear embedding (LLE) [19], etc. In addition, SVM is a machine learning method used for classification and regression [20]. The SVM using the WPT features processed by the dimension reduction algorithm, has been applied to fault diagnosis and defect recognition [21,22]. In contrast, the application for detecting internal defects in magnetic tile has not been developed yet. A novel approach based on WPT, LDA, and SVM is presented in this paper to identify internal defects for magnetic tiles using acoustic resonance signal analysis.

The remainders of this paper are outlined as follows. Next section briefly introduces the fundamental theory of the proposed method. Section 3 explains the experimental study in details. The analysis and discussion of the obtained results are described in Section 4. Finally, the conclusion and the future work are mentioned.

2. Fundamental theory

2.1. Wavelet packet transform

Mathematically, a wavelet packet function $w_{j,k}^n$ is expressed as [23]:

$$w_{j,k}^n(t) = 2^{j/2} w^n\left(2^j t - k\right) \tag{1}$$

where $j, k \in Z$ and $n \in N$ indicate the scaling parameter, the translation parameter, and the oscillation parameter, respectively.

The wavelet packet functions satisfy the following recurrence relation [24]:

$$\begin{cases} w^{2n}(t) = \sqrt{2} \sum_{k \in Z} h(k) w^n(2t-k) \\ w^{2n+1}(t) = \sqrt{2} \sum_{k \in Z} g(k) w^n(2t-k) \end{cases} \tag{2}$$

where $h(k)$ and $g(k)$ are a pair of orthogonal mirror filters and they can be associated with the following equation [25]:

$$g(k) = (-1)^k h(1-k) \tag{3}$$

WPT evolved from discrete wavelet transform (DWT). But unlike a left recursive binary tree structure belongs to DWT, as shown in Fig. 1, a full binary tree structure can be produced by WPT. Each node of the binary tree structure stands for a frequency sub-band which comprises a certain amount of WPC. Supposing the length of a discrete signal $x(t)$ is L, the WPC $d_j^n(k)$ of a node can be computed as below [26]:

$$d_j^n(k) = \int_{-\infty}^{+\infty} x(t) w_{j,k}^n(t) \mathrm{d}t \tag{4}$$

where j is the level of WPT, n is the number of nodes at level l, and $k = 1, 2, \cdots, L/2^j$ is the index of WPC.

There are many available information can be used as signal features in WPC. The energy (E) and Shannon entropy (T) of every node are the most common features of WPC, and they are represented as follows [27]:

$$E_j^n = \sum_{k=1}^{L/2^j} \left[d_j^n(k)\right]^2 \tag{5}$$

$$T_j^n = -\sum_{k=1}^{L/2^j} \left[d_j^n(k)\right]^2 \log\left[d_j^n(k)\right]^2 \tag{6}$$