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Introductory invited paper

Research on fault diagnosis of airborne fuel pump based on EMD and probabilistic neural networks

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ABSTRACT

Airborne fuel pump is a key component of the airborne fuel system, which once fails will bring a huge negative impact on aircraft safety. Therefore, accurate, reliable and effective fault diagnosis must be performed. However, the current airborne fuel pump has several difficulties: fault samples shortage, high maintenance costs and low diagnostic efficiency. In this paper, after Failure Mode, Effects and Criticality Analysis (FMECA) of airborne fuel pump, an experimental platform of airborne fuel transfusion system is developed and then a fault diagnosis model based on empirical mode decomposition (EMD) and probabilistic neural networks (PNN) is established. Meanwhile, the diagnosis model is verified by practical experiments, and the sensor layout of the experimental platform is optimized. Firstly, the vibration signals and pressure signals under normal state and six types of typical fuel pump faults are acquired on the experimental platform. Then EMD method is applied to decompose the original vibration signals into a finite Intrinsic Mode Functions (IMFs) and a residual. Secondly, the energy of first four IMFs is extracted as vibration signals fault feature, combined with the mean outlet pressure to construct fault feature vectors. Then feature vectors are divided into training samples and testing samples. Training samples are used to train PNN fault diagnosis model and testing samples are used to verify the model. Finally, the experimental results show that only one pressure sensor and one y-axis vibration sensor are needed to achieve 100% fault diagnosis. Furthermore, compared with SVM and GA-BP, the PNN fault diagnosis model has fast convergence, high efficiency and a higher performance and recognition for the typical faults of airborne fuel pump.

1. Introduction

Airborne fuel pump is one of the crucial components of the airborne fuel system, which can provide fuel of predetermined flow rate and pressure for the engine [1]. Once airborne fuel pump fault occurs in flight, it would not only affect the performance of the entire fuel system, but also might lead plane crash disastrous and huge economic losses. Therefore, its stability is important for guaranteeing aircraft reliability and safety [2,3]. With the increasing complexity of aircraft structures and battlefield environments, higher requirements of airborne fuel pump reliability and efficient maintenance are proposed. Traditional breakdown maintenance and scheduled maintenance are unable to meet the requirements of modern war for the maintenance support. Therefore, Condition Based Maintenance (CBM) is the key way to realize the aircraft fuel system prognostic and health management (PHM) [4–9].

Through the investigations of aircraft fuel pump maintenance support, we find that the main troubleshooting methods are dismantlement and depot repair, which can result in high maintenance costs, low efficiency of diagnosis and huge waste of resources. Hence, how to improve efficiency of existing troubleshooting techniques is widespread concerned [10–13]. Many researchers have done much work about fuel pump fault diagnosis [14,15]. There are several intelligent methods to detect this fuel pump defects or fault. When airborne fuel pump fault or performance degradation occurs, vibration and pressure signal will change in both time and frequency domain, thus the vibration signal and pressure signal are widely used as the fault characteristics of the fuel pump. So these diagnosis methods which only consider single signal are not ideal in the multi-fault mode. However, only few low-sampling pressure sensors are installed on the aircraft and the pressure signal is not recorded during the flight. Even worse, there is no vibration sensor on the airplane to measure the fuel pump, resulting in less fuel pump fault sample data. Therefore, it is urgent to design and develop an experimental platform of fuel transfusion system, which can simulate the normal state, bearing wear state, diffusion tube damage state and other typical types fault state of airborne fuel pump. It

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also can monitor and record the vibration and outlet pressure signals under each operating condition.

Generally, the process of intelligent fault diagnosis can be divided into four parts: 1) fault samples acquisition; 2) fault feature extraction; 3) feature subset selection; 4) feature classification. Vibration and pressure fault data can be obtained through the experimental platform, so fault feature extraction and feature classification are the key steps of fuel pump diagnosis [16]. Various time domain statistical parameters such as kurtosis, skewness, variance, root mean square, standard deviation and peak are used as fault feature to diagnosis the fault or failure [17]. Fan, et al., [18] propose an approach which extracts standard deviation, kurtosis and other statistical parameters from the raw signal and the reconstructed signal by DWT, the comparison results show that the effectiveness of the statistical parameters. In the frequency domain, spectrum plays an important role in fault diagnosis. Spectrum analysis is a fundamental method to deal with time series data and can reflect the frequency of signal and its distribution. Luo et al. [19] define the multi-scale higher order singular spectrum entropy as fault feature and combined with genetic algorithm (GA) for rotor fault diagnosis. Fast Fourier Transform (FFT) is able to convert a time domain signal into different frequency sine or cosine functions, but it has limitations in terms of resolution of time and frequency. In addition, it can only handle stationary signal [20].Unfortunately, the stationary signal is only an ideal state, the vibration and pressure signals of actual operation of airborne fuel pump are non-stationary, nonlinear signals. There are many time-frequency analysis methods that have been applied to handle nonlinear, non-stationary signals, such as Short Time Fourier Transform (STFT) [21], wavelet analysis [22], and so on. STFT is nothing but a limited time window sliding along the time axis relies on the traditional Fourier analysis. It divides the whole time domain into numerous segments of the same length of time, each time period is approximately stationary process. The size and shape of the window function is independent on frequency. Sampling interval in time domain and frequency domain is constant, so that the window size does not vary with frequency. When dealing with practical problems, we hope that time interval decreases with increasing frequency. Zhong and Huang [23] present an adaptive short-time Fourier transform which make the analysis window width is equal to the local stationary length. Wavelet analysis is another important method for nonlinear and non-stationary signal. It can adaptively change signal decomposition scale through a predetermined scale and translation schemes. Qiu et al., [24] present wavelet filtering to detect periodical impulse components from vibration signals. Talhaoui et al., [25] study the discrete wavelet transforms for extracting rotor bar faults feature. Wang et al., [26] present a detection method of weak transient signals based on wavelet transform, the results show it is effective in weak signature extraction. However, before using wavelet analysis the basic wavelet function, the scaling factor and the translation factor must have been first selected. Without the prior information of the signals, it is difficult to select the basic wavelet functions which have great influence on the performance of the wavelet analysis. Different from any of the methods mentioned above, empirical mode decomposition (EMD) can automatically decompose non-stationary, non-linear signal into several different intrinsic mode functions (IMFs), each of which has different physical meaning. EMD is widely used in engineering applications. Yang et al., [27] innovatively use EMD to research the sEMG signal to find the features of muscular fatigue. Yang [28] uses EMD to extract the underlying trends of signals. Jiang et al., [29] present a wheel fault noise diagnosis method based on EMD and neural network, which can accurately and effectively classify wheel fault patterns. Lei et al., [30] summarize the recent research of EMD in fault diagnosis of rotating machinery and discussed the possible trends. Therefore, a method based on EMD is presented for airborne fuel pump fault feature extraction.

After fault feature of airborne fuel pump is extracted, the fault feature classification is carried out subsequently. For pattern classification problems, there are plenty of methods can be used, for example: decision tree [31], Bayesian [32], K-Nearest Neighbor (KNN) [33], support vector machine (SVM) [34], neural networks and so on. Ma et al., [35] use decision tree learning method to handle uncertain data; an active belief decision tree learning approach can improve classification accuracy by querying while learning. Muralidharan [36], analyze the vibration signals of monoblock centrifugal pumps by wavelet transform, and then use SVM to classify the fault types. SVM is based on statistical and structural risk minimization, it can effectively solve the small samples, nonlinear and high dimensional classification problems, but it has great dependence on the choice of kernel function. Ali [37], carries out a research on artificial neural network for automatic bearing fault diagnosis. Neural networks need initializing a large number of

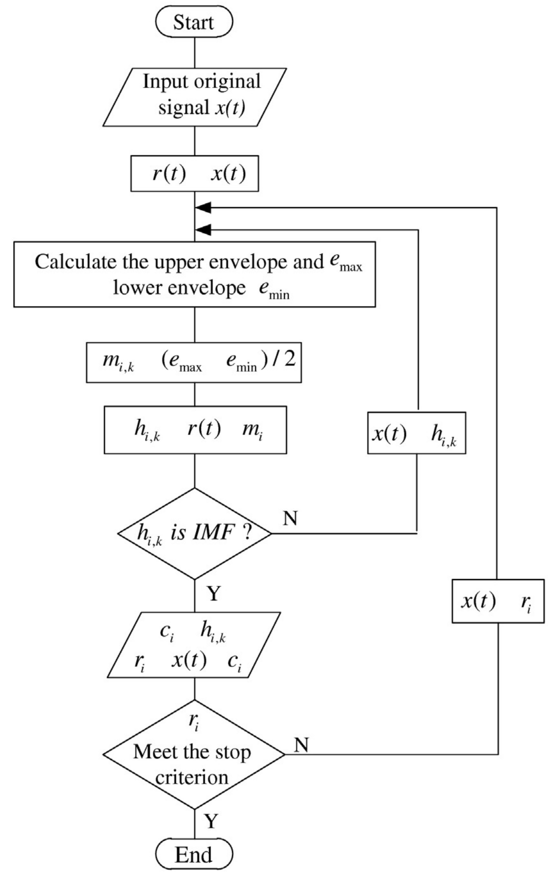

Fig. 1. Signal decomposition process by EMD.

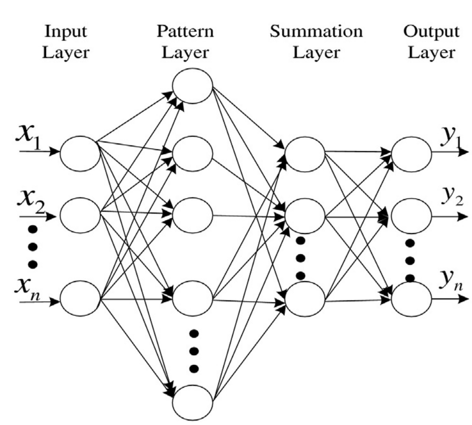

Fig. 2. The structural diagram of probabilistic neural networks.

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