Research on Auto-detection for Remainder Particles of Aerospace Relay Based on Wavelet Analysis

GAO Hong-liang*, ZHANG Hui, WANG Shu-juan

Department of Electrical Engineering, Harbin Institute of Technology, Harbin 150001, China

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Abstract

Aerospace relay is one kind of electronic components which is used widely in national defense system and aerospace system. The existence of remainder particles induces the reliability declining, which has become a severe problem in the development of aerospace relay. Traditional particle impact noise detection (PIND) method for remainder detection is ineffective for small particles, due to its low precision and involvement of subjective factors. An auto-detection method for PIND output signals is proposed in this paper, which is based on direct wavelet de-noising (DWD), cross-correlation analysis (CCA) and homo-filtering (HF), the method enhances the affectivity of PIND test about the small particles. In the end, some practical PIND output signals are analysed, and the validity of this new method is proved.

Keywords: aerospace relay; remainder particles; PIND; wavelet analysis

1 Introduction

Aerospace relay is one kind of electronic components, which is used widely in national defense and aerospace system. But at present, most relay producers, especially those in China, can’t avoid the existence of remainder particles in the cave of relay. These particles are some small objects such as metal scrap, wire, tin dreg, and ferrite dust. When the aerospace system is on duty, levitate particles are activated by collision or concussion, which will make the relay wrongly triggered or inactivate, and even cause catastrophic failure. This has become a severe problem in the development of aerospace relays, so it is very important for researching on the detection of remainder particles of aerospace relay.

Particle impact noise detection (PIND) test is a method for detecting remainder particles widely used by aerospace relay producers, and mostly it is a compulsory test for relays before leaving factories[1]. PIND is defined in MIL-STD-883E method 2020 USA[2]. The typical structure of PIND test system is shown in Fig.1.

![Fig.1 The PIND system of MIL-STD-883E_2020.7](image)

The PIND test is performed by placing the test part upon an acoustic electric transducer, which is mounted on the top of a vibration shaker. The part is shocked during vibration and the loose particles strike the walls of the package, causing acoustic waves. These waves are converted into electrical signals by transducer and the operator attempts to detect the existence of the loose particles.

The PIND is a typical semi-automatic method. The output signal is attempted by operator watching
the waveform on an oscilloscope and listening the
sound from a speaker, and it is only validated for
some large particles (mass more than 1 milligram
and diameter more than 0.001 inch). But for some
smaller particles, the traditional PIND is with low
precision, the low signal-noise ratio waveform is
difficult to be observed in the oscilloscope, and as
many subjective factors are involved, the false
alarm rate is high. Some small particles can’t be
activated for many times, the waveform can’t be
observed repeatedly, and all these cause the escape
rate of PIND test high[3]. So it is very necessary to
research a kind of new PIND test method with high
precision and little involvement of subjective fac-
tors.

2 Analysis of the Character of PIND
Output Signals and Noise

There are three kinds of signals in the output of
PIND tester: particle signal, component signal and
noise. The authors summarize the signal characters
as following:

(1) Particle signal

Particle signal is the target signal of PIND test,
and it is generated as a resonance which takes place
between the sound of impact and the piezoelectric
crystal in the sensor. The main frequency of particle
signal is in the range of 150 kHz to 160 kHz.

(2) Component signal

Component signal is the output sound of the
movable component of relay such as armature and
spring, making a forced vibration with the shaker’s
vibration. The research on how to distinguish com-
ponent signal from particle signal is presented in
Ref.[4], and in this paper, how to differentiate the
particle signal and noise is the main topic.

(3) Noise

There are several noises in the output signals:
①power source noise, of which the frequency and
harmonic are fixed and the amplitude is large;
②environment noise and heat noise from the analog
circuit, of which the frequency ranges are wide and
the amplitudes are small; ③noise from microcon-
troller digital system, of which the frequency is high
and the amplitude is small; ④noise from sensor
itself, of which the frequency is constant and the
amplitude is small.

3 Introduction of Some Methods Used
for Detection of PIND Signals

(1) Wavelet analysis method

This method is a time-frequency analysis method,
and it is favorable for finding the character of a peri-
odic time-varying signal, due to its time-frequency
locality and multi-resolution character.

Proposition function \( \Psi(t) \) is
\[
\Psi(t) = \mathcal{L}(\mathbb{R}) \cap \mathcal{L}(\mathbb{R})
\]
then the function group generated by following
equation is named analysis wavelet
\[
\Psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \Psi\left(\frac{t-b}{a}\right), a, b \in \mathbb{R}, a \neq 0
\]
and \( \Psi_{a,b}(t) \) is called the mother wavelet.

The continued wavelet transform of an energy
limited continued signal \( f(t) \) is defined as
\[
W_f(a,b) = \int_{-\infty}^{\infty} f(t) \Psi_{a,b}(t) dt = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{|a|}} \Psi\left(\frac{t-b}{a}\right) dt
\]
(3)

The discrete wavelet transform of any discrete
signal \( f(N) \) can be realized with Mallat algorithms
as following:
\[
\begin{align*}
\hat{c}_k &= f_k \\
\hat{d}_j &= \sum_{n} e_n^{j-1} h_n 2^k \\
&= \sum_{n} c_n^{j-1} g_n 2^{j-k-1} \\
k &= 0, 1, 2, \cdots N-1 \\
n &= 1, 2, \cdots N
\end{align*}
\]
(4)

where \( j \) is the level of decomposition, \( c_k \) is the
approximation coefficient, \( d_k \) is the details coefficient,
\( h_n \) and \( g_n \) are the pulse responses of con-
jugated mirror filters \( H \) and \( G \).

The difference of wavelet coefficients between
the random noise and particle signal is great, so the
wavelet analysis is an effective method for reducing
noise from signal. The main steps are: the input
signal is transformed with one wavelet base, and the
wavelet coefficients are got, these coefficients in-
clude the information of the signals in different
time-frequency ranges, and are processed with dif-
different thresholds, and the reconstruct transform is done to the new coefficients to obtain the de-noised signal.

This paper makes some work on the PIND detection for small particles of aerospace relay, especially for the case that the target signal is flooded by noise and can’t be distinguished by operator on oscilloscope.

(2) Cross-correlation analysis method

Correlation analysis is a method for anglicizing the similarity of two signals or one signal itself, and it is defined as

$$R_{xy}(k) = \sum_{m=-\infty}^{\infty} x(m)y(m+k)$$  \hspace{1cm} (5)

where $R_{xy}(k)$ is named as the cross-correlation function when $x$ and $y$ are two different signals. Cross-correlation function is commonly used to detect some signals which are submerged in noise\[7\].

Suppose $x(N)$ is the signal to be detected, and the section with frequency $f_0$ in $x(N)$ is the target information. When this section is difficultly watched from power spectral density (PSD) of $x(N)$, compute the cross-correlation of $x(N)$ with a special sine signal, and the energy of target section can be picked up.

(3) Homo-filtering technology

Homo-filtering technology is an analysis method for multiplicative signal and noise, and its main idea is: the logarithmic operator transfers a multiplicative signal into an addictive one, a band-pass or high-pass filter files some noise from this addictive signal, and the new output signal can be got by using exponential operator. The flow chart of multiplicative homo-filtering system is shown in Fig.2.

![Fig.2 The flow chart of multiply homo-morphic systems](image)

In which $f(t)$ is the input multiplicative signal, log is the logarithmic operator, FT is the Fourier transfer, $F(x)$ is the linear band-pass filter in frequency domain, IFT is the inverse Fourier transform, exp is the exponential operator, and $g(t)$ is the output signal of system\[7\].

In PIND system, the output signal of acoustic sensor (made by Spectral Dynamics, Inc USA, Model S140C/A) is a kind of non-linear amplitude-modulated signal, and the carrier is the inherent frequency of sensor (about 150 kHz~160 kHz). That is to say it is a multiplicative output signal, and there are much multiplicative noises existing in the output signal. In this paper, the homo-filtering technology is used to improve the precision of detection of PIND tester.

4 The Application of New Detection Method on PIND Signals

In order to prove the validity of this new method, the authors make some tests on many aerospace relay samples. The sample relays include different kinds of remainder particles less than 0.1 mg, metal and non-metal, and in addition, some relay samples are detected in order to prove the affectivity on reducing the false alarm rate.

4.1 The detection based on direct wavelet de-noise method

Daubechies 13 wavelet base is selected on the detection, the level transform is 5, and the threshold for de-noise is selected on mean plus the square root of standard of input signals base on principles mentioned in Ref.[8]. The waveform is shown in the Figs.3-6.

![Fig.3 The waveform of signal with remainder particles](image)

From these waveforms it can be known that most of noise in the output signal can be filtered out by using the direct wavelet method, and the SRN is improved greatly, but there still are some shortcomings: the de-noised no remainder particle signal
which is shown in Fig.6 is not very clear, it is similitude to the small remainder particle de-noised signal which is shown in Fig.4.

An experiential threshold needs to be got after a large number of tests. The authors’ reference threshold for particles can classify most of the cases into following four groups.

1. Assured with the existence of particles
   \[ \text{mean}(\text{abs}(f)) > 1V \]
   \[ \text{mean}(E(150 \text{ kHz to } 160 \text{ kHz})) > 0.1 \]
   The average voltage greater than 1V, or the average energy between 150 kHz to 160 kHz greater than 0.1.

2. Liking with existing particles
   \[ \text{mean}(\text{abs}(f)) > 0.1V \]
   \[ \text{mean}(E(150 \text{ kHz to } 160 \text{ kHz})) > 0.01 \]
   The average voltage greater than 0.1V, and the average energy between 150 kHz to 160 kHz greater than 0.01.

3. Liking without any particles
   \[ \text{mean}(\text{abs}(f)) < 0.1V \]
   \[ \text{mean}(E(150 \text{ kHz to } 160 \text{ kHz})) < 0.01 \]
   The average voltage less than 0.1V, and the average energy between 150 kHz to 160 kHz less than 0.01.

4. Assured without any particles
   \[ \text{mean}(\text{abs}(f)) < 0.01V \]
   \[ \text{mean}(E(150 \text{ kHz to } 160 \text{ kHz})) < 0.001 \]
   The average voltage less than 0.01V, and the average energy between 150 kHz to 160 kHz less than 0.001.

4.2 The combined method based on direct wavelet de-noise and cross-correlation analysis

In Section 4.1, the judgment of “liking with existing particles” in the four groups is ambiguous, and this will cause the escape rate of PIND still high. The authors developed a method, a cross-correlation of de-noised signal and a 150 kHz sine signal were made to pop out the target signal section, and the detection result could be got from PSD of cross-correlation signal, which is shown in Figs.7,8.
4.3 The combined method based on direct wavelet de-noise and homo-filtering

The judgment for “liking without any particles” in this four groups is also ambiguous, and this will cause the failure alarm rate of PIND still high. The authors developed a method for it. The raw input signal would be treated by homo-filtering before direct wavelet de-noise. Figs.9-12 are the result waveforms of this method for above two signals. Especially the band-pass filter of homo-filter is for 150 kHz-160 kHz.

4.4 The comparison and analysis of the detection data

About 100 aerospace relays were tested, while six kinds of remainder particles were involved, including metal (tin dreg, copper wire, iron scrap) and non-metal (rubber, rosin, chip shell) particles, and another 12 relays without any particles were detected for checking the failure rate of PIND. Tables 1,2 are the results of them.

Table 1 The new PIND detection results of different kinds of relays with particles

<table>
<thead>
<tr>
<th>Different particles</th>
<th>Relay numbers</th>
<th>Pick out relays by DWD (group 1)</th>
<th>Pick out relays by DWD and CCA (group 2)</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin dreg</td>
<td>20</td>
<td>12</td>
<td>5</td>
<td>85%</td>
</tr>
<tr>
<td>Copper wire</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>80%</td>
</tr>
<tr>
<td>Iron scrap</td>
<td>12</td>
<td>9</td>
<td>1</td>
<td>83%</td>
</tr>
<tr>
<td>Rubber</td>
<td>22</td>
<td>16</td>
<td>2</td>
<td>81%</td>
</tr>
<tr>
<td>Rosin</td>
<td>15</td>
<td>9</td>
<td>3</td>
<td>80%</td>
</tr>
<tr>
<td>Chip shell</td>
<td>10</td>
<td>6</td>
<td>1</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 2 The new PIND detection results of different kinds of relays without any particles

<table>
<thead>
<tr>
<th>Relay numbers</th>
<th>Pick out relays by DWD (group 4)</th>
<th>Pick out relays by DWD (group 3)</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>9</td>
<td>2</td>
<td>92%</td>
</tr>
</tbody>
</table>
From above data, it can be known that the new detection method make an effective PIND detection for remainders, the escape rate and false alarm rate are low, and the validity is above 80%.

5 Conclusions

This authors proposed a detecting method for remainder particles of aerospace relay, which based mainly on the direct wavelet de-noising, and in combination with cross-correlation analysis and homo-filtering. Some PIND test signals of relays with six kinds of small particles and some ones without any particles were detected. Moreover, some valuable conclusions are got as following:

(1) Direct wavelet de-noising(DWD) method is one kind of effective de-noising method for PIND signals, and most of noises can be eliminated by it.

(2) The combined method based on DWD and cross-correlation analysis is effective for picking out the small particles from strong noise, and it is helpful for reducing the escape rate of PIND test.

(3) The combined method based on DWD and homo-filtering is effective for detection the relays without any particles, and it is helpful for reducing the failure alarm rate of PIND test.

References


Biography:

GAO Hong-liang  Born in 1980, he received B.S. and M.S. from Harbin Institute of Technology 2002 and 2004 respectively. His research interest is PIND auto-detection technology on space relays.
E-mail: GHL111@hit.edu.cn