Measuring Method and Device for Mechanical Characteristics of AC Contactors

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Abstract. AC contactors are widely used in various low voltage electrical control circuits. The operation status of AC contactor will affect the safety and reliability of power system operation, so it is important to accurately evaluate the operation status of AC contactor. An outstanding feature of electrical intelligence is that it can be monitored on-line, which is of great significance for evaluating the performance degradation of AC contactors. Accurate acquisition of physical quantities such as speed and acceleration of AC contactor is difficult at present. Traditional method installs vibration sensor in linear motion of AC contactor. The vibration of contact system of AC contactor will inevitably produce large interference signal, which is not easy to filter and affects the acquisition and processing of useful signal. Therefore, it is necessary to have stable devices and more suitable algorithms to measure and calculate these physical quantities.

1. Introduction  
The working state of contactors directly affects the operation and safety of equipment, so the fault diagnosis of contactors is very important. However, the effect of fault diagnosis is greatly affected by background noise. Therefore, the effective separation of signal and noise is a key link in fault diagnosis[1-2]. The vibration signal of contactor is a typical non-stationary and non-linear signal [3]. For this kind of signal, there are many main denoising methods used at present. It includes wavelet threshold de-noising method [4-5], empirical mode decomposition method [6-7] and improved algorithm based on them. But the effect of wavelet threshold de-noising depends on the choice of wavelet bases. At the same time, the selection of wavelet bases is more difficult. This method does not have the adaptive decomposition characteristics of signals, which limits its application and development to a certain extent. Although EMD method aims at the adaptive decomposition of the signal itself, its noise resistance performance is poor, and how to extract IMF components accurately limits its application and development.
2. Mechanical Characteristic Measurement System for AC Contactors

The test platform needs to collect the vibration signal of AC contactor when it is running. It requires the sampling rate to be as high as possible, and it can automatically control the contactor to interrupt and save data. Refer to relevant national test standards for AC contactor test, in which specific on-off test conditions for AC contactor working under different use categories are specified in GB 14048.4-2010, some contents are shown in Table 1. Under AC-4 working condition, the electric contacts will be worn greatly, the performance of contactors will deteriorate faster, and the parameters of AC contactors can be reflected more clearly. AC-4 test conditions are selected in this life-cycle test.

This paper provides a CJX2-5011 AC contactor vibration sensor device to obtain more accurate physical parameters such as speed and acceleration of AC contactor moving contacts, so as to realize on-line monitoring and state evaluation of AC contactor. Few existing papers have done in-depth research on the installation methods of vibration sensors for AC contactors, or there are some defects and limitations in the existing methods. In order to achieve the above purpose, a new installation device of vibration sensor is proposed by adopting the following technical scheme such as Figure 1, Figure 2 is assembly drawing of device.

| Usage category | Rated operating voltage $U_s/V$ | Rated working current $I_s/A$ | Connection condition $I/I_s$ | $U/U_s$ | $\cos \varphi$ | Breaking condition $I_r/I_s$ | $U_r/U_s$ | $\cos \varphi$ |
|---------------|-------------------------------|-------------------------------|-----------------------------|--------|---------------|-----------------------------|--------|---------------|
| AC-3          | 380                           | $\leq 17$                     | 6                           | 1      | 0.65          | 1                           | 0.17   | 0.65          |
|               | 660                           | $>17$                         |                              |        | 0.35          | 6                           | 1      | 0.35          |
| AC-4          | $\leq 17$                     | 6                             | 1                            | 0.65   | 0.35          | 6                           | 1      | 0.65          |
|               | $>17$                         |                               |                              |        |               |                             |        |               |

Notes: $\cos \varphi$ error is $\pm 0.05$; $L/R$ error is $\pm 15\%$.

![Figure 1. Device assembly drawing](image1.png)

![Figure 2. Assembly drawing of device](image2.png)

The AC contactor test system needs to control the AC contactor's interruption operation accurately according to the requirements, and has the functions of automatic acquisition, storage and real-time display of vibration signal data during the interruption of the contactor.

2.1 Hardware design

The hardware of AC contactor test platform test system is mainly divided into signal acquisition unit and switch-on control unit. The hardware block diagram is shown in Figure 3.
2.2 Software design
In the design of software part, the main consideration is to enable AC contactor to automatically perform on-off operation according to test requirements, and to collect and save test data. For the automatic on-off operation of contactor, it is mainly realized by sending on-off instructions to MCU through Labview. Among them, the output signal of the single-chip microcomputer controls the relay, and then realizes the on-off control of the AC contactor. Figure 4 is the program control flow chart of the test system.

3. Genetic algorithm VMD parameter optimization and wavelet threshold vibration signal analysis method
3.1 Variational mode decomposition
VMD decomposition algorithm is actually a process of solving variational problems. In order to transform the constrained variational problem into the unconstrained variational problem, the extended Lagrange expression is as follows:

\[ L\{\{u_k\}, \{\omega_k\}, \lambda\} = \alpha \sum_i \left[ \left( \delta + \frac{1}{n} \right) * u_i(t) \right]^2 + \left[ f(t) - \sum_i u_i(t) \right]^2 + \sum_i \left( \lambda_i(t) * f(t) - \sum_i \omega_i(t) \right) \]

Using Parseval Fourier equidistant transformation, the value problem of \( u_k \) can be expressed as:

\[ \hat{u}_k^{n+1}(w) = \hat{f}(w) - \sum_{i \neq k} \hat{u}_i(w) + \frac{2}{1 + 2\lambda_k} \left( w - w_k \right) \]

According to the same method mentioned above, the update result of the center frequency is as follows:

\[ w_k^{n+1} = \frac{\int_0^\infty w|\hat{u}_k(w)|^2}{\int_0^\infty |\hat{u}_k(w)|^2} \]

VMD algorithm obtains the result in time domain by updating in frequency domain and then inverse Fourier transform. The specific process of VMD algorithm can be described as follows:
- Initialize \( \{\hat{u}_k\}, \{\omega_k\}, \{\lambda\} \) and n;
- Basis formula (2), (3) updating in frequency domain \( u_k, \omega_k \);
- Update \( \lambda \).
\[ \sum_{i} \left| \hat{x}_{i}^{n} - \hat{x}_{i}^{*} \right| < \epsilon, \text{ stop iteration.} \]

### 3.2 Wavelet Threshold Analysis

The specific process of wavelet threshold denoising is as follows:

- Choose appropriate wavelet basis function and decomposition level to decompose the noisy signal.
- Choose the appropriate threshold to deal with the wavelet coefficients properly. When the decomposed wavelet coefficients are less than the selected threshold, it is considered that the wavelet coefficients are mainly caused by noise and should be set to zero. When the wavelet coefficients are larger than the selected threshold, it is considered that the wavelet coefficients are mainly caused by signals.
- The wavelet coefficients after thresholding are transformed into inverse wavelet transform to obtain denoising results.

The expression of inverse transform of wavelet transform can be expressed as

\[
 f(t) = \frac{1}{c_{\phi}} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \psi(t, \tau) \frac{1}{\sqrt{a}} \psi \left( \frac{t - \tau}{a} \right) dt
\]  

(4)

Soft threshold processing is to shrink the smaller wavelet coefficients to zero while the larger coefficients to zero.

\[
 \hat{W}_{j,k} = \begin{cases} 
 \text{sgn}(W_{j,k}) \cdot \left( |W_{j,k} - \text{Thr}| \right) & |W_{j,k}| \geq \text{Thr} \\
 0 & |W_{j,k}| < \text{Thr} 
\end{cases}
\]  

(5)

### 3.3 Genetic Algorithms for VMD Parameter Optimization and Wavelet Threshold Denoising

Using VMD parameter optimization based on genetic algorithm and wavelet threshold denoising method, its specific implementation process is as follows:

- The genetic algorithm is used to optimize the parameters of VMD so that it can decompose the original signal accurately.
- Vibration signals are decomposed by VMD method.
- The decomposed components are processed by wavelet soft threshold.
- Reconstruct the original signal and get the result after denoising.

### 3.4 Denoising Effect Evaluation

In order to verify the effectiveness of the proposed algorithm, two objective parameters, signal-to-noise ratio (SNR) and mean square error (RMSE), are used to evaluate and compare the denoising effects of various methods.

\[
 \text{SNR} = 10 \log \left( \frac{\sum_{i=1}^{n} f(t_{i})^{2}}{\sum_{i=1}^{n} \left[ \hat{f}(t_{i}) - f(t_{i}) \right]^{2}} \right)
\]  

(6)

\[
 \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} \left[ \hat{f}(t_{i}) - f(t_{i}) \right]^{2}}{n}}
\]  

(7)

### 4. Conclusion

This test chooses Zhengtai CJX2-5011 AC contactor and MMF company KS76C100 vibration sensor. The results show that the mechanical characteristics measurement method and device of the AC contactor described in this paper have a good de-noising effect. Through Figure 5 and Figure 6, it can be clearly seen that the method can filter out the interference caused by the contact system vibration,
provide accurate data and guarantee the accuracy of the test results. Figure 7 shows the velocity and acceleration of the contact system of the AC contactor calculated by the modified device and method.

Figure 5. Original signal  
Figure 6. Processed signal  
Figure 7. Measured data

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