

# The method to estimate vibration damping ratio of robot inspecting insulators based on center of mass

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**Keywords:** robot, vibration, damping ratio.

**Abstract.** Vibration is a common phenomenon in nature and engineering. Damping is a physical effect to dissipate energy dissipation. The robot inspecting insulators works on chain insulation, and is affected by environment of the work and action of joint in course of the work. Vibration phenomena are occurred on the robot. The method to estimate attenuation vibration damping ratio based on center of mass can estimate the vibration damping ratio of the robot quickly. And this method can provide the basis for improving the vibrational state of the robot on the work. Physical concept is clear and simple in this method to estimate damping ratio. And this method is easy to carry out. The results of simulation and measurement show that the method is quick and effective.

## 1 Introduction

As shown in the figure 1, the robot model of electrical insulator inspecting contains the robot itself and the inspecting module. The robot itself includes the upper rack, the lower rack, the creeping part and the guiding part.

The gripper of the creeping part is used for completing walking by means of sticking the electrical insulator. When detecting voltage, the inspecting module needs its own probe to touch steel leg and steel cap. At the same time, the robot model makes strong vibration because of the working environment and joint movement as well. There is no doubt that this vibration could influence the stability between gripper and electrical insulator, damage the surface of electrical insulator, even affect the measuring accuracy of distribution voltage. In all, it is beneficial to analysis the vibration character for improving the accuracy and security of the robot model.

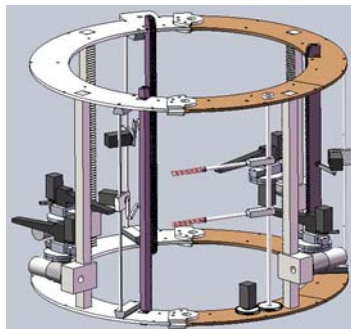


Fig.1 The model of robot inspecting insulators

## 2 The Principle of method to estimate vibration damping ratio based on centroid algorithm

### 2.1 Analysis of method to estimate vibration damping ratio

The methods to estimate damping ratio comprise method based on logarithmic decrement, method based on peak of time domain, method based on analyzing signal energy and so on. The method based on logarithmic decrement and peak of time domain are interfered by noise. So identification effect of them is poor. And they are difficult to achieve the intended purpose. Method based on analyzing signal energy analysis deterministic relationship between attenuation of vibration energy and vibration damping ratio. This method requires segmenting the vibration signal. The accuracy of recognition result is not high due to choose segment conditions.

## 2.2 Analysis of traditional method based on logarithmic decrement

The kinetic theory shows that differential equation of vibration attenuation is shown as equation 1.

$$\ddot{x}(t) + 2\xi\omega_0 \dot{x}(t) + \omega_0^2 x(t) = 0 \quad (1)$$

Vibration response of attenuation is shown as equation 2.

$$x(t) = Ae^{-\xi\omega_0 t} \sin(\omega_d t + \varphi) \quad (2)$$

$\xi$  is vibration damping ratio of system.  $\omega_0$  is intrinsic angular frequency.  $\omega_d$  is angular frequency of vibration. A and  $\varphi$  are constants and determined by the initial conditions.

$$x(0) = A \sin \varphi, \dot{x}(0) = -A\xi\omega_0 \sin \varphi + A\omega_d \cos \varphi \quad (3)$$

The formula of traditional method based on logarithmic decrement is shown as equation 4.

$$\delta = \ln \frac{A_1}{A_{n+1}} = \ln \frac{Ae^{-\xi\omega_0 t_1}}{Ae^{-\xi\omega_0 (t_1 + nT_d)}} = \xi\omega_0 T_d n = \frac{2n\pi\xi}{\sqrt{1 - \xi^2}} \quad (4)$$

$T_d$  is natural cycle among this formula. The vibration damping ratio of signal can be obtained according to formula 4.

$A_n$  is peak of signal. And the peaks are interfered by noise. So the accuracy of estimating vibration damping ratio is affected.

## 2.3 Study of the method to estimate damping ratio based on center of mass

The centroid is called the center of mass. And it is an imaginary point that quality is focused on in material system. The moments between the imaginary point and the axes are equal to the sum of moments between masses of particle and the axes. The formula of center of mass is shown as equation 5.

$$X = \frac{\sum m_i x_i}{\sum m_i} \quad (5)$$

Among them, X is center of mass.  $m_i$  is mass of i-point.  $x_i$  is coordinate of i-point. The vibration signal will appear negative number actually. So the formula of center of mass can be improved as Equation 6.

$$T_0 = \frac{\int_0^{+\infty} t \cdot |x(t)| dt}{\int_0^{+\infty} |x(t)| dt} \quad (6)$$

Initial conditions of vibration signal are that  $x(0)$  is equal to 0 and  $\varphi$  is equal to 0. So equation 6 is shown as equation 7.

$$T_0 = \frac{\int_0^{+\infty} t \cdot e^{-\xi\omega_0 t} |\sin(\omega_d t)| dt}{\int_0^{+\infty} e^{-\xi\omega_0 t} |\sin(\omega_d t)| dt} \quad (7)$$

The relationship among  $T_0$ ,  $\omega_d$  and  $\xi\omega_0$  is shown as Figure 2.

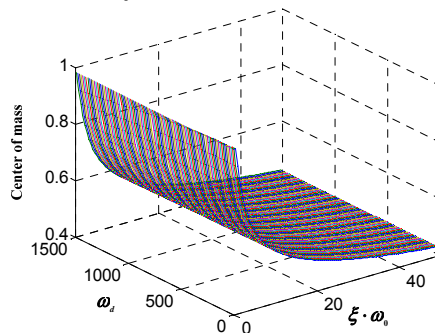


Fig.2 The relationship among  $T_0$ ,  $\omega_d$  and  $\xi\omega_0$

Figure 2 shows that the centroid position will be not change substantially when angular frequency of vibration changes. The centroid position will be change when  $\xi\omega_0$  changes. So there is a relationship between centroid position and  $\xi\omega_0$ . The relationship is shown as and Figure 3.

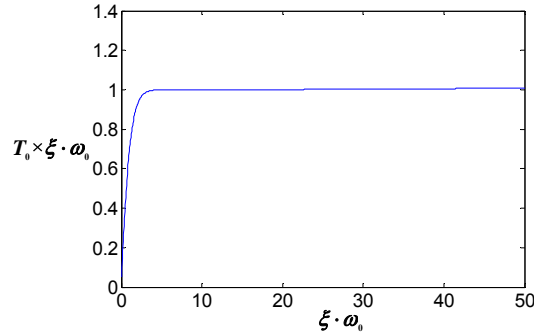


Fig.3 The relationship between center of mass and  $\xi\omega_0$

Figure 3 shows that relationship between center of mass and  $\xi\omega_0$ . And the mathematical relationship is shown as tab 1.

Tab.1 Function of  $T_0$  and  $\xi\omega_0$

$\xi\omega_0$	Relationship between $T_0$ and $a$
0.01~1	$T_0=(-0.2975a^2+0.9807a+0.0019)/a$
1~5	$T_0=(-0.013a^3+0.156a^2+0.5895a+0.2572)/a$
5~20	$T_0=1/a$
20~60	$T_0=(0.0003a+0.9947)/a$

The mathematical relationship among logarithmic decrement, angular frequency and  $\xi\omega_0$  is shown as equation 8. The mathematical relationship between damping ratio and logarithmic decrement is shown as equation 9.

$$\delta = \xi\omega_0 \cdot T_d = \xi\omega_0 \cdot \frac{2\pi}{\omega_d} = a \cdot \frac{2\pi}{\omega_d} \quad (8)$$

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} \quad (9)$$

Angular frequency can be calculated by using FFT. The center of mass can be calculated according to equation 6.  $\xi\omega_0$  can be calculated according to tab 1. At last, damping ratio can be calculated according to equation 9 and equation 10.

### 3 Simulation and experiment

#### 3.1 Simulation

There is a differential equation of vibration shown as equation 10.

$$\ddot{x}(t) + 20 \dot{x}(t) + 40000x(t) = 0 \quad (10)$$

Damping ratio is 0.05 and intrinsic angular frequency is 200Hz. Initial conditions of vibration signal are that  $x(0)$  is equal to 0 and  $\dot{x}(0)$  is equal to 100. Solution of this differential equation of vibration is shown as equation 11.

$$x(t) = 0.5006e^{-10t} \sin(199.75t) \quad (11)$$

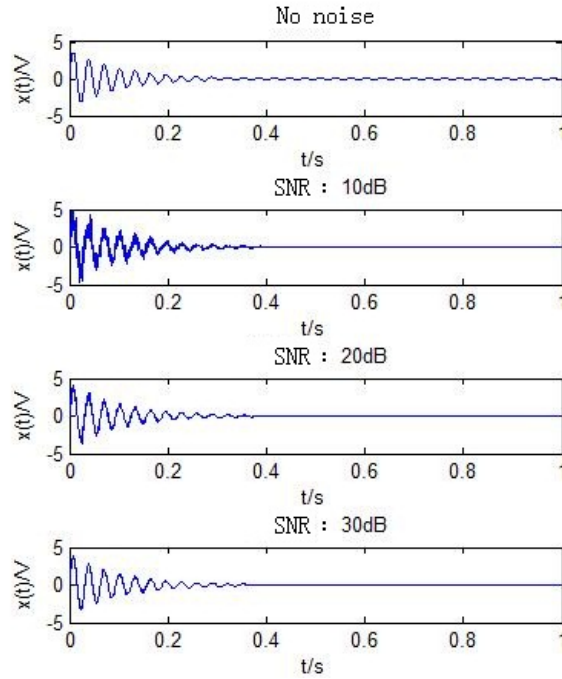


Fig.4 Waveform of signal

As shown in the figure 4, the sampling frequency of signal is 2397Hz, and the number of sampling points is 4794. There are some noises in this signal. And the SNR of noises are 10dB, 20dB and 30dB. The damping ratio of signal can be calculated according to the method to estimate attenuation vibration damping ratio using MATLAB. The results of simulation are shown as tab 2.

Tab.2 The compare of simulation results (relative error %)

SNR	damping ratio (relative error %)		
	Due value	This method	method based on logarithmic decrement
No noise	0.05	0.05(0%)	0.05(0%)
10dB	0.05	0.0498(1.4%)	0.0026(94.8%)
20dB	0.05	0.0496(0.8%)	0.0603(20.6%)
30dB	0.05	0.0501(0.2%)	0.0576(15.2%)

As shown in the tab 2, the accuracy of estimating damping ratio will be drop when SNR is dropping. But relative error of this method is smaller than relative error of method based on logarithmic decrement. So capability of this method is better on resisting to interference.

### 3.2 Experiment

As shown in the figure 5, a period of the waveform of vibration on robot inspecting insulators is obtained by using sensor. And the vibration occurs when robot inspecting insulators is working on the chain insulation. A set of signal waveforms is measured when the degree of vibration is changing. The damping ratios of these signals are estimated in this method. The results are shown as figure 6.

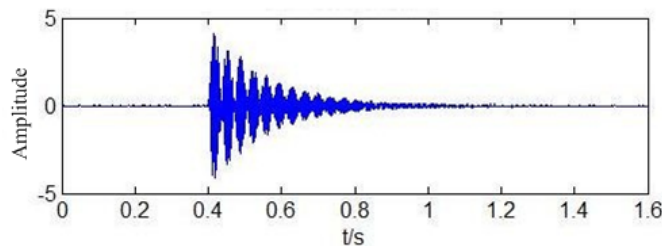


Fig.5 Waveform of vibration

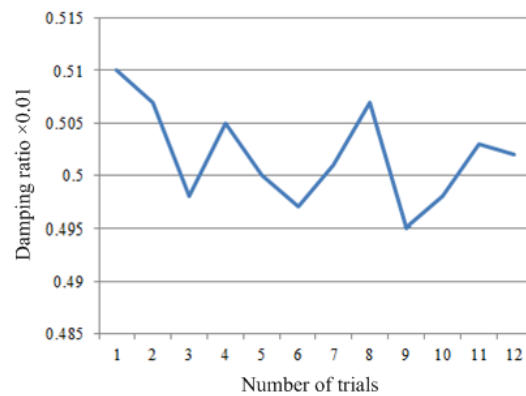


Fig.6 Test Data

The average value of this set of data is 0.005019. And mean squared error is 0.14%. The figure 6 shows that result of damping ratio estimated according to this method is stable. Application of this method will provide protection of improving accuracy of robot's action.

#### 4 Completions

Barycenter is obtained simply and quickly. Partial samples will be affected seriously by the noise. But the position of centroid is not affected. So the result of estimating damping ratio in the method based on the center of mass is good in conditions of noise. Further, this method can be used to analyze characteristics of vibration on the robot inspecting insulators.

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