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Procedia CIRP 27 (2015) 292 – 297

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13th CIRP Conference on Computer Aided Tolerancing

Weak signal detection based on adaptive cascaded bistable stochastic resonance system

Biyu Yang[1], Lele Wang[1], Ran Shenghui[1], Xiaoping Ye[2], Jiangxin Yang[1,2]*

[1] The State Key Lab of Fluid Power Transmission and Control, Zhejiang University, Hangzhou, China;

[2] Institute of Technology, Lishui University, Lishui, China;

* Corresponding author. Tel.: +86-571-87953198; fax: +86-571-87951145.*E-mail address:* yangjx@zju.edu.cn

Abstract

Stochastic resonance system is an effective method to extract weak signal, however, system output is directly influenced by system parameters. Aiming to this, a method about weak periodic signal extraction was developed based on adaptive stochastic resonance. Firstly cascaded stochastic resonance system was established in order to achieve better low-pass filtering effect. And then, variance of zero point distance was chosen as measurement index of cascade system. It's able to overcome the shortage that traditional adaptive stochastic resonance system needs to know the signal frequency beforehand. Also, it could obtain optimum system parameters adaptively. Basing on these parameters, input signal will be handled, and optimum output could be obtained. Furthermore, different periodic signal have been recognized, and finally the validity of the method is verified through simulation experiments.

Peer-review under responsibility of the organizing committee of 13th CIRP conference on Computer Aided Tolerancing
Keywords: adaptive cascaded bistable stochastic resonance, measurement index, signal extraction, signal recognition;

1. Introduction[i]

In mechanical, electronic, chemical, communications and many other fields, many useful signals are often submerged in strong noise. How to extract and recognize these signals is a hot spot of industry attention. Currently, the main way to improve the signal to noise ratio (SNR) is to suppress the noise [1-2]. But when the noise frequency and the signal frequency is closed or coincide, with the elimination of the noise of the band, useful signal is always damaged. So it is not benefit to the weak signal detection.

Stochastic resonance was first proposed by the Italian scholar Bentz [3], et al. Stochastic resonance uses non-linear system to produce synergy between input signal and noise, so as to achieve the purpose of the detection signal. The synergy is similar to the resonant in mechanics. Comparing with traditional methods, stochastic resonance does not require prior knowledge. It is a non-correlation detection method. More specifically, stochastic resonance can take advantage of noise to enhance the weak signal. Some noise energy transfers to the characteristic signal. Thus effective detection of weak signal can be achieved through the stochastic resonance. It is often used for the detection of periodic signal. Since the emergence of adaptive stochastic resonance, people continually search for the way to optimize stochastic resonance parameters. Signal to noise ratio and other indicators [4-5] are often used as a system measure index. But because of the absence of prior knowledge, the problem of parameter selection is difficult to solve.

Firstly, this paper analyzes the cascaded stochastic resonance system, selects zero point distant variance as the measure index. Then build a periodic signal extraction model based on adaptive stochastic resonance. At the same time, periodic signal types can be effectively distinguished by using the mathematical properties of kurtosis index. So the periodic signal recognition is realized. Finally, simulation experiment analysis is conducted.

2. Cascaded Stochastic Resonance

2.1. Basic theory of stochastic resonance

Bistable stochastic resonance system is described by Langevin equation. The mathematical model [6] is:

2212-8271
Peer-review under responsibility of the organizing committee of 13th CIRP conference on Computer Aided Tolerancing
doi:10.1016/j.procir.2015.04.081

$$\dot{x} = -\dot{V}(x) + u(t) + \xi(t) \tag{1}$$

Where x is the system output, $u(t)$ is the input periodic signal, for example sinusoidal signal Asin($2\pi ft+\varphi$), ξ(t) is the additional noise, $V(x)$ is nonlinear potential function, expressed as:

$$V(x) = -\frac{a}{2}x^2 + \frac{b}{4}x^4 \tag{2}$$

Where *a, b* are structural parameters of nonlinear bistable system, greater than 0. When no input signal is applied, potential function takes the minimum in the potential well ($x_m = \pm\sqrt{a/b}$), the maximum in the potential barrier($x=0$).

When the periodic signal without noise is input, if the input periodic signal system meets the system static triggering condition, $|A|>A_0$($A_0 = \sqrt{4a^3/27b}$), where A is the maximum amplitude of the input signal, A_0 is the static triggering threshold for the system. At this time, bistable potential function tilts periodically, as shown in Fig. 1, two potential wells alternately rise and fall. When periodic and noise enter at the same time, periodic changes of system potential well is brought by periodic signal, which is effective to synchronize the switch caused by noise. Thus noise energy in the system output is suppressed. So that the periodic component of the system output has been enhanced, the SNR of the output is improved. This phenomenon is essentially a synergistic effect of signal and noise in nonlinear bistable system, which is called stochastic resonance. Of course, if input signal and noise do not satisfy the system static triggering condition, system structure parameters *a*, *b* can be changed to adjust the height of the potential barrier. So that the mixed signal input to the system has sufficient energy to support particle to cross the barrier, then the system can occur stochastic resonance phenomenon.

Tradition stochastic resonance is only applicable to small signal detection, with great restriction on the application. Leng of Tianjin University puts forward a variable step size stochastic resonance. It is a method applicable to large parameter signal detection. The theory is that step length *h* does not take the reciprocal of the sampling frequency, and make $h>1/f_s$. The experience range of *h* is 0.1 to 1. By changing the system structure parameter *a*, *b* and the step *h*, signal with large parameters can be detected.

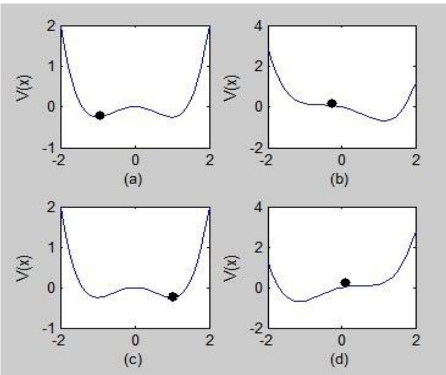

Fig.1. Moving particle in double-well potential

2.2. Bistable stochastic resonance system

Through the mathematical model of stochastic resonance, the corresponding bistable system structure diagram can be obtained, shown in Fig. 2.

Putting two bistable systems shown in Fig. 2 in series (input of the previous system corresponds to output of the next system) can constitute a bistable stochastic resonance system [7] shown in Fig. 3.

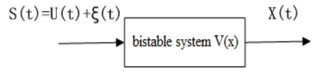

Fig.2. Structure of bistable SR system

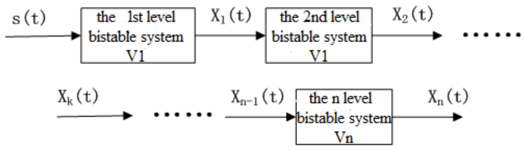

Fig.3. Structure of cascaded bistable SR system

Cascaded stochastic resonance system can improve the signal to noise ratio of the output signal. That will help to extract the useful signal and reduce noise. The mechanism [8-9] is that the output signal spectrum distributes by Lorentz distribution. That means the output signal energy is concentrated in the low frequency region, while reducing the energy of high frequency region. Thus, the noise strengthened the signal intensity instead of weakening that. By cascade stochastic resonance, energy of high-frequency signals shifts to low frequency constantly, so the energy of low-frequency useful signal increases, that of high-frequency noise components decreases. It is equivalent to filter out the high frequency ingredients. Therefore, cascaded stochastic resonance plays a role of the low-pass filter. However, after the traditional filter filtering out signal in useless band, the output signal is always becomes small. Even if the output signal is amplified, noise is also larger, so it is not conducive to the subsequent processing of signal. The cascaded stochastic resonance just does not have this defect, which can increase the output signal while weaken noise. Fig. 4 shows the simulation results of the sinusoidal signal through a bistable system processing. Taking a=1, b=1.5, A=0.5, f=20Hz, D=0.3, f_s=1000Hz during analysis. Runge-Kutta algorithm is used to calculate variable step size stochastic resonance, where calculated step size h=0.5. As shown in Fig. 4, output($x2$) waveform of two levels stochastic resonance system is smoother than output($x1$) waveform of one level stochastic resonance system. That is because high-frequency signal of $x1$ is almost completely filtered out. In a certain sense, the increase of series will help energy of high-frequency signal transfer to low-frequency signal. The resulting result is that the proportion of low-frequency characteristic components in the total signal increases continuously. So the cascaded stochastic resonance system