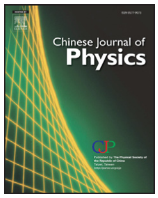
Chinese Journal of Physics 000 (2016) 1–11

Contents lists available at ScienceDirect

Chinese Journal of Physics

journal homepage: www.elsevier.com/locate/cjph



Stochastic resonance in a single-well system with exponential potential driven by Levy noise

Gang Zhang, Ying Song*, Tian-Qi Zhang

Chongqing Key Laboratory of Signal and Information Processing (CQKLS&IP), Chongqing University of Posts and Telecommunications, Chongqing 400065, China

ARTICLE INFO

Article history:
Received 11 June 2016
Revised 7 October 2016
Accepted 8 October 2016
Available online xxx

Keywords:
Exponential type single-well system
Levy noise
Stochastic resonance
Bearing fault detection

ABSTRACT

Noise and potential function are vital to stochastic resonance (SR). This paper attempts to broaden the research of the SR and explore a better potential function. Based on the absolute and exponential potentials, a generalized exponential type single-well potential function is constructed. Then the characteristics of the corresponding exponential type single-well SR (ESR) system driven by Levy noise is analyzed numerically. Firstly, the effects of the characteristic index α, symmetric parameter β and noise intensity D of Levy noise on the input signal to noise ratio (*SNRi*) are investigated. Then, the effects of system parameters a, b, r and noise intensity D on the resonant output is explored. Finally, the ESR system is applied to the fault characteristic extraction of rolling element bearings. The simulation results show that the SR phenomenon is able to be excited by tuning the parameters a, b, r and D under different values of α and β. The larger b (or a) widens the parameter interval of a (or b) which can induce SR. The ESR system is able to solve the problem that the traditional systems fail to achieve SR due to the improper selection of parameters. In bearing fault detection, the detection effect of the ESR system is superior to the bistable SR system.

1. Introduction

Stochastic resonance (SR) was proposed by Benzi et al. in 1981[1]. SR is a nonlinear phenomenon where the weak signal is able to be enhanced and the noise is weakened through the interaction among weak signal, background noise and a nonlinear random vibration system[2]. In recent years, SR has attracted considerable attention in a wide range of research [3–10]. Silchenko and Hu [11] studied the effect of SR in a noisy bistable system driven by various input signals by using a multifractal formalism. Hung and Hu [12] explored the constructive role of noise in p53 regulatory network. In further study, many new SR system models have been continually proposed. Gitterman [13] studied the SR in a harmonic trap system. SR with a joint Woods-Saxon and Gaussian potential for bearing fault diagnosis was investigated in Ref. [14].The SR in asymmetric bistable system with α stable noise was analyzed by Ma and Jin [15]. The SR in periodic potential driven by dichotomous noise was reported in Ref. [16]. The SR in the underdamped system with a pinning potential was investigated by Zhang et al. [17]. The general tri-stable system was defined and the dynamic characteristics of the tri-stable system were analyzed in Ref. [18]. Qiao and Lei et al. [19] proposed an adaptive unsaturated bistable stochastic resonance method to

* Corresponding author.
E-mail address: 740660604@qq.com (Y. Song).

http://dx.doi.org/10.1016/j.cjph.2016.10.004
0577-9073/

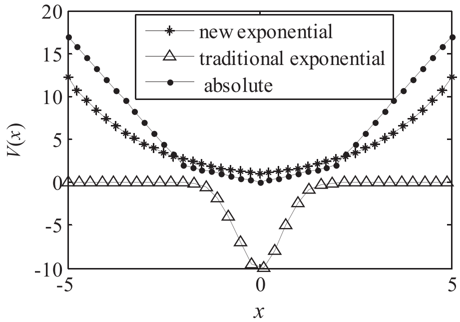


Fig. 1. Shape of the three potentials.

extract weak fault characteristics and the results show that the method has good enhancement performance and anti-noise capability. In the study of exponential monostable potential system, Grigorenko [20] found the generalized SR phenomenon which laid the basis for the study of more general SR single-well systems. The harmonic potential of the linear random vibration system was extended to the general power function single-well, and its SR characteristics driven by Levy noise were analyzed in detail [21].

In the above mentioned potential models, the traditional bistable and monostable system has been investigated extensively, where the monostable potential model has a concise form and significant SR performance. This paper attempts to broaden the research of the SR and constructs a generalized exponential type single-well potential based on the absolute and exponential potential. Moreover, the Gaussian noise is too idealistic to effectively simulate the real noise which fluctuates drastically. The waveform of non-Gaussian Levy noise has significant pulse and smear characteristics, which is able to reflect the random perturbation in the actual engineering more accurately, and therefore Levy noise is introduced as the background noise in simulation experiment, where the parameter-excited and noise-excited SR and its application researches in bearing fault diagnosis are investigated by using numerical analysis.

The rest of this paper is organised as follows. Section 2 investigates the ESR system model and the effects on *SNRi* of characteristic index α, skewness parameterβ and the noise intensity D. Section 3 performs simulation analysis for the resonant output of the ESR system governed by exponential type parameters a, b, r and the noise intensity D under different Levy noise. Section 4 verfies the practicability of the proposed ESR system in bearing fault detection. Section 5 gives the summary of this paper.

2. Models and methods

The nonlinear system model [22] driven by an additive Levy noise and a harmonic force is described as:

$$\frac{dx}{dt} + \frac{dV(x)}{dx} = A\cos(2\pi f_0 t) + D\xi(t) \tag{1}$$

where $V(x)$ is the potential function of SR system, $A\cos(2\pi f_0 t)$ is the weak signal to be detected with the amplitude A and the frequency f_0, and $D\xi(t)$ is the Levy noise with noise intensity D.

2.1. Exponential type single-well system

Although the generalized SR may be excited by tuning noise and system parameters in traditional exponential system $(V(x) = -\varepsilon\exp(-(x-x_0)^2/2\delta^2))$ and the absolute system $(V(x) = \{\begin{smallmatrix} k_1|x| & |x| \le L \\ k_2(|x|-L)+k_1 L & |x| > L \end{smallmatrix}$), the form of these potential functions are unrepresentative and relatively complex. So based on the two potential functions, a generalized exponential type single-well potential function is constructed as:

$$V(x) = a\exp\left(\frac{|x-r|}{b}\right) \tag{2}$$

The new potential model simplifies the structure parameters and effectively raises the algorithm accuracy compared to the other two potentials. The three potentials are shown in Fig. 1. We can find that the traditional exponential potential well with depth of ε converges to 0 rapidly on both the side, and the absolute potential well has two parameters specifying the slope of potential well. The new potential contains the virtue of the traditional exponential and absolute potentials, in addition, its potential well is relatively smooth and flat. So it can avoid the complicated generalized SR and has higher utilization rate of noise.

In Eq. (2), the structural parameter $a(a > 0)$ works on the depth of the potential well, parameter $b(b > 0)$ determines the steepness of the potential well and parameter $r(r \in (-\infty, \infty))$ is the offset, where the three parameters codetermine the