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Explicit internal signal stochastic resonance in a chemical oscillator

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Abstract

Explicit internal signal stochastic resonance (EISSR) is first found in the periodic-2 oscillations state of Willamowski–Rössler reaction model.

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1. Introduction

Stochastic resonance (SR) [1] is a phenomenon occurring in systems driven by a combination of a periodic signal and noise, in which the response of a nonlinear system to a weak periodic input signal is optimized by the assistance of a particular non-zero level of noise. Since SR was originally put forward by Benzi et al. [2] to account for the periodic oscillations of the Earth's ice ages, it has been investigated in a wide range of physical, chemical and biological

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systems [1,3–9]. It is well known that the interaction between nonlinear dynamics and noise can lead to stochastic resonance (SR). Usually, the system's dynamics is described by a deterministic differential equation and a noise term is added to the equation directly. Recently, it is reported that the external signal can be replaced by internal signal, such as periodic oscillations. This kind of phenomenon can be called autonomous SR [10], coherence resonance [11] or internal SR [12]. In this paper, we studied the effect of noise on the stable periodic-2 oscillations of the Willamowski–Rössler model using numerical simulations. An amusing phenomenon has been found that explicit internal signal stochastic resonance (EISSR) can happen in the periodic-2 oscillations state and the oscillation frequency is shifted little. At the same time, noise not only enhances but also weak the intrinsic signal in a system.

2. Model

The Willamowski–Rössler model, a famous ideal chemical model, was proposed by Willamowski, Rössler and co-workers [13]. The nondimensionalized chemical dynamical evolution equations of the system are given as follows:

$$\begin{aligned} dx/dt &= a_1x - k_{-1}x^2 - xy - xz, \\ dy/dt &= xy - a_5y, \\ dz/dt &= a_4z - xz - k_{-5}z^2, \end{aligned} \quad (1)$$

where a_1 , a_4 , a_5 , k_{-1} and k_{-5} are the positive parameters. We select k_{-1} as the control parameter for our study. The value of other parameters are chosen as: $a_1 = 30.0$, $a_4 = 16.5$, $a_5 = 10.0$ and $k_{-5} = 0.5$. The undisturbed model can show various types of dynamic behavior. Fig. 1 shows the bifurcation diagram for Eq. (1) with variation of k_{-1} . The parameter path contains double periodic bifurcations to chaos. To study the effects of white noise on the intrinsic periodic oscillations, we chose the control parameter k_{-1} to be located in periodic-2 oscillations vicinity and perturbed it with Gaussian white noise as the following ways:

$$k_{-1} = k_{-1}^0(1 + \beta\zeta(t)), \quad (2)$$

where β is intensity of the additive noise and $\zeta(t)$ is the Gauss white noise with zero mean value $\langle \zeta(t)\zeta(t-\tau) \rangle = \delta(\tau)$, $\delta(\tau)$ is a unit pulse function. The Runge–Kutta method was employed to solve above three-variable equations with the addition of noise or not. The signal-to-noise ratio (SNR), which is defined as the ratio of the height of the spectrum of the output signal at the fundamental frequency w_f to the average amplitude of the background noise spectrum in the vicinity of w_f , was picked as the parameter to evaluate the effect of SR. The time series of z were analyzed by the Fourier power spectrum.

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