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Nonlinearity, locking, and chaos in anomalous Josephson junctions

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The effects of external electromagnetic radiation on the synchronization of the magnetization precession and Josephson oscillations in the φ_0 junction are investigated. Their manifestation in the magnetization dynamics of the ferromagnetic layer and in the current-voltage characteristics of the junction are shown. Effects of model parameters on nonlinearity, locking and chaos in anomalous Josephson junctions are discussed.

Introduction

Phase shift in current — phase relation of anomalous Josephson junctions leads to the series of interesting features important for different applications [1–3]. Here we demonstrate the manifestation of nonlinearity in current-voltage characteristics (CVC), examples of indirect locking of magnetization precessions to the external periodic signal, and chaos.

Nonlinearity

The nonlinear properties of hybrid structures are clearly manifested in the predicted effect of the anomalous dependence of the resonant frequency on the Gilbert damping (α-effect) [4, 5]. In Fig. 1 the manifestation of nonlinearity in CVC and superconducting current I_s is demonstrated. It has been shown that the associated system of Landau — Lifshitz — Gilbert — Josephson equations can be reduced to a scalar nonlinear Duffing equation. We have shown that there is a critical damping value at which cubic nonlinearity comes into play, changing the dependence of the resonance frequency on damping, leading to the α-effect. A demonstration of the α-effect for various values as a function of the spin-orbit interaction and the ratio of the Josephson energy to the magnetic one is given [5]. We have found a formula that predicts the critical damping value as a function of the spin-orbit coupling and the ratio of the Josephson energy to the magnetic one.

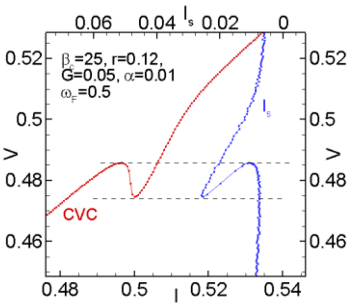

Fig. 1. Manifestation of nonlinearity in CVC and superconducting current I_s

Locking

The possibility of controlling the dynamics of magnetic precession with a superconducting current opens up wide scope for applications in superconducting electronics and spintronics. In our work [6], we demonstrated for the first time the indirect capture of the magnetic precession in the superconductor ferromagnet superconductor (*S*/*F*/*S*) junction by Josephson oscillations under the action of an external periodic signal, which is reflected by the appearance of synchronization steps in the dependence of the magnetization on the current through the junction. Fig. 2 shows the manifestation of the locking in $m_y^{max}(I)$ and CVC. We found that the position of the step is determined by the radiation frequency and the shape of the resonance curve.

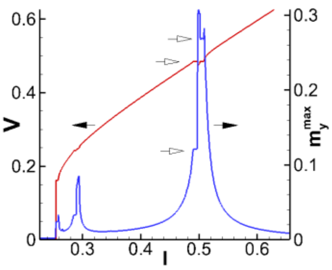

Fig. 2. Manifestation of the locking in CVC and $m_y^{max}(I)$. Simulation parameters were the same as in Fig.1, $\omega = 0.485$, $A = 0.05$

Another interesting effect under external radiation is related to the state with a negative differential resistance (NDR) in the current–voltage characteristic of an anomalous Josephson junction. Such states can be used in switching circuits and multivibrator electronic devices. We have shown that in the region with NDR, an additional step appears in the current-voltage characteristic. Detailed studies [6] showed that the oscillations corresponding to this step have the same frequency as the oscillations on the first step, but they have a different amplitude. This makes it possible to control not only the frequency, but also the amplitude of the magnetic precession in the capture area. Unique prospects arise for the control and management of the magnetic moment in such hybrid systems.

Chaos

One of the most important tasks in the field of data coding and communication security is the development of methods for chaos controlling and managing [7]. We have demonstrated a rich variety of periodic and chaotic behavior in the dynamics of the magnetic moment in the anomalous Josephson junction [8, 9]. It was also shown that the chaotic behavior of the system can be controlled by applying an external periodic signal of the desired frequency and amplitude. In Fig. 3 we demonstrate the chaos manifestation at different values of the ratio *G* of Josephson energy to the magnetic one. It is assumed that such a system can be used as chaotic logic gates in computers based on chaotic systems.

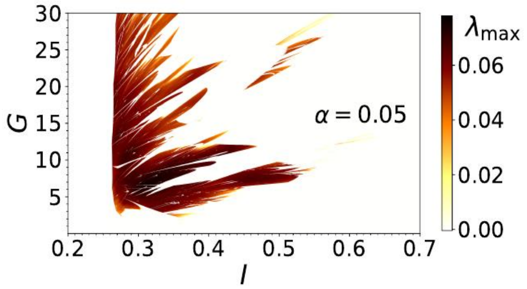

Fig. 3. Maximal Lyapunov exponent as a function of *G* (the ratio between the Josephson energy and the magnetic anisotropy energy), and the dc-bias current

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