Effect of nonzero temperature on the process of penetration of the potential barrier through the kink

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Abstract. The research focuses on studying the effect of thermal noise on the motion of a kink in a curved region of the Josephson junction. Results of simulations relying on the full field model were compared with the analytical formula proposed on the basis of the Foker-Planck equation. The obtained results show that for temperatures above 1 Kelvin the proposed analytical formula has very good agreement with the solutions of the full field model.

Introduction

In 1962 the British physicist B. Josephson presented a model describing the tunnelling of Cooper pairs between two superconductors separated by a thin insulator layer. Currently, a system composed of two superconductors separated by a thin insulator layer is called a Josephson junction. In the description of the Josephson junction the equation (sine-Gordon) appears which also has soliton solutions including the so-called fluxon defined as the soliton carrying the magnetic flux quantum.

The current research is concentrated on the impact of thermal noise on kink motion through the curved region of the long Josephson junction. We considered the kink motion in the modified sine-Gordon model with the position dependent dispersive term

$$\partial_t^2\phi + \alpha\partial_t\phi - \partial_x(\mathcal{F}(x)\partial_x\phi) + \sin\phi = -\Gamma \tag{1}$$

where the function $\mathcal{F}(x)$ contains information about the curvature of the junction. In the equation α represents the dissipation in the system caused by quasiparticle current and Γ represents the bias current. The physical motivation for the description of curvature effects in the framework of this model has been detailed in the article [1]. Based on perturbation theory applied to the sine-Gordon equation with the perturbations from bias current (which describes the effects of non-zero temperature of the system), damping and the curved structure, a model for the kink velocity was derived. This approach, uses a method not previously applied to the sine-Gordon model, based on the projection of kink energy onto the dynamical equation of motion and was presented in detail in the article [1]. The probability distribution of the kink velocity was found on the base of the derived Fokker-Planck equation. The analytical results were compared with the simulations based on the full field model. Due to potential applications in normal and high-temperature superconductors, the comparison was made from zero to $T = 50K$, $T = 20K$, and $T = 5K$.

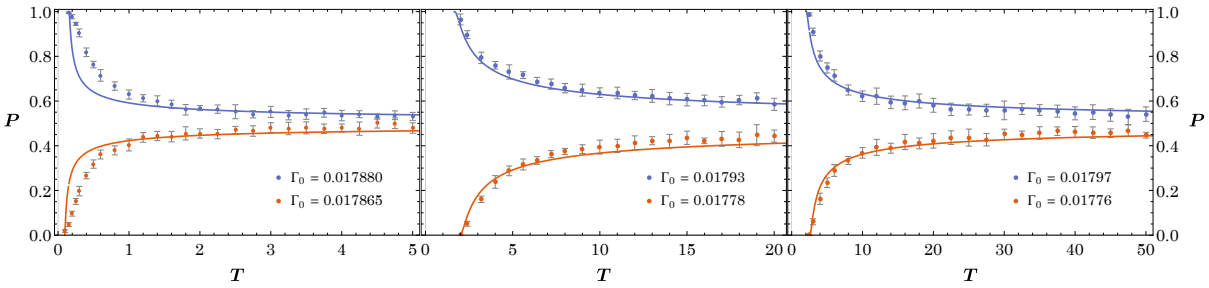

Figure 1: The probability of transition of the fluxon obtained from the field model compared in the various interval of T with the analytical formula. The blue line and points correspond to the bias current exceeding its threshold value and the red to the bias current below its threshold value.

Results and discussion

The agreement of the proposed model with the results from the full field model solutions is very good in the temperature range from $1K$ to $50K$. For temperatures below $1K$ a relativistic effect on the width of the kink was included in the analysis, but despite this, in the temperature range from $0K$ to $1K$ the model shows only partial agreement. The most likely reason for the discrepancy of the presented model with the results of the full model for temperatures below $1K$ is the presence of resonance windows, which were detected in the studed system.

References

[1] Gatlik J., Dobrowolski T. (2021) Modeling kink dynamics in the sine–Gordon model with position dependent dispersive term. *Physica D* **428**:133061.

[2] Gatlik J., Dobrowolski T. (2022) The impact of thermal noise on kink propagation through a heterogeneous system. arXiv:0706.1234 [nlin.PS].