Electromechanical Phenomena in Superconducting and Normal Nanostructures

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Akademisk avhandling för avläggande av filosofie doktorsexamen vid Göteborgs universitet. Avhandlingen försvaras vid offentlig disputation torsdagen den 30:e maj 2013, klockan 13.00 i GD-salen, Chalmers tekniska högskola, (campus Johanneberg) Origovägen 1, Göteborg. Uppsatsen presenteras på engelska.

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Avhandlingen finns tillgänglig vid

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ABSTRACT

This thesis summarizes a series of theoretical studies on the electromechanical properties of nanostructures made of superconducting and/or metallic elements. The first part of the work is devoted to the analysis of the interactions between the electronic and mechanical degrees of freedom in suspended nanowires. In particular, a metallic carbon nanotube fixed between two superconducting leads and acting as a superconducting weak link is considered. This system is denoted as a *nanoelectromechanical Josephson junction*. If biased by a dc voltage, such a nanodevice possesses the ability to self-cool through the transfer of energy from the flexural vibrations of the suspended nanowire to voltage-driven Andreev states and then to quasiparticle electronic states in the superconducting leads. The electromechanical coupling required to accomplish the energy transfer process can be attained by applying an external magnetic field. It gives rise to a Lorentz force that couples displacements of the carbon nanotube to the electrical current that is carried by Andreev states.

Further investigations of the nanoelectromechanical Josephson junction extend the analysis of the first study to a case in which the system is subjected to a nonuniform magnetic field. In this case, inhomogeneity of the field causes the conducting nanoresonator to execute a whirling movement. The analysis of the time evolution of the amplitude and relative phase of the nanowire motion shows that the coupled amplitude-phase dynamics presents different regimes depending on the degree of inhomogeneity of the magnetic field: time independent, periodic, and chaotic.

The second part of the thesis describes the dynamics of a spatially symmetric shuttle-system subjected to an ac gate voltage. In this system, parametric excitation gives rise to mechanical vibrations at the resonant frequency, *i.e.*, when the frequency of the ac signal is close to the eigenfrequency of the mechanical subsystem. The parametrically excited mechanical oscillations result in a dc shuttle current in a certain direction due to spontaneous symmetry breaking, where the direction of the current is determined by the phase shift between the ac voltage and the induced mechanical oscillations.

Keywords: Nanoelectromechanical systems, nanoelectromechanical Josephson junction, metallic carbon nanotubes, ground-state cooling, chaos, parametric excitation, dc shuttle current.