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Simulation of magnetization reversal in Phi-0 junction by the pulse of magnetic field

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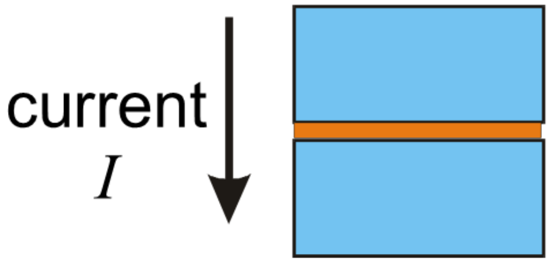
Introduction

Josephson Effect



Josephson junction

Stationary Josephson effect

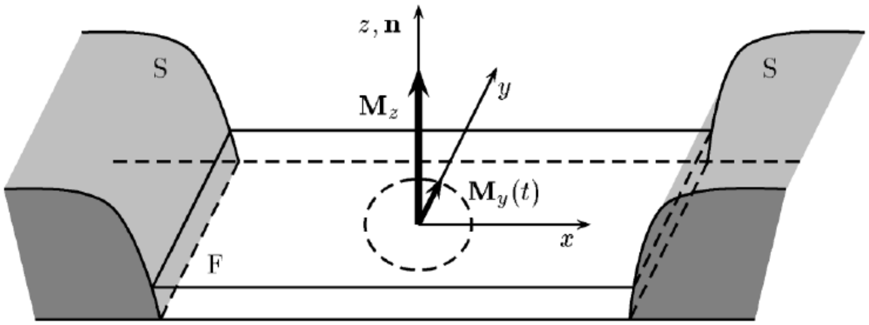
$$I < I_c \qquad I_s = I_c \sin\varphi \qquad V = 0$$

Nonstationary Josephson effect

$$I > I_c \qquad \frac{d\varphi}{dt} = \frac{2eV}{\hbar} \qquad V \neq 0$$

Anomalous Josephson Effect

► In SFS Josephson junction the spin orbit coupling in Ferromagnetic layer, leads to the direct coupling of magnetization dynamics and superconducting current.



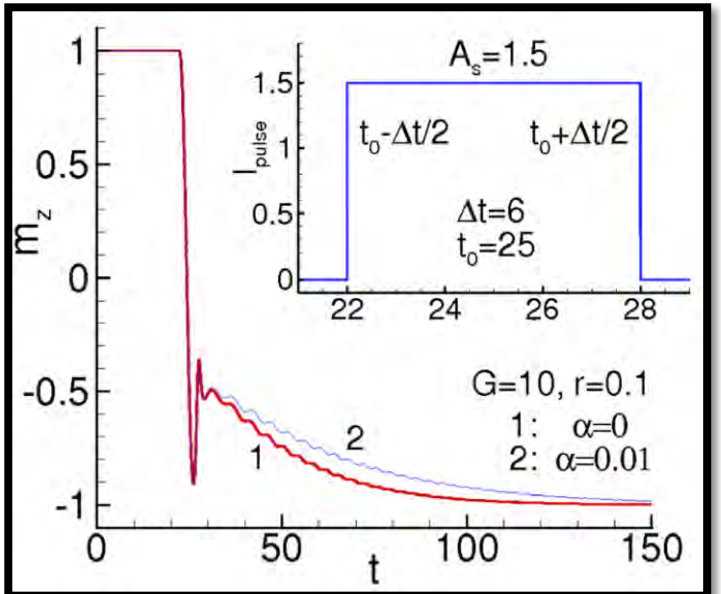
► In the current phase relation of such junctions appears the phase shifting Phi-0, and they called Phi-0 junction and observed effect called Anomalous Josephson effect.

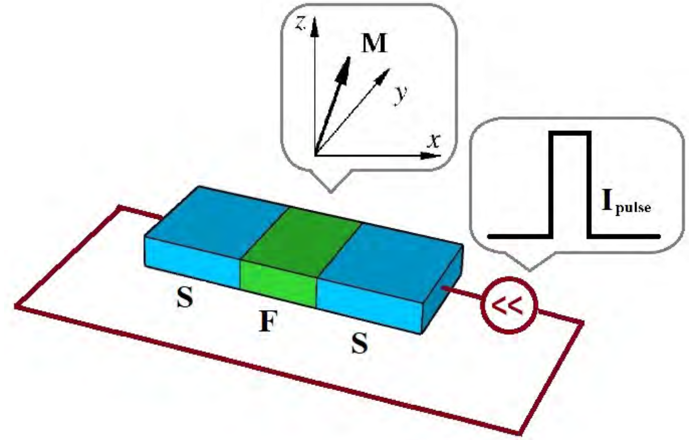
$$I_s = I_c(\sin\varphi - \varphi_0) \qquad \varphi_0 = r\frac{M_y}{M_0}$$

A. Buzdin, Phys. Rev. Lett. 101, 107005 (2008).

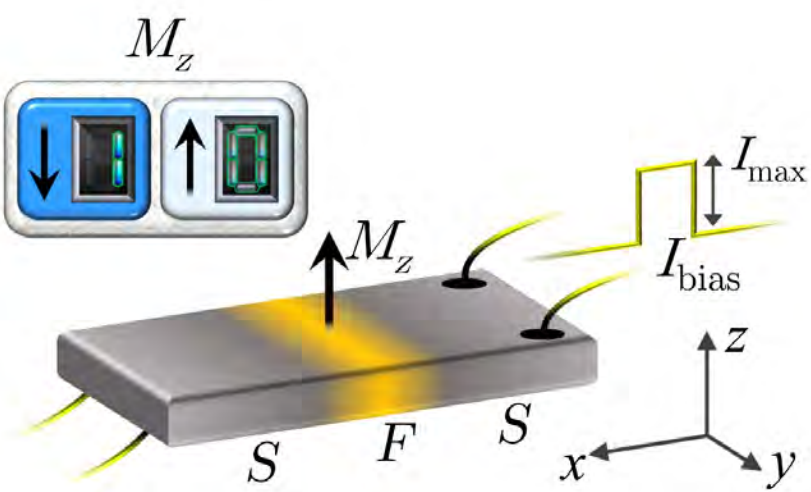
F. Konschelle and A. Buzdin, Phys. Rev. Lett. **102**, 017001 (2009)

Magnetization reversal in Phi-0 junction





Yu. M. Shukrinov, I. R. Rahmonov, K. Sengupta, and A. Buzdin, Magnetization reversal by superconducting current in u 0 Josephson Junctions, **Appl. Phys. Lett. 110, 182407 (2017)**



C. Guarcello and F.S. Bergeret, Cryogenic Memory Element Based on an Anomalous Josephson Junction, **Phys. Rev. Appl. 13, 034012 (2020)**

Motivation

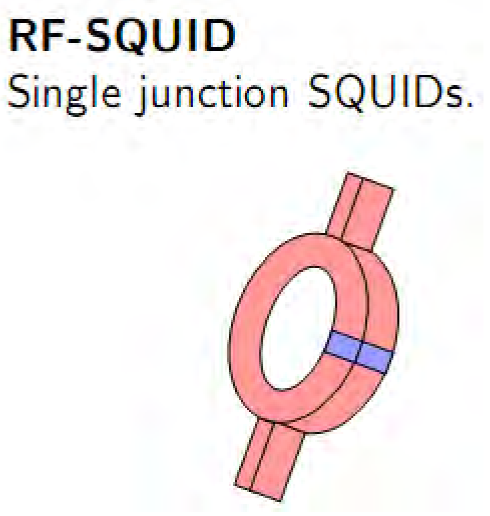
Does it exist the another way to realize magnetization reversal?

Is it possible to realize it by pulse of magnetic field?

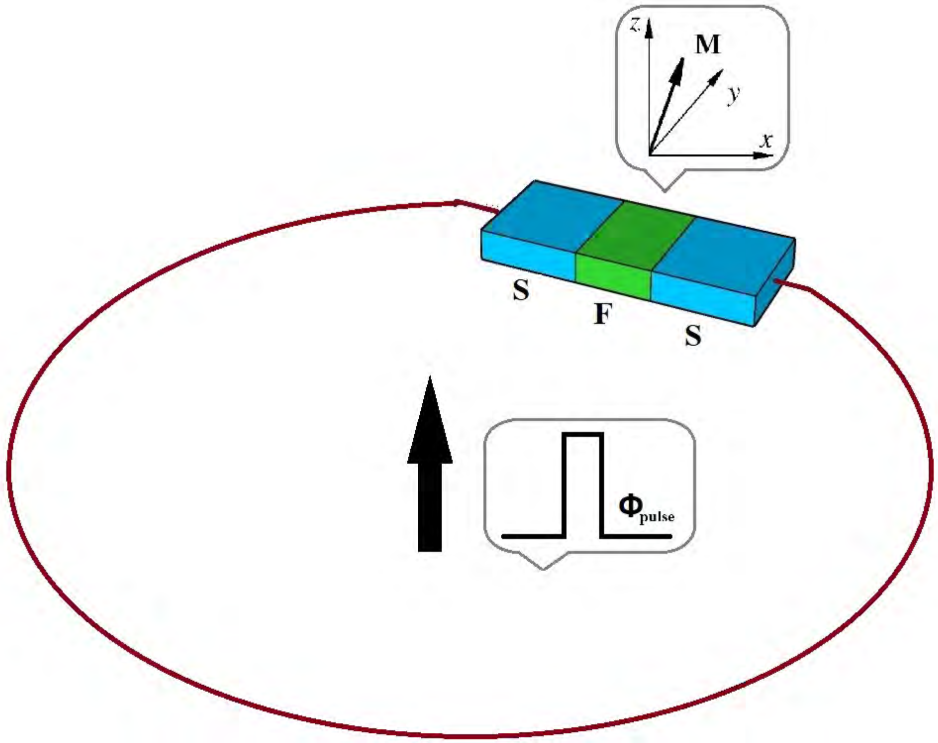
The answer is YES and we will consider this case next.

Model and numerical method

Single junction SQUID (Superconducting quantum interference device)



- The SQUIDs are superconducting devices which are ultra-sensitive to magnetic flux.



- So we consider dynamics of single junction SQUID with Phi-0 junction under the pulse of external magnetic field.

Model equations

- Total magnetic flux Φ trough the SQUIDs has form

$$\Phi = \Phi_{pulse} - LI \qquad (1)$$

Φ_{pulse} is magnetic flux created by external field, L is inductance of SQUID and I is current trough the SQUID, which is determined as

$$I = \frac{I_c}{\omega_c}\frac{d\varphi}{dt} + I_c \sin(\varphi - rm_y) \qquad (2)$$

$\omega_c = \frac{2\pi I_c R}{\Phi_0}$ - is characteristic Josephson frequency

$\Phi_0 = h/2e$ - Magnetic flux quantum

Expression for phase difference has form $\varphi - rm_y = \frac{2\pi}{\Phi_0}\Phi$ (3)

Combining (1) and (3) we can rewrite

$$\varphi_{pulse} - \frac{L}{L_0 I_c} I = \varphi - rm_y \qquad (4)$$

Model equations

- Finally combining (2) and (4) we obtain in normalized variables

$$\frac{d\varphi}{dt} = \frac{\varphi_{pulse} - \varphi + rm_y}{L} - \sin(\varphi - rm_y) \quad (5)$$

Time is normalized to $\omega_c = \dfrac{2\pi I_c R}{\Phi_0}$

and inductance normalized to $L_0 = \dfrac{\Phi_0}{2\pi I_c}$

The magnetization dynamics can be described by the Landau_lifshitz Gilbert equation

$$\frac{d\mathbf{M}}{dt} = -\frac{\Omega_F}{1 + (\mathbf{M}\alpha)^2}\{[\mathbf{M}\mathbf{H}_{\mathrm{eff}}] + \alpha[\mathbf{M}(\mathbf{M}\mathbf{H}_{\mathrm{eff}}) - \mathbf{H}_{\mathrm{eff}}\mathbf{M}^2]\}$$

$\mathbf{M}$ is magnetization vector

$\mathbf{H}_{\mathrm{eff}}$ is effective field

Ω_F is frequency of ferromagnetic resonance

Model equations

► Finally in normalized variables we can write coupled system of equations

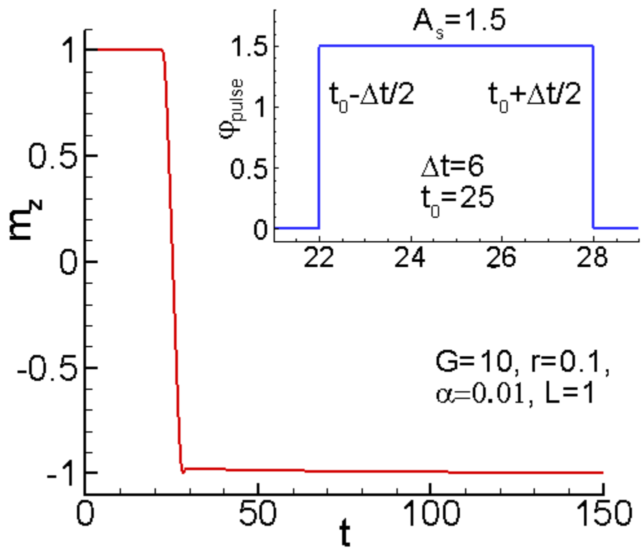
$$
\begin{aligned}
\frac{dm_x}{dt} &= -\frac{\omega_F}{1+(m\alpha)^2}\{(m_y h_{\text{eff},z} - m_z h_{\text{eff},y}) \\
&+ \alpha[m_x(m_x h_{\text{eff},x} + m_y h_{\text{eff},y} + m_z h_{\text{eff},z}) - h_{\text{eff},x} m^2]\} \\
\frac{dm_y}{dt} &= -\frac{\omega_F}{1+(m\alpha)^2}\{(m_z h_{\text{eff},x} - m_x h_{\text{eff},z}) \\
&+ \alpha[m_y(m_x h_{\text{eff},x} + m_y h_{\text{eff},y} + m_z h_{\text{eff},z}) - h_{\text{eff},y}]m^2\} \\
\frac{dm_z}{dt} &= -\frac{\omega_F}{1+(m\alpha)^2}\{(m_x h_{\text{eff},y} - m_y h_{\text{eff},x}) \\
&+ \alpha[m_z(m_x h_{\text{eff},x} + m_y h_{\text{eff},y} + m_z h_{\text{eff},z}) - h_{\text{eff},z}]m^2\} \\
\frac{d\varphi}{dt} &= \frac{\varphi_{pulse} - \varphi + r m_y}{L} - \sin(\varphi - r m_y)
\end{aligned}
$$

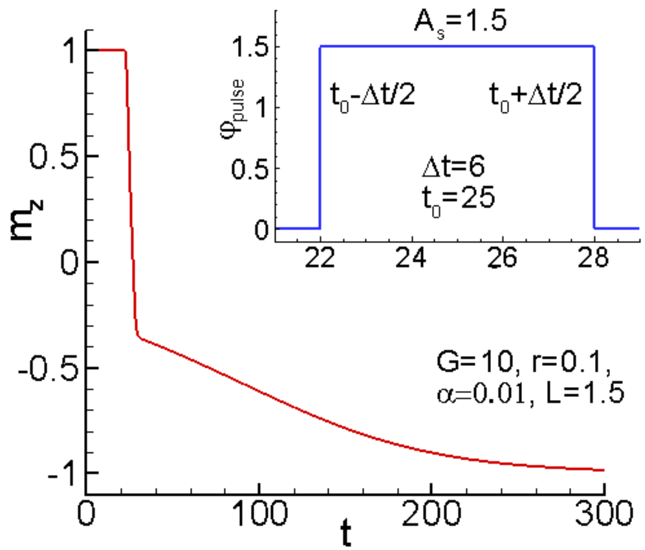
$$
\begin{aligned}
h_{\text{eff},x} &= 0 \\
h_{\text{eff},y} &= Gr\sin(\varphi - r m_y) \\
h_{\text{eff},z} &= mz
\end{aligned}
$$

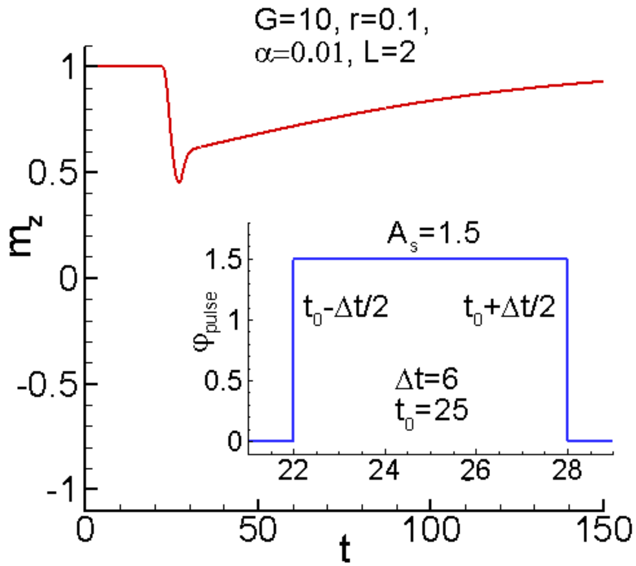
This system of equations is solved numerically with the 4th order Runge Kutta method

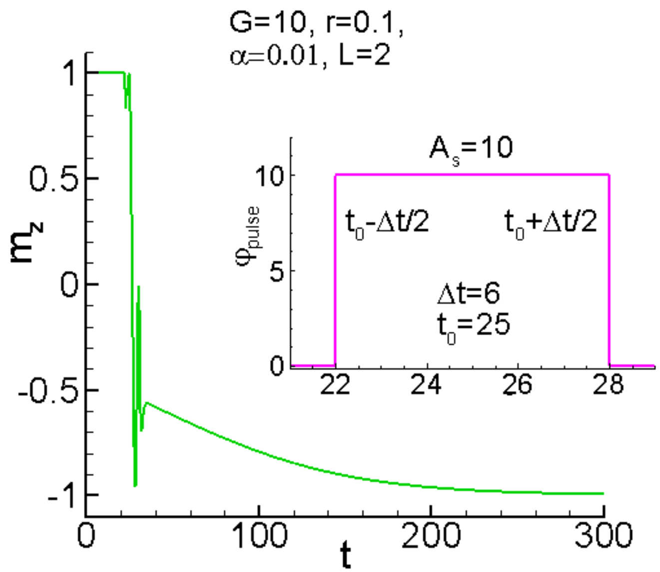
Results

Influence of model parameters









Conclusions

We simulate dynamics of single junction SQUID (superconducting quantum interference device) with the Phi-0 junction.

We demonstrate that under the pulse of external magnetic field can be realized magnetization reversal in the ferromagnetic layer.

The influence of the model parameters of the systems on magnetization reversal is investigated in detail.

The detail analysis of system is planed in the nearest feature

Thank you for attention