The formation of IV-characteristics of long Josephson junctions at zero-field steps

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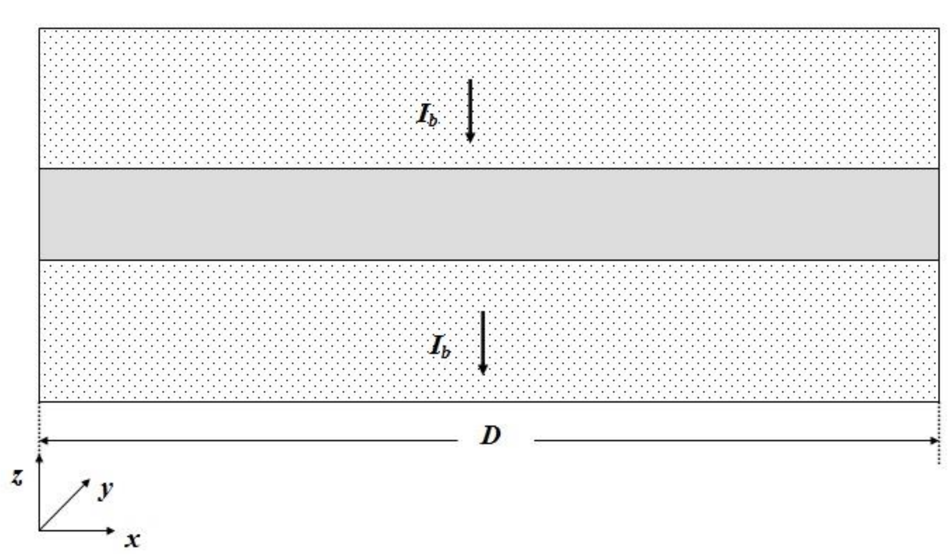
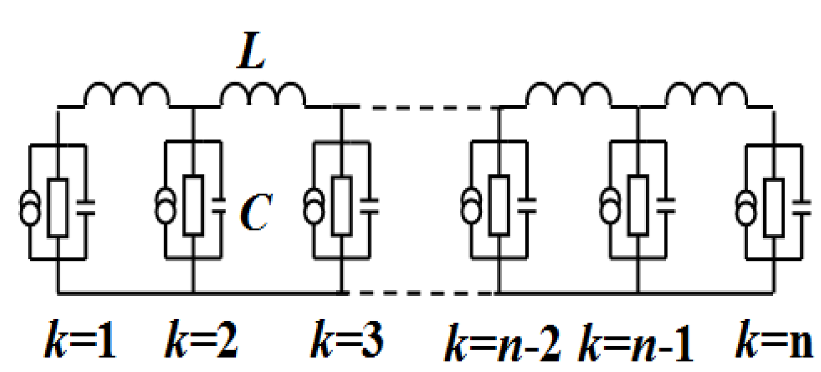
ABSTRACT

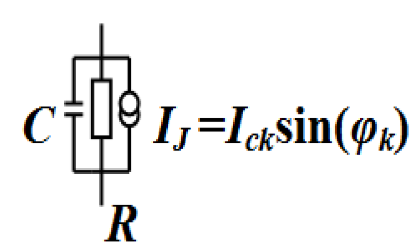
We calculated IV – characteristics of the long Josephson junction in the vicinity of the first zero-field step by two different methods. In the first method we used the numerical solution of dynamic equations. In the second method we used the analytical solution which took into account merely the movement of vortices in the junction of the infinite length. We modeled the long junction and calculated widths of vortices at the first resonance step. The IV – characteristic calculated by the second method exceeded significantly the IV - curve found from the solution of dynamic equations in the nearest vicinity of the resonance step.

The model oh the long junction

the high-frequency scheme of the junction:







The junction is divided to n segments with the length ξ.

For each of the segments the resistively and capacitively shunted model of the Josephson junction was used [1].

$$\frac{\Phi_0 C}{2\pi}\frac{d^2\varphi_k}{dt^2} + \frac{\Phi_0}{2\pi R}\frac{d\varphi_k}{dt} + I_{ck}\sin\varphi_k = I_b - I^R_{k-1,k} + I^R_{k,k+1},\quad k = 1\ldots n\text{-}1, \tag{1}$$

$$I^R_{k-1,k}L + \left[\frac{\Phi_0}{2\pi}(\varphi_{k-1} - \varphi_k)\right] = 0,\quad k = 2\ldots n\text{-}1, \tag{2}$$

where $I^R_{k-1,k}$ is the circulated current in contours between junctions k-1 and k.

The condition $\bar{c} = \frac{\xi}{\sqrt{LC}}$ must be satisfied,, where c' is the velocity of light in the junction..

The calculated value of voltage

- averaged voltage over the whole junction: $V = \frac{\Phi_0}{2\pi n}\sum_{i=1}^{n}\overline{\left(\frac{d\varphi_k}{dt}\right)}$ (3)

Zero-field steps

Zero-field steps appear in IV-curves of single long junctions in the absence of external magnetic field if there is some distribution of critical currents along the junction. They appear at voltages which correspond to Fiske steps. If the distribution of critical currents does not have sharp odd functions, only even Fiske steps remain.

$$V_p = \frac{\Phi_0 \bar{c}}{D}p,\quad p = 1, 2, 3, \ldots . \tag{4}$$

There is a periodical movement of Josephson vortices at zero-field steps.
The moving vortex has the 'relativistic' contraction of the length λ [2]:

$$\lambda = \lambda_0\sqrt{1 - \frac{v^2}{c^2}}, \tag{5}$$

where v is the velocity of the vortex, λ_0 is the static Josephson length of the penetration of magnetic field in the junction.

The IV – characteristic stipulated by merely the movement of vortices was calculated analytically for voltages in the vicinity of the zero-field step for the junction of the infinite length:

$$I_b = \frac{V}{\left(\frac{\pi^2}{2\sigma D^2}\right)\sqrt{1 - \frac{v^2}{c^2}}}, \tag{6}$$

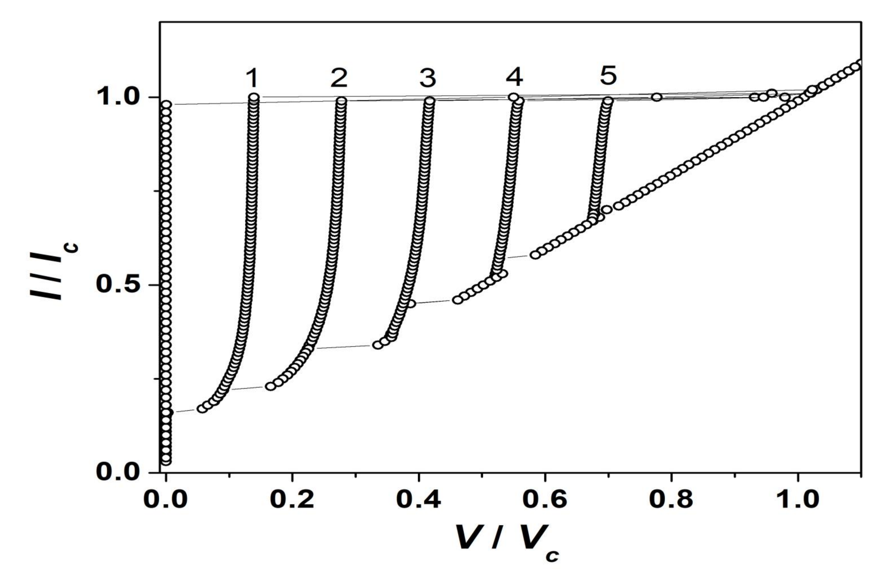
where σ is the electrical conductivity of the junction per unit length.
In the present work we checked the validity of the expression (6) for the junction with finite length.

[1] A. Grib, P. Seidel, IEEE Trans. Appl. Supercond., 26, 3, 1801004, 2016

[2] T. A. Fulton, R. C. Dynes, Solid State Communications, 12, 57, 1973

RESULTS OF CALCULATIONS

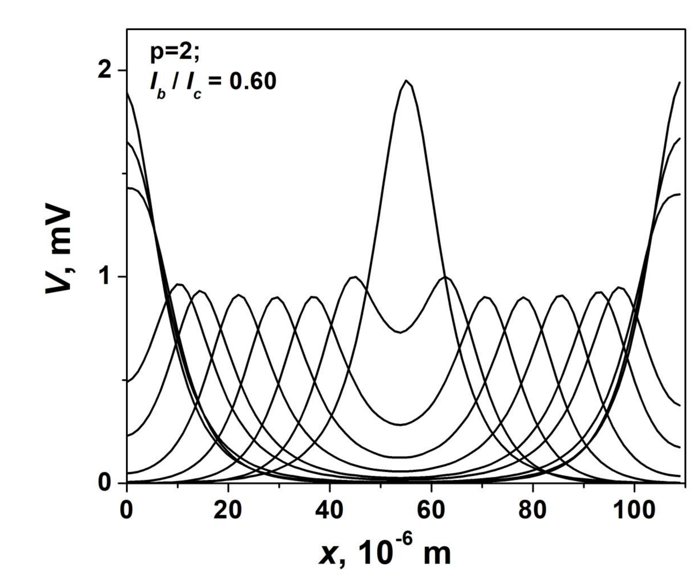
The IV – characteristic of the long junction

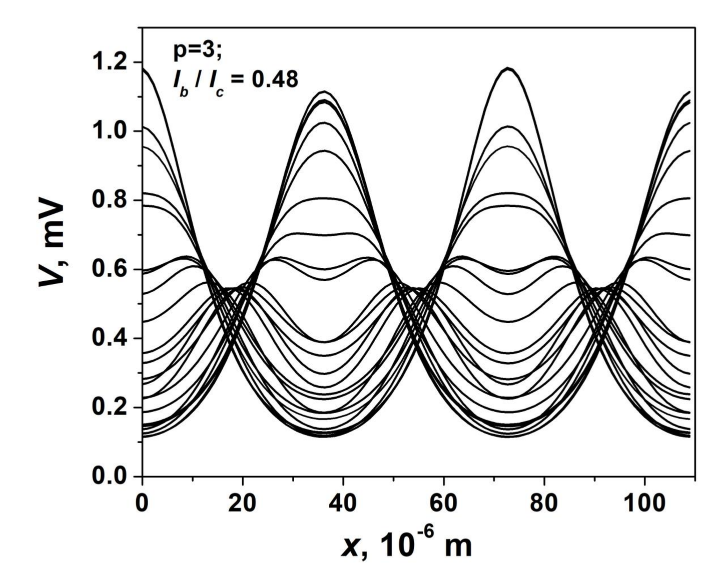


In one of the sections of the junction the value of Ic was smaller on 0.001%

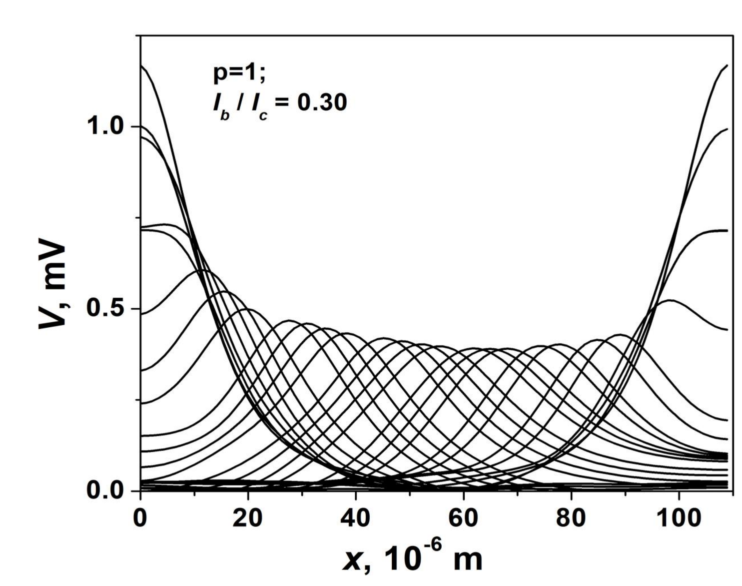
Parameters of the junction:
D== 1.1·10^{-4} m;
I_c = 1.706·10^{-3} A;
V_c =1.2·10^{-3} V;
n=1600;
$\bar{c}$ = 8.896·10^{6} m/s;
ξ =6.875·10^{-8} m;
$\frac{(V_{p+1} - V_p)}{V_c}$=0.139;
λ_J =1.556·10^{-5} m;
$\frac{D}{\lambda_J}$ =7.07; β_C =40.86

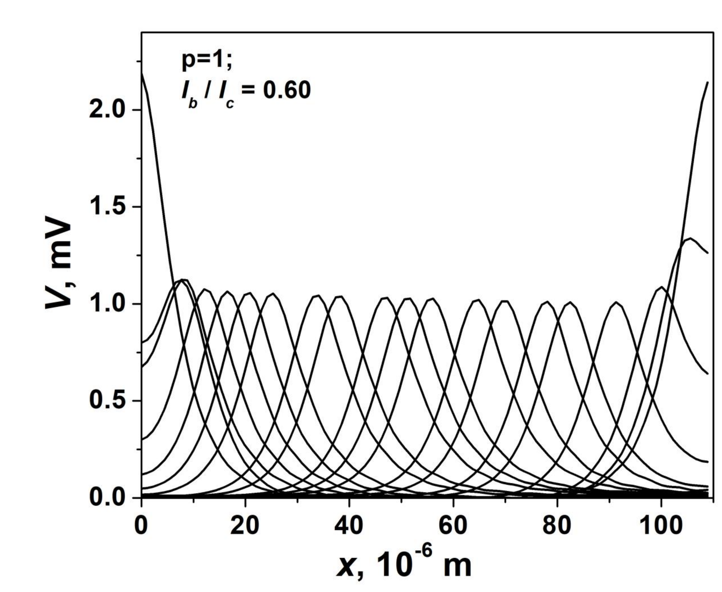
The movement of vortices



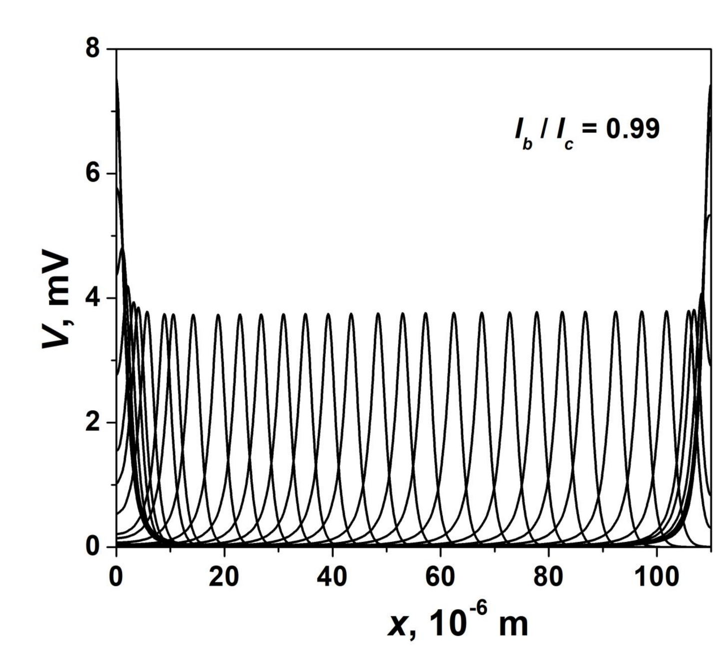


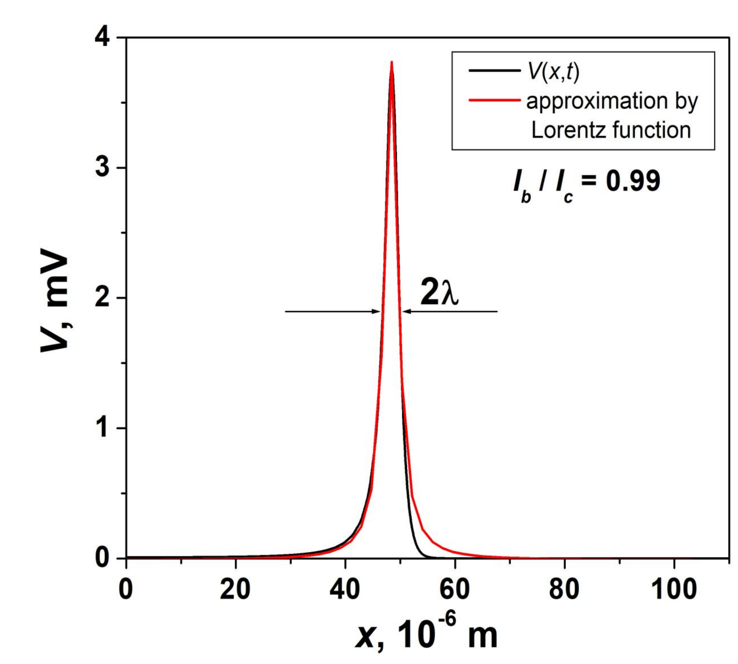
Widths of Josephson vortices for different bias currents



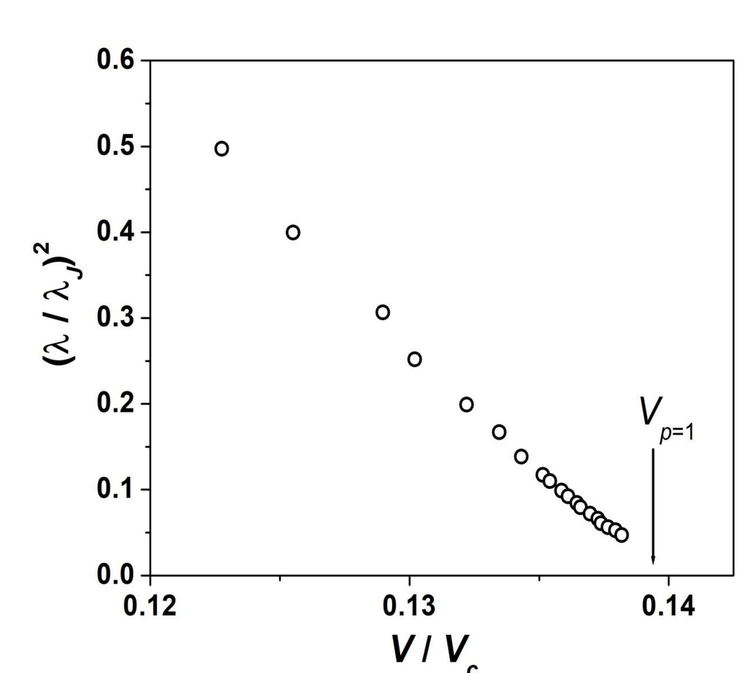


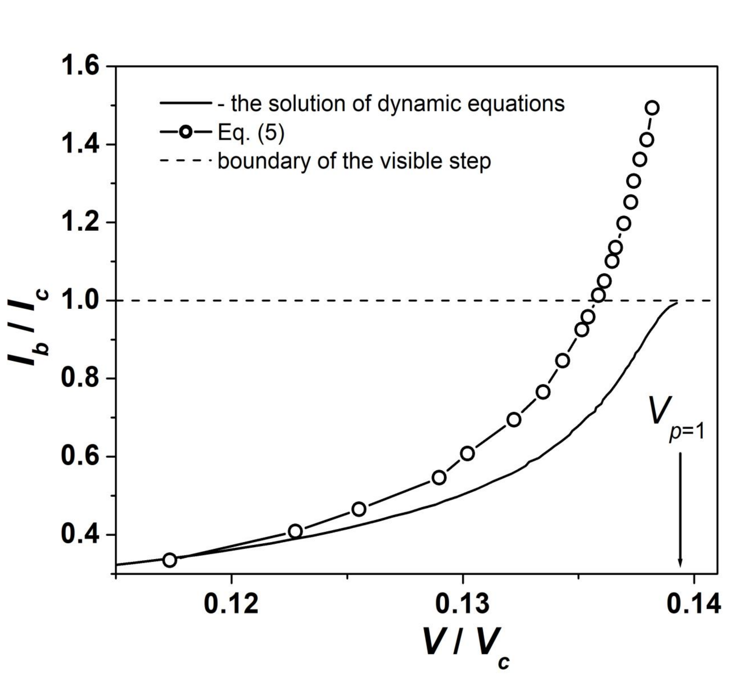
The calculation of the width of the Josephson vortex





The calculation of the IV - characteristic





CONCLUSONS

1. **We modeled dynamics of the long Josephson junction with a small irregularity in one local place of the junction.**
2. **Zero-field steps were found in the IV – characteristic. There was the movement of Josephson vortices at the resonant steps.**
3. **We calculated the IV – characteristic in the vicinity of the resonant step according to derived in Ref. [2] analytically expression which took into account merely the movement of vortices in the junction of the infinite length. We found that this IV – curve exceeded significantly the IV - curve found from the solution of dynamic equations in the nearest vicinity of the resonance step.**