Current–voltage characteristic of a dependent Josephson contact

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It has recently been shown theoretically[1–3] that point Josephson contacts can behave randomly if placed in a sufficiently strong monochromatic external field. This was confirmed experimentally in Ref. 4, where a noisy contact voltage was noted. In this note we show that random behavior in a sufficiently strong external field should cause the current step at zero voltage to disappear from the current–voltage characteristic, an effect which should be readily observable experimentally.

The phase difference φ in a specified external current $I_0 + I_1 \cos(\Omega t)$ with allowance for the capacitance of the contact is given by the equation[5]

$$\ddot{\varphi} + \gamma\dot{\varphi} + \sin\varphi = i_0 + i_1 \cos(\omega\tau), \qquad (1)$$

where the time is measured in units of the reciprocal plasma frequency: $\tau = \omega_j t = (2eI_c/\hbar C)^{1/2} t$; $i_0 = I_0/I_c$, and $i_1 = I_1/I_c$ are the dimensionless dc and ac external currents; $\omega = \Omega\omega_j^{-1}$; $\gamma = (RC\omega_j)^{-1}$. The average dimensionless contact voltage is $v = \langle\dot{\varphi}\rangle$; the I–V characteristic is the function $i_0 = i_0(v)$.

The solution of φ of Eq. (1) behaves randomly for sufficiently large i_1; in this case, analytical methods break down and recourse to numerical analysis is necessary. We specify the values $\gamma = 0.2$ and $\omega = 0.64$ and initially set $i_0 = 0$ and consider the time evolution of φ in Eq. (1) as i_1 increases.

For small i_1, φ behaves synchronously, i.e., the phase φ oscillates periodically at the same frequency as the external force, and the magnitude of the oscillations is bounded only by the potential well $U(\varphi) = 1 - \cos\varphi$. For $i_1 = i_{1c} \approx 0.55$, φ starts to behave randomly and the oscillation swing is so large that the phase may jump out of one potential well $U(\varphi)$ and into another (although in principle random behavior in which φ remains bounded can occur, this was not observed for the specified values $\gamma = 0.2$, $\omega = 0.64$). For $i_0 = 0$ the phase dynamics is similar to a random walk (diffusion) over the potential $U(\varphi)$.

For a nonzero external dc current $i_0 \neq 0$, the dynamic behavior of φ differs qualitatively for $i_1 < i_{1c}$ and $i_1 > i_{1c}$. If $i_1 < i_{1c}$ a finite perturbation i_0^1 is required to disrupt bounded periodic behavior and produce a state in which the average change in the phase is nonzero, $\langle\dot{\varphi}\rangle \neq 0$; this corresponds to a step $-i'_0 < i_0 < i'_0$ on the I–V characteristic at zero voltage. For $i_1 > i_{1c}$, the phase is unbounded for $i_0 = 0$ and a small perturbing dc current i_1^0 alters the probability of a jump from one potential well $U(\varphi)$ to another. A systematic phase drift is therefore superimposed on the diffusion; the drift rate is proportional to the dc component of the current, $v = \langle\dot{\varphi}\rangle \simeq \text{const} \cdot i_0$, and there is no current step for $v = 0$. We note that for $i_1 > i_{1c}$ current steps may exist for nonzero v. Figure 1 shows some I–V characteristics calculated from (1) for $\gamma = 0.2$, $\omega = 0.64$, and $i_1 = 0.1$ (1) and $i_1 = 0.7$ (2) as i_0 is increased.

We note in closing that the disappearance of the current step from the I–V characteristic in a strong ac field is similar to the smearing out of the characteristic that results when strong fluctuations are allowed for.[5] However, unlike the latter case in which a small external noise can cause the step to disappear, in a periodic field the step gradually becomes smaller and vanishes at a definite threshold $i_1 = i_{1c}$.

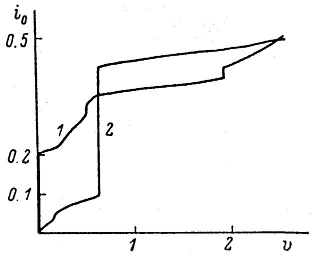

FIG. 1

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