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QUASIPERIODIC ROUTE TO SOFT TURBULENCE IN LONG JOSEPHSON JUNCTIONS

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We present a numerical study of the onset of a turbulent-like regime in long Josephson junctions. We show that the local generation of different linear combinations of frequencies in the quasiperiodic regime leads to the breakdown of coherence of the spatiotemporal profile.

The long Josephson junction (LJJ) provides a field in which experiments and simulations may act interactively in the study of spatiotemporal phenomena. The interplay between temporal chaotic dynamics and solitonic structures in LJJ has received a great deal of attention in recent years. Even richer behavior can also be exhibited by LJJ, like turbulent-like behavior, an interesting and fundamental dynamical state which is not well understood.

In this paper we explore the transition to the turbulent state in LJJ. We show that the onset of the turbulent-like regime is preceded by a quasiperiodic regime which suppposes the generation of a spatiotemporal excitation which oscillates unlocked to the driving frequency. We show for this quasiperiodic regime that different local generation of linear combinations of the two basic frequencies (the frequency of the driving force and the one of the spatiotemporal excitation) affect the coherence of the spatiotemporal profile. When the system is driven harder the coherence of the spatiotemporal profile decreases. This last state can be regarded as a soft turbulence regime, i.e., a regime globally disordered in space and in time (1).

The forced LJJ considered by us has been discussed extensively (2). We model this system with the usual sine-Gordon-like equation,

$$\phi_{xx}-\phi_{tt}-\sin\phi=\alpha\phi_t-\rho\sin(\Omega_d t) \quad (1)$$

where $\phi = \phi(x,t)$ is the phase difference of the superconducting order parameter between each side of the barrier and the term $\alpha\phi_t$ represents quasiparticle loss. The distance is normalized to the Josephson penetration depth, time is normalized to the inverse of the Josephson plasma frequency, the rf amplitude ρ is normalized to the critical current and Ω_d is the normalized applied frequency. The external applied field is taken into account through $\phi_x(0,t)=\phi_x(L,t)=\eta$, where L is the junction length and η is a measure of the external magnetic field. In this paper parameter values are $L=10\lambda_J$, $\alpha=0.252$ and $\Omega_d=0.65$. We employ open boundary conditions, $\eta=0.0$, homogeneous forcing and flat initial conditions so that the pattern formation phenomena is fully spontaneous.

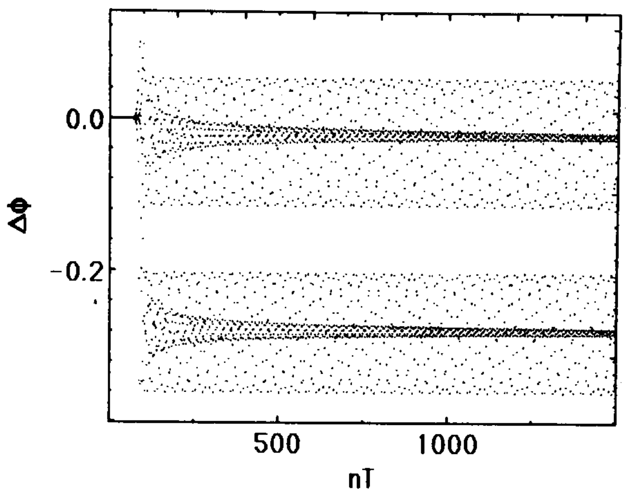

FIGURE 1

Figure 1 plots the phase difference $\Delta\phi$ between two points of the junction for each period of the rf drive. In this Figure solutions for two values of the amplitude of the driving force ($\rho=2.0079$ and $\rho=2.010$) are presented superimposed. Both solutions exhibit an initial spatially homogeneous transient followed by the spontaneous formation of a spatial profile.

For $\rho=2.0079$ Figure 1 (inner bands) reveals that once the breather forms from the initial flat condition there is a long transient both in space and time. These long

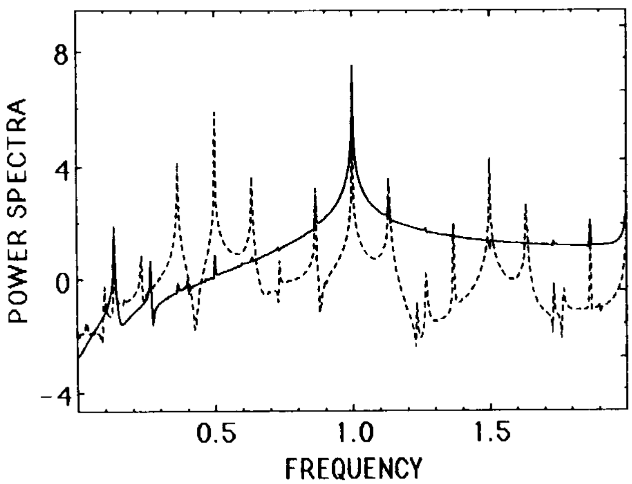

FIGURE 2

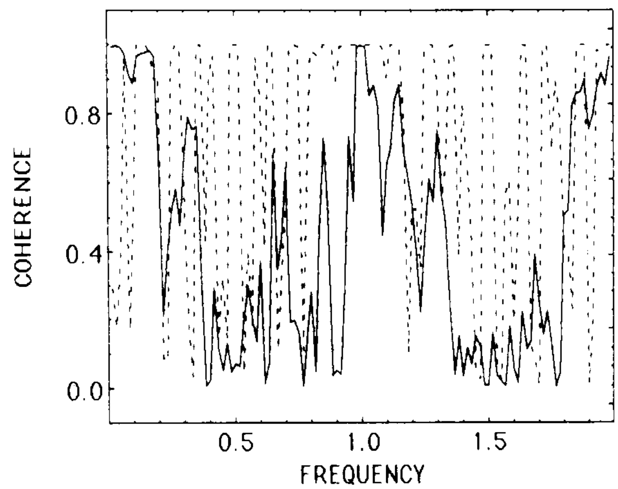

FIGURE 3

transients for the dissapearance of complex patterns have received attention in recent years (3). In the present case this phenomenon corresponds to the increasing difficulty of the system to attain a response which oscillates locked to the frequency of the driving force. The final state for $\rho=2.0079$ corresponds to a breather oscillating with a frequency equal to half the driver.

As the system is driven harder the system ceases the long transient behavior (in space and in time) via generation of a quasiperiodic response: the system generates at the onset of pattern formation a breather-like excitation unlocked to the frequency of the driving force. This corresponds to the outer bands in Figure 1 ($\rho=2.010$).

In Figure 2 the continuous line represents the power spectrum of the voltage ($V \propto \phi_t$) at the middle of the junction for $\rho=2.010$. At this value of the amplitude of the driving force the quasiperiodic regime exhibits a doubling of the torus: the response of the system has a frequency ($\Omega/\Omega_d=0.1333$) inconmensurate with the driving force as well as the double of this one. The dashed lines in Figure 2 represent the power spectrum of the phase difference $\Delta\phi$ between two points of the junction: besides the increasing complexity of the spatiotemporal response, this denotes, in comparison with the local power spectrum, that different points of the junction differ in the way the different frequencies linearly combine. This has the effect of reducing the coherence of the spatiotemporal profile: there is a competition between local (single-particle) and global (collective) dynamics. In effect the system is becoming uncoupled.

The coherence of the spatial profile decreases as the forcing is increased further. This phenomenon can be characterized studying the correlations in space (1). The dashed lines in Figure 3 show the coherence spectrum for the previous quasiperiodic regime ($\rho=2.010$) whereas the continuous line corresponds to $\rho=2.040$. This last state corresponds to a soft turbulent-like regime, a regime in which there is a breakdown of the pattern formation ability of the system (1). The dynamic attractor for $\rho=2.040$ does not exhibit fractality and reveals a high-dimensional regime distinct from low dimensional chaos.

Finally, we emphasize that the transition from the two frequency quasiperiodicity to turbulence is direct: only two inconmensurate frequencies appear in the onset of turbulence in contrast with suggested routes which require at least three (5). The transition from quasiperiodicty to turbulence found in this work is also different to the universal route from quasiperiodicity to low-dimensional chaos (4) which supposes the multifractalization of the torus.

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