ASYNCHRONOUS OSCILLATIONS NEAR THE SYNCHRONIZATION BAND IN A WIDE-BAND, SELF-OSCILLATING SYSTEM WITH DELAY

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In the present work the effect of the nonlinear properties of an amplifier on the characteristics of asynchronous oscillations near the synchronization band is analyzed for a self-oscillating system with delay. This consists of a nonlinear amplifier, the input and output of which are connected via a delayed, linear, feedback circuit.

We know that for a Thomson self-oscillator in non-autonomous regime the form of the asynchronous oscillations (pulsations) near the synchronization band depends on the characteristics of the limits ("soft" or "hard") of departure of the signal's amplitude, from the amplitude of the stationary self-oscillations [1]. Even with different synchronization mechanisms of the Thomson oscillators (damping of the natural oscillations by external forces) and of the relaxation-type systems (locking of the frequency by modulation of the nonlinearity with an external force), one can expect that, also for the self-oscillators considered here, the form of the asynchronous oscillations near the synchronization band will depend on the nature of the nonlinearity of the amplifier

$$U_{\text{out}} = \Phi[U_{\text{in}}].$$

We selected two limiting cases of systems under examination: (1) a system with "soft" limits of departure of the oscillation's amplitude from the amplitude U_0 of the stationary self-oscillations:

$$\left|\frac{d}{dU}\Phi[U]\right|_{U=U_0} \ll 1$$

and (2) a system with "hard" limits

$$\left|\frac{d}{dU}\Phi[U]\right|_{U=U_0} \sim 1.$$

For the actual work a model of a self-oscillating system was used [2-4] for which the oscillations are described by the following nonlinear integral equation

$$F[U(t)] = \int_0^t h_\delta(t-\xi)U(\xi)d\xi + f(t),$$

where F[·] is the "inverse" nonlinear transfer function of the amplifier, which expresses the signal at the amplifier's input F[U(t)] in terms of the signal at its output U(t); $h_\delta(t)$ is the impulse response of the feedback circuit; f(t) is the external force.

For the calculations of the asynchronous oscillations in the non-autonomous system a method of numerical modeling of the process was used [4]. The computation was carried out in two steps. First, assigned some initial force f(t), for example a rectangular pulse, we computed the process of buildup of the natural oscillations in the autonomous regime over a time interval $[0, t_1]$ of the order of the characteristic time of the transient process in that system. Then, assigned a harmonic external force $f(t) = v\cos(pt)$ for $t > t_1$ and using the instantaneous values of the signal U(t) computed for $t < t_1$, we calculated the process of setup of the oscillations in the non-autonomous system in the time interval $[t_1, t_2]$, of the order of the same characteristic time of the transient process.

In Fig. 1 asynchronous oscillations are shown, computed for a system with an LC feed-

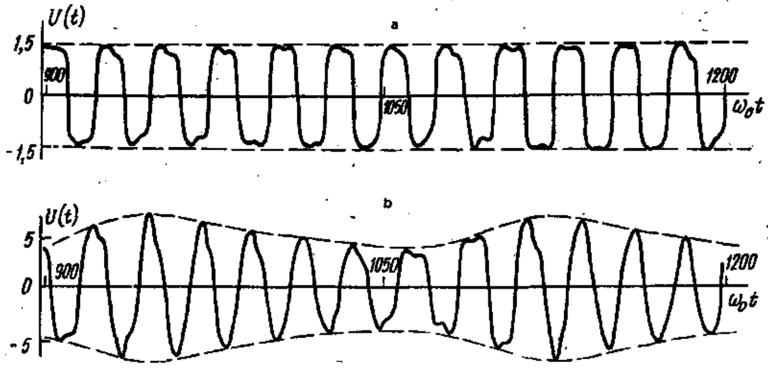

Fig. 1. Asynchronous oscillations computed for systems with "hard" (a) and "soft" (b) limits of amplitude variations (ω_0 is the cutoff frequency of the LC feedback circuit).

back circuit composed of six sections. The first process represents asynchronous oscillations in a system with "hard" limits of amplitude variations and, as one can see from the figure, it does not have a clearly defined envelope. In the case of the system with "soft" limits of amplitude variations (second process) the asynchronous oscillations have, as shown in the figure, an evident, well-defined envelope. Then, in the approximation that the frequency of the external signal is within the synchronization band limits, the form of the envelope departs more from a sinusoid, but its period increases. From the calculations it follows that the partial frequency entrainement of the fundamental tone by the external force is larger for the system with "soft" limits of amplitude variations than for the system with "hard" limits. This is explained by the fact that in the first case the amount of modulation of the nonlinearity of the amplifier $\left|\frac{d}{dU}\Phi[U]\right|_{U=U_0} v/U_0$ by the external signal is considerably larger than in the second case.

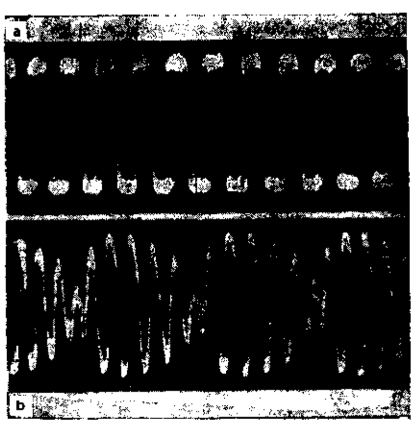

Fig. 2. Experimental record of asynchronous oscillations in the case of "hard" (a) and "soft" (b) limits of amplitude variations.

Such a behavior, as we know from [1], is typical of single-frequency, non-autonomous systems. Therefore, in first approximation, a similar wide-band system can be considered as a single-frequency one by neglecting all the harmonics except the fundamental tone. However, as the computation shows, the finite band-width of the considered system and the presence of a dispersion delay cause a series of discontinuities connected with the appearance in the spectrum of the nonlinear oscillations of the other, non-equidistant, normal frequencies of the system. The role of such discontinuities is small in the considered case of strong delay dispersion (less than 12 sections), when only regimes of regeneration are possible, in the spectra of which the amplitude of the fundamental tone dominates. In this case the interaction of the excited natural frequencies with the harmonics of the self-oscillation is small because of the substantial detuning of their frequencies and the small amplitude of the harmonics. In the case of a small delay dispersion one should expect primarily the effect of properties connected with the finite band-width of the system.

In Fig. 2 we show experimental oscilloscope traces of asynchronous oscillations in the case of "hard" and "soft" limits of amplitude variations. The processes, photographed in the continuous development regime, were for system parameters and external forces similar to the calculated ones. The experimental investigation confirms the correctness of the model chosen for the description of the non-autonomous generation regime in the considered real self-oscillating devices.

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