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# AUTOOSCILLATIONS IN ZINC*

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The phenomenon of automodulation can be observed in the course of internal friction studies of nonlinear anelastic solids. It is particularly pronounced in the vicinity of stress-induced phase transformations [1,2], but has also been observed to occur in zinc [3,4]. In this letter, we will report on the automodulation of the amplitude in zinc and show how the experimental observations relate qualitatively to the theory of nonlinear anelasticity [2,5].

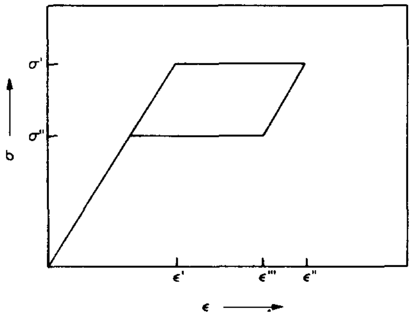


FIG. 1
Conceptual stress-strain curve when twinning occurs.

Consider twinning, the idealized stress-strain curve of which is presented in Fig. 1. The figure shows the elastic stress-strain relationship at very small, slow deformations. Twinning is represented by the spontaneous strain ($\varepsilon''-\varepsilon'$) which develops at a characteristic stress $\sigma'$. Upon reducing the stress, the twins deform elastically until they disappear at the stress $\sigma''$, provided the twins are so small that the accommodation stresses around them are predominantly elastic. Note that this stress-strain curve resembles closely the ones observed when stress inducing martensite [6], which may be considered twinning of a more general sort. The authors have shown [7] how the stress-strain curve shown in Fig. 1 is readily interpreted in terms of the nonlinear anelastic solid.

Consider next, oscillations of a solid known to deform by twinning. At amplitudes smaller than $\varepsilon'$, oscillations will be purely sinusoidal and the resonance curve will have its well-known symmetrical shape [8]. At amplitudes larger than $\varepsilon'$, the resonance will no longer be symmetrical, it will be skewed toward lower frequencies because the deformation becomes "easier" as more twins are nucleated. This is shown in Fig. 2 (see next page) for the case of zinc. The graph represents a copy of the data taken by an x-y recorder. The apparatus used for the measurements has already been described [2]. It should be noted in Fig. 2 that the deformation is finite but small, so that it may be expected that twinning occurs reversibly. This expectation is supported by the reproducibility of the data.

Skewed resonance curves observed in nonlinear anelastic solids may be considered to represent a modification of the resonance characteristics of linear anelastic solids. The former

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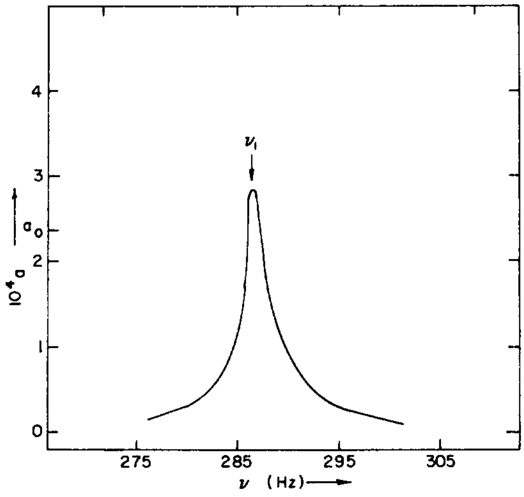


FIG. 2
Resonance curve of a zinc single crystal reed taken at room temperature.

solids may, however, display another phenomenon which cannot occur in the latter. This is the phenomenon of autooscillations which may semiquantitatively be understood as follows. As twinning commences at the stress $\sigma'$, the solid deforms spontaneously by an amount $(\varepsilon''-\varepsilon')\Delta V/V$ where $\Delta V/V$ is the volume fraction of twins. In the course of an oscillation, this extra strain is induced every cycle when the amplitude of the externally applied periodic stress $\sigma$ is larger than $\sigma'$. The extra strain is induced with a time lag characterized by a relaxation time $\tau$, i.e., it is nonlinear anelastic in nature. The oscillation of a sample made of such a nonlinear anelastic solid has already been analyzed using the Bogoliubov-Mitropolski method [9]. The main result of this analysis is that the amplitude a and the phase $\phi$ of the oscillation become slowly time dependent when $\sigma > \sigma$

$$\varepsilon(t) = a(t)\cos[2\pi\nu t + \phi(t)]. \quad (1)$$

Considering the fact that close to resonance the sample acts as a filter sorting out the predominant term [10], the oscillations are given by:

$$\varepsilon(t) = a\{1 + \Delta a/a \sin[2\pi(\nu_0-\nu)t]\}\sin(2\pi\nu). \quad (2)$$

It may therefore be said that two kinds of oscillations exist in the twinning nonlinear anelastic solid. One is the ordinary or heterophase oscillation impressed onto the solid by the external excitation frequency $\nu$. The other is the extraordinary oscillation, the amplitude of which is automodulated with the frequency $\nu_0-\nu$. Here $\nu_0$ is the natural frequency of the sample which is determined by the combination of its geometry, amplitude of oscillation and relaxation time for the twinning process.

The automodulation of a 99.995% pure single crystal zinc sample vibrating with the frequency $\nu_1$ (see Fig. 2) at room temperature is shown in Fig. 3 (see next page). It can be seen that the automodulation is approximately sinusoidal. Its frequency is small in comparison to $\nu$, as must be expected on the basis of Eqn. 2. Fig. 4 (see next page) shows the frequency of the automodulation determined as a function of the frequency of excitation $\nu$. It can be seen from this figure that the experimentally determined modulation frequency $\nu_m$ is proportional to the drive frequency $\nu$, hence also to the beat frequency $\nu-\nu_0$ as $\nu_0$ is approximately constant. By comparing Figs. 2 and 4, it can further be seen that the region of proportionality is restricted to frequencies larger than the resonance frequency. Qualitatively, this can be understood by observing that the resonance curve is unsymmetrical with respect to the resonance frequency. Therefore, the beat phenomenon must be unsymmetrical as well, as follows also from the more detailed analysis [2,9].

It was noted above that automodulations are expected only if the externally applied stress is sufficiently large. This will translate into a threshold amplitude of oscillation below which automodulation will not occur. This amplitude, $a_0$, is indicated in Fig. 4.

Strictly speaking, the eigenfrequency depends on the amplitude and through it on the degree by which various twins contribute to the deformation process. For a full discussion of the phenomenon, the idealized stress-strain relationship shown in Fig. 1 should thus be replaced by an average curve featuring rounded corners. As a consequence, both the resonance frequency $\nu_0$ and the threshold amplitude $a_0$ will be characteristic of the twin and stress distribution in the sample. The observation of a well-defined threshold amplitude $a_0$, suggests that this distribution is not very wide.

In this paper, both nonlinear resonance and automodulation data were described and qualitatively interpreted using the concept of the nonlinear anelastic solid. Both represent the interaction of the externally applied, periodic stress with the nonlinear phenomena occurring in the solid. Hence, the dynamics of this interaction and thus the process giving rise to the nonlinearity; i.e., twinning in the present case, can be studied by varying the natural frequency of the sample. Such studies are presently underway and will be reported on later.

## References

1. W. de Jonghe, R. DeBatist, L. Delaey and M. DeBonte in Shape Memory Effects in Alloys, edited by J. Perkins, Plenum Press, New York (1975).
2. M. Wuttig and T. Suzuki, Scripta Met. 14, 229 (1980).
3. Shuchiro Takahashi, J. Appl. Phys. 23, 866 (1952).
4. Toshio Yokoyama, private communication.
5. M. Wuttig and T. Suzuki, Acta Met. 27, 755 (1979).
6. See Reference 1 for various examples.
7. M. Wuttig and T. Suzuki, Met. Trans. 12A, 1362 (1981).
8. A.S. Nowick and B.S. Berry, Anelastic Relaxation in Crystalline Solids, Academic Press, New York (1972).
9. M. Wuttig and T. Suzuki, Proceedings of the International Conference on Ultrasonic Attenuation and Internal Friction, Lausanne, Switzerland (1981).
10. N. Minorsky, Nonlinear Oscillations, Van Nostrand, New York (1962).

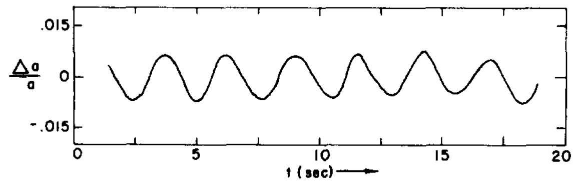


FIG. 3
The automodulation occurring when driving the zinc reed at the frequency $\nu_1$ shown in Fig. 2

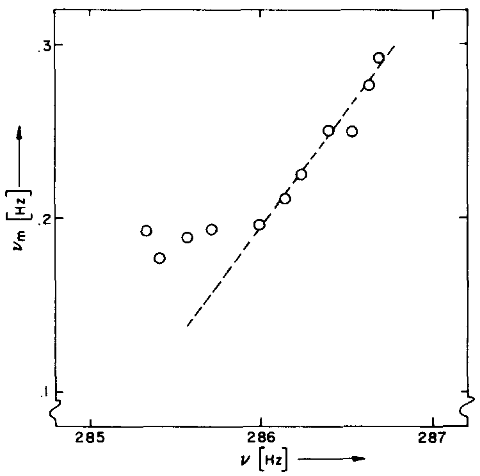


FIG. 4
The experimentally observed automodulation frequency $\nu_m$ as a function of the drive frequency.