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The Origin of Vibration Redemption Effect for Shape Memory Alloys

Shape memory alloys (SMA) components can affect through two mechanisms the vibrations of structures. The stresses from a SMA element that realize phase transformations, as a result of vibrations, have an effect on the frequency-amplitude characteristics. In addition, a dissipation of energy due to hysteresis in a SMA element can reduce the natural frequency and affect forced vibrations.

1. Introduction

The origin of vibration redemption effect is one of the characteristics of pseudo elastic SMAs, due to progressive reduction of coefficient of elasticity at unloading, as well by mechanical energy absorption through internal friction. On a conventional scale for coefficient of amortization, steel has a 0,1 coefficient; aluminum has a 0,3 coefficient; SMAs Ni-45% Ti can attempt 30 as coefficient and SMAs Mn-Cu based can attempt the maximal coefficient of 40. These values sustain the affirmation that SMAs have a vibration redemption capacity up to 200 times higher than classical materials.

2. Analysis.

The mechanical redemption capacity is often identified with internal friction, defined as the effect of irreversible transformation of mechanical energy into thermal energy, dissipated. To characterize the internal friction (F) it is utilized a quality factor (Q), being transposed to internal friction:

$$Q = 1/F \qquad (1)$$

Internal friction is dependent of several factors, such as: 1-temperature, 2-deformation degree, 3-material status, 4- amortized oscillations frequency. The dependence between internal friction and temperature is schematized in **Figure 1**.

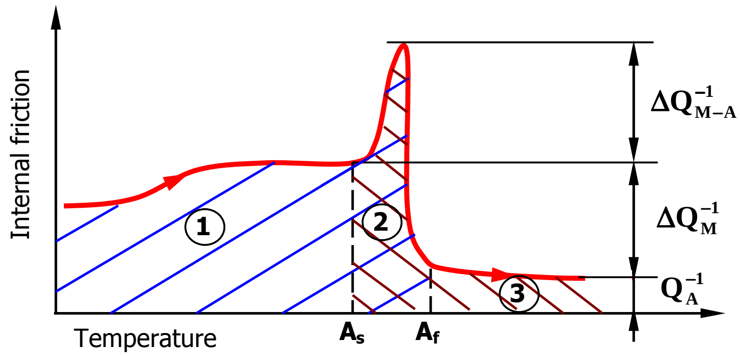

Figure 1. Variation diagram of internal friction with temperature to SMA

In region 1, the material is in martensitic estate, being characterized by high internal friction. In region 2, the material is in transition estate, so martensite coexists with austenite. The redemption capacity and internal friction are maximal. In region 3, the material is in austenitic estate, and the internal friction Q_A is very low.

To illustrate the cumulated influence of the *deformation degree* and of the *material estate* over the internal friction is presented **Figure 2**. The three curves, notated 1-3, correspond to the three zones from Figure 1.

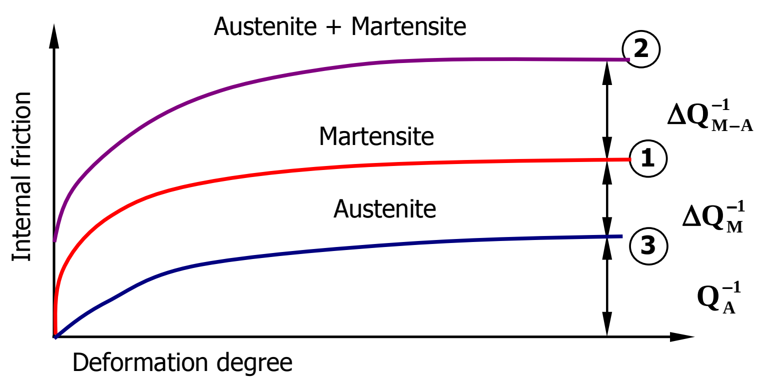

Figure 2. Influence of deformation degree and material estate over the internal friction to SMA

The difference between internal friction of the material in austenitic estate and the one of the material in martensitic estate was marked with $\mathbf{Q^{-1}_{M-A}}$.

Differentiate from austenite, where the internal friction has an order of 10^{-4}, being caused by the reversible displacement of dislocations and punctual defects, in martensite, the internal friction has an order of $5 \cdot 10^{-3}$, being associated with the reversible displacement of the interfaces between the variants of the martensite plates. So, $\mathbf{Q_A^{-1}} \approx 10^{-4}$ and $\mathbf{Q_M^{-1}} \approx 5 \cdot 10^{-3}$.

In the transition zone 2, the internal friction is caused by the reversible displacement of the austenite - martensite interface, reaching values of 10^{-2}. It results that $\mathbf{Q_{M-A}^{-1}} \approx 10^{-2}$.

3. Influence of oscillations frequency.

The influence of the fourth factor – *oscillations frequency* – over the internal friction is presented in **Figure 3**.

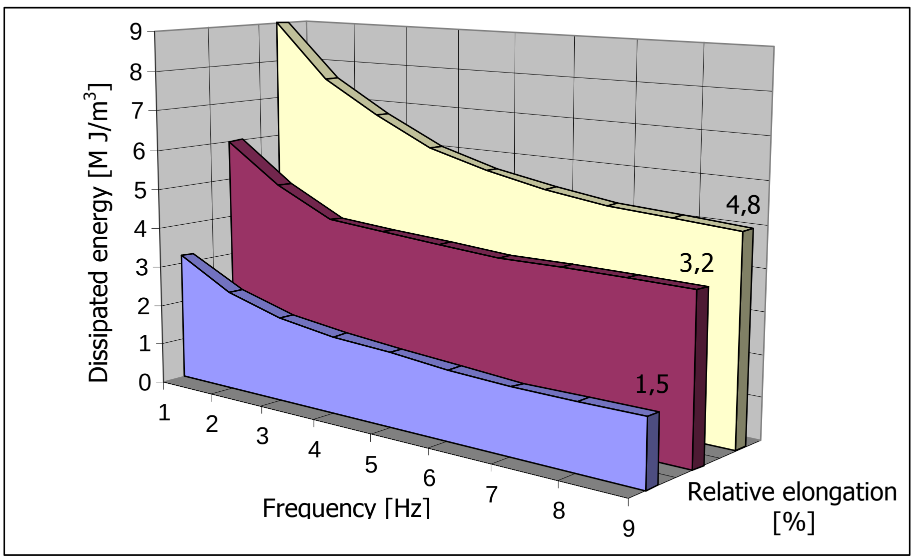

Figure 3. Influence of deformation frequency and deformation over the dissipated energy (redemption capacity) to SMA

The internal friction was expressed by mediation of dissipated energy on volume unit, by one frame of a loading-unloading cycle. This specific energy is determined by the area between the loading and discharge curves of a closed superelastic loop. It is obvious that the dissipated energy (and therefore internal friction too) augment at one time with the relative elongation, forasmuch grows the loop area. As loops area come down at one time with frequency increment, this going down is reflected by **Figure 3.** The reduction of redemption capacity at one time with excitation frequency growth was explained by introducing an elasticity complex module for SMA:

$$E = E_{rigid} + i \cdot E_{amort}$$

where E_{rigid} is energy storage module, which is characteristic to rigid materials (being named *stiffness module*) and E_{amort} is the energy loss module, which is characteristic to shock absorber materials (being called *redemption module*).

4. Conclusion

According to the diminution of the internal friction to frequency augmentation, was observed a sudden come down, up to 50 % of the redemption module to the rising of excitation frequency up to cca. 6 Hz. Beyond this value there were not observed any diminutions.

The stiffness module too presents a loss, but to the amplitude augmentation, not the frequency one.

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