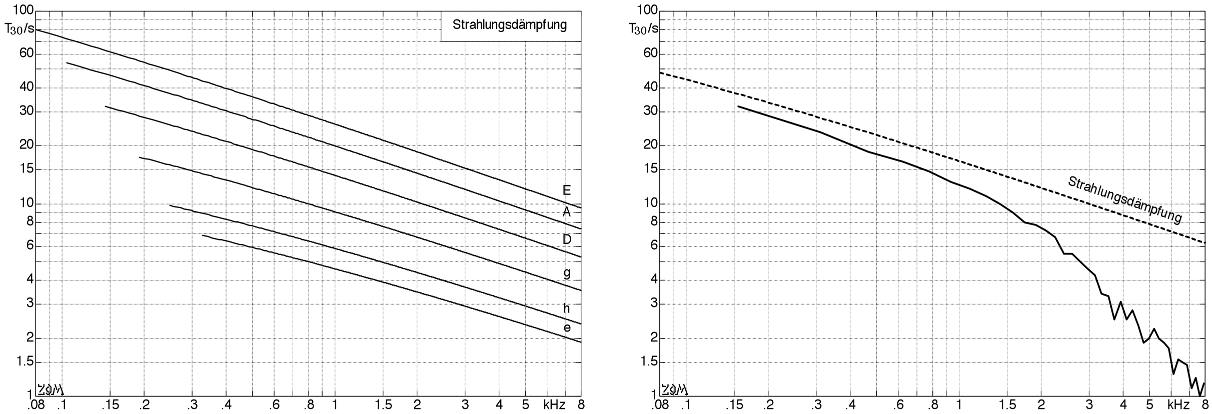

Fig. 7.63: Decay time T30 caused by attenuation by radiation (= air damping) for guitar strings (hybrid, 9/46). The right-hand diagram shows the decay time measured with a steel string (∅ = 0.7 mm) mounted on a stone table as well as the corresponding calculated attenuation by radiation. Only the low-frequency decay behavior only can approximately be explained that way. “Strahlungsdämpfung” = attenuation by radiation.

The attenuation by radiation can explain the decay behavior only when measuring in the low and middle frequency regions (right-hand diagram), and even then only if the bearing attenuation is very small. In the region of higher frequencies, additionally a loss mechanism taking place inside the string does have an effect, as will be discussed in the following.

7.7.2 Internal damping

When oscillating, the string changes its shape, i.e. its curvature and length, and energy is correspondingly required. For the main part, this is **reactive energy** temporarily stored as potential energy within the resilient string, but there is also **active energy**, causing minimal warming of the string. The active energy is lost to the oscillation process, and therefore such *attenuation (damping) mechanisms* are also termed *loss mechanisms*. If the losses occur within the string they are designated **internal losses**. In engineering mechanics, loss coefficients are defined as the *imaginary* part of the complex spring impedance (or admittance), which is in marked contrast to electrical engineering, where *real* loss resistance is assigned, for instance to an inductance. Both paths will lead up the mountain because in both cases, orthogonality is ensured.

In machinery acoustics and materials engineering, internal losses are commonly described using the **loss factor** d, with d interconnecting the imaginary part E_2 and the real part E_1 of the complex Young’s modulus $\underline{E}$: $\underline{E} = E_1 + j \cdot E_2$, $d = E_2 / E_1$. However, it is very difficult to find reliable statements concerning d. This may be due to the fact that the split of $\underline{E}$ into merely two components is just a very simple model, but also due to the fact that e.g. steel appears in different types, not all of which can be assigned the same loss factor. The loss factor and the dissipation model based on it are therefore adequate as a first approximation only. Fleischer [2000] sets d = 0.001[§], with the cautionary remark "tentatively estimated", and a few years later reduces this value to 0.0004 [Fleischer 2006]. Lieber[♣] specifies d = 0.00017, Kollmann[♥] d = 0.0001, and Cremer/Heckl [11] offer $0.2 - 3 \cdot 10^{-4}$.

§ Fleischer designates the loss factor with η, as usual in the older literature.
♣ Lieber, E.: Vibration of stretched strings, acta acustica 1996 Suppl. Vol. 82, p.187.
♥ Kollmann F. G.: Maschinenakustik, Springer 1993.

Cuesta/Valette♣ extend the above-mentioned formula of the decay coefficient by another two terms, thereby also taking into account dislocation processes in the crystalline structure as well as heat conduction (stretching has a cooling effect, compression a warming effect):

$$D_1 = d; \qquad D_3 = \frac{\pi^3 \cdot E \cdot \rho \cdot D^2 \cdot d}{4 \cdot \sigma^2}; \qquad \delta(f) = D_0 + D_{1/2} \cdot \sqrt{f} + D_1 + D_3 \cdot f^3$$

Herein E stands for Young´s modulus (modulus of elasticity) and σ for the normal stress in the string. Using $d = 0.7 \cdot 10^{-4}$ for the decay coefficient in these equations leads to the curve shown on the left in **Fig. 7.64**. Measured were the decay times T_{30} of the partials for a vibrating steel wire (∅ = 0.7 mm) stretched between two bearings on a heavy stone table.

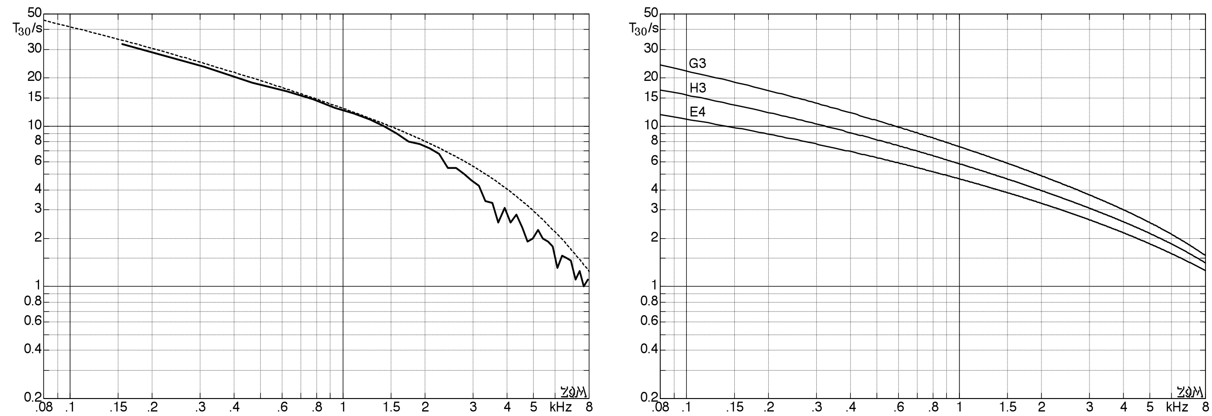

Fig. 7.64: Left: comparison of measurement and model calculation. Right: orientation lines (10/13/16 plain). “G3” = G-string, “H3” = B-string, “E4” = high E-string (E_4).

The decay times calculated with the model may certainly be *longer* than the measured times because besides radiation damping and internal damping there are further damping mechanisms that shorten the decay time (Chapter 7.7.3). It is beyond of the aim of the present work to attribute the individual components of the oscillation damping to material-specific causes. The matter is a complex one, as already acknowledged by a more authoritative source: *The physical processes that cause the internal damping of metals are very complex and have not yet been completely investigated. Moreover, it is not that simple to measure the often very small loss factors, and therefore some of the values found in the literature do not actually describe the losses within the examined material, but rather tell us about losses within the measurement equipment, or about losses due to sound radiation [11]*. Therefore, very pragmatically, **lines of orientation** (Fig. 7.64, right-hand section) are given in the following. These lines provide a basis to classify and assess decay times measured with guitars. As a working hypothesis, we assume that the decay behavior specified in the lines of orientation is primarily determined by radiation-damping and internal damping. As additional findings become available, the curves may be moved further upwards. For the **treble strings** (G-B-E_4) the orientation lines provide a good working basis; for wound **bass strings** (E_2-A-D), however, bigger discrepancies are to be expected: to calculate internal losses, the model of a solid steel cylinder cannot be used. Rather, three damping mechanisms need to be taken into account; damping in the core wire (steel), damping within the winding (nickel or steel), and gap damping at the contact surfaces. All this would be time-variant – of course …

♣ Cuesta C., Valette C.: Evolution temporelle de la vibration des chordes de clavecin, Acustica Vol. 66, 1988.

