7.7 **Absorption of String Oscillations**

When plucked, a string registers an input of a few mW´s of potential energy that will be converted into heat while the string remains oscillating. This **dissipation** is based on several mechanisms, some of which have their origin in the string itself and some in its immediate surroundings. While Chapters 1 and 2 encompassed the un-damped wave propagation, we will now focus on individual damping mechanisms in more detail. According to the predominant opinion in musicians' circles, it is the **body wood** that causes the damping of string oscillations. Highly desirable is long **sustain**, i.e. a long lasting decay process of a plucked string; however, allegedly not all woods will cooperate with the musician as desired. Whether indeed the wood itself represents the main cause of the damping of string oscillations (and therefore also shapes the sound) will be the subject of the following chapters.

7.7.1 Attenuation by radiation

The oscillation energy of the string is reduced, among other factors, by the fact that a frictional resistance must be overcome when moving in air – if the string were to oscillate in a vacuum this resistance would not be present (i.e. nil). This effective resistance can be seen as the real part of the complex **radiation impedance** – its imaginary part, a tiny mass, may be ignored. The real part dampens the string oscillation; it therefore is termed *air damping*. Given a damped oscillation with an exponentially decreasing amplitude, the decay speed can be defined via the **time constant** τ, or its reciprocal, the **decay coefficient** $\delta = 1/\tau$. These terms contain a constant term (D_0) and a frequency-dependent term ($D_{1/2} \cdot \sqrt{f}$). According to Stokes (summary in [1]), the following holds:

$$D_0 = \frac{4 \cdot \rho_{air} \cdot \nu_{air}}{\rho \cdot D^2}; \quad D_{1/2} = \frac{4 \cdot \rho_{air} \cdot \sqrt{\pi \cdot \nu_{air}}}{\rho \cdot D}; \qquad \delta(f) = D_0 + D_{1/2} \cdot \sqrt{f}$$

Herein ρ_{air} and ν_{air} are, respectively, the density and the kinematic viscosity of air; ρ is the density of the string and D is the string diameter. Fletcher/Rossing [1] combine both attenuation terms into one formula, therein specifying the decay time constant of the energy. In order to avoid confusion, only the **decay time**[♣] $T_{30} = 3.45/\delta$ shall be used in the following.

Given 7.9 g /cm^3 (not an unusual value for the density of steel) for solid strings and 7.1 g / cm^3 for wound strings, the frequency-dependencies of the decay time T_{30} of the partials are obtained as shown in **Fig. 7.63**. According to the above formula, T_{30} approximately depends on the reciprocal of the square root of the frequency, and on the reciprocal of the string diameter – sets of heavier strings give a longer sustain (in this respect!). We arrive at a decay time of about 80 s for the fundamental of the E_2-string (0.046"), and of about 6.8 s for the fundamental of the E_4-string (0.009"). These results (from using the model) will in the following serve merely as orientation values; we will not further investigate whether the radiation impedance of the oscillating cylinder should not be modified, after all – given that reflectors (guitar body and fingerboard act as such) are positioned in direct vicinity. But even avoiding an escalating of theory: the almost **unending sustain** that some wonder guitars are imputed with … that is impossible solely as a result of the attenuation by radiation (which colloquially could be called "air damping") alone.

[♣] During T_{30}, the level decreases by 30 dB [Fleischer 2000].

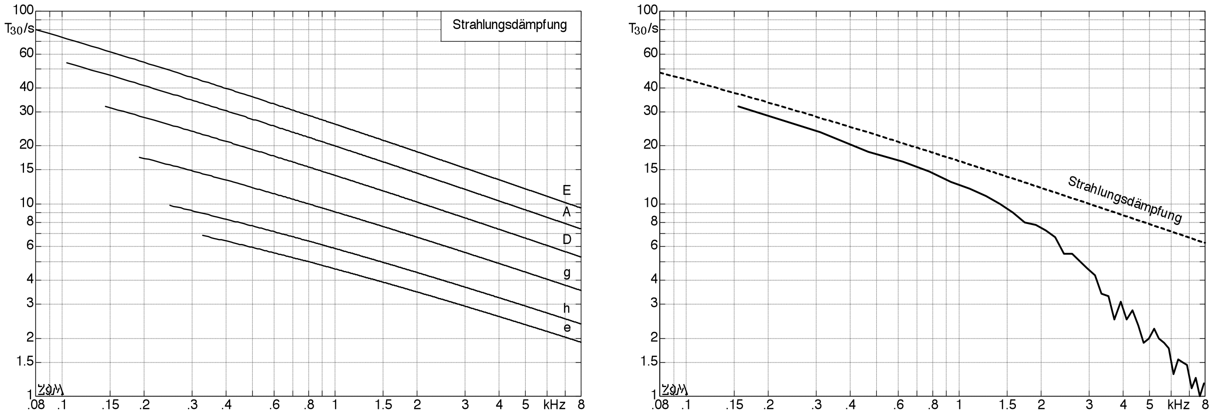

Fig. 7.63: Decay time T30 caused by attenuation by radiation (= air damping) for guitar strings (hybrid, 9/46). The right-hand diagram shows the decay time measured with a steel string (∅ = 0.7 mm) mounted on a stone table as well as the corresponding calculated attenuation by radiation. Only the low-frequency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

