3.3 Magnetic parameters of the strings

When it comes to strings, manufacturers swiftly turn into poets: "*Gleaming nickel squiggles around Swedish hex-steel and guarantees brilliant* (sic!) *tone with never-ending sustain. These are your weapons of choice to deal with any degree of overdrive and get assertive solo-sounds with bite at absolutely unbelievable killer distortion. Hotter'n Hell!*", opines **Gibson sales**. Which one of those not-so-few-anymore and probably not-quite-resting-in-peace deceased 6-string-slingers will have signaled this under-worldly temperature assessment to the ground floor?

It would appear that the required high breaking stress cannot leave a lot of latitude for differences in the magnetic parameters. The solid strings and the core wires of the wound strings differ only little when it comes to magnetics. Even the effects of different winding wires remain unspectacular: measurements with nickel-wound string (Fender 150) and steel-wound strings (Fender 350) show no difference when subjected to the shaker-equipped test bench. The string wound with nickel-coated steel wire yielded a level higher by 1 dB … but half of that effect is due to the somewhat thicker core wire. That does not mean that these strings must sound the same: the mechanical vibration-behavior may well differ – but the magnetic properties are still very similar, even if nickel and steel show different hysteresis curves. The core-characteristics are equal in all three string-types, and together with pre-magnetization- and saturation-effects this leads to similar magnetic parameters.

To measure these magnetic characteristics is not easy but still just about doable with sufficient precision – and with justifiable effort. Since every measurement process includes inadequacies inherent in the system, we will present – in the following paragraphs – several methods of analysis to gather the magnetic data of strings. An extensive presentation of electromagnetic fields follows in Chapter 4.

3.3.1 Measurements with the string-ring

Measuring magnetic parameters is complicated: the magnetic field in not homogenous, and there is a non-linear relationship between the field strength H and the flux density B. A substantial simplification can be obtained if the field-geometry can be shaped in such a way that it can approximately be seen as homogenous. An annulus-shaped (torus-like) examination piece that is completely wound with copper wire on its lateral surface will generate an azimuthal circulatory magnetic field. When described using cylinder coordinates, this field may be seen – in the space within the examination piece – as location-independent … at least as long as DC-current flows though the copper wire. Two challenges need to be mastered in this scenario: manufacturing a ring made of steel as it is used for strings, and the measurement of the magnetic flux density.

For the following measurements, guitar strings were wound to form a ring. Winding a string of a length of 85 cm into 6 turns yields a "string-ring" with a diameter of 4,5 cm. Start and end of the string should join up as much as at all possible to minimize the effects of the unavoidable air gap. The magnetically effective cross-sectional area of this ring is the 6-fold of the cross-sectional area of the individual string – in the case of a 17-mil-string this will give us an overall area of 0,9 mm^2. The ring as a whole is wound – along its 14-cm-long "core" – with a single layer of enameled copper wire (∅ = 0,5 mm); in the present experiment, 239 turns were required.

The azimutal magnetic field strength H in the interior of this annular coil amounts to:

$$H = \frac{N_1 \cdot I}{\pi \cdot D}$$ Field strength in the annular coil

In this formula, N_1 is the number of turns of the primary coil (in our example 239), I is the excitation current, and D represents the diameter of the ring (45,8 mm). Given I = 5 A, we calculate H = 8,3 kA/m – this is a value sufficiently high for string-steel. In order to measure the magnetic flux density, a second winding is wound – as a secondary coil – onto the first one. In our example this has N_2 = 100 turns. Using AC-operation, an AC-voltage is induced into the secondary coil. This voltage depends – among other factors – on the change of the flux density B (law of induction, Chapter 4.10).

The voltage induced into the N_2 windings is $U = N_2 \cdot d\Phi / dt$. The flux Φ is calculated from the product of flux density and surface area. Because the string is – compared to air – the much better conductor for magnetic fields, we need to use (in this example) not the cross-sectional area of the coil but six-fold the cross-sectional area of the string used. For the sake of completeness is should be mentioned that this simplification reaches its limits as the magnetization approaches saturation. **Fig. 3.4** presents measuring results from a 17-mil-string. On the left we see the sinusoidal current (f = 10 Hz) and the impulse-shaped induction voltage. Since this voltage is the time-derivative of the flux density, it may be integrated to obtain B (right-hand graph). Clearly visible is the almost square-shaped B-curve that points to a pronounced saturation.

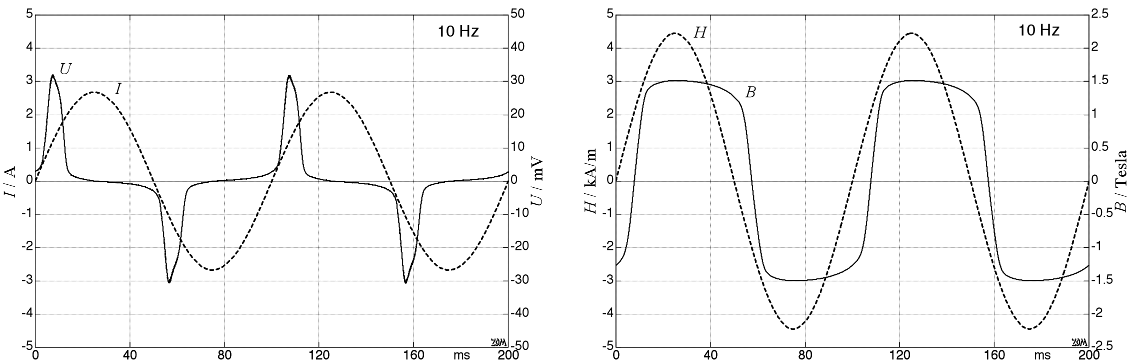

Fig. 3.4: Excitation current I and induction voltage U (left); Fields strength H and flux density B (right).

As we vary the **frequency** of the excitation current, shape and phase of the B-curve change, as well: evidently there are delays in the build-up of the magnetic field that could not be really expected given the low frequencies at work here. The reason for the delays is the **skin effect**: eddy currents weaken the H-field, and only as they decrease, the field can be built up to strength. The H-field reacts to changes in the current in a delayed fashion, and therefore the magnetic flux also reacts with a delay to such current changes (Chapters 3.3.2 and 4.10.4). To minimize the effect, all string-rings used were fashioned using lacquered strings – that way, eddy currents can circle only within the individual string (Figs. 3.5 and 5.9.17). To measure the hysteresis, eddy currents do not need to be determined quantitatively: it is sufficient to decrease the frequency in successive measurements until the differences become smaller than the envisaged measuring error. For this, imprinted voltage is more purposeful than imprinted current.

 Translation by Tilmann Zwicker