4.5 Magnet-Aging

Provided it is properly made and treated, the life of a modern permanent magnet is, to the best of our knowledge, infinite. McCaig [26] will probably not be able to prove this statement – but also does not have to. Modern permanent magnets will last forever. The magnetic field will decrease measurably only during the first hours following the initial magnetization. At the start some of the magnetic domains are in a meta-stable (unstable or weak) state and rather small energy additions may cause a shift into a more stable energy level. As time progresses these exchange effects will become increasingly less important. To avoid misunderstandings: these processes are called after-effects or aging (ageing, relaxation, magnetic creep, magnetic viscosity, time effect) and not demagnetization. Total or partial demagnetization means the forced shift of the working point to smaller flux values as may be induced by load change or the application of an external field. If a nail attracted by a horseshoe magnet is detached, the flux density will decrease and the working point shifts down to the left on the hysteresis curve (= demagnetization curve) in the 2nd quadrant. This is, of course, not what is meant by aging. If, however, a magnet has lost 5% of its flux density after 10 years of storage without being used, then it has aged. Between these boundaries there is, however, a grey area with components from both worlds.

The main causes for aging are changes of load and temperature; other sources do not play any role for pickups. Reversible aging can be compensated by new magnetization and the magnet then appears “like new”. During irreversible aging, however, the internal crystal structure is changed and the former values will not be reached again.

A quantitative description of aging processes needs the application of high-precision measuring equipment and much patience. Prediction is difficult, especially into the future – not different from stock prices. If the flux density has decreased by 0.1% in the first year and the precision of the measuring equipment is of the same order, one cannot make exact predictions for the next 10 years. On the other hand, a measurement covering 10 years is also not without problems, because a great many parameters have to be kept constant during the entire measurement period.

The natural aging without external interference is described by a logarithmic law:

$$B(t) = B_0 \cdot \left(1 - k \cdot \lg(t/\tau)\right), \qquad t \text{ may not be too close to zero}$$

where *B(t)* depicts the time-dependent flux density, k is a material constant (which can also be dependent on geometry and size) and τ is a reference time, e.g. one day after production. For $t = \tau$ one gets $B = B_0$ the flux density after one day. $k = 0.01$ would mean that B has decreased by 3% after 1000 days. A decrease by 4% would, according to this formula, happen only after 10000 days and a further decrease of *B* by 1% (to 5% in total) would happen in 10^5 days – which is approximately 274 years. The actual *k*-values of good Alnico-magnets are still considerably lower, after 10 years typically only 0.1 to 1% is missing. The natural aging thus does not play any role for static magnetic parameters of pickup-magnets♣. Pickup-guru Bill Lawrence is of the opinion that Alnico-5 decreases <5% in 100 years [Billlawrence.com].

♣ Effects on the permeability will be discussed in chapter 4.10.

Temperature changes will result in reversible as well as irreversible changes of flux and field strength. The reversible changes of approx. ± 0.5% are negligible for typical temperature changes. Irreversible changes will occur only beyond +500°C. Some authors, however, quote this limit to be +200°C; every guitarist has to decide whether he considers this as critical.

Load changes in the magnetic circuit (chapter 4.6) and external magnetic fields may, however, lead to dramatic changes. Since the hysteresis loop has two branches, which can only be run through in different directions, successive changes of the field strength $-\Delta H$ and $+\Delta H$ will not lead back to the original working point (**Fig. 4.13**). If, for example, the magnet is removed from a speaker and afterwards built back in again, the flux density and subsequently the efficiency will be reduced from that time on. For pickups, however, a considerable load change (a disconnection of the magnetic circuit) is practically not possible because of the large air gaps involved. They are exposed only to minor load changes by the location and direction dependent magnetic field of the earth (approx. 0.5 Oe = 40 A/m) on one side and by the vibrating string on the other side. Both effects will change the flux density by less than 1‰ so, practically, not at all. In contrast, the magnetic field changes in electric motors are much stronger – and do not lose their magnetization, either, do they? Magnets used in this way are certainly **stabilized**, though, i.e. they are artificially aged. This procedure should actually be applied to every permanent magnet.

During **stabilization** the freshly magnetized permanent magnet will be exposed several times to a field and/or temperature change with absolute values slightly higher than the future specifications. Usually between 10 and 20 load cycles are sufficient. The magnet will loose flux density (e.g. 1 – 5 %), but will become less susceptible to external load changes. After stabilizing, the reversible permeability (and also the pickup inductance) may slightly increase; these details will be revisited in magneto-dynamics (chapter 4.10). If one considers small changes in the lower per cent region, a very fundamental consideration may not be overlooked: the magnetic parameters may vary considerably more due to the production procedures. A scatter of ± 10% is not the exception but the rule.

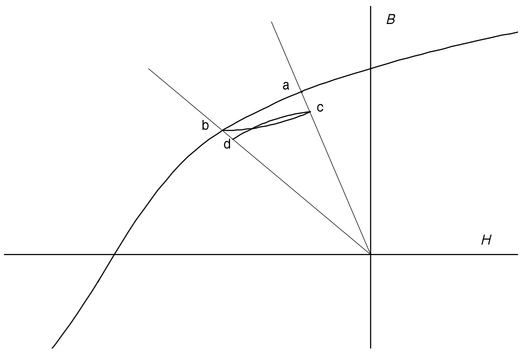

Fig. 4.13: Hysteresis-curve.
Decreasing field strength from point **a** to **b**, and subsequently increasing to **c**, will yield a smaller flux density, i.e. **a** is not identical to **c**. An additional change in field strength will not lead to **b**, but rather to point **d**. After several cycles, however, a lancet-shaped equilibrium state will be reached that will be located slightly below the **d-c** curve. (cf. also Fig. 4.6). The two straight lines represent curves of equal load (Chapter 4.6).

From guitar-literature: a) *"Fender-type pickups will noticeably loose magnetic power after 2 years, Gibson-type ones after 3 years"*. This is physically not justified.

b) *"The magnetizing values of Alnico-2 are matching that of aged Alnico-5 pretty much"*. The forced aging thus would have led to an extreme demagnetization, refer to Fig. 4.11.

c) *"As time goes on, older magnets lose some of their power. The less power the magnets have, the better the strings can vibrate. So maybe after 30 years, the magnets are at their 'ideal' power, thus producing 'ideal' tone."* Guitar collectors beware: Throw away your Les-Pauls and Nocasters from the fifties now – all mag-power lost!

Storage and handling of magnets needs special expertise. If one recognizes in photos, in a professional journal, how the pickup guru has a handful of magnets laying in the drawer, one hopes, of course, that these are non-magnetized blanks, which will be instantly magnetized (behind the kitchen table also shown?) in a super-strong field. Since, if these were bar magnets which are stuck together in a jumble and are mixed up daily, one cannot seriously consider long-term stability and aging (cf. **Fig 4.14**)

Permanent magnets keep their polarization over a long time, but they are not indestructible. Extreme temperatures and force or field impacts may weaken the magnetic field permanently. One should not be worried that a magnet will become weaker when it only falls on a tabletop but, rather, one should be careful with other ferromagnetic materials and other magnets in its vicinity. The working point of an unloaded (open) magnet is located in the second quadrant: negative field strength and positive flux density. If the working point is, however, pushed beneath the "knee", the kink of the hysteresis-curve, the original working point will not be restored again after detachment of the other magnet. McCaig [26] reports on drop impact tests where an Alcomax-III-Magnet has hit a hard wooden floor from a height of 1 m; the measured change was much less than production variation (-0.5 %). In contrast, the magnetic stray field of a second magnet can result in complete demagnetization (-100%).

The following advices may be helpful for the handling of magnets:

- Magnetized permanent magnets should only be shipped with a yoke (keeper). Cautiously remove the keeper before using.
- Do not press magnets with the same poles to each other.
- If attracting parts need to be separated, do not slide them but rather pull them apart.
- The wall of a cylinder magnet should not come into contact with ferromagnetics.
- SmCo- and NFe-magnets may shatter if they collide.
- The attracting forces of strong magnets may possibly be unexpectedly high, resulting in crush injuries.

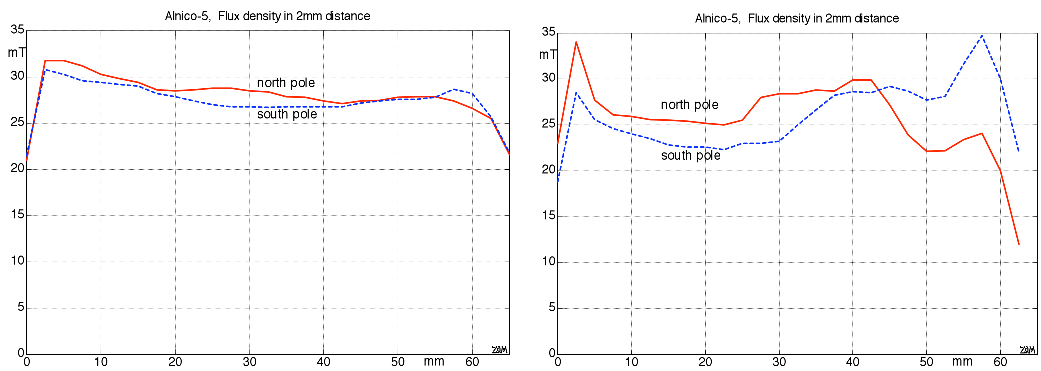

Fig. 4.14: Magnetic flux density measured at a distance of d=2mm along the long side of two Humbucker bar-magnets from two different manufacturers. The operating point of the Humbucker-bar-magnets is at a rather disadvantageous position and need to be handled with care.