The MAC-Guitar

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For decades, pickup-manufacturers and -dealers have instilled in us guitar players that every magnet-material has its own sound: *if ya ain't happy with the 70's-sound of yer Strat, grab this luscious sixties-sound-pickup-set; it sets you back a mere $ 550.-*. Or another one for a cool grand, sporting allegedly resistance-free silver wire. These stupefying advertising shenanigans downright ask for a listening experiment … and so it came to pass that a special **magnet-change-guitar** was built in Regensburg, Germany. It could just as well be called "magnet-comparison-guitar", or "test guitars for investigating the transfer behavior of different magnetic alloys" … or simply "MAC-guitar".

Fig. 1: The MAC-guitar with its fast-change single-coil pickup arrangement.

A Harley-Benton kit bought for € 85.- formed the starting point. Fast delivery, contents complete – great! O.k., a few bolt holes didn't line up exactly and had to be newly drilled, but that's no big deal. The neck feels really good and sits tightly in its body cutout – not always a given, that, for such el-cheapo guitars. **The action, however** (**Fig. 2**)… about a mile off the neck. Dear manufacturer: this construct is supposedly targeting beginners that are not exclusively planning to play slide. They will quickly loose all motivation if they have to learn the trade suffering from action unacceptably high just to avoid excessive fret-buzz. No, that ain't good enough for a beginner. And neither for listening experiments. Off to the local luthier, then, for a fret-dressing. That doubled the price and caused the expert to frown: never had he had to file down **frets so soft**. They will be soon worn down, he says. Implying that if you acquire such a lowest-price-product, you should rather plan for an additional € 350.- to get the frets replaced. Not purposeful? Then go for quality right away. For our listening experiments, however, the endurance of the frets is – in any case – of no concern.

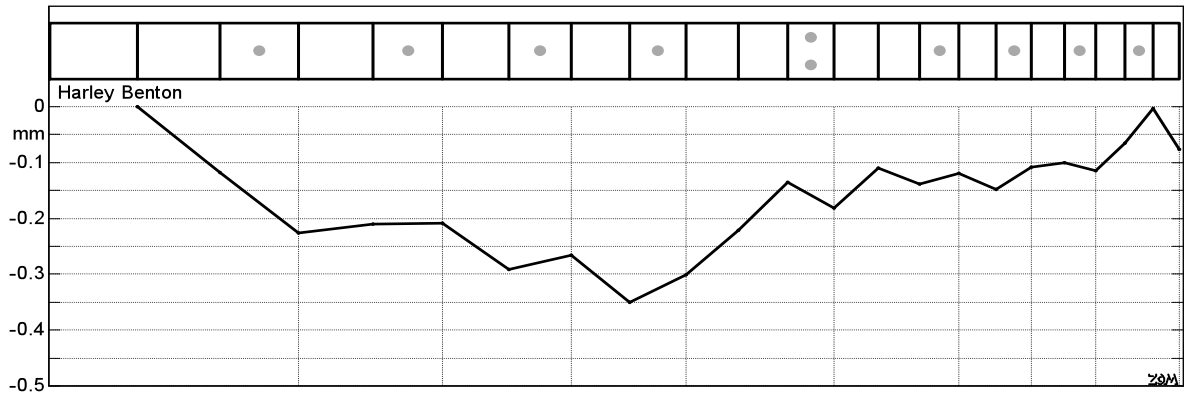

Fig. 2: Harley Benton: fret heights referenced to the fist and second-last fret (prior to the dressing of the frets).

It is the purpose of the guitar to demonstrate in a listening experiment the influence of different pickup magnets on the sound. For this, a **turntable** was installed onto which 4 pickups of equal build are mounted. Three of these are fitted with Alnico-magnets (Alnico-2, Alnico-3, Alnico-5). Six countersunk screws (M3x10) are placed within the fourth coil, and a ceramic bar magnet is positioned below it. **Countersunk screws** are unusual; slugs made of steel would be typical for the genre. However, steel slugs would result in a substantially larger inductance – which also would make for an interesting comparison, but a different one, after all. The screws acquired at the hardware store proved to be suitable: the inductance was increased only little compared to the Alnicos. The four coils of the pickups are all connected in series but each shorted via a magnet-switch that only opens as the pickup is vertically positioned under the strings. This ensures that only one coil is active at any time. It would have been an alternative to mount the pickups on a drum (with its axis perpendicularly to the strings). This would have enabled us to compare single coils, as well – but the magnetic fields would have been not as well separated as in the turntable-version.

To conduct a listening experiment is not as trivial as it seems. **Criterion #1**: the break between the test sounds to be compared has to be short. Much too much time passes if a pickup needs to be first taken out of a guitar, and then another one is installed. The test person to compare the sounds will have forgotten the previous sound by then. With this guitar, that is not a problem: just "turn the table" and play on. **Criterion #2**: the test sounds must not be too long. Comparison tests on the world-wide-web often give the impression that the main purpose the experiment-conducting guitarist is to show off his fingerwork. The latter may certainly be genius but it will only distract from the essential: the comparison of two products. Ernst Pöppel (professor at the Ludwig-Maximilians-University in Munich) has shown as early as in the 1960's that only events of a duration of no longer than 3 seconds can be perceived as a contiguous event. Thus: don't shred for minutes but compare short sequences. **Criterion #3**: achieve reproducibility. This is the difficult part, because nobody can do it with sufficient precision. Put differently: the experiment will only work if the differences in the sound are big enough (e.g. if bridge- and neck-pickups are compared). If differences of only a few dB are to be detected (as is the case here), the guitarist would have to be able to repeat playing with an accuracy of a tenth of a dB. Not even a true pro is able to do that.

The differences between the magnets are small, as measurements using inductive excitation show (**Fig. 3**). It is not about the loudness yet (we'll deal with that later) but only about the spectral differences in sound; this is why all transfer curves are referenced to 0 dB. The figure shows almost identical curves for Alnico-2 and Alnico-3; for Alnico-5 the inductance is slightly smaller (due to the smaller permeability). The screws-&-ceramic-magnet variant (red) results in a slightly higher inductance but also in a lower Q-factor (due to eddy currents within the screws).

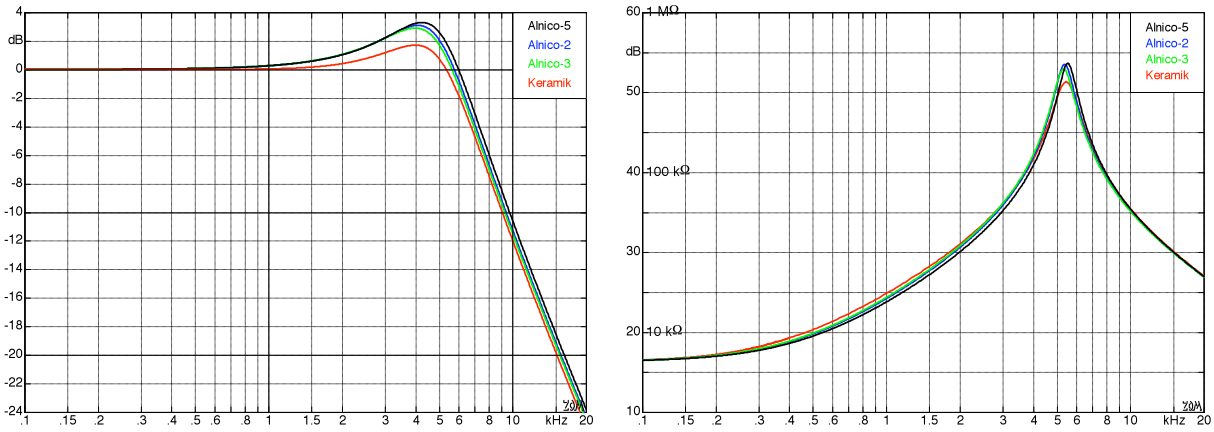

Fig. 3: Frequency responses of transmission and impedance of the four pickups in the guitar seen in Fig. 1. "Keramik" = ceramic

To show such small differences in a listening experiment, the guitarist would have to repeat his playing with an accuracy of 10th's of a dB (as already mentioned). Nobody can do that. If the guitarist knows which pickup (i.e. which magnet) is switched on at any given time, there is danger of "advance obedience": Alnico-5 has to give a more brilliant sound (the ads say so), and so the fingers will pick "more brilliantly", too. With blind-tests, such influences can be excluded; statistical fluctuations in the picking remain, though. Precursory listening experiments showed that they did not allow for any reliably conclusions. In order to curtail these problems, the guitar was not played by a guitarist, but the string excitation was taken care of by a **pendulum (see appendix)**. The guitar was hung from its rear strap-pin and the pendulum struck the string next to the bridge-saddle with good reproducibility. **Fig. 4** depicts the result: per pickup we see a third-octave spectrum averaged over 40 ms. At low frequencies the curves are very similar; above 1 kHz, there is a tiny treble increase for the Alnico-5 magnets (black), while we see a slight treble loss for the screws-&-ceramic-magnet variant (red). It is not possible to distinguish between Alnico-2 and Alnico-3.

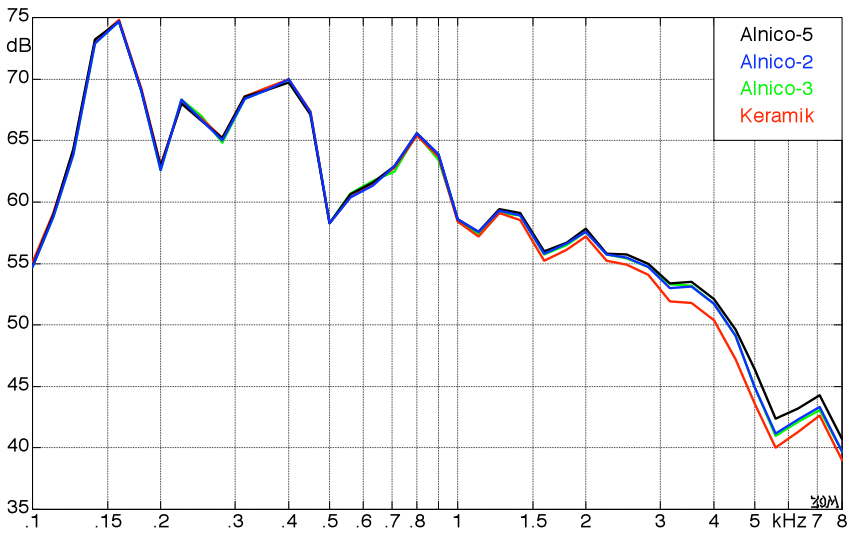

Fig. 4: Spectra averaged over 40 ms (analysis of main and secondary third octave band); "Keramik" = ceramic bar magnet + M3 screws.

The curves in Fig. 4 are scaled such that they correspond at low frequencies; thus they show only the spectral differences but not the level differences that were also present. In this respect, Alnico-2 and Alnico-3 are identical; Alnico-5 is louder by 3 dB, and ceramic+M3 is softer by 0.8 dB.

Alnico-2 and Alnico-3 correspond spectrally as well as with respect to level – which raises the question whether they are in fact different magnet-alloys. Couldn't it be that the dealer always reaches into the same box? No, not in this case. Both the inductance measurement and the DC-field-measurement done with a precision Tesla-meter show tiny but significant differences. In the inductance, for example:

Coil w/out magnets = 1.70 H, Alnico-5 = 2.17 H, Alnico-2 = 2.30 H, Alnico-3 = 2.36 H,
w/ M3-screws + ceramic magnet = 2.60 H (compare to Figs. 3 and 5).

For a supplementary measurement, a further coil (of identical build) was fitted with 6 typical **slugs** (5x17.5 mm). Inductance and eddy-current damping are now clearly higher, and the inductance is strongly dependent on frequency (**Fig. 5**).

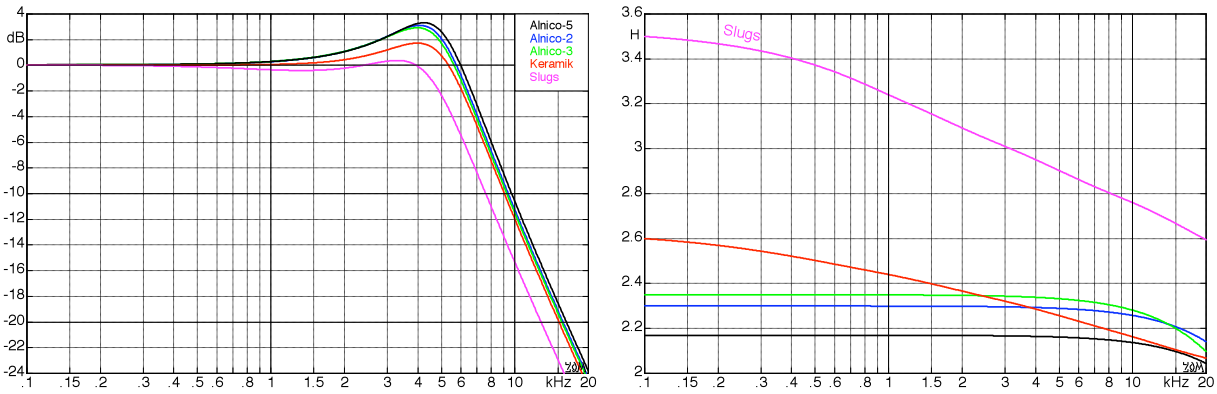

Fig. 5: Frequency responses of transmission, referenced to low frequencies levels; load = 500 pF // 110 kΩ.
"Keramik" = ceramic w/bar-magnet and 6 M3-screws; Slugs = bar-magnet and 6 slugs 5x17.5 mm.
The right graph shows the dependency of the respective inductance on frequency.

The result of this investigation is clear: Alnico-2 and Alnico-3 can be distinguished only by measurement; pickups fitted with them sound entirely the same in the listening experiment. Alnico-5 is slightly louder; the minimal treble increase is not unambiguously perceivable. Pickups with a bar magnet positioned underneath the coil and with field-guiding ferromagnetics (screws, slugs, etc) show – with customary build – a lower Q-factor of the resonance and a larger inductance (given identical coil data) … i.e. audibly weaker treble. Not that this would have to be a general disadvantage: some seek a brilliant sound, others prefer more mid-range – that 's all a matter of taste.

However, the present results must not be misunderstood in such a way that all pickups would have to sound the same. No, the differences can be very marked, even if we limit ourselves only to Stratocaster-type pickups. With the number of turns in the coils, the manufacturers have access to a parameter that can very easily be varied: the more turns, the louder and the less trebly the sound of the pickup gets. Moreover, the kind of winding has an influence: in contrast to a "wild" crisscross winding, a precise winding in layers results in a somewhat smaller volume and thus in a slightly smaller inductance (given the same number of turns). If the wire is not directly wound onto the magnets (as it was the case for early Fender pickups) but onto a coil former (bobbin), again the inductance is increased a bit (given equal turns number). Using heavier (or more heavily lacquered) wire will give a larger volume of the coil and thus a larger inductance. In the end, the transfer function of an Alnico-fitted pickup will always have the characteristic of a second-order low-pass – with the three parameters of resonance frequency, resonance Q-factor, and basic transfer-factor.

These parameters can very easily be changed via the winding data but the guitarist him/herself has no direct access to this – winding wire on or off the coil rarely being an option. There are, however, two other parameters that the sound-determining resonance frequency is dependent on: the inductance, and the load capacity. The latter is given by the cable capacitance to begin with, but it can easily be increased by bringing in additional capacitors (C-Switch or Timbre-Plug®). In **Fig. 6**, two alternative frequency responses are depicted; they have been achieved by changing the RC-load. A resistor and a capacitor will cost merely a few cents which is in any case much more reasonable than a pickup-swap. Also, do note that you don't need to "invest" in an oil-paper- or otherwise-voodoo'd-capacitor. Any regularly working cap will do.

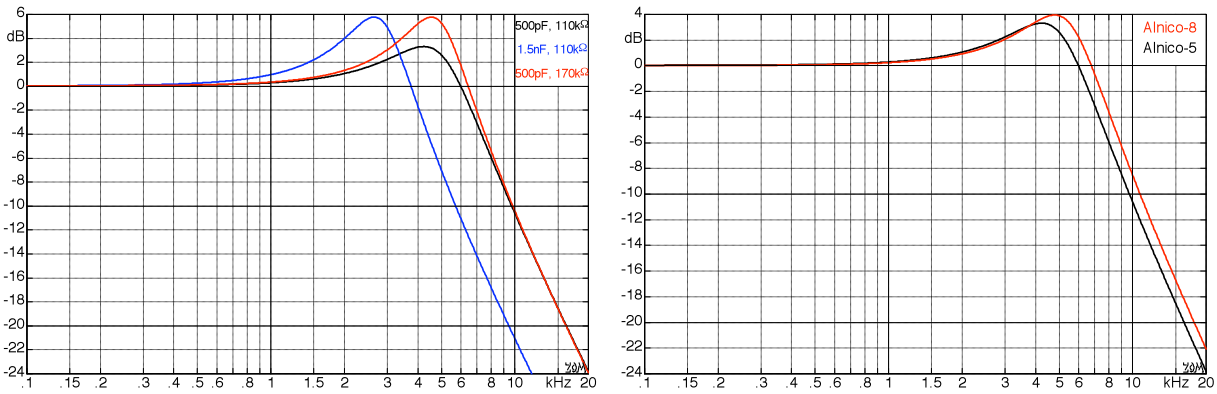

Fig. 6: Frequency responses achievable via different RC-load; (left). Alnico-8 vs. Alnico-5 (right).

In closing, let us also commemorate a few other magnet alloys: **Alnico-4** and **Alnico-6** are very close to Alnico-5 so that a swap will not bring any kind of improvement. **Alnico-8** generates a stronger magnetic field; the resonance frequency will be pushed to higher values due to the smaller inductance, though. This means that the pickup will sound a little bit more brilliant (all other data being kept the same) – see **Fig. 6** (right-hand graph). The stronger magnetic field will, on the other hand, exert a stronger string pull that could lead to beating and chorus-like effects. If one would see the treble gain shown on the right in Fig. 6 as a must, it would also be conceivable to just shorten the cable. Reducing its length from 6 m to 5 m would have a similar effect. Most important, though, after you cut the cable: believe … make sure you DO BELIEVE.

Further literature:

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Appendix

The pendulum mentioned above and used to pluck the string of the MAC-guitar in a reproducible manner is shown in Fig. A1. Please note that the photos shown were not taken during the measurements on the MAC-guitar discussed above but during an earlier experiment that involved the Ovation guitar depicted.

Fig. A1: Pendulum and setup used for exciting the string vibration in a reproducible manner.