11.7 Alnico vs. ceramic magnets

Alnico! Guitar players feel that this word connects them to the innermost circle of magic. Pickups? Only those fitted with Alnico. Loudspeakers? Same! For ceramic magnets „don't sound right" … sometime, somewhere, an enlightened shaman has expressed this, and his disciples keep repeating it all over the world. The **Celestion Blue**, "*the world's first dedicated guitar loudspeaker"*, sported – of course! – an Alnico-magnet. As the manufacturer that produces "*the finest guitar loudspeakers that money can buy*", you owe that much to yourself. Give me Alnico or give me death! However, as we take off the rose-colored glasses of the ad-writer, things become less euphemistic: Alnico-magnets were the industry-standard to generate strong magnetic fields. Carbon-steel magnets were produced until 1910 [21], from 1917 there were cobalt-steel magnets, and from the mid-1930's we see magnetic alloys that contain, besides steel, also aluminum (Al), nickel (Ni) and cobalt (Co): AlNiCo-magnets. They appear in many compositions designated with numbers and letters, and even according to prescription, if more precision is required: 8% Al, 14% Ni, 24% Co, 3% Cu, the rest Fe. However, the effect of a magnet is not only the result of the formula – it's the crystalline structure that does it. So if the label says Alnico-5 on two magnets, the impact may still be different. For this reason, there are subgroups such as e.g. Alnico 5-A, or 5-B, or 5-C, 5-7, 5-BDG, 5-ABDG, or whatever their designation may be. To trust the conjecture that there would be a magnet-material named Alnico-5 that generates that wonderful "vintage sound" – that's believing in a fairytale. In fact, there is a multitude of Alnico-5 materials featuring rather different characteristics. We must also not forget that, because of competition amongst manufacturers, we also have Ticonal, Nialco, and Coalnimax. All these materials have a very high remanent flux density of between 1.2 – 1.35 T, and therefore are of excellent suitability for loudspeakers. However, as a side effect of WW II, supply bottlenecks and restrictions on "metals needed for the war effort" with corresponding cost-explosions happened, and so the manufacturers were very happy that low-cost **ceramic magnets** became available as replacements. Guitarists were less happy, because "ceramic does not have the sound of Alnico". Well then, what makes ceramic magnets so distinct over their ceramic imitators?

Assuming the same volume, Alnico-magnets are stronger than ceramic magnets. That is no knock-out criterion, though, because it only pushes up the weight of ceramic-magnet loudspeakers. The flux density in the air-gap is not limited by the magnet (that could be enlarged almost at will) but by the saturation of the field-guiding pole-plates. Considering that, for operation in the optimum operating point, Alnico magnets need to be oblong while ceramic magnets need to be disc-shaped, both materials can serve equally well to reach similarly high flux densities (and flux). Hearsay has it, however, that, as the material became warm during operation of the first speakers fitted with ceramic magnets, the flux density dropped. Indeed, the flux density decreases with almost 0.2% per °C, and depending on the material, 100 °C are not out of the question when pushing the speaker. For voice-coil carriers made of paper, this was kind of a maximum allowable temperature, anyway. However, as high-temperature-resistant materials (Nomex, Kapton, glass fibre) were introduced the maximum temperature for the coil rose to above 250 °C, and at that point it is conceivable that some ceramic magnets had problems. Corresponding difficulties have been largely overcome by now, and industry offers ceramic magnets that tolerate loudspeaker-typical temperatures. Also, the heat generated in the voice-coil does not directly flow fully into the magnet material, and the magnet does not become as hot as the voice-coil. And incidentally, the main allegation towards the ceramic-faction is not that it's weak-kneed but that there's a sound-deficit, somehow, kinda. Alnico has that "vintage" sound, and thus sounds good. Vintage, that's more treble, or (depending on the source) less treble; either way: simply better.

Eminence, *the world's largest loudspeaker manufacturing company, with the finest voice coils in the industry*, explains the Alnico-sound as: *"warm, bluesy tone"*. **Jensen**, on the other hand, *the inventor of the loudspeaker*, sees *"their sparkling trebles"* as the Alnico-characteristic. **JBL**, *world's leading loudspeaker manufacturer*, defines Alnico via "*it's low distortion performance*", **Jensen** does so via *"their dirty midrange"*. Everybody can find his/her own thing with Alnico.

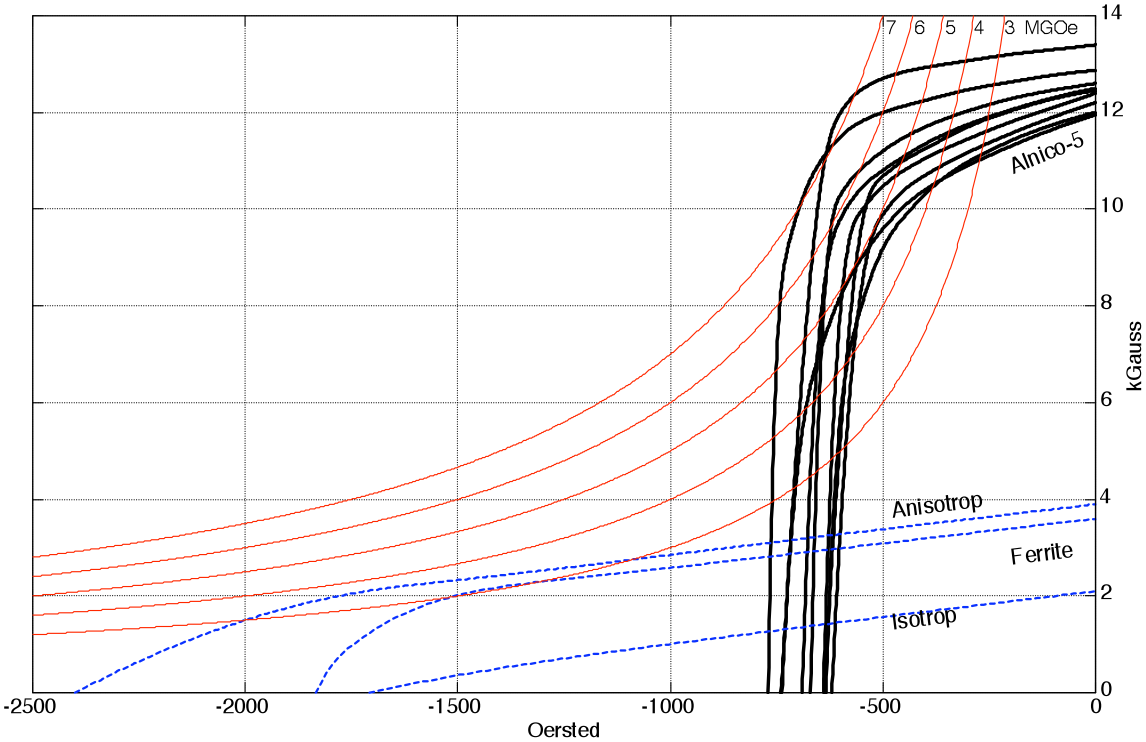

Fig. 11.75: *B/H*-characteristics of various Alnico-5 magnets [22, 23]. 1Oe = 80A/m, 10kG = 1T.

In **Fig. 11.75** we see hysteresis curves of various Anico-5 magnets in comparison to three ceramic magnets. The remanent flux density of regular Alnico-5 magnets is just short of four times that of anisotropic ceramic magnets – conversely, the coercitive field strength of the latter is 3 times larger that that of the Alnico-5 magnets. Again, just to be clear: there is no *one* Alnico-5 magnet nor is there *the* ceramic magnet, and moreover the data on remanence or coercitivity allow merely for approximate conclusions regarding the operating point. A **comparison** can highlight the fundamental differences of the two material groups. A 100-W-lamp (10V/10A) is to be lit up; batteries of 1V/10A and 10V/1A are at our disposal. Whether we connect 10 of the 10-V-batteries in parallel, or 10 of the 1-V-batteries in series does not make any difference to start with – both variants enable the lamp to receive 10V/10A. That does not mean that there are no differences at all anymore: the 10-V-batteries might be a bit more expensive, or larger, or come from a country to which (despite unbelievable successes in sports) economic relations are for the time being uncalled for … anyway, the normative force of facts will call for the 1-V-batteries. The clever businessman will however still try to give the 10-V-batteries a chance, and may for example advertise the source of their energy as "directly from the sun" (sustainability is "in"). He might give 0,5% of the unfortunately 50%-higher sales price back to the estranged country (with the imperative condition that an English-language crèche is financed with the money). This diversification increases the market share, makes for a nicer company-car, and enriches the world by another crèche.

To transfer this scenario to loudspeakers: the volume-specific energy of the magnetic field (the energy density) w corresponds to half the product of flux density B and field strength H. Alnico facilitates higher B-values than ceramic but does not reach the high field strengths of the latter. To compensate, Alnico magnets need to be long and slender, ceramic magnets need to be short and wide. That's just like a series circuit compares to a parallel circuit. Both magnet materials enable the realization of the required specific energy of the magnetic field: ceramic corresponds to the standard, and Alnico sort of corresponds the crèche in the above example.

Why exactly does the ***BH*-product** of a magnetic material have that kind of importance when the definition of the transducer coefficient includes only B but not H? It is true, indeed: the Lorentz-force depends – except for the length of the wire – only on the flux density B. However, in air (as in air gap) the flux density is connected with H via μ_0 such that inevitably a specific H is connected to a correspondingly specific B. The Cu- or Al-winding also located within the air gap does practically not change anything about that – because these materials are not ferromagnetic. The product of the field strength in the air gap and the flux density in the air gap happens to correspond exactly to double the **energy density** w_L of the field within the air gap. With the air-gap volume V_L, the energy in the air gap computes to $W_L = w_L \cdot V_L$. The energy must be made available by the magnet; for the ideal magnetic circuit, this holds: $W_L = w_L \cdot V_L = W_M = w_M \cdot V_M$. Spelled out: magnet-energy = air-gap-energy. Within the magnet, the formula $w_M = 0.5 \cdot B_M \cdot H_M$ holds; consequently for a small volume of the magnet, the BH-product of the magnet needs to be as large as possible. As an **example**: for an air gap of an area of 10 cm^2 and a width of 1 mm, the air gap volume is to 1 cm^3. Given B = 1.5 T, the energy in the air gap is 0.9 J = 0.9 Ws. This value is not directly connected to the sound power to be generated: one may imagine the magnetic field as a kind of catalyst that is necessary but will not be used up. The radiated sound energy is not sourced from the magnetic field but from the electrical energy (fed from the power amplifier). Assuming the BH-product characterizing the magnet to be 45 kJ/m^3 (not untypical for Alnico-5), a volume of the magnet of 40 cm^3 (or a magnet mass of 286 g) results. A ferrite magnet generating only as little as BH_{max} = 22 kJ/m^3 would require 81 cm^3 (or 390 g). This would be the situation for the ideal (i.e. loss-free) magnetic circuit. Alas, this idealization is not even approximately realistic, and so the magnet needs to be bigger: for Alnico 2 – 3 times, for ferrite 3 - 4 times … or still bigger, depending on the individual realization. To achieve comparable air-gap energy, ceramic magnets are therefore larger and heavier than Alnico magnets. Still, any differences in sound or efficiency cannot be substantiated that way.

The energy within the air gap is, however, only a first parameter in the electro-acoustical transducer process. As already shown by Fig. 11.1, the **shape of the magnet** (long/slender vs. short/wide) causes different geometries in the magnetic circuit, and from this shape, two different behaviors may result in dynamic operation (i.e. given current-flow and displacement). It is therefore not sufficient to merely check the static magnitudes in the air-gap – the membrane is to move, after all. Indeed, there is a dynamic magnet parameter showing differences: the so-called **permanent permeability**. In a permanent magnet, it characterizes the B/H-relationship for small shifts in the operating point. For a field-change forced by a current, the operating point does not move along the limit-curve of the hysteresis but within it on a smaller slope. This slope is the permanent permeability, also called reversible permeability. It is about 5 in Alnico-5 and about 1 in ceramic. These data are relative permeabilities, i.e. for *small field changes* the ceramic magnet behaves like air while Alnico is already perceivably ferromagnetic. Globally seen (for large changes in the field), both magnets are of course ferromagnetic, but for differential considerations material-specific differences emerge.

It is, however, insufficient to regard merely a differential magnet-parameter (the permanent permeability) und predict differences in the operational behavior merely based on this. In the respective operating point, not only the slopes of the hysteresis characteristics differ, but the coordinate values, as well. Since, compared to the Alnico magnet, the ceramic magnet features smaller *B* and larger *H*, a kind of transformation needs to be done via an area-reduction: from the wide magnet cross-section to the comparably small air-gap cross-section. This **transformation** will not only adapt *B* and *H* correspondingly, but also the slope of the hysteresis such that the effective permanent permeabilities become closer to each other. Whether they in fact become equal or whether differences still remain, depends on the individual design, and on the all-decisive stray-flux.

This holds for both magnet materials: parameter-variations that may already result from smallish construction-changes are so considerable that is of no purpose to generally speculate about type-specific idiosyncrasies. Rather, **measurements** are to reveal typical differences – if such exist to begin with. One quantity that is easy to measure and that gives indications about differential field changes is the electrical impedance. Its high-frequency increase is determined by the loudspeaker-**inductance**, and thus by the magnetic field. In **Fig. 11.76** we see the frequency responses of the impedances of several 12”-loudspeakers. On the left, only marginal differences show up – although two loudspeakers with different magnets were measured (Celestion “Blue” vs. G12-H). In the right-hand section, however, three Alnico-loudspeakers were analyzed – and specifically here clear differences emerge. Conclusion: there is no special “Alnico-impedance”.

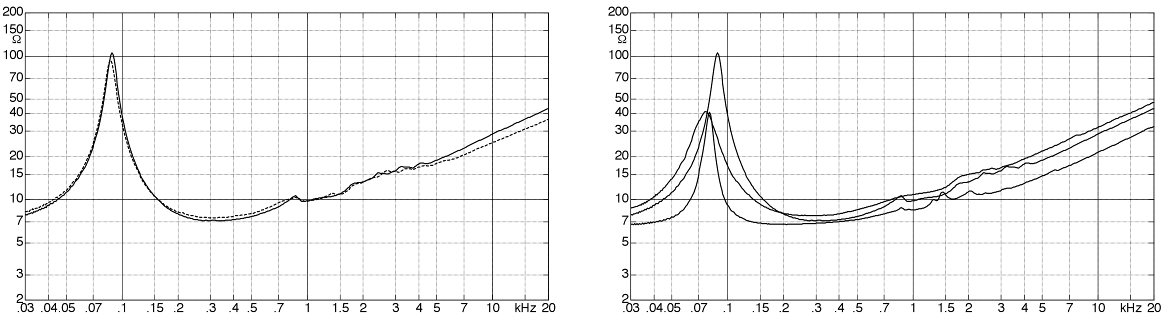

Fig. 11.76: Frequency responses of the impedances of various 12”-loudspeakers (w/out enclosure).
Left: Alnico (——) vs. ceramic (----). Right: 3 different Alnico-speakers (Celestion "Blue", Jensen P12-R, P12-N).

Impedance-measurements will only expose a small-signal characteristic. Loudspeakers will, however, predominantly be operated at large signal levels, with high currents and often close to the power limit. As already shown in Chapter 11.6, non-linear processes step into the foreground here: the voice coil pushes into the fringe-regions of the magnetic field rendering the transducer constant (the force-factor) dependent on the displacement. The membrane-stiffness becomes displacement-dependent, as well, and the inductance shows non-linearity, too. It is certainly possible that the secret of the dearly bought Alnicos lies in the specific non-linearity, and that their **harmonic distortion** shows magnet-typical idiosyncrasies. The magnet should however not be held responsible for any non-linearity of the membrane: that the centering (the spider) becomes progressively stiffer with increasing displacement really has nothing at all to do with the magnetic material. The displacement-dependent inductance, on the other hand, is connected to the magnet, and the signal-dependent transducer constant is, too. Both these non-linearities result from the magnetic field penetrating the voice coil, and because this field is displacement-dependent, the transducer constant becomes signal-dependent. The component of the electrical impedance that stems from the mechanics (that would be everything except the Cu-resistance), consequently becomes non-linear.

A non-linear impedance can be measured by either feeding a sinusoidal current to it from a stiff current source ("imprinting" the current) and measuring the voltage, or by feeding it with a sinusoidal voltage from a stiff-voltage source ("imprinting" the voltage), and measuring the current. The two principles lead to different results because there is no proportionality anymore for non-linear systems. For the following measurements, the voltage was imprinted. Mostly, 10 V were applied, corresponding to a nominal 12.5-W-load for an 8-Ω-speaker. The loudspeakers were not mounted in any enclosure, this leading to larger membrane displacements compared to installation within an enclosure. The harmonic distortion of the loudspeaker current was analyzed, in particular the 2nd- and 3rd- order distortion. It is shown as distortion dampening a_{k2} and a_{k3} (**Fig. 11.77**). 60 dB ≙ 0.1%, 40 dB ≙ 1%, 20 dB ≙ 10%.

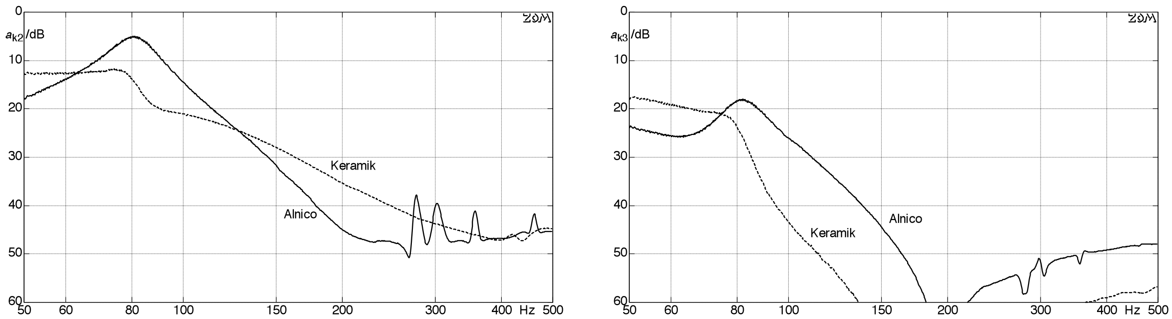

Fig. 11.77: Non-linear distortion of the loudspeaker current for sinusoidal imprinted voltage (10V). Alnico = Celestion "Blue", ceramic ("Keramik") = Celestion G12-H.

In this figure we clearly see significant differences: the 2nd-order harmonic distortion differs by a factor of 3, the 3rd-order distortion even up to a factor of 10! The 2nd-order distortion generally dominates over the 3rd-order distortion, but their frequency dependency differs specifically depending on the loudspeaker. In the range of the main resonance, the Alnico-speaker distorts more than the ceramic-speaker; however, at higher frequencies the differences should be treated with caution. Also, distortion generated by the guitar amplifier – as a rule rather significant – should be considered.

It is only a small step from the measurements shown in Fig. 11.77 to statements such as: **Alnico-loudspeakers distort more than ceramic-loudspeakers**. That is, however, not really entirely correct since from 124 Hz upwards we see the 2nd-order distortion dominating in the ceramic speaker. So, what catchy message should we take home from these measurements? Best would be none – the comparison between two loudspeakers cannot be taken as a significant sample. **Fig. 11.78** offers supplemental analyses: a Jensen C12-N (Alnico) is compared to a Jensen C12-N (ceramic). Now, suddenly, the situation is reversed: the k_2 of the Alnico-speaker is smaller than that of the ceramic speaker.

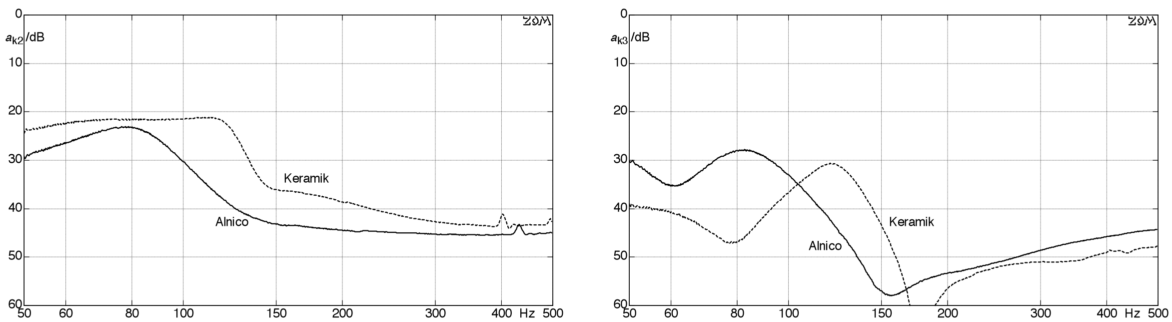

Fig. 11.78: Non-linear distortion of the loudspeaker-current given sinusoidal imprinted voltage (10V). Alnico = Jensen P12-N, ceramic ("Keramik") = Jensen C12-N.

In fact, the two **Jensen-loudspeakers** (Fig. 11.78) represent an ideal pair: both are sourced from the same manufacturer, both have a 12"-diameter, both play in the same power-league: 50 W, 1,5"-voice-coil. Only the material of the magnets is different: ceramic (C12-N) vs. Alnico (P12-N). O.k. – the price is also different … we understand: the expensive cobalt. What some of us do not understand: why do the resonance frequencies of these two speakers (bought at the same time) differ, too? By 56%, after all – specifically 120 Hz (C12-N) vs. 77 Hz (P12-N). Don't start with "the magnet change might retune the resonance" – the mechanics do not require any magnetic field for that. At least the stiffness of the membranes is very different, as a simple push with the fingertip confirms. So, there's not just another magnet included, but the membranes are entirely different, as well! One can imagine the kind of "wisdom" that results if, after comparing these two loudspeakers, musicians post their findings on the internet. Without a doubt, there are type-specific differences in the non-linear behavior of the loudspeakers, but it is not possible to derive any Alnico-specific characteristic from these.

Checking out two **Celestion loudspeakers** may serve as a counter-example to the above comparison: Vintage-30 (ceramic magnet) vs. "Blue" (Alnico-magnet). **Fig. 11.79** indicates the corresponding comparison-analyses. Up to 250 Hz, we in fact recognize merely a slightly different resonance frequency in the k_2, and in the frequency range above the effects of the modes of partial oscillations can be seen. In the k_3, the differences are somewhat larger but by no means classifiable as a characteristic. But now it gets really interesting: in the second row of the figure, two Alnico loudspeakers, specifically two Celestion "Blue" bought at the same time, are compared. The differences between these two speaker-specimen (both Alnico, both of the same construction!) are, as a whole, larger than the differences between the differences found between the Alnico- and the ceramic-speaker shown in the upper row in the figure!

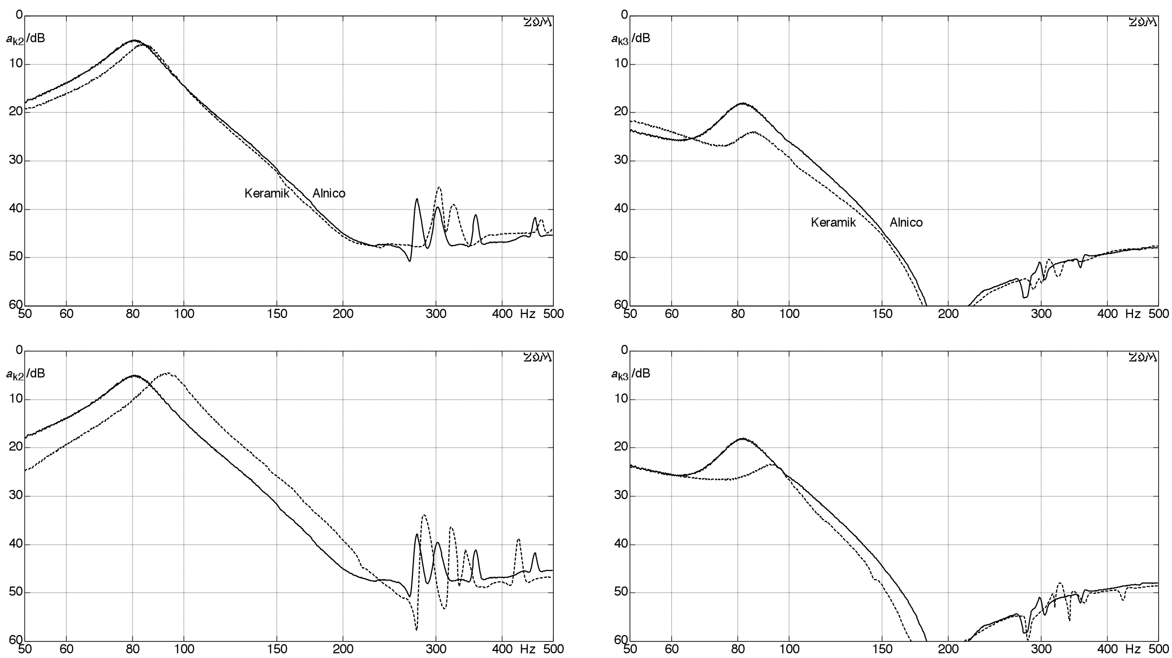

Fig. 11.79: Non-linear distortion of the loudspeaker-current given sinusoidal imprinted voltage (10 V).
Alnico = Celestion "Blue", ceramic ("Keramik") = Celestion Vintage-30.
Lower row: two Celestion "Blue" specimen.

To conclude these measurements, **Fig. 11.80** shows comparisons across 4 Alnico- and 5 ceramic-loudspeakers. Again, the effects of different membrane-suspensions dominate, while an "Alnico-characteristic" is nowhere to be found.

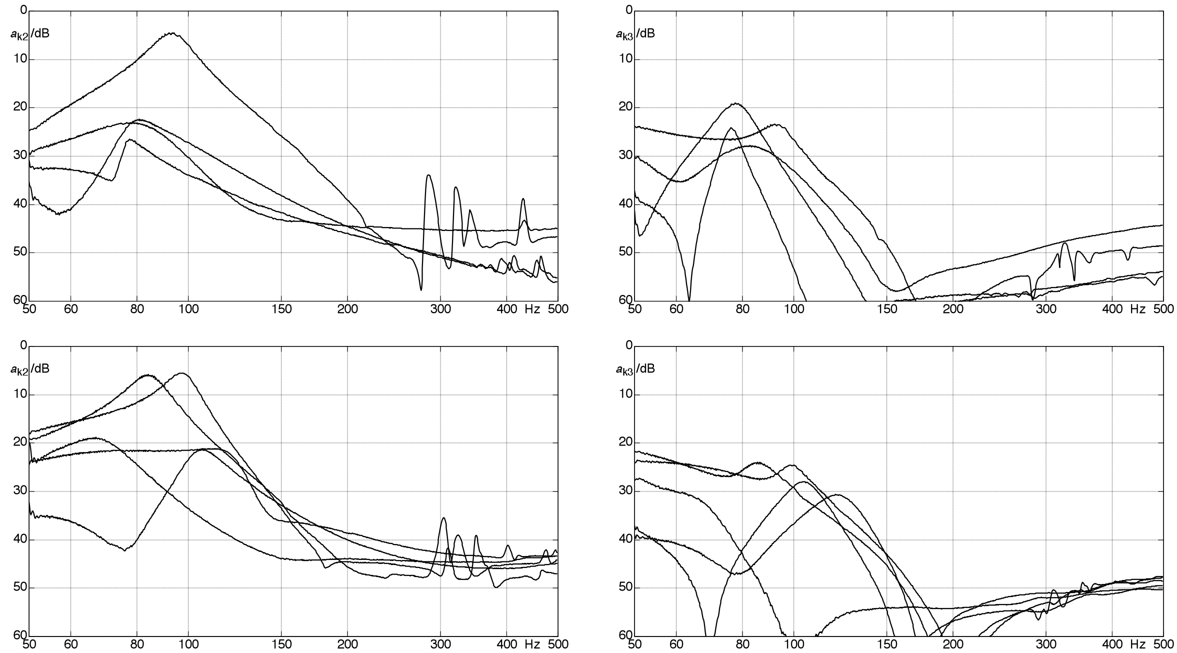

Fig. 11.80: Non-linear distortion of the loudspeaker-current given sinusoidal imprinted voltage (10 V).

After this analysis of the electrical two-pole parameters we of course need to pay tribute to the transmission parameters. After all, the meaning of life for the loudspeaker is not just to offer a load to the amplifier – it is supposed to radiate sound. Still, the trend found in the distortion measurements continues here (**Fig. 11.81**). The differences between Alnico-speakers of the same type are similar to the differences between Alnico-and ceramic-speakers – there is nothing whatsoever to be found that could be interpreted as a magnet-specific sound. That does not mean at all that using Alnico-speakers is pointless. Jensen and Eminence, for example, do not offer an immediate ceramic-alternative to the P12-N and the "Legend 122", respectively. If you want to have the sound of these legends, you will have to buy them – the C-12N and the “Legend 125”, respectively, differ in more than just the magnet. With Celestion, the situation is different: a serious alternative to the Celestion “Blue” stands ready in the form of the Vintage-30, with the latter having four times the power capacity but still costing only one third of the former – or even only one twelfth, if you calculate per watt. However, the flair surrounding “the Blue one” is so attractive that there is no cure for its lure. And so there will always be true-Blue devotees to the brilliant (or soft) and the dirty-distorted (or distortion-free) sound of the Alnicos.

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Fig. 11.81: Differences in SPL between two specimens of the Celestion “Blue”, and between the “Blue” and the Vintage-30. Measured in the AEC; 1W @ 1m; speaker mounted in the enclosure of an AD60-VT.