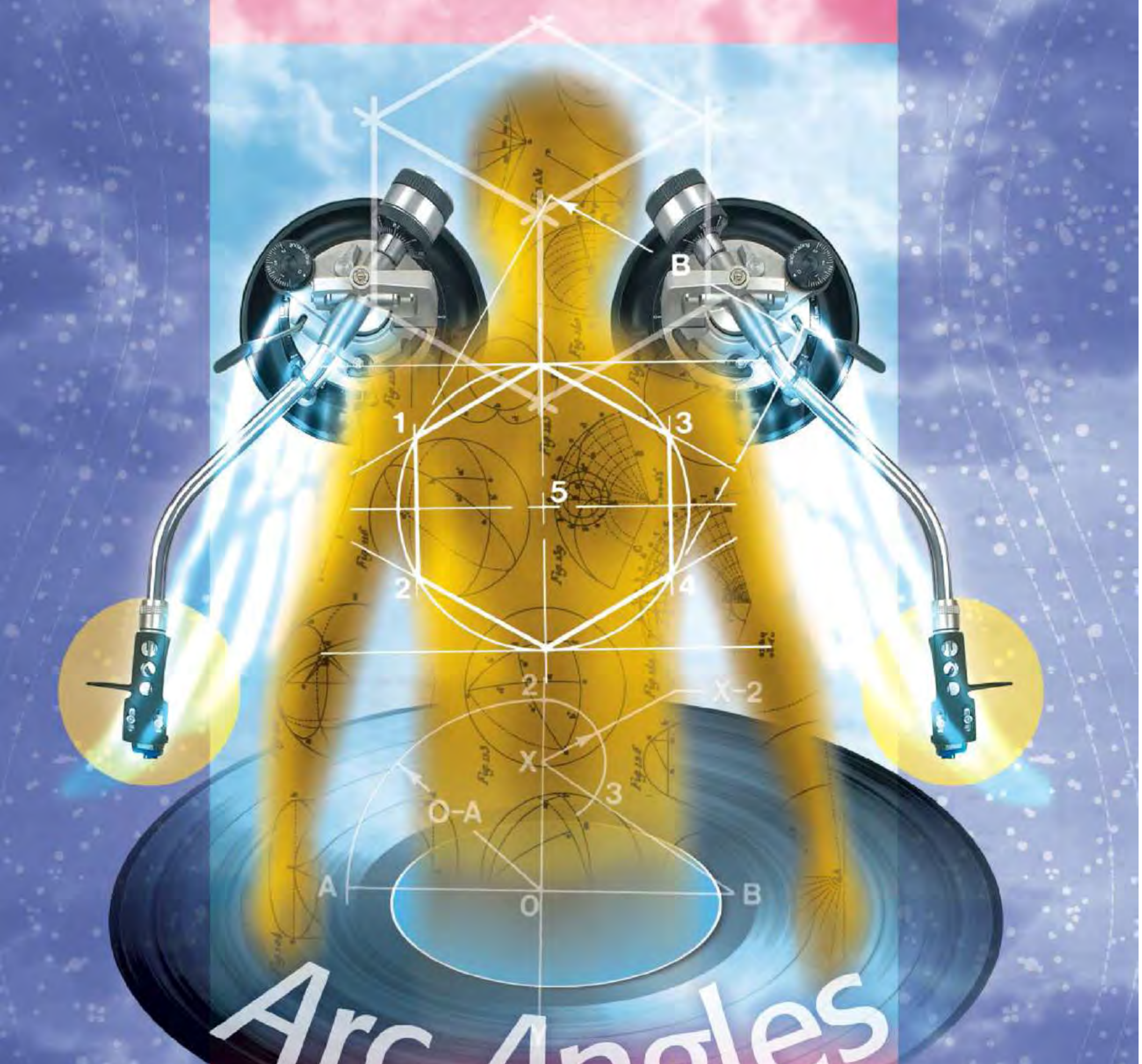

Arc Angles

Keith Howard looks at the thorny problem of optimizing tonearm geometry

As Chester Rice, co-inventor of the moving-coil loudspeaker, once ruefully observed: "The ancients have stolen our inventions." So often, what is painted as new and innovative turns out to be something someone thought of long before. We have a habit of forgetting, and that applies not only to inventions, but to knowledge of other kinds as well.

If you've been reading audio magazines for the past 30 years or more, you may recall that in the late 1970s there was a short-lived furor, first in the US and then in the UK, about forgotten lessons of tonearm/cartridge alignment. It turned out that seminal work on the subject by H.G. Baerwald, published in 1941[1] and refreshed by J.K. Stevenson in 1966,[2] had been disregarded by many pickup-arm designers, presumably because they'd never been acquainted with it. (It has since come to light, princi-

1 H.G. Baerwald, "Analytic Treatment of Tracking Error and Notes on Optimal Pick-Up Design," *Journal of the Society of Motion Picture Engineers*, December 1941.

2 J.K. Stevenson, "Pickup Arm Design," *Wireless World*, May and June 1966.

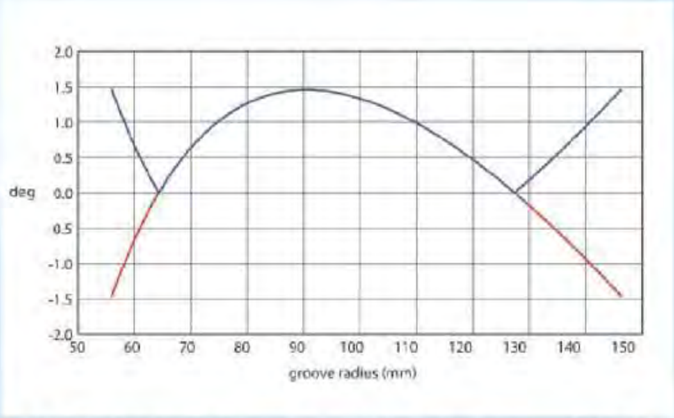

Fig.1 Lateral tracking error versus groove radius for an arm aligned according to Wilson's equations. The red and blue traces are the same except that in the blue trace all negative angles are shown as positive.

pally through the work of Graeme Dennes,[3] that Erik Löfgren first published the optimum alignment equations more generally credited to Baerwald over three years earlier, in 1938. Perhaps because Löfgren's paper was in German and Baerwald's in English, the latter's became the recognized reference. Löfgren's paper has since been translated by Klaus Rampelmann.[4])

At the time this all blew up, LP was thriving, of course. Some would argue that it is beginning to do so again, but either way, we're talking 30 years ago. In the interim, the same process of forgetfulness and obfuscation has inevitably occurred, so that today, once again, despite the recent efforts of Michael Fremer and some fine Web resources,[5] many audiophiles—and perhaps even some new-generation turntable designers—will be unclear about what's involved in optimally aligning a pickup cartridge. Fewer still will know about the history and theory of the subject, and the important ramifications that theory has for the design of pickup arms and their use. If you're interested in the more complete picture, then this introductory article will give you a good grounding, and point you in the direction of further reading.

To do the history part right, we have to go back before Löfgren and Baerwald, and turn our gaze to England in 1924, the second year of publication of *The Gramophone*, cofounded and edited by novelist (later Sir) Compton Mackenzie. The magazine's technical editor was the remarkable Percy Wilson, a larger-than-life character whose mathematical background was used to good effect at the time, not only in modifying the flare of the exponential horn on the more realistic assumption of spherical rather than planar wavefronts, but also by being applied to what, in an article published in the September and October 1924 issues,[6] he termed "needle track alignment."

What was then already understood was that (using modern terminology) because tonearms or pickup arms were pivoted, but cutter heads ran on a linear drive mechanism, angular errors were inherent in record replay—and exactly the same remains true today.[7] The cutting stylus traverses a radius of the disc, so that the lateral groove modulation is nominally at right angles to a tangent to the groove at all times—whereas the replay stylus traverses an arc, so that the modulation is generally read with some angular disparity, which generates distortion.[8] Today we know that angular disparity as *lateral tracking error* (LTE), and the resulting nonlinearity as *lateral tracking error distortion* (LTED).

Wilson calculated what alignment of the replay components would minimize LTE across the disc, basing his figuring on the assumption—wrong, as we will see—that this would also minimize the resulting distortion. To achieve this, he found, the radius of the stylus (needle) arc had to be greater than the distance from the arm pivot to the center of the disc, by a distance that today we term the *overhang*; and the pickup cartridge had to be twisted relative to a line joining stylus to arm pivot by an angle termed the *offset*. This overhang-plus-offset geometry, Wilson's great contribution to arm/cartridge alignment, is still used today, even though his equations for calculating the two parameters have been superseded.

If we assume an arm effective length (that is, the horizontal distance from stylus to arm pivot axis) of 230mm, which is about the 9" of many modern pickup arms, and maximum and minimum modulated groove radii of 146.3 and 56mm (more

Many audiophiles—and perhaps even some new-generation turntable designers—will be unclear about what's involved in optimally aligning a pickup cartridge.

on this later), then Wilson's alignment gives the result shown in fig.1. Actually, this is two graphs superimposed: the red trace, which is partly overlaid by the blue trace, shows LTE *vs* groove radius, and the blue trace the absolute value of LTE *vs* groove radius, which results in a W shape that will become more familiar as we continue. There are two important features to note about this graph. First, the alignment minimizes the maximum LTE by setting it equal at three points across the disc: the innermost modulated groove radius, the outermost modulated groove radius, and a point in between represented by the peak of the curve. (The sign of the LTE is irrelevant; a positive angle gives rise to the same distortion as an equivalent negative angle.) Second, the LTE is zero at two points across the disc termed the *zero tracking error radii*, here 64.3 and 127.4mm.

The latter feature is necessary to achieve the first, but I know from three decades of writing on this subject[9] that it

3 Graeme Dennes, "An Analysis of Six Major Articles on Tonearm Alignment Optimisation," 1983, updated 2009, downloadable from http://downloads.nakedresource.com/download_centre/index.php?Tonearm_Geometry_Analysis_by_Graeme_F_Dennes_1983-2009_February_2009.pdf.

4 Erik Löfgren, "On the Non-Linear Distortion in the Reproduction of Phonograph Records Caused by Angular Deviation of the Pickup Needle," originally published in German in *Akustische Zeitschrift*, November 1938, Vol.3, pp.350–362; downloadable in English translation from http://downloads.nakedresource.com/download_centre/index.php?loefgren_2008.pdf.

5 Such as www.vinylengine.com and www.audioasylum.com/audio/vinyl.

6 Percy Wilson, "Needle Track Alignment," *The Gramophone*, September (pp.129–131) and October (pp.167–169) 1924. Available from *Gramophone*'s online archive, www.gramophone.net/ArchiveExplorer/, these articles can be downloaded, a bit laboriously, as PDFs. Only the September article contains alignment equations.

7 I ignore here radial-tracking (aka linear-tracking or parallel-tracking or tangential-tracking) arms since they remain rarities, and those pivoted arms with headshell-rotation mechanisms—such as that on the Garrard Zero 100 of yesteryear (www.tnt-audio.com/sorgenti/garrarde.html)—because they are rarer still.

8 I was once upbraided by a reader for forgetting, along with everyone else who had ever written about arm/cartridge alignment, that the record groove is a spiral, and therefore its tangent is never truly at a right angle to a radial line drawn from the center of the disc through the stylus. While true, this is irrelevant to the alignment issue, since the aim is not to align the cartridge front-back axis as closely as possible to a true tangent to the groove, but to align it as closely as possible to the front-back axis of the cutting head, which is aligned (nominally, at least) at a right angle to the disc radius. Even if it were relevant, the angular error is tiny. If we assume a groove pitch of 0.135mm, then even at the inner modulated groove radius of an LP, the angular difference between a tangent to the groove spiral and a tangent to a circle of the same radius is just 0.022°. For comparison, the LTE of an optimally aligned 9" arm at this radius is 0.85°; *ie*, almost 40 times greater.

9 A collection of some of the articles I wrote about arm/cartridge alignment for *Hi-Fi Answers* and *Practical Hi-Fi*, beginning in 1978, can be found on my website at www.audiosignal.co.uk/archive.html.

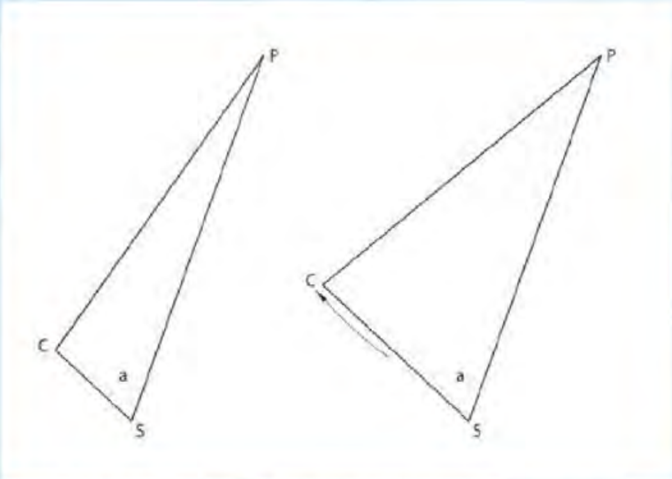

Fig.2 Illustrating why there are two zero-tracking-error radii across the disc with optimal arm-cartridge alignment. Point P represents the arm pivot, point S the stylus, point C the disc centre and angle "a" is 90 degrees minus the cartridge offset angle. Fig.2a (left) represents the inner zero tracking error radius, Fig.2b (right) the outer tracking error radius. See text for further explanation.

puzzles many people. So, using some straightforward geometry, let's clarify how it comes about. Fig.2a shows a triangle representing a pickup arm aligned at the inner of the two zero-tracking-error radii (distance SC). Point S represents the stylus position, point P the arm pivot, and point C the center of the turntable platter. The distance SP is the effective length of the arm and exceeds the distance CP by the overhang: if we use the figures quoted in the last paragraph, then Wilson's equations give this to be 18.56mm. Angle "a" is 90° minus the cartridge offset angle (24.63° from Wilson's equations), and so the line SC is along a radius of the disc and the cartridge front-back axis is at a tangent to the groove. If we now extend the line SC beyond C and rotate PC about P, we find that there is a second triangle (fig.2b) where the same conditions are met, and the tracking error is therefore again zero. Thus there are *two* zero-tracking-error radii, and distance SC now represents the outer of them.

Where Wilson went wrong in his analysis was to assume that the distortion caused by LTE is proportional only to LTE itself. In fact there is another vital parameter, namely linear groove speed (that is, the speed at which the groove passes the stylus), which varies by a factor of about 2.5 from the outermost to innermost modulated groove radius of an LP. LTED, it turns out, is inversely proportional to linear groove speed, and so the same LTE at the innermost modulated groove radius of an LP will result in about 2.5× higher distortion than the same angular error at the outermost modulated groove radius.

As we now know, the first person to realize this and correct Wilson's equations was Erik Löfgren. But in the late 1970s, when headlines about arm geometry began to appear in the audio press, this breakthrough was still accredited to Baerwald, and therein lies a tale. For reasons that puzzle me to this day, Baerwald decided to publish in his paper an approximate equation for optimum overhang that many people subsequently used, assuming it to be sufficiently accurate. In fact, it isn't, as fig.3 illustrates. This time, the graph plots distortion *vs* groove radius (exactly *what* distortion I'll describe shortly), the red trace showing the proper, non-approximated Baerwald alignment, and the blue trace the alignment with Baerwald's approximated overhang. Again, this is for a 230mm arm across the groove dimensions already given.

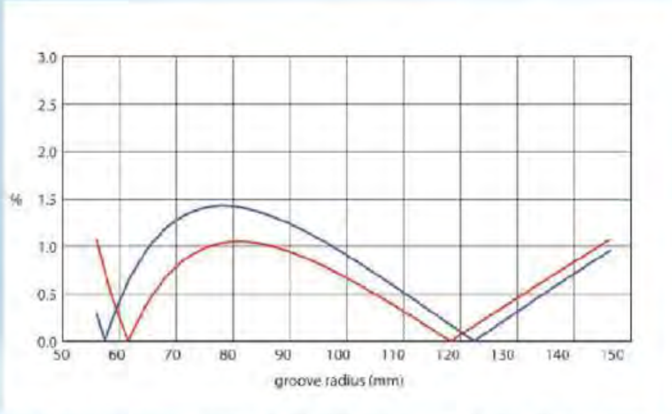

Fig.3 Distortion versus groove radius for an aptimally aligned arm and cartridge according to the Löfgren and Baerwald equations (red trace). Baerwald also published an approximate equation for optimal overhang, which gives rise to the compromised distorion characteristic shown by the blue trace.

The shape of the red trace is reminiscent of that in fig.1, and shares the same key features: there are two zero-tracking-error radii and three equal maxima. What has changed is the positioning of the zero-tracking-error radii, now at 61.6 and 118.4mm, both of which have migrated toward the innermost recorded groove radius in order to "weight" the LTE appropriately across the disc to give the three points of equal maximum distortion. The blue trace is obviously in error, caused by Baerwald's approximate overhang being 15.84mm when the correct figure is 16.43mm.

Is LTED audible, or are we getting our underwear in a bind over nothing here?

Bear this in mind if you read some of the material published on arm alignment in the late 1970s and early 1980s, as some authors quoted overhang figures calculated using the approximate equation. When writing on this subject three decades ago, I took to referring to the "self-consistent" Baerwald alignment to indicate that the non-approximated overhang was used. Now I know that it deserved to be called the Löfgren alignment all along, or "Löfgren A," as Dennes refers to it—Löfgren also offered a second option, more of which later.

Now we know what the distortion characteristic of an "optimally aligned" arm-cartridge combination should look like: the red trace of fig.3. But this just prompts a series of secondary questions: How are we to achieve this alignment? What are the effects of alignment inaccuracies? What minimum and maximum modulated groove radii should we use? Is a 12" effective-length arm really superior to a 9" one in this respect? Is this alignment truly optimal? Is LTED audible, or are we getting our underwear in a bind over nothing here?

Audibility

Let's tackle that last issue first, since the answer to it justifies all that follows. And let's begin by clarifying what nature of distortion LTE produces, and what exactly is plotted on the vertical axis of fig.3.

As Löfgren and Baerwald both demonstrated, the largest nonlinearity resulting from LTE is second-order, which on a pure-tone signal gives rise to second harmonic distortion. This is what is plotted in fig.3, and in all the other graphs of LTED *vs* groove radius that I have ever seen. Higher-order harmonics are also produced, but at progressively lower levels. The amount of distortion depends not only on LTE[10] and linear groove speed but, as usual, also on signal amplitude, represented in the distortion equation by recorded velocity. Because of this, all graphs like fig.3 should state exactly what recorded velocity is assumed. A figure of 10cm/s Root Mean Square (RMS) is commonly adopted, and applies to all graphs of distortion *vs* groove radius in this article. This represents a moderately high recording level, but bear in mind that when, in the 1970s, Shure Brothers measured recorded velocities from commercial recordings, they found peak figures in excess of 80cm/s, equivalent to over 57cm/s RMS—not that any cartridge could track that. The relative level of second harmonic distortion is proportional to recorded velocity, so 1% second harmonic at 10cm/s becomes 4% at 40cm/s—but most cartridges will be mistracking before that level. On complex signals such as music, LTE distortion introduces intermodulation components as well as harmonic ones and, as I've described before in these pages,[11] these are likely to be much more audibly significant.

Another factor that graphs like fig.3 should state is whether RIAA weighting is applied, as suggested by J.K. Stevenson. Because the RIAA deemphasis (*ie*, replay) curve, ignoring the IEC amendment,[12] declines from +19.4dB at 20Hz to –19.5dB at 20kHz (using the equation in IEC 60098)—an average rolloff of 13.0dB/decade or 3.9dB/octave—Stevenson suggested modifying Baerwald's distortion equation to account for this. If this change is made, then the 1.07% maximum second-harmonic distortion of the red trace of fig.3 is reduced to 0.68%.

The justification for this is perfectly reasonable, of course, but I still wish Stevenson had never suggested it, for three reasons:

1) it introduces confusion between distortion figures and graphs that have or haven't been RIAA-weighted;

2) there are parts of the RIAA curve where the effective slope is less than 3.9dB/octave, notably between 500Hz and 2kHz, where the average slope is 2.6dB/octave and the second harmonics fall at frequencies where the ear has high sensitivity; and

3) intermodulation distortion introduces sum and difference components: the former are reduced in relative level by the RIAA EQ, but the latter are *increased.*

It isn't clear from the figures alone whether LTED will be audible, particularly as the dominant second-order nonlinearity is known to be quite benign. Settling the issue by listening test is the only way to be sure, and the only way this can be reliably achieved, without other unknowns intruding, is by digitally simulating LTED. I did this back in 2004, when writing a feature for *Hi-Fi News*[13] that asked whether radial-tracking arms are justifiable, and the Windows software utility I wrote to perform the simulation remains available from my website's freeware page, if you'd like to determine the issue for yourself.[14] I concluded that the worst-case LTE distortion of an optimally aligned arm of 9" effective length is audible—a finding that, assuming you don't try the software yourself, may reassure you that the rest of this article isn't built on sand.

I concluded that the worst-case LTE distortion of an optimally aligned arm of 9" effective length is audible.

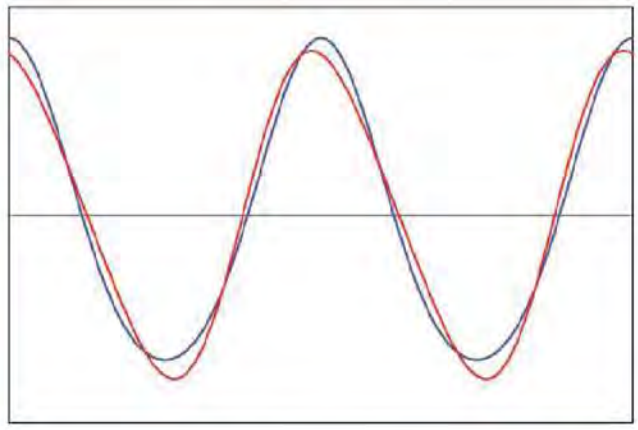

Fig.4 Comparison of the waveforms resulting from 10% second harmonic distortion generated by lateral tracking error (red trace) and, say, a solid state amplifier (blue trace). The disparity occurs because in each case the second harmonic component is at a different phase to the fundamental.

A couple of further observations about LTE distortion before we move on:

First, LTE distortion affects only the stereo groove's lateral modulation, not its vertical modulation, so it will be heard most obviously toward the center of the stereo soundstage. Vertical modulation is affected by its own tracking-error distortion mechanism caused by disparities between record slant angle and cartridge vertical tracking angle—a tale beyond the remit of this article, and even more complex (and perhaps subjectively more significant) than the one unfolding here.

Second, the nature of the distortion introduced by LTE is worth noting. Fig.4 compares the waveform resulting from 10% second-harmonic distortion introduced by lateral tracking error (red trace) to that resulting from the same amount of second-harmonic distortion in, say, a solid-state amplifier (blue trace), the high level of the distortion being to make the disparity in the waveforms clear. The difference arises because the cosine phase of the second harmonic in the LTE case is 90° to the fundamental. To the best of my knowledge, no one has ever demonstrated whether this difference in harmonic phase can be heard or is subjectively irrelevant, even though it can occur elsewhere in audio equipment. I highlight it merely as an engaging curiosity.

Disc Dimensions

The next matter that needs addressing is which maximum and minimum radii to assume for the modulated portion of the record groove, since disagreement on this—more often

10 Strictly, the distortion depends on tan(Θ), where Θ is the LTE, but for small values of Θ the approximation Θ=tan(Θ) is sufficiently accurate. Note that this requires Θ to be in radians, not degrees.

11 K. Howard, "Euphonic Distortion: Naughty but Nice?," *Stereophile*, April 2006, Vol.29 No.4; www.stereophile.com/reference/406howard/.

12 See K. Howard, "Cut and Thrust," *Stereophile*, March 2009, Vol.32 No.3; www.stereophile.com/features/cut_and_thrust_riaa_lp_equalization.

13 K. Howard, "Straight Line to Nowhere?," *Hi-Fi News*, December 2004.

14 www.audiosignal.co.uk/freeware.html.

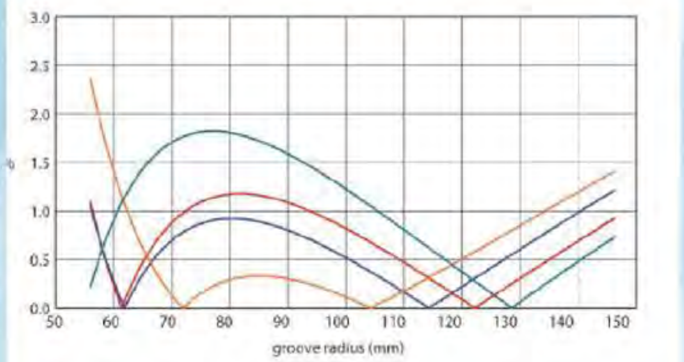

Fig.5 Second harmonic distortion versus groove radius for departures from the optimum alignment of +0.5mm/+0.5° (red trace), –0.5mm/–0.5° (blue trace), +0.5mm/–0.5° (orange trace), and –0.5mm/+0.5° (green trace).

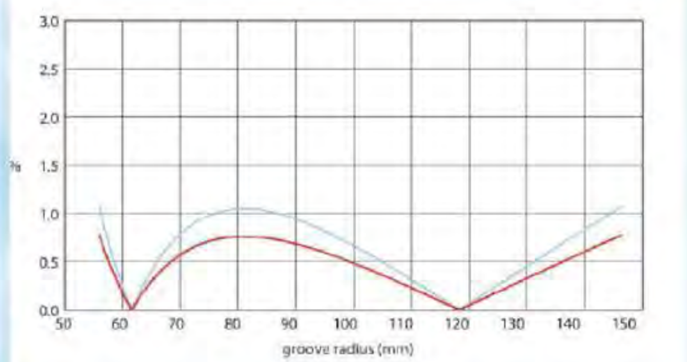

Fig.6 Second harmonic distortion versus groove radius for an optimally aligned 12" arm (effective length 305 mm, red trace) versus that of a 9" arm (effective length 230mm, light blue trace).

implicit than explicit—is rampant. Here I restrict the discussion to LP, since I can't imagine that there are many people reading this who would like to optimize their arm/cartridge alignment for 7" singles.

Let's first dispose of the maximum allowable radius of the modulated portion of the groove, since this is stated in IEC 60098[15] (clause 8.5) as 146.3mm, equivalent to 5.76". This includes a minimum of one turn of "plain" (unmodulated) groove, but that's nothing to fret about because the inner radius is actually the more important figure. As you can see from fig.3, the distortion due to LTE rises rapidly in this region, so if we overestimate the minimum radius, end-of-side distortion will sometimes be worse than anticipated. And guess what? This overestimation of the minimum radius is precisely what many writers on this topic have done.

There is a widespread misconception that the minimum allowable radius for the modulated portion of an LP groove is 60.325mm. Well, it isn't. When I laboriously measured my LP collection 30 years ago, I found a significant proportion had minimum radii down to 58mm, which I subsequently recommended as a realistic figure to use in alignment calculations. IEC 60098 doesn't explicitly state a minimum modulated radius, but it can be calculated from the specified locked groove diameter (106.4mm, ±0.8mm), and minimum number of turns (1) and acceptable pitch (6.4mm, ±3.2mm) for the runout groove. If you do the arithmetic (53.2–0.4+3.2), it turns out that the minimum permissible radius for the modulated portion of the groove is 56mm.

15 IEC 60098, third edition, 1987-11: "Analogue Audio Disk Records and Reproducing Equipment," available from www.iec.org.

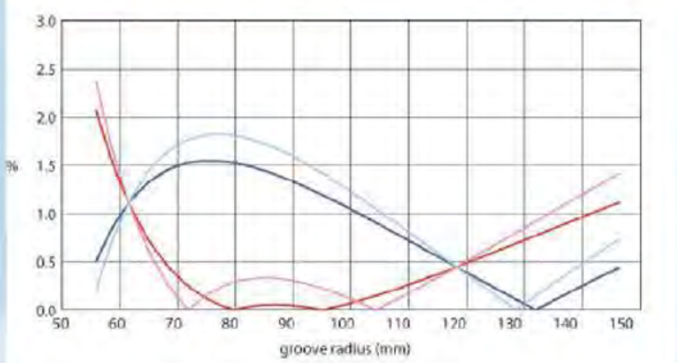

Fig.7 Second harmonic distortion versus groove radius for 305mm effective length arm with departures from the optimum alignment of +0.5mm/–0.5° (red trace), and –0.5mm/+0.5° (blue trace), with equivalent curves for a 230 mm arm (light colors).

I still believe that 58mm is a good practical figure to use, but for the reason already stated, there is good justification for playing safe and using the theoretical minimum of 56mm—as I have done throughout this article.

Alignment Errors

Although this issue is often conveniently ignored, accurate cartridge alignment is very difficult to achieve, not least because the overhang and offset have to be set within extremely tight tolerances if anything like the distortion behavior shown in the red trace of fig.3 is to be realized in practice.

Let's demonstrate this by assuming that we can achieve accuracies of ±0.5mm in overhang and ±0.5° in offset—tolerances that are extremely difficult to achieve in practice, particularly the latter. Fig.5 illustrates the variability in distortion *vs* groove radius behavior encompassed by this error range by plotting the results for the four combinations of maximum error: +0.5mm/+0.5°, –0.5mm/–0.5°, +0.5mm/–0.5°, and –0.5mm/+0.5°.

As the plots show, you can strike lucky. If both errors are in the same direction (+0.5mm/+0.5° or –0.5mm/–0.5°, red and blue traces, respectively), then their effects are almost complementary and the result is acceptably close to the optimum. But if the errors are in opposite directions (+0.5mm/–0.5° or –0.5mm/+0.5°, orange and green traces, respectively), then the results are very much worse. The point, of course, is that you don't get to choose: If your tolerances are ±0.5mm and ±0.5°, you are as likely to suffer a bad result as a good one.

The message to take away from this is a stark one: accurate arm/cartridge alignment is a high-precision process. Achieving distortion behavior close to optimal in practice is no trivial task.

Arm Length

Because increasing the effective length of the pickup arm reduces the curvature of the arc through which the stylus traverses the record, an optimally aligned 12" arm generates less LTE distortion than an optimally aligned 9" alternative. This is why 12" arms were traditionally favored for professional disc-transcription purposes.

But because the optimum overhang and offset are both smaller for a 12" arm, a given misalignment will have a larger effect. So let's repeat the exercise above and see what transpires with alignment tolerances of ±0.5mm and ±0.5° in the case of a longer arm. For an arm of 305mm effective length, the optimum alignment requires an overhang of 12.19mm and an offset of 17.15° (compared to 16.43mm and 23.02° for a 230mm arm), and gives the distortion plot shown

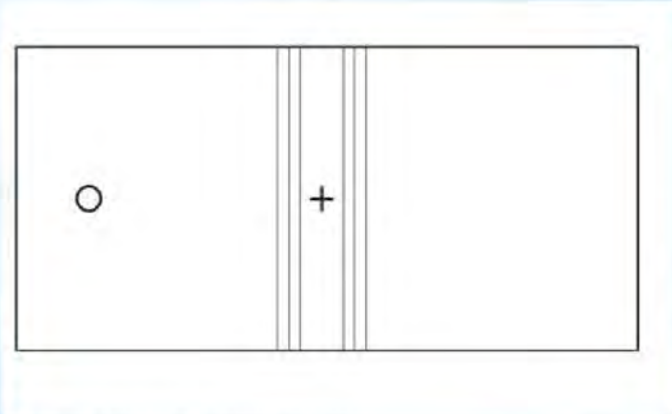

Fig.8 Single-point alignment protractor

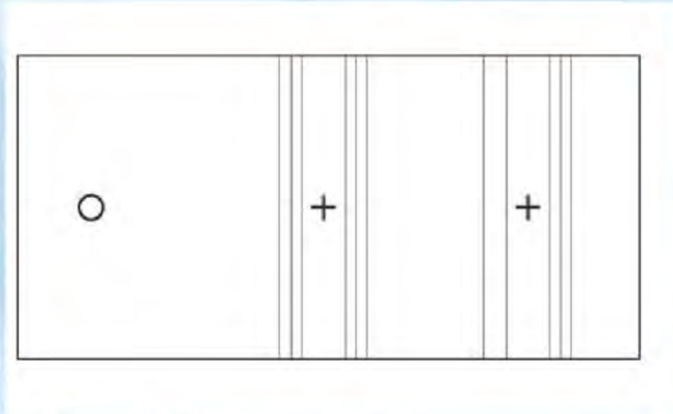

Fig.9 Two-point alignment protractor

in red in fig.6, with the equivalent for a 230mm arm (*ie*, the red trace from fig.3) shown in light blue for comparison. The additional 75mm of effective length has cut the peak second-harmonic distortion (at 10cm/s RMS recorded velocity) from 1.07% to 0.78%, a reduction of 27.5%. So far, so good.

Fig.7 shows the effect on the 305mm arm's distortion plot of misalignments of +0.5mm/–0.5° and –0.5mm/+0.5° (red and blue traces, respectively), again with the 230mm equivalents in the background for comparison.[16] If we take the maximum distortion in each case, the results are as in Table 1. From these we can see that, in the +0.5mm/–0.5° case, the 305mm arm's improvement in peak distortion decreases to 13%, and in the –0.5mm/+0.5° case to 15%. If we increase the alignment tolerance to ± 1.0mm and ± 1.0°, then the 305mm arm's advantage is reversed in the +1.0mm/–1.0° case, and cut to 9% in the –1.0mm/+1.0° case—so honors are now about even with a 230mm arm on the basis of maximum distortion.

Table 1

Misalignment	Maximum Distortion (%)	
	230mm arm	305mm arm
+0.5mm/–0.5°	2.36	2.06
–0.5mm/+0.5°	1.82	1.55
+1.0mm/–1.0°	3.07	3.35
–1.0mm/+1.0°	2.65	2.41

Whether a 12" arm's improvement in LTED is worth its higher effective mass, and reduced bending and torsional stiffness, has always been a judgment call. What these figures show is that unless a 12" arm is very carefully aligned, even that advantage can easily be squandered.

Alignment Protractors

Arm/cartridge alignment is traditionally set using an *alignment protractor.* The terminology doesn't strike me as quite appropriate, but there we are: it's set in stone. Human ingenuity being what it is, numerous different designs of alignment protractor and other alignment tools have appeared down the years, some of them demonstrating a profound misunderstanding of the problem at hand. I won't attempt a history or taxonomy of them here; instead, I'll quickly describe the two that you're most likely to encounter, as they

Numerous different designs of alignment protractor and other alignment tools have appeared down the years, some of them demonstrating a profound misunderstanding of the problem at hand.

are commonly supplied by pickup-arm manufacturers.

The first, the single-point protractor (fig.8), used to enjoy a hegemony. It was an oft-repeated (and misleading) mantra of the 1960s and 1970s that "lateral tracking error should be zero at the innermost groove," and so the one-point protractor typically placed the stylus at the supposed innermost modulated groove radius (often 60.375mm) and incorporated setting lines to which the cartridge sides should be aligned.

Readers of a mathematical bent will already see what's wrong with this type of protractor. Correct arm/cartridge alignment requires that two independent parameters, overhang and offset, both be set correctly. As is drummed into math students when they learn simultaneous equations, to solve for two independent variables, you need two independent equations in those variables—or, in the case of an alignment protractor, you need two setting points. So achieving optimum alignment with a single-point protractor is a matter of luck. The only thing in its favor, apart from its simplicity, is that it tends to produce errors in overhang and offset that are of the complementary type; *ie*, if overhang is set too long, then offset is likely to be set too large, and vice versa.

Far better is the two-point protractor (fig.9). Usually, this exploits the fact that there are two zero-tracking-error radii across the disc, and that these are *independent of arm length.* The latter factor is vital, as it makes the two-point protractor a universal device. In use, the stylus is placed first at one zero-tracking-error radius, then the other, and the overhang and offset adjusted systematically until the cartridge sides align with the setting lines at both points. It is fiddlier than the single-point protractor and requires a little thought from its

16 You may notice in these graphs that all four traces cross at the zero-tracking-error radii for the optimum alignment—an intriguing property that I've noticed for the first time here and can't yet explain.

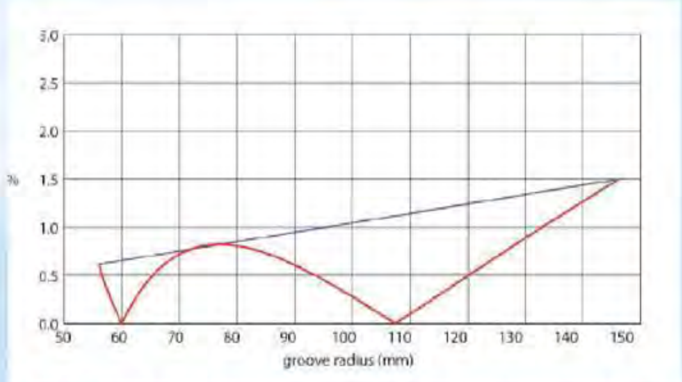

Fig.10 A possible alternative alignment, which accounts for increasing tracing distortin towards the end of side. Distortion values at the inner radius, central peak, and outer radius are still aligned but the trend (blue trace) now slopes downwards towards the inner radius.

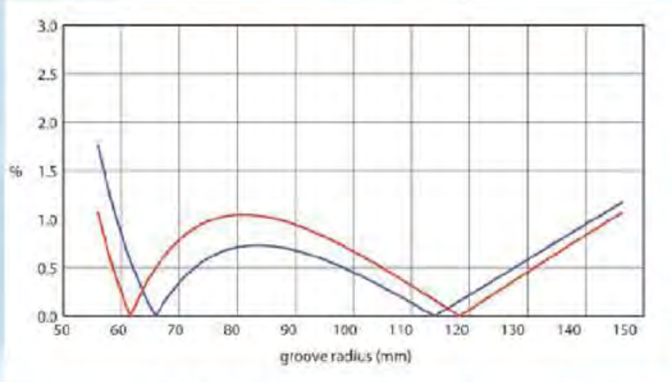

Fig.11 Comparison of the Löfgren/Baerwald alignment (red trace) with Löfgren's suggestion ("Löfgren B," blue trace), which trades lower distortion over the central section of the disc for higher distortion at either extreme.

user, but it has at least the potential for setting both overhang and offset at their optimum values.

Of course, this assumes that the two zero-tracking-error radii are correctly chosen, which often is not the case. If you have a two-point protractor, check them carefully with an accurate ruler. For a modulated-groove-radius range of 56–146.3mm, they should be at 61.6 and 118.4mm; or, for 58–146.3mm, at 63.6 and 119.6mm. If you don't have a two-point protractor, or you do but it has the wrong zero-tracking-error radii, a Windows utility called ArmGeometer, available from the freeware page of my website, will draw a two-point protractor for you, and perform other alignment calculations besides.

The two-point alignment protractor is an excellent device—or would be if only it were easier to set cartridge offset more accurately than is generally the case. Many pickup arms' headshells obscure the cartridge sides, and we have even been regaled on occasions with cartridges having nonstraight, nonparallel sides, and even circular cross sections. As a result, accurately setting the offset is usually the biggest challenge in achieving optimum alignment.

Decades ago, I suggested a simple solution that fell on deaf ears. If I ruled the world, every pickup cartridge would be supplied with a simple, lightweight, clip-on device that, while allowing the stylus to be placed accurately on an alignment protractor, would project long straight edges, parallel to the cartridge front-back axis, to either side of the headshell, where they could be easily checked against long setting lines. If widely adopted, this one innovation would do more for the cause of accurate arm/cartridge alignment than a whole host of costly aftermarket alignment tools, which, whatever their accuracy (an issue I don't intend to get into), will only ever be deployed by a minority of LP users.

Of course, we depend in all this on the generator mechanism within the cartridge being very accurately aligned within the cartridge body—but then, all alignment devices presume that. Whether this trusting assumption is justified is not something I have ever seen investigated, and it wouldn't be an easy job. But the findings would make very interesting reading.

The surest way to achieve accurate arm/cartridge alignment would be to measure cartridge second-harmonic distortion *vs* groove radius. Curve-fitting software could then analyze the result and specify the required overhang and offset adjustments. This wouldn't just require special software: a special test disc would also be necessary, with an assurance that it had been cut with a meticulously aligned cutting head. Although software is available (Adjust+ from www.adjustplus.de) that assists cartridge-azimuth alignment and has various other features, it doesn't help with overhang and offset adjustment. Even if you'd be prepared to go to all this trouble, don't hold your breath.

Optimal or Not?

In all that has gone before, we have assumed that the Löfgren-Baerwald approach of minimizing the maximum LTE distortion across the modulated extent of the groove is indeed the optimal one. But there is good reason to suppose that it isn't, because lateral-tracking-error distortion is only one form of distortion afflicting vinyl-disc replay. Another source of distortion is tracing error, caused by the replay stylus being unable to follow the same path through the groove as the cutting stylus. In large part this is a function of the shape of the replay stylus, and depends critically on groove curvature. Because of this, tracing distortion worsens toward the end of a record side, as the waveform cut into the disc bunches up.

I expect Löfgren would be amused to know that, more than 70 years after the publication of his paper, we still agonize over this issue.

Although tracking-error and tracing-error distortions are different, there is clearly a case for supposing that, as tracing error increases toward the end of the side, tracking error should decrease. In this case, the optimal arm/cartridge alignment might be one that results in a distortion-*vs*-groove-radius curve like that in fig.10. But as tracing error differs according to stylus type, this approach also suggests that arm/cartridge alignment should vary accordingly, with a bigger disparity from the conventional alignment for a conical stylus than a line-contact stylus. The concept of a single "right" alignment would then be redundant.

I'm not aware of anyone having experimented with this approach, but if someone out there has, I'd be very interested to hear of their findings. As already alluded to, Löfgren suggested an alternative alignment in his 1938 paper, which Dennes calls Löfgren B, but its raison d'être is different. It gives the result shown in fig.11, from which you can see that it lowers distortion over the middle portion of the disc at the expense of higher distortion toward either groove extreme, particularly the end of the disc side—an approach that just doesn't make sense to me.

But I expect Löfgren would be amused to know that, more than 70 years after the publication of his paper, we still agonize over this issue.