An introduction to hifi

ARMS AND TURNTABLES

A mix of geometry & physics

Having discussed groove characteristics in conventional analog phono discs, playback cartridges and styli, we now turn to pickup arms, turntables, drive systems and other aspects of phono decks. As before, precision and attention to detail determine the ultimate playback quality.

by NEVILLE WILLIAMS

A pickup arm may appear, at first glance, to fill a fairly routine role in supporting the playback cartridge as it moves across the surface of the disc. In fact, the reverse is true, as will become evident from a closer look at the geometry of the system.

When inscribing the original groove in a master recording, the cutting head is guided across the surface by a leadscrew mechanism, broadly similar to the tool feed in a lathe. As indicated in Fig.1a, the stylus tip follows a straight line (radius) path from the perimeter of the disc towards the spindle.

With the stylus support axis at 90 degrees to the traverse path, it will form a tangent, at the point of contact, with the groove being cut. Lateral movement of the stylus, with modulation, will therefore be in line with the radius and at right-angles to the incremental direction of the groove.

If all recordings used a spiral of uniform pitch, the above geometrical relationships could conceivably be preserved during playback by using a matching transport system for the pickup head. But that is not to be because, in practice, groove pitch varies widely from disc to disc.

When recording program material in which the signal level is modest and uniform, record producers tend to use relatively close spacing, making possible a longer playing time. With music involving frequent loud passages, the opposite applies.

In addition, groove spacing is further manipulated to provide run-in and run-out grooves and identifiable gaps between selections.

A playback pickup must consequently be able to follow the track spiral on any given recording, without imposing significant sideways pressure on the groove walls. By far the most common approach is to fit the playback head to a pivotted arm, as illustrated in Fig.1b.

Tracking error

It will be apparent from the diagram that, with a pivotted arm, the playback stylus moves across the record surface in an arc rather than a straight line, pointing up an obvious discrepancy between recording and playback geometry.

By selecting the distance between the pivot point and the turntable spindle, the stylus axis can be tangential to the groove at a particular radius but, elsewhere, the stylus will be tracing the groove from an oblique angle.

As a result, it will respond in a slightly different way to the inward and-outward excursions of recorded waveforms. The problem is described as "tracking error" and the end effect as "tracking distortion".

Tracking error can be reduced by using a longer arm and thereby describing a shallower arc but it is not a very practical solution. Longer arms are more awkward to accommodate and, being heavier, they are also less compatible with high compliance cartridges.

Another option is to use an articulated design, such that the head swivels on the end of the arm as it moves across the surface of the disc. The idea works, as evidenced by the now discon-

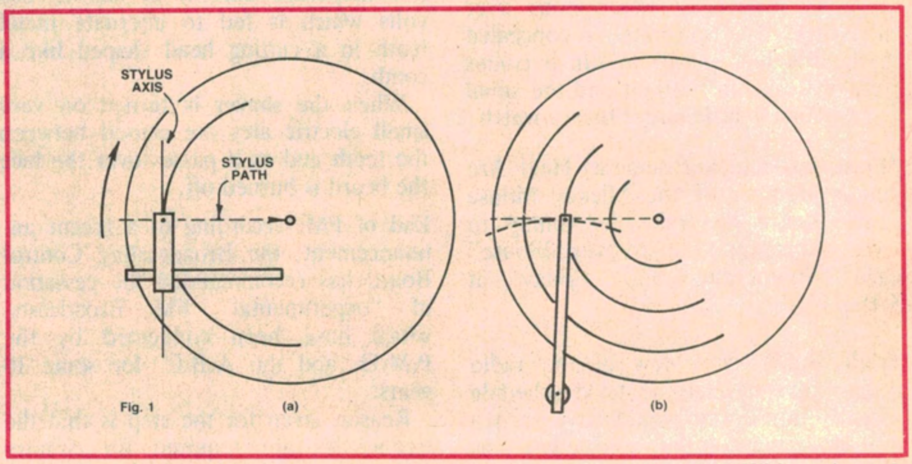

Fig.1: A recording stylus (a) travels across the record in a straight line. With a pivotted playback arm (b), the stylus travels in an arc, leading to problems with tracking error and tracking distortion.

Pt.5

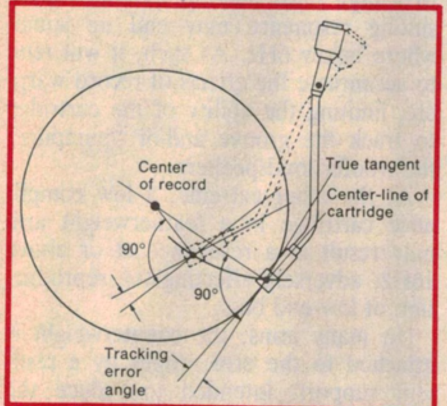

Fig.2: By offsetting the headshell and cartridge axis, relative to the pivot-stylus line, it is possible to obtain much improved — but still not perfect — tracking.

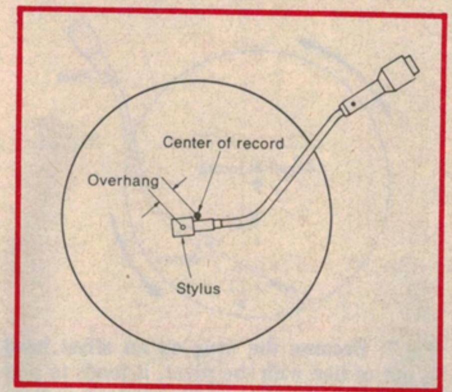

Fig.4: Assuming that a pickup arm has been correctly designed, and the cartridge correctly fitted, optimum tracking will normally be obtained if the overhang is as specified by the manufacturer.

tinued Garrard "Zero-100" player, but it presents problems in terms of complexity, cost and quality control.

The preferred and virtually standard approach is to use a rigid arm but to offset the head, inclining it inwards, as in Fig.2. Correct tracking becomes possible at two radii, while the error elsewhere is considerably reduced, compared with an in-line head, for the same pivot-stylus distance.

The shape of pickup arms — or "tonearms" — has long been the subject of unfounded claims. The fact is that the determination of offset angle for an arm of any given pivot-stylus size is a purely mathematical exercise, which can yield zero tracking error at two nominated radii and predictable — but unavoidable — discrepancies elsewhere.

It is immaterial, as far as tracking is concerned, whether the specified offset involves a headshell attached obliquely to the end of a straight arm, as in Fig.3 (left), a J-shaped arm (centre), an S-shaped arm (right) or any other conceivable contour.

The mathematically based arm dimensions that govern ultimate tracking characteristics are the head offset angle, the pivot-stylus distance, and the "overhang", as illustrated in Fig.4.

Where an arm is an integral part of a deck, care is necessary when replacing a cartridge, to ensure that it is positioned in the headshell so that the stylus/pivot distance and/or the overhang are as specified — or as before.

Where an arm is to be fitted for the first time, all three dimensions should be cross-checked: spindle/pivot, stylus/pivot and stylus overhang.

Some arm and cartridge manufacturers provide alignment guides for setting up their products. While these may be helpful in ensuring that the system conforms to the best calculated tracking compromise, they cannot eliminate the basic problem.

Fig.5 is a graph of the tracking characteristic of a typical high quality phono player. Note that one region of minimum tracking error includes the critical inner grooves (60-70mm radius) where the recorded wavelengths are small and tracking distortion is likely to be most troublesome.

Balance & anti-skating

Normal practice is to provide an adjustable counterweight at the rear of a pickup arm to balance the weight of the arm, headshell and cartridge. With the phono deck on a level surface, it should be possible to adjust the counterweight so that the arm floats freely, with the stylus tip just clear of the record surface — a condition described as "static" balance.

By careful distribution of mass and the placement of the respective pivot axes, it is possible for a pickup arm designer to achieve a condition described as "dynamic" balance, whereby the stylus will continue to float in the same position relative to the surface of the

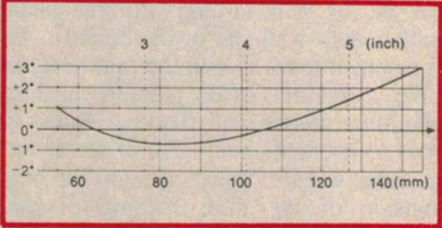

Fig.5: The published tracking error curve for a high quality Technics phono deck using a conventional S-shaped pivotted arm. It would be typical of other 230mm (9-inch) pickups.

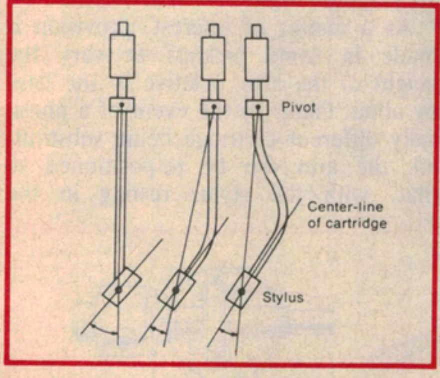

Fig.3: In terms of tracking characteristics, the shape of the pickup arm is immaterial. What matters is the distance from the pivot to the stylus and the offset angle of the head relative to the pivot-stylus line. (See also Fig.4).

Linear tracking turntables

Over the years, a few playback turntables have been released, fitted with a linear tracking arm mechanism. In most cases, the arm is supported by a rail but pulled along, as necessary, by an electronically controlled, motor-driven loop or belt.

Sensors at the pickup head, operating in conjunction with a servo system, ensure that the pickup arm moves along the support rail at a rate commensurate with the groove pitch. Automatic or user push-button controls take care of start, skip, reject, end of play functions, etc, to obviate the need for manual handling.

As the name implies, linear tracking turntables do obviate the tracking problems of radial arms, reducing error to less than 0.1 degree. But, as with articulated arms, they introduce other complications which reduce their appeal to hifi devotees as, for example, a limited choice of compatible replacement cartridges.

Their main application, to date, has been in push-button "space age" compact music centres, rather than in traditional audiophile systems but they are available in the hifi marketplace, if you look for them.

An introduction to hifi

disc, even if the whole deck is gently nudged or tilted.

While there may seem to be little point in striving for this capability, the fact is that, in typical listening rooms, vibration from foot-falls and high-power bass loudspeakers can "nudge" phono decks and produce spurious sonic effects. By stabilising the pickup arm, dynamic balance helps to minimise the problem.

Straight arms, with an offset head, as in Fig.3 (left) lend themselves to dynamic balance, relying on a spring to apply the requisite playing force to the stylus.

Most manufacturers, however, tend to favour J- or S-shaped arms — particularly the latter — for their ability to accommodate interchangeable shells and cartridges. Dynamic balance can still be a design objective, while tolerating sufficient residual unbalance to allow the playing weight on the stylus to be determined by adjustment of the counterweight (Fig.6, right) — claimed to be more predictable than a spring system.

A complication of any offset head is that the drag of the groove on the stylus (A in Fig.7) is in line with the head rather than with the pivot (dotted). As a result, it tends to pull the arm inwards (B), increasing stylus pressure against the inner groove wall. The side-thrust is said to average about 12% of the stylus playing weight, being greatest at the outside of the disc, because of the greater groove velocity.

To offset the side-thrust, quality phono players include "anti-skating" devices of one kind or another, intended to swing the arm gently outwards. On the left, in Fig.8, a small weight and a nylon thread serves the purpose; in the centre a weight and a couple of small levers achieve a similar result. On the right, a spiral spring is fitted in the base, with a knob allowing the anti-skating bias to be adjusted according to the selected playing weight.

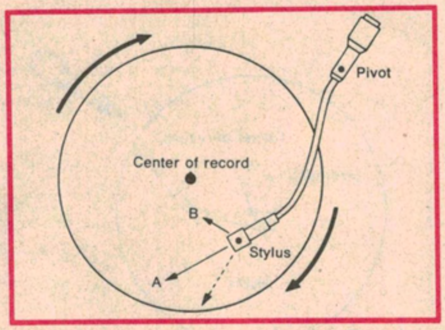

Fig.7: Because the drag on an offset head is out of line with the pivot, it tends to pull the pickup inwards, calling for some form of anti-skating bias to equalise the pressure on the respective groove walls.

Moving mass

While it is usually possible, by means of a spring or a counterweight, to achieve static balance and correct playing weight with arms, headshells and cartridges of relatively high mass, another problem has to be considered, namely that of "moving" mass.

The greater the mass of the above components, the greater their inertia and the effort either to initiate or restrain movement. For example, in the presence of undulation or eccentricity in the record grooves, the effort needed to lift the head or move it sideways may be sufficient to displace the cantilever of a high compliance cartridge from its normal median position, resulting in higher distortion.

A lightweight cartridge and headshell — with the counterweight wound in closer to the pivot — presents less of a problem. Similarly, lightweight arms are preferred, although the design and the material used in their construction must provide adequate rigidity and relative freedom from structural vibration modes.

Bass resonance

In this general context, consideration also has to be given to the natural mechanical resonance which occurs between the mass of the arm, etc, and the compliance of the stylus system.

If a highly compliant cartridge is fitted to a high mass moving system, the resulting resonance may end up somewhere below 6Hz. As such, it will tend to accentuate the effects of record warp, etc, limiting the ability of the cartridge to track the groove and/or "pumping" the woofer loudspeakers.

At the other extreme, a low compliance cartridge in a featherweight arm may result in a resonance at or above 16Hz, adversely affecting the reproduction of low-end bass.

(In many arms, the counterweight is attached to the arm proper by a resilient support, intended to reduce the "Q" — therefore the severity — of the overall system resonance.)

Arm suspension

With the progressive refinement of groove, stylus and cartridge technology, it is essential to ensure that the vertical and horizontal pivotting arrangements for the arm are as near to friction-free as possible. At the same time, they must support the arm positively and firmly, so that the player will be practical and reliable as a consumer product.

Simple bushed bearings are unacceptable, as also are the one-time mechanical trips and levers of mass-produced automatic players and record changers. Modern high quality decks may, indeed, offer automated play facilities but using optical or electronic sensing rather than mechanical trips, and (typically) miniature bearings of "watchmaker" precision.

Such precautions, along with suitably flexible connecting leads, can reduce the total mechanical friction, in either direction, to a few milligrams at the stylus tip — two orders of magnitude less than the playing weight.

As a matter of interest, provision is made in some pickups to vary the height of the arm, relative to the base by about 6mm. In the event of a physically different cartridge being substituted, the arm can be re-positioned so that, with the stylus resting in the

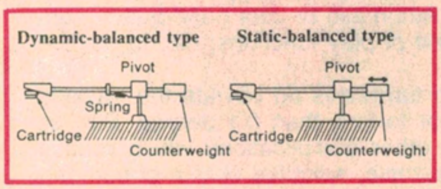

Fig.6: A fully dynamically balanced arm relies on a spring (left) to provide the tracking pressure. Most rely on gravity for the playing weight (right), even if dynamic balance is compromised.

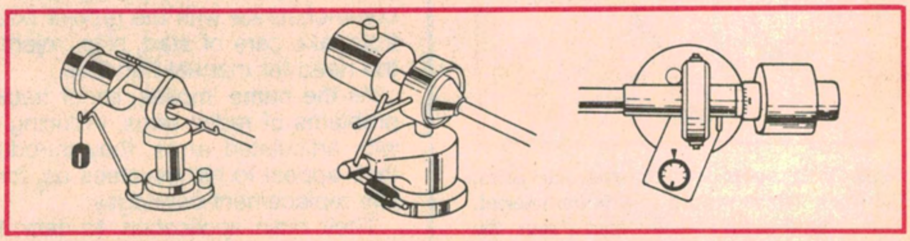

Fig.8: Typical anti-skating devices. They may not exactly cancel stylus drag at all radii but manufacturers' recommendations should be followed in setting them up.

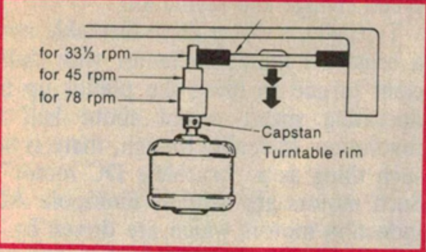

Fig.9: Well suited to mass production, idler wheel drives are popular in budget priced record players. A resilient idler, however, offers only limited isolation between the motor and turntable.

groove, the underside of the arm and cartridge are parallel to the record surface.

Phono turntables

As with pickup arms, there is a lot more to phono turntables than the mere ability to spin discs at the appropriate speed. An indifferent turntable can compromise the sound in various ways and those found in quality decks normally reflect a high level of precision in both design and finish.

Whereas budget priced turntables are normally pressed from steel plate, quality units are more commonly die-cast and machined from aluminium or a non-magnetic alloy, both for accuracy and to obviate interaction with magnetic cartridges. Individual static and dynamic balancing ensures that they will run smoothly, even if operated on a non-level surface.

The mass, normally concentrated close to the rim, is usually kept as high as practical, in order to achieve a good flywheel effect but not so high as to prejudice normal starting and stopping.

Special care is taken with the main bearing, to ensure that it is free from rumble and that the turntable runs absolutely true. Rumble can all too easily be communicated to the stylus and cartridge and be amplified along with the recovered signal. Needless to say, these qualities have to be displayed in long term — not just when the player is new!

A point which needs to be watched is that a turntable must not behave like a gong, chiming spontaneously when tapped with a knuckle! It should be as acoustically inert as possible, so that noise and vibration reaching it from an extraneous source will not be reinforced and passed on to the stylus and cartridge.

Turntable mats can have an important bearing on the acoustic qualities of turntables and, as such, are the subject of frequent debate. They range from a felt-like texture, through rubber and plastic in a variety of patterns to glass-wool.

Curiously, while most hifi manufacturers favour fairly heavy machined aluminium turntables (2.5 to 3.0kg) a few opt for very lightweight platters. NAD International, in their 5120 model, use a thin aluminium platter with a 7mm thick dense rubber mat, which they consider to be acoustically inert.

Without seeking to debate such options, it is reasonable to assume that turntables from specialist hifi manufacturers will do a good job, even though they may differ widely in their design philosophy.

Turntable motors

With the introduction of microgroove records, it became necessary to devise a turntable drive mechanism more amenable to multi-speed operation than the old-style governor type electric "gramo" motors. Hopefully, it would be possible simultaneously to reduce 50Hz hum radiation, along with bearing and governor rumble, and to ensure more predictable playing speeds.

The initial answer was the system depicted in Fig.9 — a mains powered induction motor, with a stepped capstan, driving the inside rim of a (normally) pressed steel turntable, per medium of a resilient idler wheel. A knob or lever allowed the idler wheel to be re-positioned to engage the required step on the capstan.

Turntable speed was determined by — and dependent on — the nominally synchronous speed of the motor, stepped down by the diameter ratio of the capstan and turntable rim.

The rim drive system remains a popular choice for budget-priced record players but suffers the basic problem that a resilient idler wheel can provide only limited mechanical isolation between the drive motor and turntable.

As a result, residual vibration and rumble from the motor, plus noise from the idler wheel, can still be communicated to the turntable and thence to the stylus and cartridge. Even speed regulation is likely to be no better than passable.

While these limitations can be countered by more demanding — and costly — design and production standards, the idler rim-drive system still equates more to economy players than to true hifi equipment.

Belt drive systems

When the limitations of the idler drive system became apparent, hifi buffs turned to belt drive, on the assumption that a flexible rubber or neoprene belt

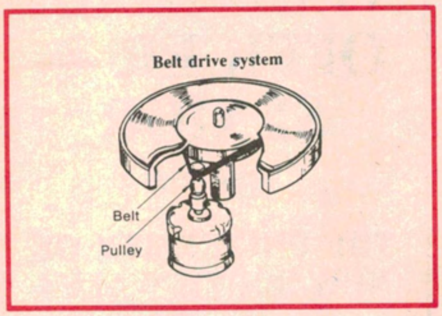

Figure 10: Belt drive offers good isolation between turntable and motor but tends to need more care and maintenance than other systems. Some audiophiles prefer them, however.

would more effectively isolate the drive motor from the turntable. This certainly proved to be the case, although manipulation of the belt for speed change purposes proved to be more of a problem.

Fig.10 illustrates belt drive to an inner drum from a two-step pulley (speed change lever not shown). The thinking behind this is that, by driving an inner drum, the heavy outer rim is able to function more effectively as a flywheel, smoothing out residual vibration and speed variations.

At the other extreme, systems like the Australian "JH" used a tiny synchronous motor to drive the outside rim of an extremely light aluminium platter, with a round rubber belt of about 1.5mm diameter!

While belt drive proved smooth and substantially noise-free, it had its own problems in the way of belts that variously slipped, perished, sagged and fell off, and for which replacements were often difficult to locate.

Nevertheless, they built quite a following among audiophiles and, even today, some of the most prestigious record players boast the time honoured "high quality AC synchronous motor" and "precision neoprene belt drive".

Back to direct drive

Then in the early '70s, the major Japanese hifi manufacturers came up with an alternative to gears, idler wheels and belts: ultra low speed, direct drive (DD) motors, requiring no intervening drive mechanism and relying, in most cases, on electronic control for speed change and regulation.

Typically, a direct drive turntable uses a brushless multipole motor with sufficient torque to bring the platter up to operating speed within about half a revolution. In reality though, there is no such thing as a "brushless DC motor". Such motors are actually multipole AC induction motors which are driven by a set of four transistors in bridge configuration from a DC source.

These motors were originally developed by the Japanese to solve the problem of commutator hash in battery operated turntables and tape decks.

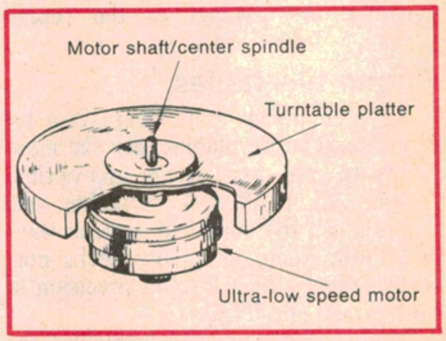

Fig.11: The Technics SP-10 (1970) claimed to be the world's first high performance, multi-speed direct drive turntable. In later designs, the turntable is more intimately integrated with the rotor.

From there they were improved and used in increasingly refined speed control circuits which culminated in "servo controlled" and "quartz controlled" turntables which have now been on the market for about 15 years or so.

These work as follows. Under the rim of the turntable is a set of optical or magnetic markers and sensors which allow the unit to generate a train of pulses which are directly proportional to its speed. These are processed by a frequency/voltage converter into a DC voltage, as indicated in Fig.12, and compared in a voltage comparator to a preset reference voltage appropriate for the required speed — 33 or 45rpm.

The difference, fed as a control signal to the DC drive transistors, adjusts the torque of the turntable motor accordingly. It is, in effect, a feedback or servo system which matches the speed of the turntable to a predetermined standard, as signified by the reference voltage. Its potential accuracy is a function of the precision and sensitivity of the electronic circuitry.

For the ultimate in accuracy and stability, a quartz oscillator and phase comparator stage can be added (dotted in Fig.12) to provide a continuous and instantaneous comparison between the phase of the pulses from the turntable and divided-down reference pulses from the crystal.

In circuitry of this general type, it is possible to provide a vernier speed adjustment (pitch control) which, in its most ambitious form, can provide for a speed variation up to about ±10%, crystal locked and accurately calibrated.

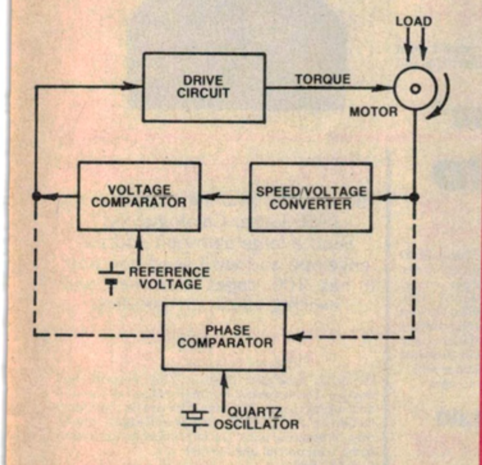

Fig.12: Most direct drive turntable motors operate on DC, with a feedback or servo system to ensure accurate and constant speed. Many have supplementary "quartz" circuitry (dotted) for extreme precision.

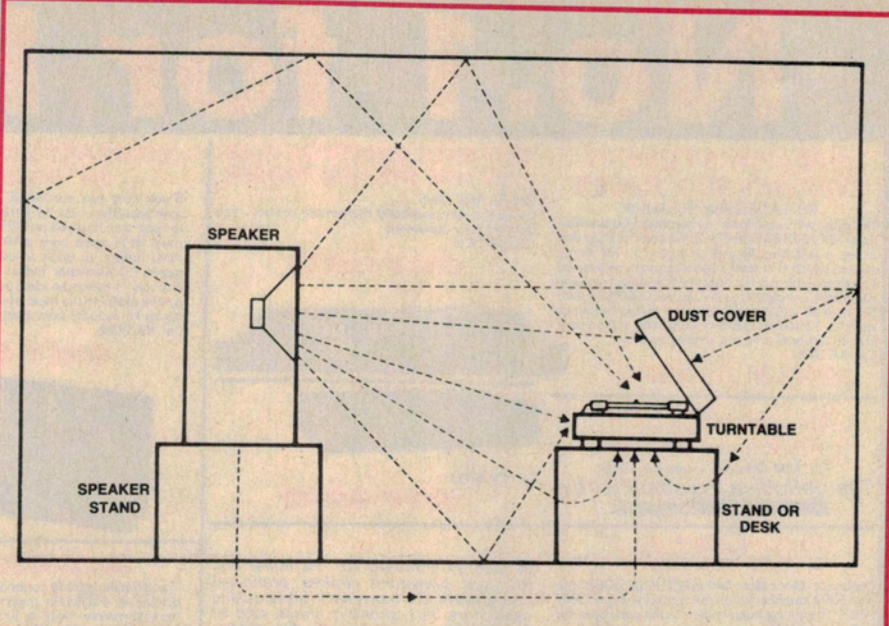

Fig.13: Acoustic feedback can adversely affect the sound from a phono player. Good basic design helps but care also needs to be taken with its placement.

Add to this logic and timer circuitry for the panel controls and the auto return and switch-off facility and it amounts to quite a package of electronics, usually concentrated nowadays to one or more dedicated ICs.

Reservations?

Not surprisingly, this "high-tech" approach has had its own problems, one criticism having to do with "cogging" — a slight roughness or flutter caused by magnetic interaction between the multipole rotors and stators. Fortunately, it appears to have been sorted out.

Even so, quite a few traditional hifi devotees seem still to prefer the belts and pulleys, which they can see and understand, to the enigmatic mysteries of high-tech electronics.

In fact, the performance specifications of typical good quality quartz DD electronic turntables are generally rather better than those of prestige audiophile belt drive models, although both are subjectively adequate.

DD speed accuracy and stability is typically greater than with a synchronous AC motor (±0.002% compared with ±0.5%). Wow and flutter is lower (0.025% RMS v 0.4%) and S/N ratio (rumble) better (−73dB DIN-B v. −70dB).

Acoustic feedback

A phono disc and cartridge together form a rudimentary microphone. The disc can respond to vibration and noise which, when communicated to a stylus and cartridge, produces an electrical signal, capable of being amplified and heard through loudspeakers.

Perhaps the most serious aspect of this is that a phono player can "hear" the sound from high powered loudspeakers, as illustrated in Fig.13, giving rise to a complete feedback loop: an electrical path from the player to the loudspeakers and an acoustic path from the loudspeaker back to the player.

If the gain around the feedback loop is high enough, the system may become unstable and break into a howl or roar. But, even with a lower loop gain, the feedback can affect the quality of the reproduced sound, tending to make bass notes "boomy" and adding a sense of noise and intermodulation to the middle and upper register.

Well designed phono players incorporate means of cushioning the pickup and turntable jointly from the external framework of the player, plus the provision of resilient feet. A dynamically balanced pickup arm helps, while the perspex lid can also block some of the sound waves.

Try to avoid having the player on the same shelf, or in the same structure, or even any closer to the loudspeakers than it strictly needs to be. To quote an old but helpful maxim: if you have big loudspeakers on a springy floor, bracket your phono deck to a wall!

Footnote

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