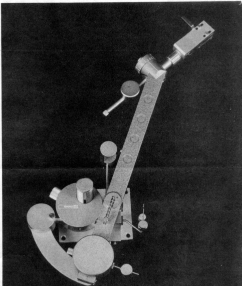
Structural rigidity in

. . . or why a stiff one is better than a floppy one. Philip Mount looks at what is required of the pickup arm and explains why the cartridge needs a stable platform and a tight bond to eliminate suck-outs and coloured reproduction.



Looking through various research and technical papers for this article made me think that what at the moment seems a matter-of-fact subject in arm design might well be seen in the future as a whole step forward in development. And the subject in question is that of arm rigidity. If my explanation of this is successful you will see that rigidity in an arm is absolutely fundamental to its operation, but until recently it has been largely assumed that arms were sufficiently rigid for their purpose. Well, now we know better, but I can find little or virtually no mention of the subject historically, whereas the topics of geometry, friction, damping, etc were well charted between 1920 and 1940, for instance.

The introduction of stereo in the late fifties certainly accelerated arm development in order that a new breed of cartridges equally compliant vertically as well as laterally and of increasing sensitivity could be accommodated. The emphasis here was on reduced effective mass and lower values of pivot friction for greater freedom of movement, though. One of the earliest acknowledgements I can think of toward a solid but well damped arm structure was the use by Garrard of rosewood and aluminium for the arm tube in, as far as I can recall, a sandwich construction. This company also clung to use of the headshell slide rather than the SME style removeable headshell to avoid the structurally troublesome plug-in connector.

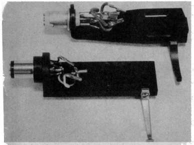
SME have also been aware of the need for structural rigidity but while most arm designers have shown only a cursory awareness of this property, little seems to have been recorded on the subject until recently when Peter Rother of Thorens presented a paper to the AES during March 1976 entitled 'Aspects of Low-Inertia Tone Arm Design'.

Before having a closer look at this topic it is best to get an idea of how a cartridge works and why it needs a rigid arm in the first place. A conventional magnetic cartridge is in effect an adapted and highly specialised form of electric generator. The stylus and stylus bar are driven by the groove as shown in Fig 1, and this causes a small but relatively powerful magnet at the top of the stylus bar (within the cartridge body) to move in sympathy. Magnetic flux from the magnet 'cuts' the signal coils within the cartridge body to generate an electrical signal. With stereo recordings the stylus will be moved laterally, vertically and at all angles between these two planes. In fact it moves in a complex fashion and may even rotate.

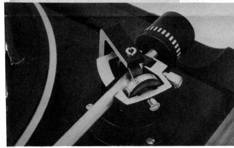
Say however, for the sake of argument that the signal in the groove moves it laterally, or from left to right (this would produce a central image between the two speakers). If the whole cartridge were to move in unison with the stylus and follow its motion there would be no relative movement between the stylus assembly and the cartridge body and therefore the generating magnet at the end of the stylus bar would in effect be stationary relative to the signal coils. The result of this would be no output which isn't exactly what is required.

It is obvious from this argument that ideally what we want is the reverse of such a situation where the cartridge body remains completely stationary whilst the stylus 'reads' or is driven by the groove. The only problem here of course is that while clamping the cartridge in a vice would appear to be one solution

the pickup arm



A good arm design is not all a question of rigidity. It's vital at the 'business end', but equally important for low coloration is a decoupled counter-weight.



to the problem it wouldn't be so good in allowing it to traverse the disc or ride over warps. Luckily enough, warps, disc eccentricities and inward speed on the groove spiral are all low speed effects compared with the signal in a groove and we tailor an arm mechanically, more or less, to move in sympathy with these low speed effects resulting in no output from the cartridge due to them, whilst it remains stationary to groove movements of faster rate or higher frequency.

The difficulty lies in ensuring that the cartridge body does in fact remain stationary at higher frequencies, since we cannot allow even fractional movement for optimum fidelity. This is 'the stable platform' concept where the headshell is seen as a perfectly stable platform to which the cartridge is bolted. If the arm structure is anything other than perfectly rigid, it will tend to flex under mechanical forces exerted by the groove modulations through the cartridge body and this results in headshell movement and either loss of output from the cartridge or, in the case of an anti-phase condition during resonance, a reinforcement of output. In practice few modern arms are so good that they are structurally rigid, most having a noticeable affect on cartridge response.

Take for example a metal arm tube and imagine that you can hold it on its own. Tap one end lightly and the tube will ring like a bell at its natural resonant frequency determined by distributed mass and compliance along the length of the tube. The ringing is caused by vibration of the tube in the same way a tuning fork can be seen to vibrate when struck. Now imagine this tube within the structure of a pickup arm and you can see that potentially if it rings then the headshell will vibrate at the ring frequency. This happens in practice, with the tube effectively held steady by counterweight mass at one end and excited by energy from the cartridge at the other. Our stable platform is now not stable at all — in fact it is continuously vibrating in practice like that tuning fork and this colours reproduction.

Peaks and troughs

Measurement reveals the effect clearly as suckouts and peaks in the frequency response and crosstalk traces of a cartridge fitted to the arm. Remember that if the headshell moves in sympathy with stylus motion then resultant output from the cartridge will decrease but if it moves in a direction opposite to that of the stylus then output will increase. What happens in effect is that mechanical structures like the arm tube resonate and at one frequency will be moving in sympathy or in-phase with the stylus and then relative movement will oppose the stylus or go out-of-phase, leading first to suckouts and then to peaks respectively.

The most successful way of detecting this phenomena is to use a frequency response disc cut at high level in order to put as much energy into the system as possible in order to excite it. Small blips appear in the frequency response of a cartridge but very large disturbances are apparent in the crosstalk traces where random vibrational movement of the headshell is not hidden by the signal in the groove. There is one fairly recent test disc available from CBS Technology Centre in the States that has been cut at a high level precisely for this sort of investigation, although little use has been made of it in this respect so far. Look at Graph 1 to see the significant aberrations on frequency response and crosstalk of a Stanton 681EEE caused by structural arm resonances in both Thorens and Pioneer pickup arms. The left hand set of traces are for a Thorens Isotrack arm which is now obsolete and the right hand set for a budget Pioneer design. Circled are peaks and suckouts caused by resonances within the arm structure and they reach levels of up to 10dB in the crosstalk traces of the Thorens arm for instance!

One of the problems experienced by both these arms is lack of counterweight decoupling (which is why I chose to measure them!) which results in a resonant system being formed between arm tube compliance and counterweight mass. Although counterweight decoupling was originally meant to fulfil another function altogether historically, it is now incorporated to avoid this sort of resonance. It is interesting that because pickup arms are often very similar in construction they display the same mechanical characteristics, and one of these is an arm-tube-compliance/counterweight-mass resonant frequency placed at around 200Hz. An unfortunate coincidence is that belt drive turntables

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using four pole synchronous motors tend to rumble or 'drone' at this frequency too (4pole x 50Hz), the net result being noticeable amplification of this drone by up to +10dB. As a result you will sometimes see it said that arm decoupling is used to minimise rumble, but this is really only an additional benefit that occurs under certain circumstances.

While on the subject of counterweight decoupling I should mention that it was originally suggested as a means of cancelling out the main low frequency resonance of an arm by the use of a resonant sub-system, a mechanical technique that has been understood and applied to various problems, including car suspensions for instance, since the turn of the century at least. Unfortunately, for this idea to work properly in our modern tone arm the compliant suspension for the counterweight must be extremely floppy which poses problems of location. But next time you see a modern Dual deck, give its counterweight a friendly tweak and watch it wave back at you.

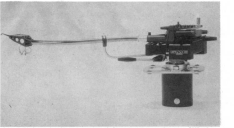
It is true to say that when an arm does not possess counterweight decoupling it will suffer marked structural resonance and in use will be in a continual state of ringing, leading to coloured reproduction. It is easy enough to check this feature — just hold the arm tube stationary and see if the counterweight wobbles on its support tube. In many cases the support tube itself is compliantly suspended behind the main pivot, achieving the same end.

Rigid?

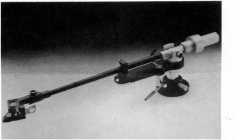
As you can see, there is more to this problem than meets the eye and what may superficially appear to be a rigid component on a pickup arm may in fact be quite the opposite. Any departure from complete rigidity will allow headshell movement and thus mar definition of a signal from the cartridge and cause colouration too. Let us for the time being continue to focus attention on the arm tube and consider what is required of it. As I mentioned earlier, the signal in a groove produces lateral and vertical movement in the stylus assembly as well as movement in any direction between these two planes. This doesn't translate mechanically to a similar set of forces acting on the headshell, though.

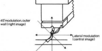
As Fig 2 shows, the headshell cannot see a purely lateral or sideways force upon it, but primarily suffers torsion or twisting and, to a lesser degree, an upward bending force through its axis from pure vertical movement of the stylus. Vertical modulation in the stereo groove represents out-of-phase centre signals and although a vertical component of movement is nearly always present it is minimised during disc cutting simply so that the groove doesn't become too shallow or disappear altogether due to the cutter lifting right out of the acetate. For strength it is important to use a tube that resists torsional flexure and whilst both aluminium and titanium exhibit this property, carbon fibre does not.

In fact the use of carbon fibre in arm tubes is a complex subject in itself because this material can be fabricated many different ways and few of them seem particularly appropriate to arm tube manufacture. If the fibres are laid lengthwise along



Advanced materials have been used in the search for better arm performance, SME using titanium in the Series III and ADC carbon fibre for the LMF-1 and LMF-2.





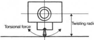
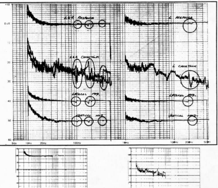


Fig. 1. The stylus moves in all directions on a stereo recording, and this diagram identifies the images produced from its action.

Fig. 2. The stylus movements shown in Fig. 1 translate mechanically as shown here into a 'normal' force that passes through the arm tube axis and exerts a vertical bending moment on it and a twisting or torsional force. It is worth reflecting on the fact that various combinations of cartridge and headshell will exert different twisting moments on the arm tube according to the dimension I have labelled 'twisting radius', which is the distance between the arm tube axis and the disc surface. The smaller this distance is made the better, which calls for low cartridge height and a low slung arm tube.



Graph 1. The left hand set of traces show structural resonances in a Thorens 'Isotrack' tone arm while on the right is the behaviour of a budget Pioneer tone arm. Note how small blips evident on the frequency response traces of the Stanton 680EE test cartridge are indicative of a structural resonance that is far more serious in effect when looked at on the crosstalk traces. The latter peaks are a truer indication of magnitude of the resonance and with disturbances of up to 10dB such resonances are obviously significant. While left and right channel test signals provide both normal and torsional excitation of the arm, thus exposing most problems, lateral and vertical test signals are useful in helping to pinpoint troublesome areas since arm construction is not always symmetric.

the arm tube axis as they are in the ADC arms for instance, then whilst the tube that is formed resists bending forces it is weak in torsion. This can be checked easily by twisting the headshell of these arms. The only way to counteract this with carbon fibre is to spirally wrap the fibres but this is expensive (about £10 per arm tube instead of £2 for axial fibres) and the tube is then weak in the bending mode. On balance, then, carbon fibre tubes have problems that aren't apparent in simple assessments of carbon fibre alone without taking fabrication techniques into account.

More promising is titanium which is strong and reasonably light, although of higher density than aluminium. It is not particularly easy to work with however and doesn't weight-for-weight show remarkable increases in rigidity compared with some aluminium alloys. A titanium tube untreated rings rather markedly too and so in practice needs to be damped. Furthermore, cost is high.

One of the few materials that really does appear to offer very significant improvements in strength/weight ratio is berylium but it is nearly impossible to work with and toxic too. Beryllium rods are used for stylus cantilevers at present and perhaps some time in the future somebody will attempt to make a pickup arm out of it, but such pursuits hardly seem worthwhile because in fact there is little wrong with aluminium when it is used properly. Aluminium tubes are adequately rigid and the metal can be worked and alloyed to achieve varius different properties, one of which is good inherent damping. One of the few arms currently available that is entirely free of the resonances shown in graph 1 is the Hadcock GH228 and it simply uses an aluminium arm tube, which isn't of course half so expensive as some of the more complex structures currently available (and which do display resonances in spite of price and complexity). It is probably also possible to construct a good arm from various plastics but whether anyone would ever believe that such a material was in fact suitable is another matter. It is worth remembering that some modern plastics are very strong however and their internal damping good.

Use of suitable materials is only one pre-requisite for a non-resonant arm structure however. As I explained earlier, there's no avoiding certain simple constructional facts such as the need for counter-weight decoupling. Similarly headshell connectors are a weak point where compliance exists and some headshells are not as rigid as they should be either. Eliminating the common plug-in headshell adds to rigidity, reduces effective mass and can even reduce manufacturing costs! Consequently we are likely to see more variations on this theme in the future, but in the meantime Thorens, Stratheam and SME all use plug-in arm tubes, mainly for reduced mass allied with the convenience of a removeable assembly.

Also likely to become more popular is use of viscous damping near the arm tube pivots since this not only controls the main low frequency arm resonance very effectively but it also helps terminate the arm tube resistively, dissipating energy and so reducing the effect of resonances. This type of damping does exert some drag on the arm which should be borne in mind but it is common to shape the immersed damping vane such that rotational drag is minimised.

At present there are surprisingly few mass produced arms you can buy for a reasonable price that are adequately rigid and this is testimony to the current lack of understanding about even some simple mechanical design practices.

The situation is changing fairly rapidly in Britain at least, and we are about to receive two new pickup arms in the near future that should be worth waiting for. Both are designed in this country and embody some novel ideas. One of them is being handled by Mission Electronics, uses an aluminium arm tube, fluid damping applied in the same fashion as that on the SME arms and loaded ball-race pivots that provide positive location whilst avoiding the pendulum instability and difficulty of use of a unipivot. The other arm I can say less about, other than it is magnetically suspended and holds magnetic fluid between the bearings for control.

Until the last year or two pickup arm design has been crude and largely empirical. It still is in most companies I assure you. This will change though and there are signs that in Japan the nettle is being grasped firmly by one or two companies. Enough is known about mechanics and about electro-mechanical modelling to put arm design on a much more solid foundation than exists at the moment and Sony are one company that have adopted this approach. Their early computer model suffered from over-simplicity but it did predict structural resonances in aluminium and carbon fibre tubes quite dramatically and was a step forward in analytical development technique if not in arm design itself.

It is not difficult to translate the mechanical structure of a tone arm into an electrical analogue, one of the most interesting and adaptable being developed by F.A. Firestone at the University of Michigan in 1933. An equivalent electrical circuit possesses the advantage of being easily excited by both pulse and steady state signals in order to see how it, and of course its mechanical counterpart, behaves. Since we understand and can modify and experiment with electrical circuits much more thoroughly and effectively than mechanical structures, either practically or through computer simulations as Sony chose to do, arm behaviour should become less of a mystery and far better charted. I believe that in five or ten years time our current position will look appallingly backward and many of our ideas simply naive. There should be one or two decent arms around by then — or else laser scanned, digitally encoded disc storage systems will have replaced them altogether!