Audiomods Rega conversion

The RB250 arm has been around so long now that it's easy to forget how radical the design was when it first appeared. Firstly, the geometry was, within the practicality of rounding the measurements, correct. This might appear an obvious starting point but, amongst the top twenty 1970s tonearms, only the SME III and Michell had a correct offset angle, all the others being up to five degrees out. The armtube design with fixed headshell was radical and, in an S-shaped market, influenced just about every design that came after it.

The great strength of the Rega design is the armtube. It's a very well executed thin-wall magnesium/aluminium alloy die casting with a one-piece headshell and double taper. Die casting is a far better way to make an arm than using a tube or even machining it from solid but it's prohibitively expensive unless, as in the Rega case, it will be a mass-market product with a long life.

The rest of the arm is exceptionally well designed for production at its price point but that's also its great weakness when we are looking for real performance.

The bearings and the way that they are fixed is very compromised by price. The design of the RB250 depends upon careful setting up of a loose-tolerance bearing. There is no way to improve upon them unless we completely rethink the bearings and the way they are held

The search for an improved arm and the resulting product was never, and isn't, a commercial project but it has resulted, after some years of experiment, in a very limited quantity of bespoke, hand-built arms as well as DIY kits for fellow enthusiasts.

At commercial rates the design is simply too complex and time-consuming and uses some rather expensive parts to be translated into a series production product so it will only ever be hand made in tiny quantities.

Modifying the arm

The starting point for the design is that it is cheaper to use the armtube from a rough or damaged RB250 than to create one of equivalent quality. Casting is impossible for small quantities, tubes are compromised and machining from solid is both very time consuming and gives us the wrong grain structure.

The design targets were to be able to use the arm tube casting as a starting point but to use very high quality bearings of lower inertial mass than the originals and to mount them in a way that gave better control and much higher precision.

Bearings and arm yoke

Can we fit high quality, close tolerance bearings to a standard Rega arm?

Not really. The RB250 is designed around bearings that have a degree of "play" so that they can be set up within the limits imposed by the way they are held in place. A very close-tolerance bearing wouldn't be an improvement and is more likely to increase resistance.

After lots of experiments we've settled on small ceramic hybrid bearings (ceramic balls in steel races) for our rebuilds. These are very high precision, wonderfully smooth right from the start and the whole installation has been designed around using these properly. They just wouldn't work as substitutes in the standard location. Unfortunately, these bearings are maybe forty times the cost of the ones going into the original arms, but worth it!

This type of bearing has big advantages:

• Very low "sticktion". It's almost always said that an arm should have very low friction, but that's not really the case. We are, after all, using ball bearings in a way they really aren't designed for. The 10x3mm ones shown here are designed to run at up to 50,000rpm with a 50kg load. Then the running friction would be important. Our bearings make tiny, continuous to-and-fro movements so what we are interested in is the starting friction. As part of the load "seen" by the cantilever, bearing friction is small compared to arm mass inertia. What we really want is low "sticktion" – the tendency for a bearing to stick-and-go – which results in jerky, rough movement. The smoother the bearings, the better they can be adjusted.

• Lower internal inertia. The ceramic balls have lower mass. This might seem insignificant, but an arm makes constant, tiny movements so the direction of the bearings is always reversing. The lower the ball mass, the less likelihood that the balls will skid rather than roll. (This is a big weakness of the originals.)

• Very high precision bearings can achieve a play-free setup with less pre-load.

jeff@audiomods.co.uk

The disadvantages are:
• Very high precision bearings need very high precision mountings.
• Hybrid bearings are far more expensive than the best quality steel ones.

The final design relies upon making the bearing housings easily adjustable to achieve the precision we need. It isn't necessary to measure the final bearing adjustment, but it's a factor of probably 10x finer than the original setup.

From serial number 21, the horizontal and vertical bearings have different lubrication applied because of their different loadings - all the horizontal bearing balls are evenly loaded whilst the upper balls of the vertical ones bear no direct load.

The arm yoke is machined from solid HE30 aluminium with removable bearing caps, rather like car main or camshaft bearing journals. The journals are made to very fine limits so that the bearings will lock into place with very little pressure on the screws. The caps "float" and are located by the bearings themselves.

The bearings are held in the arm tube by press-fitting a solid aluminium carrier with a one-piece, ground silver steel shaft for a very high-precision fit.

The bearings are now much farther apart for stability(41mm centres rather than the original 19mm) and the arm yoke is more massive than the original. This has the advantage of adding inertial mass in the horizontal plane. We tailor the yoke mass to match the cartridge compliance range. See the section on antiskate and bias control to understand why this is so important.

The vertical bearings are also completely new.
The Rega vertical bearing has two weaknesses:
• The bearing position, which is dictated by two factors: a large distance between yoke and bearing because of the position of the antiskate magnet and a narrow distance between bearings because of the need to accommodate the wiring plug. These are just the opposite of what we want for stability: minimum overhang and wide spacing.
• The base is also the bearing housing so the bearings are coupled directly to the armboard/plinth, perhaps creating a feedback loop.

The redesign of the vertical bearings is intended to address these issues. The result is:
• Better shaft design with positive bearing spacing
• Much wider bearing spacing (30mm centres, originally 15mm)
• More accurate, adjustable location from a split housing
• Bearing housing decoupled from the base
• Built-in VTA
• Fine adjustment of mounting distance

Counterweights
There are a lot of counterweight modifications available for the Rega arms, each of which might help the performance to a degree.

In the standard arm, the plastic end stub tends to decouple the arm from the weight. This is not particularly good because the mass of the weight doesn't control resonance in the armtube and the difference in materials properties tends to stop transfer of energy from tube to stub. If we simply fix a metal stub rigidly to the armtube, then the tube will tend to dissipate energy by trying to vibrate the weight as well but the weight can releases that energy and feed it straight back to the armtube, slightly out of phase with the original. We hear this as a smearing of the sound. So the aftermarket weights that use solid stubs screwed into the armtube may create more problems than they solve.
The Origin Live counterweight achieves a real improvement by coupling the stub to the armtube in a way where the stub's natural frequencies are very different from the arm's and it now uses low-area contact for the weight (early versions didn't).

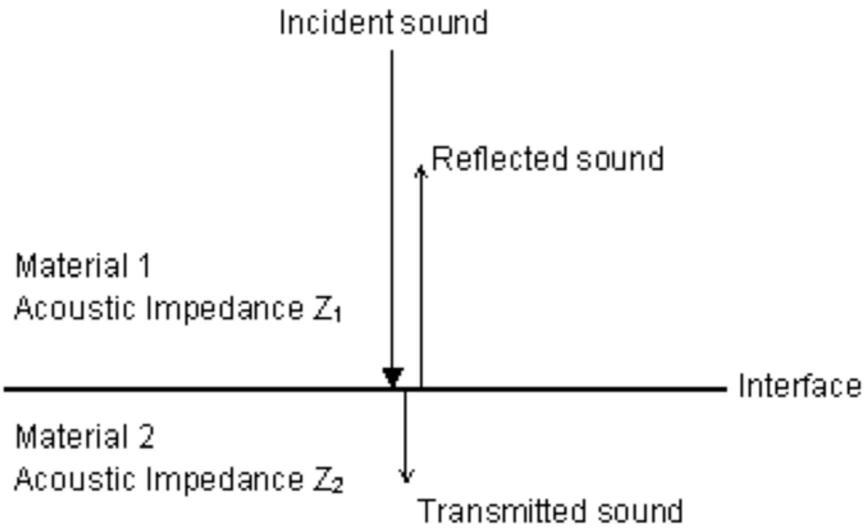
Our design also alters the path from armtube to weight. The stub retaining screw is threaded into the bearing carrier, not the armtube. The result is a rigid structure but one that uses the different characteristics of the interfaced parts to control but not reflect the energy.

Materials choice
The way in which sound is transmitted across the interface between two parts depends upon the "acoustic impedance" value of the materials they are made from.

So, if we have an aluminium-to-aluminium interface such as the one between the armtube and our bearing carrier, the AI value is the same so the two parts will tend to react rather like one.

jeff@audiomods.co.uk

In the stub and counterweight the aluminium/brass/lead/brass interfaces have very different AI values, so energy will reflect rather than pass through. Like this:



The values can be expressed as:

$$RE = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2 \times 100\%$$

Where RE is the reflected energy and Z1 & Z2 are the acoustic impedances.

Material	Acoustic Impedance
Aluminum	17.3
Brass	36.5
Glass	17.4
Lead	27.2
Magnesium	9.90
Perspex	3.2
Stainless Steel	44.8
Tungsten	100.0

The weight is a complex layered structure: brass, 3 layers of lead, then brass or stainless steel, held under considerable pressure by 3 high tensile allen bolts. It's machined in such a way that only the lead and the nylon locking screw is in contact with the stub. We do this by accurately boring and reaming the weight, then pulling the bolts down to the final torque. This "spreads" the soft lead a tiny bit, leaving it slightly proud of the reamed hole. Having two dissimilar metals bonded strongly together stops "ringing" and tends to convert mechanical energy into heat. The effect is to absorb but not reflect vibration from the arm. We can see from the table that tungsten would be a very good substitute, but this is not a commercial project and the complex machining and threading is simply too difficult.

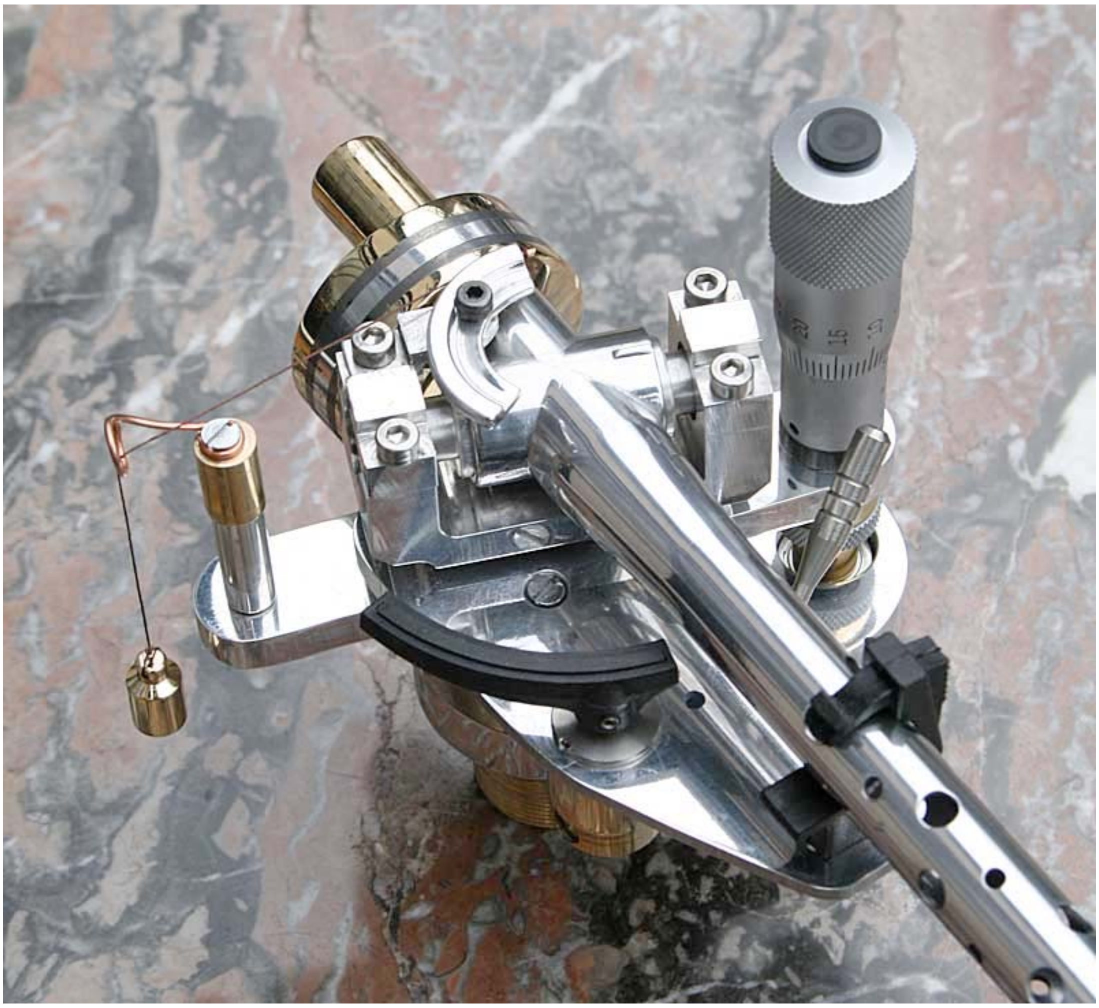
Low-cg counterweights
If we rigidly fix loads on the end of a pivoted beam, the more they are below the pivot point, the more "stable" the beam is, ie the more it will tend to return strongly to horizontal when deflected. If the mass were exactly on the centreline the beam would be happy to stop in any position. So if we make a tonearm whose counterweight has a very low cg it will tend to return strongly to level when it is displaced by a warped record. The downside of this is as the cartridge goes up, vtf increases; as it goes down, vtf decreases. This effect is most serious with highly compliant cartridges where the cantilever will be most displaced. At the other extreme, if the arm is balanced exactly along the centreline it will only have the vtf of the cartridge to return it to the correct position and exactly the opposite will happen.
A very low cg might also help prevent chatter in poor bearings by evening out dynamic bias (torsion) forces, and this may be the reason that such weights seem to offer a quick bolt-on improvement for Rega arms. The real answer is to get better bearings!

If you look carefully at the Michell counterweight, you will notice that, as well as lowering the cg, it moves the mass outward in plan. This will have an effect on the yaw inertia, the same as we do with the heavier arm yoke, and for the same reasons it will help the performance. It's a clever design.

For the best compromise we need to create a counterweight whose mass is biased a little low to exert some control without over-stabilising. A precise calculation would depend upon the exact cartridge compliance, cartridge mass and the amount of warp we find acceptable. So we just take an average.
Our counterweights are lightened above the centreline and the fine adjustment weight sits well below it to put centre of mass about 15% below the centreline, useful for controlling warp tracking without overstabilising. By changing the mass of the fine adjustment weight, we can tailor the arm for different cartridge compliance ranges.

Antiskate

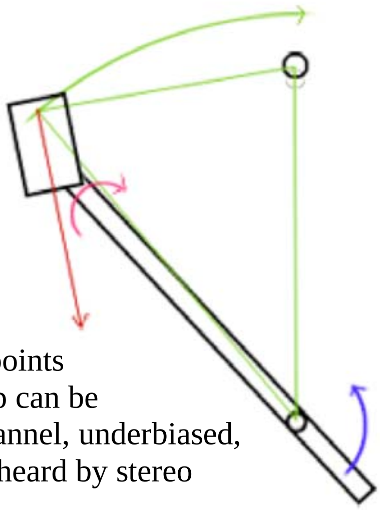
The standard Rega antiskate works OK. You can’t really trust the numbers to set it up by and it doesn’t apply a really consistent force across the whole record, but this is a budget arm.



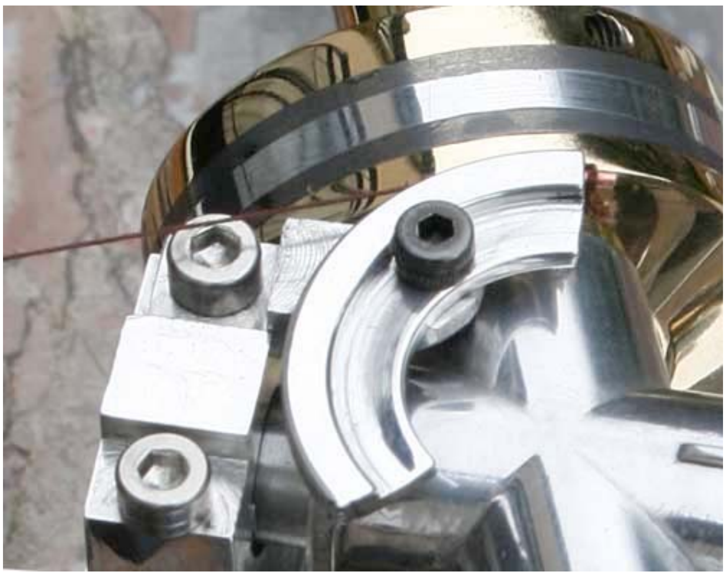
Antiskate is much more important to good reproduction than is often thought, because the forces we need to counteract are created by the music, not just the track of the groove. It’s a very complicated subject.
Why do we need it? Passing the stylus through the record groove causes drag. If the cartridge were aligned straight down the arm and at a perfect tangent to the groove this force would act squarely on the bearings with no sideways component at all. This, rather than the lack of tracking error, is what makes linear trackers so good.
But it doesn’t work like that. The cartridge is at an angle to the armtube to make the geometry work, so the drag force becomes a torque on the arm that’s translated into a movement towards the centre of the record. This torque is transmitted to the arm bearings, the cause of chatter in poor bearings.
If we don’t have any antiskating then the inner (left signal) groove of the record gets pushed against more strongly than the outer groove and we hear distortion in the right channel. So we must add a little counteracting force outward to stabilise it.
The problem is how much.

The amount of antiskating force we need to apply is affected by many things:

• Groove friction. This is affected by the friction coefficient of the record and very much by the stylus profile. This effect is stronger at the outer grooves where velocity is highest.
• Tracking error. Going across the record this starts high, reduces to zero, climbs, falls back to zero then finally climbs again. Just how much this affects the drag depends on the stylus profile.
• Groove modulation. The more energy put into the stylus by the signal, the more drag. This is a reaction to the energy used to excite the cantilever and the energy used to create electrical current in the generator. This effect is more marked at the end of the side than on the outer grooves and low frequencies create the most drag.



So we have a force constantly varying as the record is played that we must counteract without knowing its exact value. Setting up on a blank disc is not accurate because it doesn't reflect the real drag value of the cartridge in the groove or an average value of the dynamic drag. Setting up with a test record is much better but here it's important to set up at a number of points across the record. Careful listening with a known record is the final test. Listen carefully at outer and inner grooves, around the null points and halfway between them. Distortion from bias setup can be identified because it appears on one channel: right channel, underbiased, left channel, overbiased. A slight mismatch might be heard by stereo image moving to left (under) or right (over).



Our quadrant antiskate does help you to optimise the force across the record, weighting it at the outer and/or inner grooves. The setting arrived at will be influenced by the kind of music you play.
Depending upon the stylus profile, simple acoustic music will probably be more neutrally biased, whilst orchestral or opera that tends towards crescendo on the inner grooves might need a bias weighted towards the record's centre. A high-compliance cartridge might need a bias slightly weighted towards the outer grooves. Only listening will tell.

Arm tube modifications

The most important modification is the effect of the solid pressed-in bearing carrier, which changes the characteristics of the RB250 armtube to rather like the RB300, but the other changes also contribute significantly to the sound.

Polishing an arm tube
Unless you intend to carry out other mods to the arm tube, removing the paint will make it sound far worse than standard.
There is no sonic advantage in polishing the arm tube. It looks nice.

There are advantages in bead-blasting the arm tube Michell style, because that affects the surface hardness a little. It also makes good commercial sense for them, because it's quick and hides surface imperfections.

Drilling an arm tube
This does have sonic advantages. The pattern and number of holes isn't critical, but there are mechanical and sonic advantages in the spiral drilling with graduated hole sizes that we've developed. The exact layout and size depends on the target mass and the range of cartridge compliance aimed for. Michell and Origin Live now drill/slot their armtubes. We started in 2003. Enough said.

You could choose either spirals or a row of holes underneath (Michell) style.
Spiral holes have the advantage of reducing mass if that's needed for a high-compliance cartridge.
Slots: I have reservations about slotting the arm tube, though I have no test or experimental data to support it. The strong point of the Rega arm tube design is that it is deliberately very rigid. It would be expected that reducing the rigidity by cutting a long slot would tend to introduce bending vibration modes. Maybe this is OK, like second harmonics in a unipivot.

Earthing the arm tube
The arm is originally earthed by a strap fixed into the counterweight thread. This can cause problems even on standard arms.
If you are using our upgrade kit then the armtube must be earthed – ceramic bearings won't conduct!
Our method is to drill the armtube to add a very small copper stud onto which the earth wire can be soldered. This is kept completely separate from the signal wiring and taken direct to ground.

Arm cross bracing
This is a very effective way of controlling resonances in the arm tube.
Aluminium discs are fitted into the arm tube approximately 1/3 and 2/3 along. They need to be of a very precise diameter to fit properly. The width is varied according to the target arm mass. Calculation suggests that the normal mode of the tube changes from around 850Hz to 130-190Hz in the sections.

References

Much of the really technical analysis of the behaviour of arms and cartridges was done many years ago when the vinyl record market was huge. Some very knowlegable engineers devoted serious study to the problems and their work still remains the best basis for understanding the subject and designing solutions.

A number of the papers below are available for download from *www.audiomods.co.uk*

"*Analytic treatment of tracking error*" HG Baerwald
"*Pickup Design*" JK Stevenson (Wireless World, 1968)
"*Tonearm Geometry and Setup*" M Kessler & D Pisha, (Audio, Jan 1980)
"*Determination of sliding friction between stylus and record groove*" R Pardee, Bell Corporation
"*The skating force phenomenon*", J Kogen (Audio, Oct 1967)
"*Pickup arm design techniques*" TS Randhawa (Wireless World, March 1978)
"*Sensitivity of Phonograph turntables to normal loads*" TS Cole, (AES Journal May 1968)
"*A stereo groove problem*" G Alexandrovich (AES Journal, Jan 1961)
"*The cartridge alignment problem – a new approach*" RJ Gilson, (Wireless World Oct 1981)
"*Resonance in a tube*" Victor Reijs
"*An introduction to acoustics*" RH Randall
"*A textbook of sound*" AB Wood
"*Properties of sound waves*" JC Drury

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