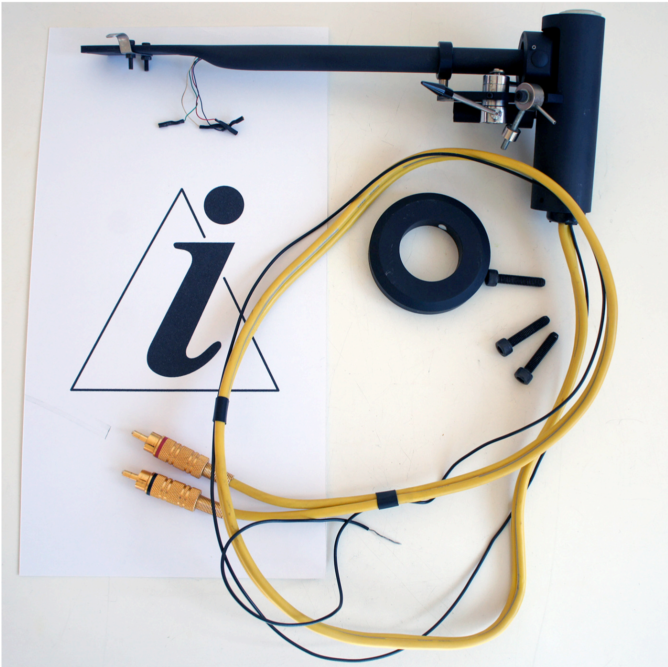
Revisiting Vinyl Record Pick-Up Tone Arms : 'Delta Inertia' and 'Mag Lev'

The Mechanics of Counterweights, Springs & Pseudo Magnetic Levitation

More photos, movies & more information here:-

https://tinyurl.com/Delta-Inertia-Mag-Lev



1. Aims

1. To describe in words the forces a pickup stylus reacts against whilst playing a vinyl record (hopefully at least partially achieved here).

2. To produce a robust written mathematical description of the physics and mechanics of the inertial and gravitational mass of a cartridge and tone arm combo, against which vibrations induced by a vinyl record in a pickup stylus react against (beyond my ability).

3. In particular, descriptions and comparisons between a) the (pseudo) 'Mag Lev' vinyl record playback tone arm, b) the 'Delta Inertia' which uses a spring, and c) standard tone arms with counter weights (hopefully at least partially achieved here).

4. To be published as a short historical archive on a new web page (e.g. as a post on e.g. DIY Audio / Vinyl Addict forums / my Google Drive / downloadable .pdf on archive.org etc...) with pictures, videos and relevant links - done, you're reading this!

2. Technology

Springs: In the early 1990s I was asked by Audio Innovations (now Audio Note UK) to design a new tone arm that employed a spring instead of a counterweight called 'Delta Inertia'. I designed and constructed dozens of prototypes with many hundreds of hours of experimenting / listening tests, then set up a production run of around 120 all sold via retail dealerships. Everyone thought a sprung tonearm yielded significantly better sound reproduction c/w a counterweighted tonearm, especially in the bass and dynamic contrast.

But we didn't know how to apply solid body mechanical analysis resulting in little objective agreement on the physics accounting for how & why replacing the counterweight with a spring could improve sound quality. Springs had been used before in 'juke boxes' to enable records to be played vertically, but not for improved sound quality. We also knew about the Leak 'Dynamic Pickup' tone arm for playing 78RPM records from the 1950's that featured an adjustable spring on a slider under the arm instead of a counterweight.

Proxy for Tracking Weight: On the 'Delta Inertia' a spring tension screw is manually adjusted to achieve the same deflection of the cartridge's cantilever when placed on a record surface, as it would do in a conventional counterweighted tonearm, (where the optimum tracking weight e.g. 2 grams is adjusted by shortening or lengthening the distance between the counterweight and pivot).

Drawback: The 'Delta Inertia' had a spirit level fitted because a tone arm without a counterweight must keep its 'side to side' horizontal pivot plane level with gravity to maintain constant stylus pressure in the groove (i.e. tracking weight).

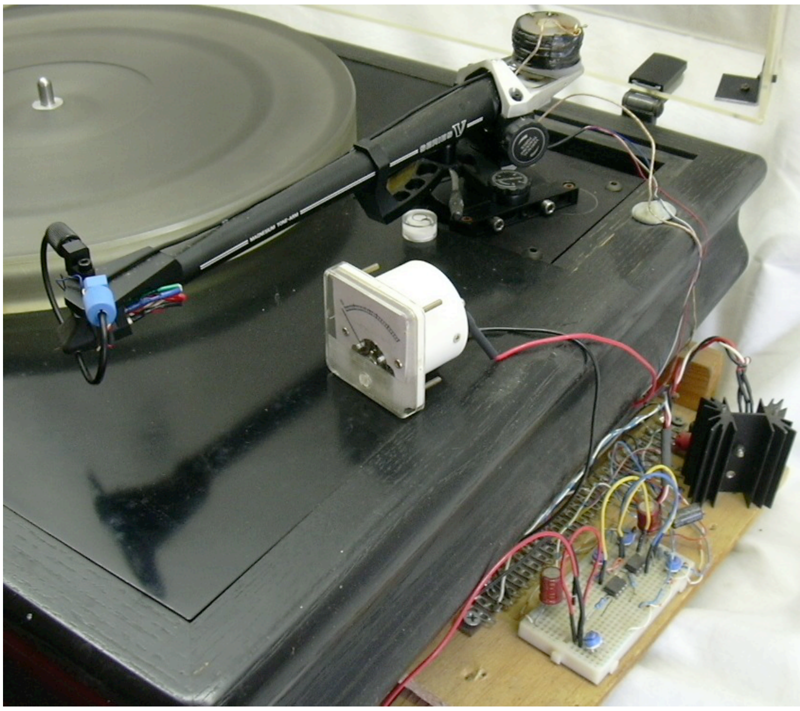
However, this proxy applies only at the surface of the record, not even a few millimetres above or below it. This could be a tricky adjustment, especially on a sprung sub-chassis turntable. Also, a cartridge might wear out and prematurely fail due to such unusual forces on its cantilever suspension. In the real world these fears proved insignificant, and none were ever reported. Nevertheless, despite attracting an underground reputation as being 'ultra rare and exotic' with many long term dedicated users, sales were slow so the project was terminated ostensibly on these grounds.

Magnets: I thought these drawbacks could be overcome. So in 2003 I built a version that replaced the spring with two permanent magnets in opposition. Magnets it turned out enabled better record warp riding ability, and far more stability bouncing around on spring sub chassis turntables than tonearms with springs or counterweights could.

Electro-magnets: To be able to fine tune the proxy tracking weight, whilst the record was playing, I put a coil around one of the permanent magnets. Its ability to repel the other permanent magnet could thus be modified with a simple circuit connected to a fully stabilised DC power supply to vary the current flowing through the coil thereby set its induced field strength.

Feedback: Then I built an active version. Cantilever displacement would send a continuously variable analogue electronic signal to control coil current. This was achieved with a gap in a fibre optic cable engineered into the left & right sides of the body of a Goldring 1040 cartridge, adjacent to where the cantilever exits. This enabled cantilever deflection to vary the intensity of light across the gap, thereby providing the control signal for a circuit designed to control the electromagnet coil current. The proxy tracking weight could then be actively set in real time. Sound quality remained very good, same as without feedback applied.

Revisiting Vinyl Record Pick-Up Tone Arms : 'Delta Inertia' and 'Mag Lev'
The Mechanics of Counterweights, Springs & Pseudo Magnetic Levitation



Warps: Additionally, I expected such a sensor control circuit could (in theory) be tuned to track record warps even better than the passive magnets version, by both following warps in real time, and by damping any resultant resonance in the arm levitation magnets, and in turn perhaps also damping cartridge and turntable suspension resonances. However, active feedback yielded little if any improvements in these areas compared to the already very good passive electromagnet version.

Prior Art: I was ignorant in the early 1990s whilst working on the 'Delta Inertia' tone arm, that in 1978 Lewis Eckhart was granted US patent 4,114,895 on a tone arm using both spring and (pseudo) magnetic levitation. Indeed I first saw it July 2021 researching this essay. Eckhart aimed to reduce inertial mass to better track record warps by replacing the counterweight and stem it rides on with a leaf spring of same length. A permanent magnet is attached at the spring's far end. And a curved bar magnet is fixed underneath.

As records are played, the tone arm, and its leaf spring / magnet assembly follows the path of the curved magnet below, with like poles arranged facing each other to achieve (pseudo) levitation. Any inertial changes induced in the tone arm mass whilst riding warps are compensated for by the spring flexing, with the tracking force kept constant by the (pseudo) magnetic levitation assembly. Groove tracing accuracy is likely to be significantly improved by such a spring / magnet assembly actively modulating the resultant forces exerted on the stylus by record warps trying to throw the stylus out the groove.

Post Art: In 2009 GB patent 2459273A was granted to Eric Vant on another tone arm with no counterweight, claiming “Superior audio reproduction is possible due to the improvements in stylus trace accuracy and a more constant tracking force”. It employs (pseudo) magnetic levitation, and like all such tonearms, upwards arm movement whilst riding a warp increases the gap between magnets, thereby they “dynamically increase the effective mass (weight) of the tone arm cartridge” to better track warps.

Vant's (pseudo) magnetic levitation assembly is mounted at 90 degrees facing upwards, directly above the gimbal bearing pivot planes. This is done to minimise changes in the direction of gravity on the tonearm's geometry / mass whilst it tracks inevitable record warps, thereby minimising oscillations in its moment of inertia. Vant claims this is an improvement on Eckhart's spring / magnet, and indeed on all counterweighted tonearms.

Same old Drawback: Eckhart (1978) claims his tonearm “maintain[s] a relatively constant downward pickup tracking force over a relatively wide range of variations in the vertical displacement of a record surface”. But like Vant (2009) Eckhart also fails to note all tonearms without a counterweight must in the first instance be carefully mounted level to reliably maintain tracking weight, whatever system is then employed to apply it.

3. Analysis

Gimbal Bearing: All tone arms including the 'Delta Inertia' and the 'Mag Lev' can only move in 2 degrees of freedom (up and down & side to side) of the 6 available (3 translational + 3 rotational). All others movement must be rigidly fixed to a mechanical impedance ground except a) following undulations in the path of the groove as the record rotates, and b) orientating the stylus to only pickup acoustic vibrations in groove walls.

Pick Up Cartridge: Acoustic vibrations i.e. spacial displacements impressed onto the sides a record groove are converted to an electrical signal. In a moving coil design, the magnet side of such a converter, from which the cantilever pivots, forms a mechanical impedance ground by being rigidly fixed to the tonearm's gimbal bearing and the turntable.

Reference Pivot Point & Mechanical Impedance: At audio frequencies this pivot point should have a high mechanical impedance, so it can act as a reference for audio vibrations coming from its other side, i.e. so the cantilever, signal coil, and stylus tip, have something solid to act against. This parameter is crucial to obtaining accurate mechanical measurements of the impressed acoustic vibrations on groove walls, so the cartridge can reliably convert such stylus oscillations into the most faithful electrical signals possible.

Mechanical Filter & Resonance: In other words vibrations above 20 Hz must not disturb the pivot point, or signal is lost. At these higher frequencies it must present as high a mechanical impedance as possible. But lower frequencies must be transmitted i.e. low impedance, or else the arm / cartridge body cannot follow the path of the groove or record warps, plus cantilever suspension failure rapidly becomes more likely.

Conventional Counterweighed Tonearm: Is a beam with a mass at each end, with a 2 degrees of freedom gimbal bearing mounted between them. It is a seesaw or flywheel. All together the moving mass typically weighs circa 300 grammes. But its so called 'effective mass' is a lot lower. Its conventionally determined by calculating the moment of inertia about the pivot, then calculating the equivalent mass required at the effective tonearm length to provide the same moment of inertia. Typical values drop out at around 10 grams.

Revisiting Vinyl Record Pick-Up Tone Arms : 'Delta Inertia' and 'Mag Lev'
The Mechanics of Counterweights, Springs & Pseudo Magnetic Levitation

Effective mass: is presented as a crucial parameter for tuning cantilever suspension resonance(s) to be lower than bass frequencies (c20Hz) but higher than warp frequencies (c5Hz). However, as we shall explore further below, big sound quality and warp riding improvements can be won by arranging for all the tone arm mass to be available (not just the 10 grams or so 'effective [inertial] mass') without exciting cartridge suspension resonances. This increases the mechanical impedance, for audio frequency groove vibrations to react against at the cartridge reference pivot point, avoiding mechanical impedance non-linearity and incoherence wrought by counterweights.

Axis of Rotation & Gravity: Such 'effective mass' calculations maybe correct, but appear misapplied and / or irrelevant and / or persist due to unexamined faith in counterweighted tonearms being good enough and / or overlooking the following two factors.

First, the weight (potential energy due to gravity - Kgf) of a counterweighed tonearm has the opposite sign on opposite sides of its pivot axises thereby cancelling out (save circa 2g tracking weight). As audio frequencies get lower, it behave's more and more like a flywheel with a 2 gram weight offset plus its circa 10 grams inertial 'effective mass'. It can more easily and quickly store and release forces, back and forth through the reference pivot point in the direction normal to its input axis as inertial (10 grams side to side and up & down) and / or gravitational potential energy (2 grams but only up and down).

Second: Forces at 90 degrees to normal groove direction, such as signal vibrations impressed onto the groove wall, don't always react against all the (above calculated) 'effective mass' throughout the entire cycle of signal excursion. At zero signal crossing points forces delivered by the groove wall are normal to groove direction and react entirely against the tonearm gimbal bearing and however many kilograms of turntable mass. As signals peak, the 10 grams 'effective mass' begins to contribute more to the mechanical impedance, and the gimbal less. In other words, the further from normal to groove direction the angle of the cantilever is following vibrational peaks, the less 'effective mass' plus the gimbal bearings 'effective mass' (due to it only having 2 axis of freedom) is available to react against at the reference point - a 3 or so orders of magnitude swing.

Gimbal bearing 'effective mass': can be arranged to be available all the time, by mounting the (pseudo) magnetic levitation equipment at 90 degrees facing upwards, directly above both pivot point planes (as described above 2009 GB patent 2459273A).

Distortion: Such frequency dependent mechanical impedance oscillations, coupled with amplitude variation of several orders magnitude, must significantly distort accurate mechanical measurements of the impressed acoustic vibrations on groove walls.

It appears counterweighted tonearm 'effective mass' calculations erroneously assume some static value or another is always fully available to act agains at the reference pivot point, for all possible signal vibration directions, frequencies and amplitudes.

'Mag Lev' Tonearm: Has an order of magnitude higher mechanical impedance at the reference pivot point, capable of delivering significantly higher resolution (all other factors being equal), compared to a counterweighted tone arm. 'Mag Lev' is a beam with a pivot at one end and a mass at the other suspended at 90deg to gravity's direction of pull by (pseudo) magnetic repulsion (or a spring in the case of the 'Delta Inertia'). Its like a simple pendulum with its pivot fixed in space (i.e. mounted on a turntable).

The entire 100grams of mass is thus suspended where all its potential energy (acceleration due to gravity) is available as a reaction force at the cartridge's reference pivot point, against which the cantilever, signal coil and stylus can measure groove vibrations.

In other words, compared to a counterweighed tone arm's 10 grams 'effective mass', 'Mag Lev' has 100grams of 'actual mass' at the reference pivot point.

This will reduce the above mentioned mechanical impedance distortion by one order of magnitude (i.e. distortion due to frequency dependent oscillations between 'effective mass' and tonearm gimbal bearing geometry, caused by the signal being at 90 degrees to groove direction, and the pick up stylus being a short pivot).

Linear Law: The force between each end of a spring changes linearly with distance: double the force, double the distance. On the scale of tonearms, gravity also acts linearly.

Square Law: However, magnetic force obeys an inverse square law with distance. If the distance between two magnets is halved the force between them will increase to four times. But if the distance is doubled the force falls to a quarter. This means vibrational forces from the groove in both the up and down directions react against the following two counter forces in the cartridge reference pivot point:

Up: In the 'Mag Lev' tone arm, groove vibrational forces in the up direction increases the gap distance between the two levitation magnets causing the magnetic repulsion force to rapidly fall off as distance increases. As the amplitude of groove vibrational forces in the up direction increase, the levitation effect of the magnets on the mass of the arm decreases. This means groove force rapidly reacts against more mass force due to the arm's 100 grams of gravitational potential energy.

Down: When Groove vibrational forces decrease the distance between magnets, they react against a steep increase in reaction force with distance due to magnetic square law.

A Valley of Stability: is thus created at the cartridge's reference pivot point for groove vibrations to react against. The 'Mag Lev' implementation of pseudo magnetic levitation mechanism may explain the improved suspended sub chassis compatibility and warp riding performance compared to springs or counterweights.

Gimbal Bearing Torsion: Repelling magnets are not stable, unlike attracting magnets that tend to centre on one another. They are actively trying to push one another off axis. Bearing surfaces in the gimbal's up and down axis are thus additionally tensioned compared to the tension a counterweight or spring would exert, reducing 'bearing chatter'.

Conclusion: A conventional counterweighed tone arm with a moving mass of circa 300grams has four distinct disadvantages:

1. Mostly cancels out inertia forces for groove vibrations to react against as seen from the cartridge reference pivot point due to the see saw / flywheel effect; and

2. Offers only circa 2 grams of residual mass (due to gravity) to react against but only in the up and down axis; and

3. No square law magnetic force advantages for groove vibrations to act against; and

4. No gimbal bearing pre tension.

Compared to the (pseudo) 'Mag Lev' tone arm, which has four distinct advantages:

1. In the side to side axis its 100grams gravitational mass is not configured as an inertial energy store like a seesaw or flywheel - thus eliminating this source of mechanical impedance distortion at the cartridge's reference pivot; and

2. In the up / down axis a significant square law magnetic force mechanical impedance advantage for groove vibrations to react against at audio frequencies (above c20hz) compared to spring or gravity forces due to all its circa 100grams mass being suspended in a 'Valley of Stability' by magnetic force; and

3. Improved warp riding sub-sonic frequency stability (below c20hz) compared to both springs and counterweights, again due to square law behaviour; and

4. Pseudo levitation configuration of magnets places gimbal bearings in torsional tension thereby reducing distortion inducing chatter in bearing surfaces that are by definition always present and potentially excitable by groove vibrations.

Natasha Thoday, Brighton UK, 5 july 2021

Links:

- https://tinyurl.com/LeakToneArm
- https://www.vinylengine.com/library/audio-innovations/delta-inertia.shtml
- https://tinyurl.com/DeltaInertiaDescription
- https://tinyurl.com/DeltaInertiaEbay
- https://twogoodears.blogspot.com/2014/06/audio-note-ai-rear-weightless-tone-arm.html
- https://en.wikipedia.org/wiki/Magnetic_levitation#Methods
- https://www.kjmagnetics.com/blog.asp?p=repelling-magnets
- https://sme.co.uk/audio/product/series-v/
- https://socratic.org/questions/how-does-distance-affect-magnetic-force
- https://patents.google.com/patent/US4114895
- https://patents.google.com/patent/GB2459273A/en