The Compliance of a Cartridge and the Resonant Frequency of the Tonearm & Cartridge Combination

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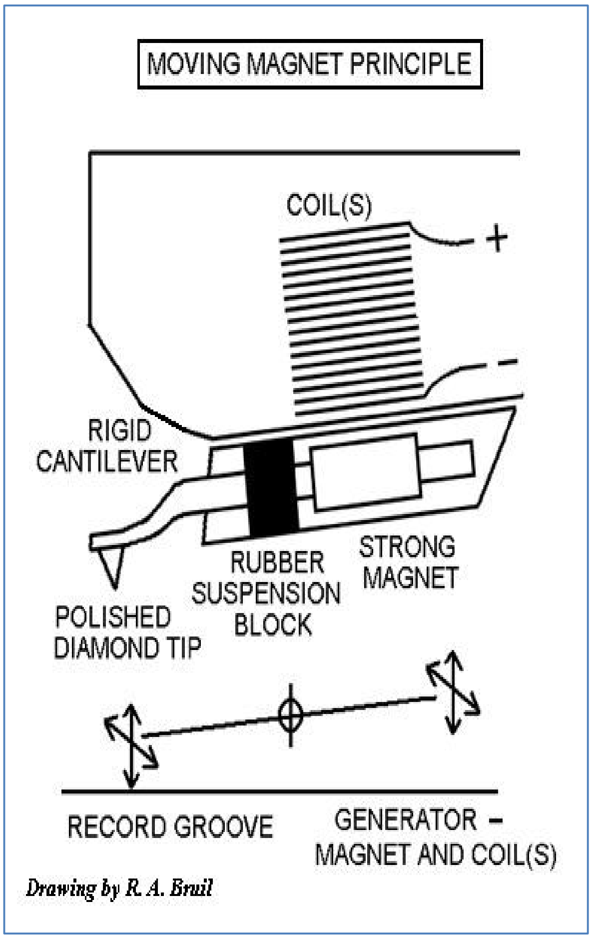
With this topic we enter the arcane world of analog technology which has an abundance of confusing information to the lay person. Check the internet and you can get a huge variance in answers and sometimes even misguided or plainly wrong information.

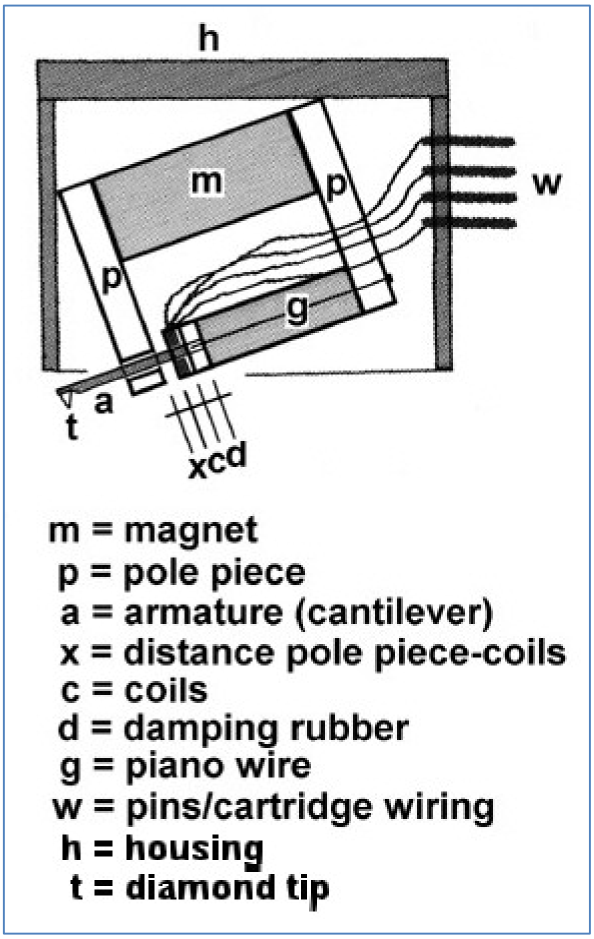
So what does it matter if the cartridge and tonearm aren't precisely matched? Will I even hear the difference? Well to establish some basic foundations, you can still get music from a really badly matched arm and cartridge. It just won't be as good as you can get from a well-matched combination. When you consider that you can get sound from a tin needle into a 1920's windup phonograph horn the method of mechanical pickup can be fairly rudimentary.

At the heart of issue with modern cartridges (or pickups) is the tiny suspension of the cartridge cantilever to cartridge frame (body) interface. There are several different designs in the market which include moving magnet, moving iron, moving coil and strain gauge and optical sensor variants. Some designs like the London Decca and early Neumann DST use a different suspension design to bring the coil system closer to the moving magnet/iron to reduce the effects of bending and flexing cantilever tubes and rubber suspension resonances.

For the purposes of this analogy we will use the well-known moving magnet or moving coil designs.



(Figure 1: Exploded diagram of moving magnet cartridge)



(Figure 2: Exploded diagram of moving coil cartridge)

So where do the problems lie? It is the Rubber Suspension Block or the damping rubber shown in the diagrams above that are the critical flexing component in a standard cartridge. This mechanism forms a spring damper system necessary for the diamond tip to read an LP modulated groove. The issue is the softness or hardness of this rubber. We call it compliance in elastomeric terms. How "bouncy" is it, how much shock will it absorb.

Well let's look at the problem from another perspective. An automobile engineer has similar problems to solve.

How so? Imagine if every road you ever drove on was going to be perfectly flat and smooth. You could drive a car with no suspension on this perfectly flat and smooth road and the car ride could be acceptable to the average passenger.

Now imagine that same car with no suspension has to drive over a bumpy potholed country road. You wouldn't be able to keep the car steady or the ride safe and comfortable as the wheels would bounce as they would react sharply to each bump.

Enter the suspension engineers who with careful design of the weight of the car and the knowledge of the tyre technology then specify a series of springs at each wheel and a damping mechanism such as a shock absorber to even out the shock loads from the regular oscillations the spring system is designed to handle.

With a tight curvy race track the engineers would change the stiffness of the springs and the damping of the shock absorbers to make the car handle the tighter curves and long straights.

If you take that car to the local hardware store and then load the boot (trunk) with an overload of cement bags, the springs will sag (as they are not designed to carry such a heavy load) and the original design for safe handling will be changed to the point that the car will feel sluggish and very soggy and not be able to handle the corners as well without losing traction.

So now let's reimagine the car as a phono cartridge. The tyre can be likened to the diamond as it contacts the road surface. The suspension arms that hold the wheel in place can be likened to the cantilever tube as that transfers the diamond movement to the body. The rubber grommet that forms a spring and shock absorber system on the cartridge (to allow the cantilever to flex sideways and up and down and in a polar motion) can be likened to the spring / absorber on the car. The winding roads can be likened to the grooves in the record.

The tonearm wand and counterweight assembly can be likened to the car body.

So the tyre and suspension design engineers were given a brief to deliver a good quality system which can drive over the majority of roads.

The car designer was given the brief to design a car body that would work with the majority of tyres and spring settings in the market to drive on the widest variety of roads.

Now we come along and decide to choose our own tyres, and suspension settings and expect them to bolt onto any car we like from any era to go driving down the winding road. Yeah right! That's going to be 100% successful every time ;-)

In the analog world we would like to be able to swap any cartridge into any tonearm and get magic 100% of the time. Just like the car analogy that's unlikely to be 100% successful every time ;-)

So when you're shopping for a new cartridge or new tonearm you need to do some homework or rely on a trusted engineer to advise you in how to get the best performance combination.

As a start you need to select a cartridge with a published suspension design that will specify if it is High, Medium or Low compliance.

A High compliance cartridge suspension will be very “soggy” or “soft”. This means it won’t like a heavy car body to perform at its best. It will prefer a lighter body so the suspension can react nicely and evenly to the undulations of the road (i.e record groove).

A Medium compliance cartridge suspension will be between “soft” and “firm”. This means it won’t like a heavy car body or a super light one to perform at its best. It will prefer a medium weight tonearm (car body) so the suspension can react nicely and evenly to the undulations of the road (record groove).

A Low compliance cartridge suspension will be “firm” or quite stiff unladen. This means it will need a heavy car body to perform at its best. It will prefer a heavier weight tonearm (car body) so the suspension can react nicely and evenly to the undulations of the road (record groove).

So how do we pick from the myriad of options out there?

Fortunately most good cartridge manufactures will specify a Compliance rating. They specify this in a unit of measure called a “Dyne” or they publish it as a “C” for Compliance rating.

The symbol “C” refers to the compliance of a cartridge. The lower the compliance, the higher the value of C. Practically, there will be more elasticity if the value of C is lower.

When a constant or frequent force is applied to the cantilever, its moving at the height of the stylus is indicated in cu (one millionth of a centimetre). This force is measured in Dyne.

Simple yeah? Well the world of cartridge manufacturing is split between Europe, Asia and USA. Just like the automobile standards there are different industry bodies who publish performance and ratings.

So “Dyne’s ain’t Dyne’s” to paraphrase an old TV commercial

The Japanese have their own way of measuring the “Dyne”, the Europeans and USA another. Some measure the “vehicle” as it drives on the undulating road (the Dynamic method) others put a weight in the “boot or trunk” and measure how low the suspension sits with a standard number of cement bags loaded (the Static method).

The manufacturers of cartridges do not always state a useful value for C (compliance). Some (sadly) do not publish any numbers (don’t worry as there is a way to solve this by physical observation when the “rubber hits the road” i.e when you play the record).

To get a common ground to compare from all manufactures it is useful to use a cartridge compliance reference of 10Hz (Hertz is a measure frequency or resonance).

Published figures of C coming from Japan usually are measured at 100 Hz and are Dynamic. So to get a simple standard number we can take a Japanese specification and multiply by a factor of 1.5-2 to get similar to a 10Hz specification.

Figures of C coming from USA often are static values, so they should be halved.

Most figures of C coming from Europe are already stated at 10 Hz

Why 10Hz?

Well we are trying to match cartridges with tonearms and it is desirable to achieve an end result of a dynamic natural resonance between 8hz and 12Hz as this band of frequencies are above the “warp wow” resonances of a record and below most recorded music signals (except for those pesky cannons on Telarc 1812 Overture;-). The Resonant Frequency RF is the frequency at which the arm/cartridge combination resonates. A cartridge that resonates does not touch the groove perfectly loses contact with both sides of the groove and causes audible distortion and mis-tracking.

A diamond must be kept perfectly stable and “stuck” to both sides of the groove. If the tonearm is too heavy for the suspension it will affect the precision and dynamics in instantaneous tracking. If it is too light the same problem of bumping into natural resonances occurs.

The RF is very important because it has to fall down into a precise band of frequencies between 8 - 12 Hz. On one hand, if the RF is too high, the cartridge/arm combination will not track the groove perfectly because the musical frequency in the groove is on those same frequencies the stylus will naturally resonate at due to the suspension compliance (or non-compliance).

If the RF is too low, the stylus will resonate on the frequencies where often the records are affected by inaudible spurious low frequency vibrations such as platter wobble and warped records or rumble from cutting lathes and bearings.

If the RF is rated between 8 and 12 Hz, where there is usually no signal, the stylus will not resonate at all.

In the car analogy this is a well-balanced design that can drive on sporty winding roads and comfortably float over potholes and bad bumps. Pure driving pleasure ;-)

When we say that an X cartridge has a compliance of 10 cu/dyne at 10 hertz, we are stating that its cantilever will move over 10 millionth of a centimetre at 10hz signal being present.

The compliance should be as constant as possible in every polar direction. This outcome depends on many factors, in particular on how the combination of suspension is devised (stylus, cantilever, rubber dampers, coils/magnets) and in which grade these elements are to affect the compliance. For the stereo stylus, the movement of the cantilever inside the groove is recorded on both channels. This needs to be free to move in a “circular” pattern (left, right, up, down, roundabout, but not back and forth).

The compliance can be measured both statically (zero Hz) and dynamically (10, 100 and very rarely 1.000 Hz).

When the compliance is measured in a static way, the mean value is approximately the double of the value we would measure at 10 Hz and the quadruple of the value at 100 Hz.

On average, the value of the compliance at 100 Hz (usually referred to Japanese cartridges) must be simply doubled to find its correspondence at 10 Hz. The static compliance (usually on US cartridges) must be halved in order to find its value at 10 Hz.

Knowing the compliance at 10 Hz is very important. In fact, to calculate the Resonant Frequency (RF) of the arm/cartridge combination there is a formula that considers the insertion of the compliance data rated at 10 Hz. This rate refers to the European cartridges, since their compliance is almost always at 10 Hz.

Calculations vs reality.

It is important to note that calculations are not to be confused with actual performance. The ultimate check on performance is to use a specialised test record with resonance bands that are designed to stimulate the frequencies between 2-100hz to measure actual peak modes. These can be displayed on an oscilloscope or PC version thereof. This is one of the ways to confirm real world combinations.

Calculations are handy to plan for a potential purchase or evaluation on your system.

The calculation roughly takes into account the fact that the tonearm has its own RF, which depends on many factors like the arm pivot, the materials, the shape of the rod and the “height” of the pivot with respect to the stylus. To keep it simple we can use the following calculation as a good approximation.

A good formula for calculating the RF of an arm/cartridge combination is:

$RF = A \div \sqrt{} M \times C$

Where:

A = 1.000 ÷ 2 π = 159.23 (you can also use the fixed value of 159)

M = sum of all masses (arm, screws and cartridge)

C = compliance (at 10 Hz)

For example:

Say we have an arm of with a published Effective mass of 12 grams and a Japanese cartridge weight of 10 grams, with a compliance of 5cu/dyne/100 Hz.

Effective Mass of the arm is another topic in its own right and often not published by the arm manufacturer or not published accurately. But for our example we are using a trusted arm manufacturer with good engineering design.

We want to know the RF of the tonearm/cartridge combo. The first thing we have to do is to transform the compliance from 100 Hz to 10 Hz by doubling the value of 5, which will become 10.

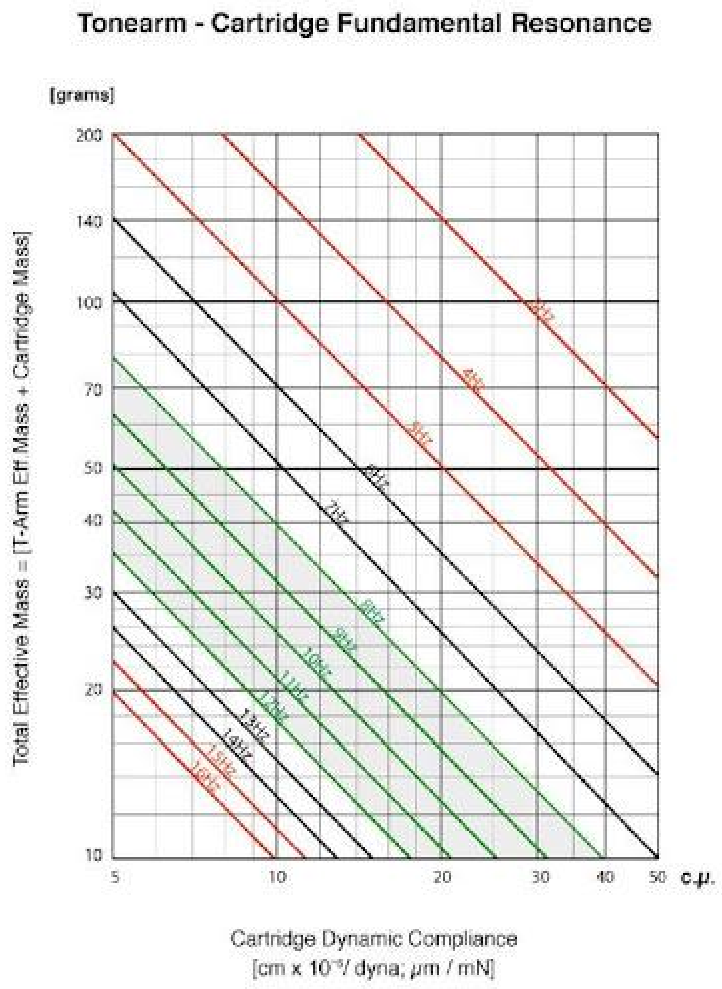
Next we will add up the different masses: 10 g (stylus) + 12 g (arm) +1 g (screws) + other things (like finger lift, in this case let us say they are zero) = total 23 g.

Then we multiply 10 x 23 = 230

The square root of 230 is around 15.17.

Finally: 159 ÷ 15.17 = 10.48 Hz, a value that places itself in the desired interval of 8 -12 Hz.

Another quick way to check compatibility is to plot the predicted resonance using the graph below. Add the weight of cartridge and screws to the Effective Mass of the Arm (manufacturer should publish this). Look across to the Dynamic Compliance (manufacturer should publish this) and hopefully it falls somewhere in the 8-12hz zone.



All that demonstrates how the compliance of the cartridge and the masses in the system can influence the choice of the cartridge that has to be matched with the arm or vice versa. In this instance we could safely purchase the arm or cartridge knowing it has a good chance at being compatible.

You might not like the sound after all that but at least you have given it the best chance.

Currently, it is easy to find cartridges with low-compliance that are quite heavy and cartridges with high-compliance that are light because they have been conceived to match with medium mass tonearms.

Some older 1950's and 1960's design tonearms had high mass and won't pair well with modern cartridges. Lightweight 1970's typically arms won't pair well with modern cartridges as they are often too light.

The tricky bit is when an arm design has an extended era of production and clients wish to try new modern era cartridges.

When paired correctly analog magic can ensue. When paired incorrectly you can experience mixed feelings and then perhaps complain about how good or bad a system sounded which is not the fault of either the tonearm or cartridge manufacturer.

Why would you put Formula One tyres and suspension spring settings on a 1950's Cadillac and expect to race on a Sunday? Put the right tyres and springs on the right car body and you will have very nice motoring and enjoyment of the ride.

The experience of a good knowledgeable analog specialist comes in very handy. They should have the skills and tools with which to check and advise on your purchase plans before you make the decision. Once set up right you will be ready for the analog journey. Happy motoring!!!!