F: Tonearm cartridge resonance:

Tonearm and cartridge are as one body supported by diamond tip over rotating point.
Cantilever with diamond tip is a small rod elastically fixed in cartridge body. In reality acts as a spring.
Tonearm with cartridge slowly follows the diamond tip across the record. Groove modulation quickly moves the diamond tip and cantilever moves coils (or magnets) thus creating electrical signal.
Now imagine that tonearm with cartridge has very low mass. In this situation diamond tip will via cantilever move the whole tonearm and cartridge and there will no movement of coils in magnetic field and no signal.

Now imagine real tonearm with cartridge and if we move diamond tip very slowly tonearm also moves along- like when diamond tip follows eccentrical record which would be in the range of 0.5 Hz.
Cartridge output would be null. But if we start moving diamond tip very fast, tonearm with cartridge will not move but coils will and we will have an electrical output.
But between these two situations when we do not have ouput (0 Hz) and we have 100% linear output (above 20 Hz) is an area where we go mixed output. Somewhere there is a resonance frequency.
Typical can be between 2-20Hz.

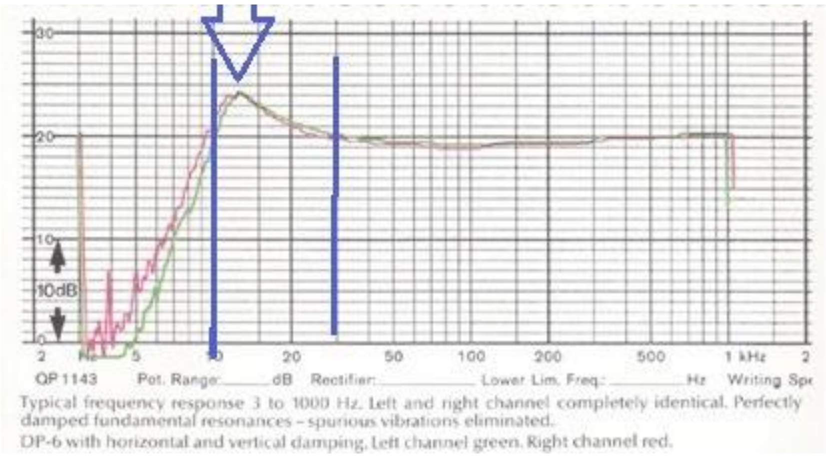
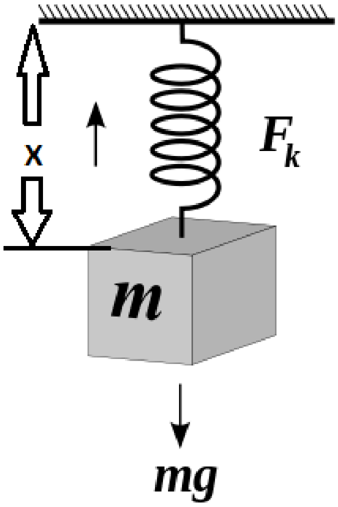


Fig. 22. Frequency response with peak resonance at around 12-13Hz

We need to observe situation when diamond tip slowly moves cartridge body with tonearm but not coils
(no output) and when diamond tip quickly moves coils but not cartridge(full output).

This can be shown on a simple spring mass system.Fig. 23. We hold up in hand spring with weight (apple if you want). Spring will stretch due mass for certain distance (X= 100%)
Now we start very slowly going up and down with our hand and observe distance X. If we move very slowly (very low frequency) X will stay the same. But if the start moving down a bit faster, then due inertia of mass spring will stretch a bit more then 100% and when we go up there will be also a bit of delay due longer travel and mass will start traveling up. But due inertia mass will travel higher and thus distance X will be less then 100%. If we move faster(higher frequency), more delay it will be and X will be more and more changing. At some rate our hand will go up while mass will travel down. At this situation X changes will be the biggest. If we then move very fast, mass inertia will keep mass in same position while our hand will move up and down and spring will absorbe all changes. At rate when X has biggest changes we say that system has a resonance. Biggest X means biggest output in cartridge combo. See Fig.22. We divide response in three areas: below resonant freqency, resonant frequency and above resonant freqauency. In reality resonance is not just one frequency but it looks like a peak.
Also it means that very little energy at resonant rate is needed to create high amplitude.



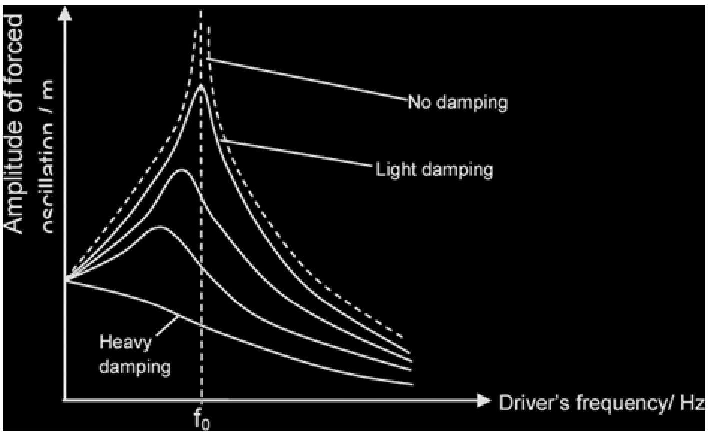


Fig. 23. Weight on string- X distance Fig. 24. Effect of damping on resonance's amplitude

Lets look at graf. Fig. 24. You can see that amplitude in theory goes at resonance in infinity. But all systems have some damping build in or we add external damping. Imagine if in our spring system mass would be submerged in water- that would slow down movement. This is the effect of heavy damping. Imagine car absorber on springs but without damping. You can see that heavier damping decrease amplitude peak but broaden output above resonance frequency.

Tonearm with cartridge and elasically suspended cantilever is a spring mass systems. With known parameters we can calculate where will resonant frequency.

Above resonance we will have linear output, below resonance we will no output and at resonance we will have too big output.

So we can not put resonance in the music area between 20-20.000 Hz. We can not put it above 20.000 Hz beacuse it is too high due real mass systems.
We need to go below 20Hz. But we must avoid any frequencies which are nerby resonant frequency due creating high amplitude- meaning tonearm will shake with the same resonance.

We have: eccentricity, warps, bearing and belt noise and it was generally accepted that best is if it is between 8-12 Hz- where is the least chance that noise will act on resonanc freqency and start vibrating tonearm itself.

We need to know what mass has tonearm and cartridge and how elastic is spring (cantilever suspension).
Mass is in grams while spring parameter is how much spring strech for given mass (gr/ mm).
But beacuse we need to know what is happening at the diamond tip we can not simply use tonearm mass because tube, counterweigt is on some distance from tonearm bearings (vertical and horizontal).

Effective mass is a fiqure in grams how sees diamond tip rotating – moving tube around tonearm bearing.

It is like a lever to lift up heavy objects- longer lever less force is needed to lift up.
In principle is like this:
For example tube has a mass of 20 grams- centre of mass is in the middle of the tube. Fig. 25.
Lets say tube is 200 mm long and therefore centre of mass is only 100 mm from bearing. But diamond tip is at the end of the tube on 200 mm and beacuse tube mass is nearer to the bearing and diamond tip »sees« it as less mass- therefore effective mass of the 20 gr tube is only 5 gr.
Matematics is about the moment of inertia but we will not talk about it here.
So similar calulation is for counteweight. Mass is 100 gr and distance of 50 mm from bearing but diamond tip will see it as effective mass of 6.25 gr. (calculation is simple). Tonearms have effective mass between 6- 30 gr.
But because cartridge mass is on 200 mm its mass is same as effective mass. So to get total effective mass we add together cartridge mass and effective tonearm mass and calculate resonance frequency.

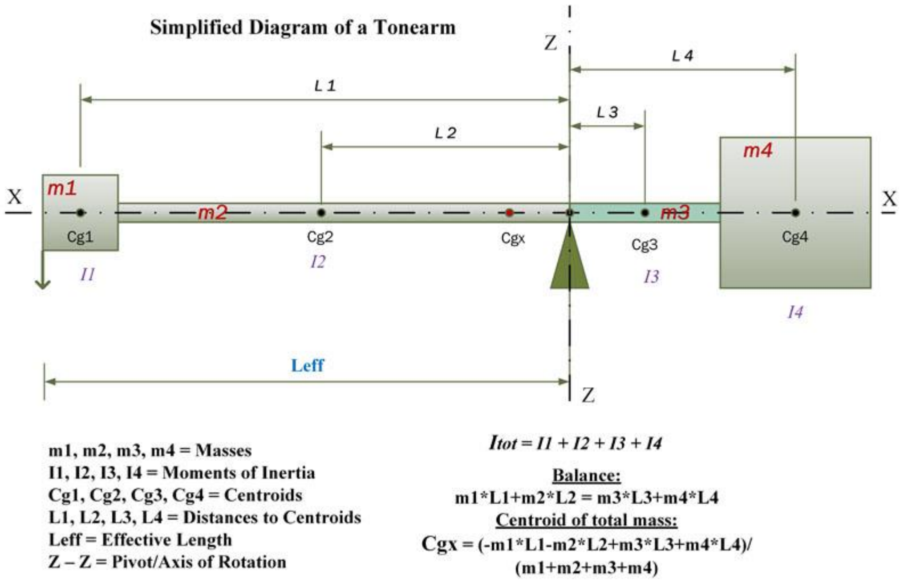


Fig. 25. Tonearm mass and effective tonearm mass- inertia

Cantilever suspension- compliance ofter refered as CU is expressed in micronmeter deflection of mN force. I will not go here in details but usefull number is 10-50. Lower number are low compliance cartridges and 50 are very high.
Usually MC cartridges have lower compliance and MM cartridges has higher. In past was idea that higher the CU better is the tracking. But in reality is not just one factor important for good sound.
But in graf below you will see that low CU requires higher effective mass of cartridge. Fig. 26.

If we look for optimal 10Hz resonance we could chose:
10 gr with 25 cu
13 gr with 20 cu
17 gr with 15 cu
25 gr with 10 cu

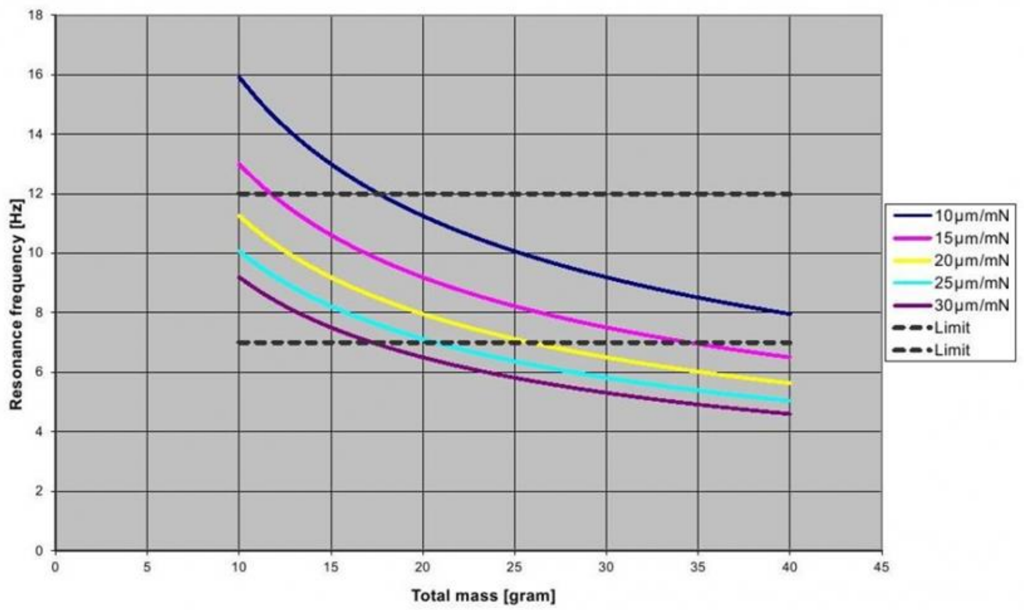


Fig. 26. Optimal effective mass tonearm& cartridge choice

Low compliance cartridges requires higher tonearm mass- there is also more feedback into tonearm but higher mass allows to construct more robus tonearm.
Resonance can go lower then 6 Hz (tangential tonearms in horizontal direction, added damping.....)