Skating force - Misunderstanding and misinformation about it.

Hakan Agustos

Hello audiophile friends.

First I must admit that I am not an authority or guru about this subject and open to comments and corrections if anything I am going to say contradicts science or math or physics.

I am an amateur hobbyist, a retired dentist who has some knowledge just enough to build DIY tube and ss amps, preamps and tonearms and turntables etc.

The reason why I decided to say something about this subject is that although fine articles have written by writers like Kogen* and Bauer* who are technical experts on the subject, there is still some misunderstanding how this phenomenon happens and even analog gurus who have a strong influence on the analog community, spreading the misinformation that the reason is "Offset" tonearms. I am saying no, not like that and try to explain here.

And these explanations will be based on science but will not be too difficult to comprehend.

I'll try to explain with a different perspective than others and you'll see some information you can't find elsewhere.

Please enjoy.

1- When playing vinyl, there is a **friction** between stylus and vinyl. Friction is important because if it doesn't exist there will be no forces causing skating.

But friction is not enough to have this force because with linear tracking arms there is also friction between stylus and vinyl but no skating force. So we must have one more thing to have skating force moving the tonearm sideways (I did not say inwards, instead said sideways and I will get to that).

This one more thing is; we have majority of tonearms with a **stationary (non-moving) horizontal pivots.**

So we have now **two main factors** causing the skating force. One is **friction** other is **non-moving pivoted tonearms**.

- **At this point someone can ask a question about "overhang" and why I did not mention it. I would say overhang is important for positive skating forces but there is and will always be a skating force with a stationary pivoted tonearm whether it is overhung or underhung, only the forces vary by being positive or negative.**
- **Even tangential pivoted tonearms; if they have a fixed pivot will have this side-force.**

Later I will elaborate that.

And **how much force we are talking about? It's roughly **10% to 12% of the VTF**.

So, a cartridge tracking at 2 grams will have roughly 0.2 to 0.24 grams of side-force (skating force, side thrust etc...)

Things that are related to and affect/not affect friction;

1a- Friction is proportional to VTF and this means higher the VTF there will be more friction between stylus and record and lower the VTF there will be less friction between stylus and record.
1b- The record turning speed does not affect, or has a very small effect that can be considered insignificant on friction, this means in practice there will be no significant change of skating force between record speeds of 33rpm and 45rpm.
1c- Modulation levels of the grooves also affect and proportional to the friction. This means highly modulated (loud) grooves have more friction levels. But in normal record playing conditions modulation levels are not that high to have a dominant effect.
1d- Record formulations have an effect on friction and so this also affects the generation of skating force.
1e- Stylus shapes also affect the friction. For example, elliptical shapes have a little more friction than spherical types. Not only stylus type but the polishing of the stylus has an effect on friction.

For the friction part above; VTF (vertical tracking force) has bigger contribution on friction, followed by groove modulation. Others have less significant effects.

Groove radius is also important and determines the varying skating force on the groove area.

Skating force is not a constant force, it varies also with groove radius, this means, it differs according to the position on record where the stylus is.

It also differs whether the tonearm has overhang or underhang.

2- So far we have discussed one of the main ingredients which is friction and now we can try to see with the presence of friction and the second ingredient stationary pivoted tonearm how skating force occurs and varies with groove radius.

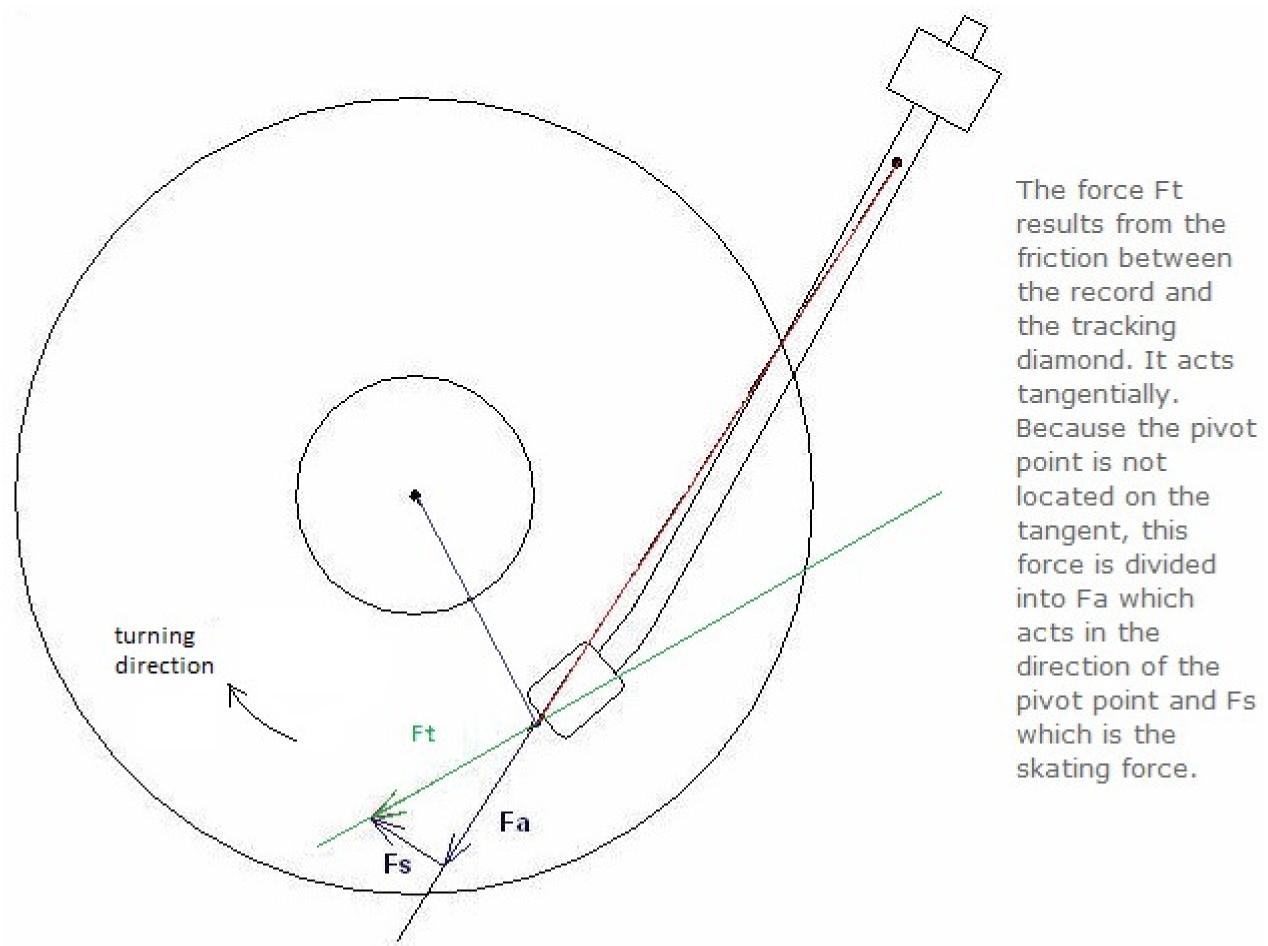
And let's see how this happens;

When we draw a line which is tangent to groove (from the point where stylus touches the groove) which is perpendicular (90 degrees) to the second line from spindle and passing through stylus point, and if the line we draw from groove tangent passes over the exact horizontal tonearm pivot, there will be no side-force generated.

Turntables are turning clockwise, this means due to friction and drag (pulling) force, tonearm wants to move forward, but since tonearms are fixed in position at the axis of forwards and backwards, it can't move.
If groove tangent line passes through the pivot, as in linear trackers or moving pivot tangential pivoted tonearms, even there is a forward drag (pulling) force exists, there is no side-force because the drag (pulling) force is only at the direction of stylus to tonearm pivot, not sideways.

With the stationary (non-moving, fixed horizontal) pivoted tonearms, groove tangent line is not passing through the pivot, and because of this, in addition to forward pulling force, there is a second force vector, since tonearm can't go forwards, it moves sideways according to added force vector.

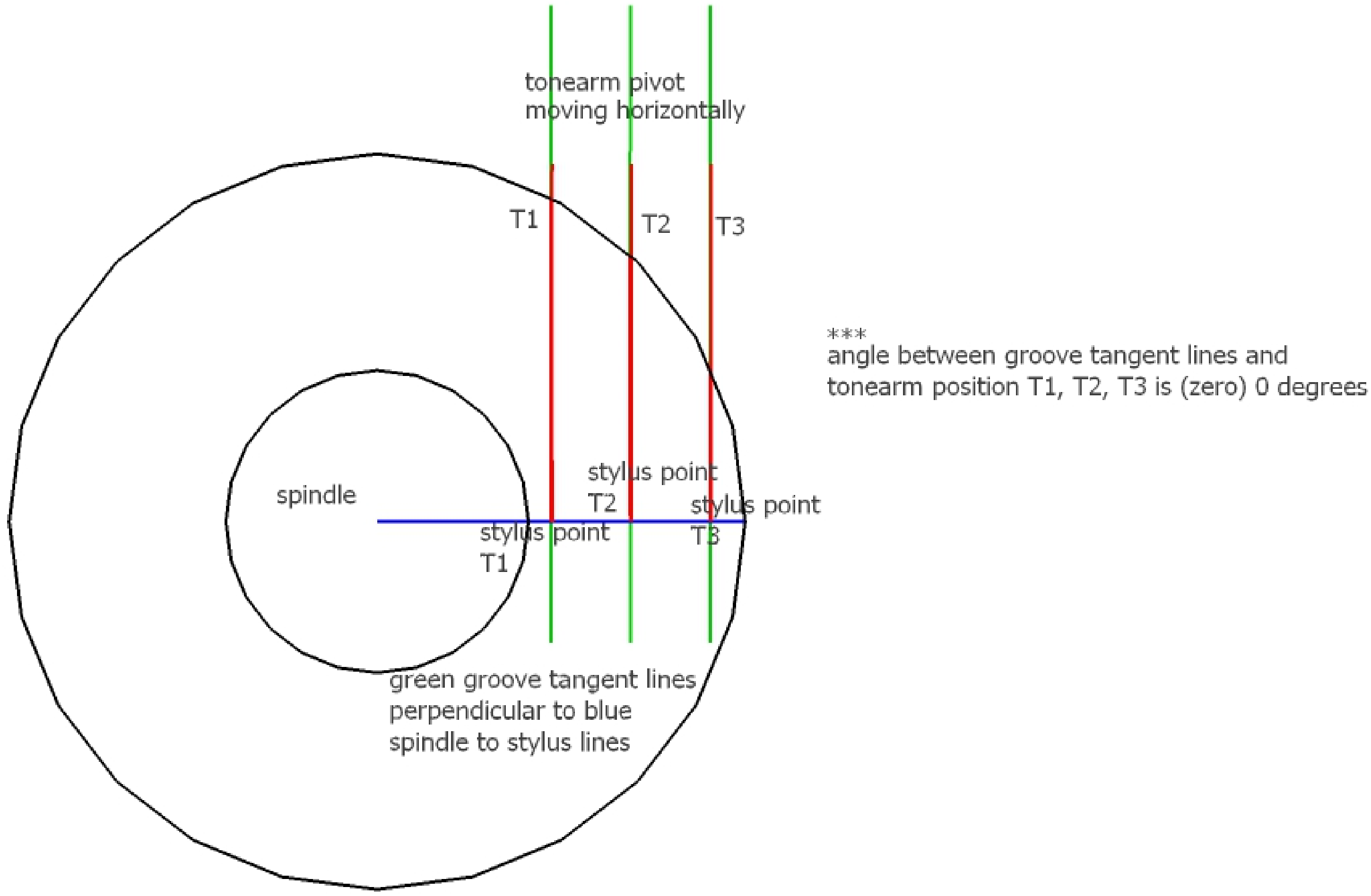
Below is the vector diagram;



Note: Picture taken from a post by John Elison in Audio Asylum forum. I made a few changes.

- **Let's take as an example linear parallel trackers first;**

Because these will be our reference for not having a skating force.



As you see, because tonearm **pivot is not fixed** and **moving accordingly**, at every position of the tonearm, **groove tangent lines always passing through the tonearm pivot** and **angle between groove tangent line and tonearm stylus-pivot line is 0 (zero) degrees.**

This is important, when this angle is (zero) 0, there is no side-force to move tonearm sideways.

Now we have a reference.

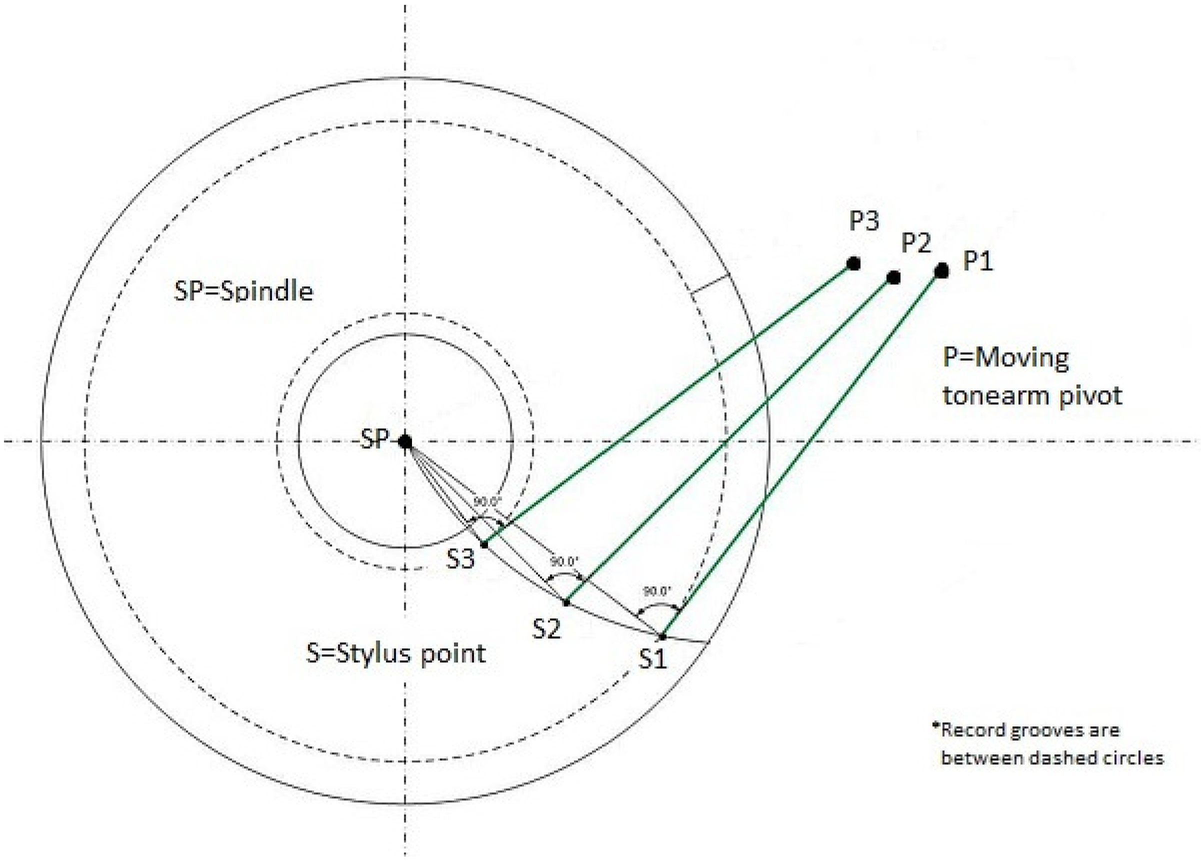
The reference is;

- **If the angle between groove tangent line and tonearm stylus-pivot line is 0 (zero) degrees, there is no side-force to move tonearm sideways.**
- **If the angle is more than zero, there is always skating force.**
- **Bigger the angle, the more the skating forces.**
- **Smaller the angle, (means closer to our reference 0 (zero) degrees where there is no side-force), the less the skating force.**

- **Let's check our situation with a pivoted tangential tonearm which also has a moving pivot**.

- What do we expect? We can say, because it has a moving pivot not fixed, it will behave like a linear tangential tracker.

Here is an example; (I took the picture from Reed's website without permission and made a few changes, I want to thank them and hope they don't mind because it's for educational purpose)



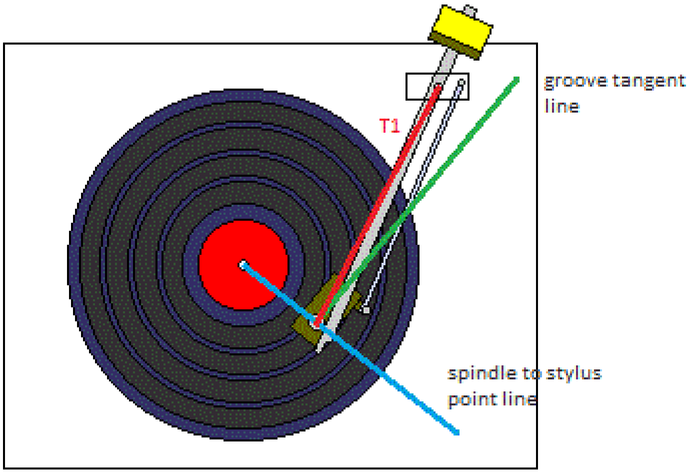
As you can easily see, at every tonearm position, groove tangent line is passing through tonearm pivot, and because pivot is not fixed but moves accordingly, the angle between groove tangent line and stylus-pivot line remains 0 (zero) degrees.
It proves that our reference is correct.

You can read the tonearms specs in their websites and one of the advantages they say their tonearm has;
"No need for anti-skating mechanism"

- Let's take another example;
Garrard Zero tonearm.

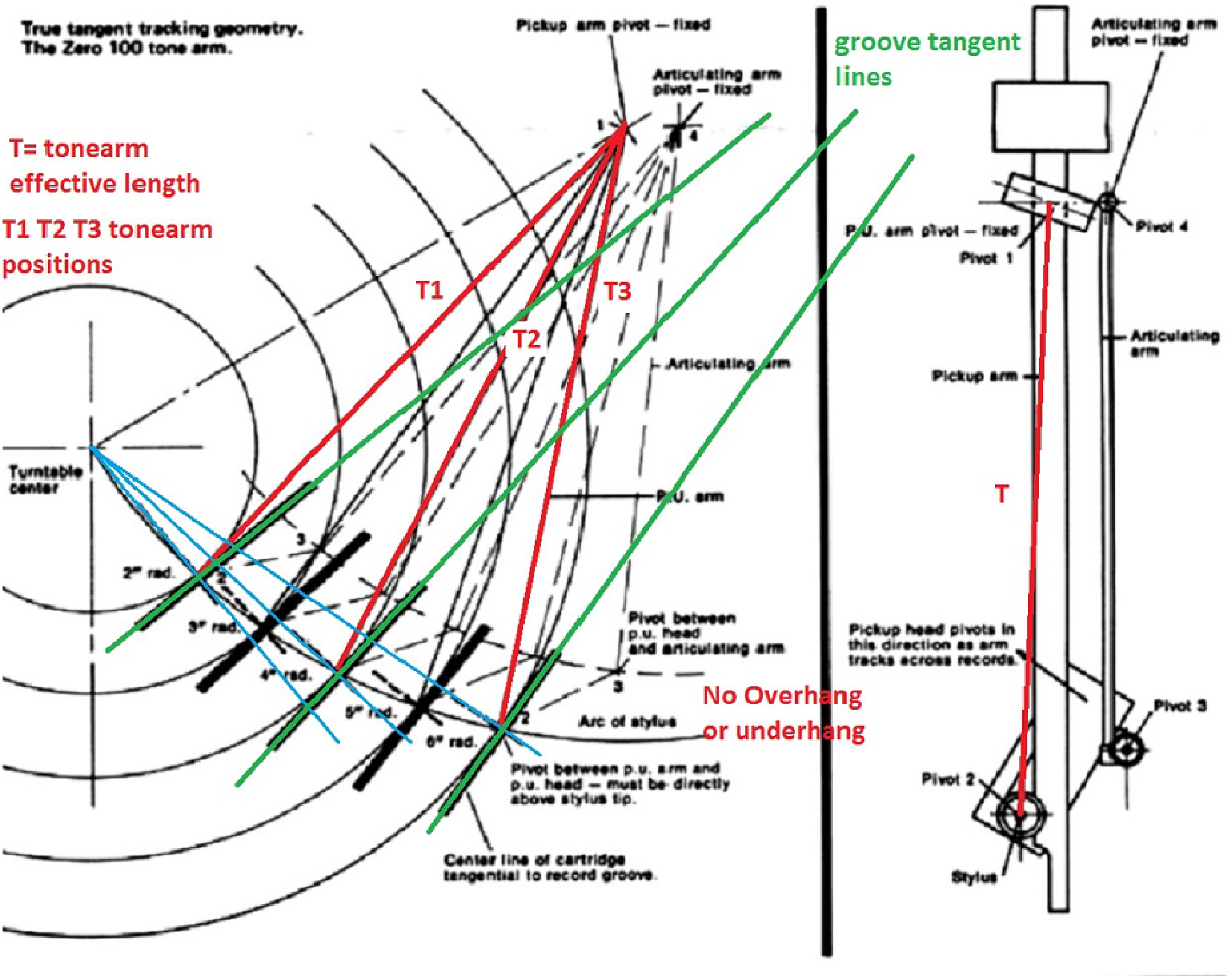
What is the difference between Garrard Zero and Reed 5T?
Garrard Zero is also a pivoted tangential tonearm, also has no overhang or underhang same as Reed (The arc which stylus follows passes over the spindle).

The main difference is Reed has a moving pivot, Garrard has a stationary (fixed, non-moving) pivot. This makes the difference side-force-wise (skating force).

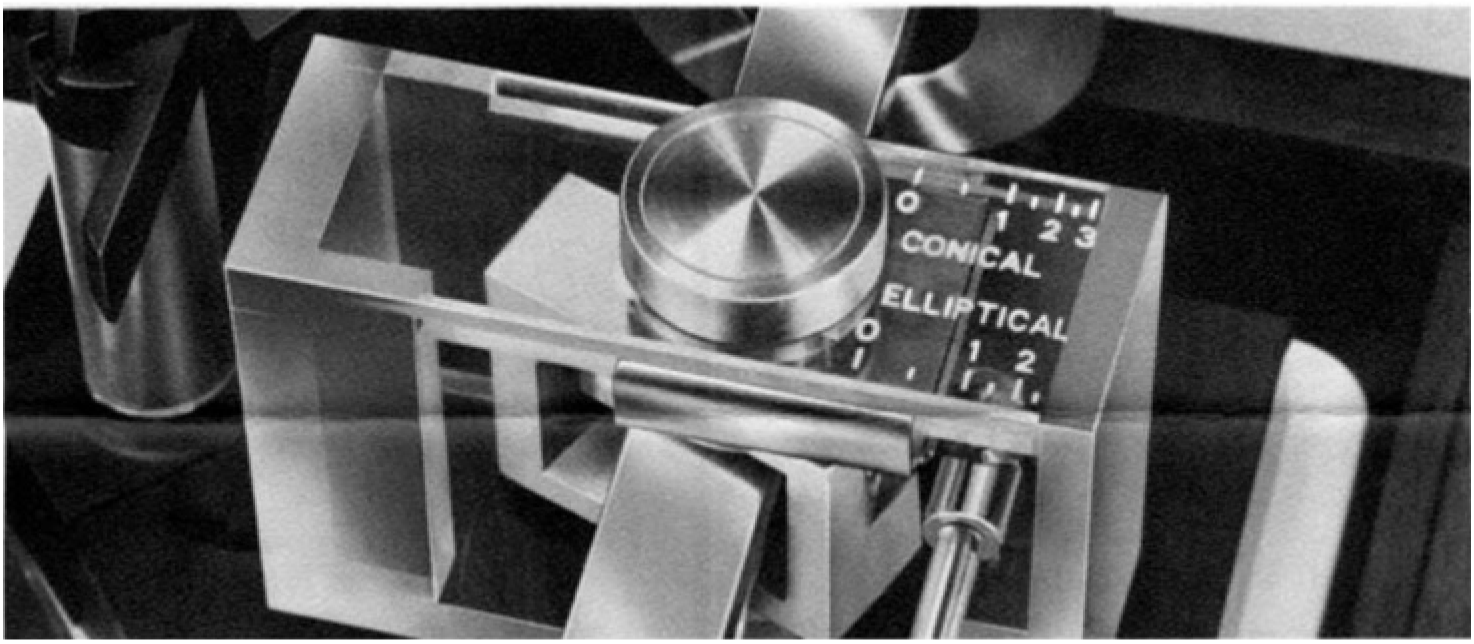


The angle between green groove tangent line and T1 tonearm stylus-pivot line is more than (zero) 0 degrees because groove tangent line does not pass through the tonearm pivot. So there will be skating force, even it does not have an overhang, but because of this lack of overhang there will be a much less side-force.

Again Garrard Zero, more detailed picture.



As a proof of what we said, Garrard of course put an anti-skate mechanism on this tonearm.



You can easily see, they also made the distinction between two stylus shapes. Yes, stylus shapes affect friction but because there is no overhang so skating force is lower than as in normal pivoted tonearms, in presence of a too small force, even smaller force difference between stylus shapes, it is debatable if this is useful or beneficial or just for marketing.

- **Now it's the much frequently used tonearm's turn, which is, pivoted tonearm with overhang**.

This means, tonearm's stylus arc passes beyond spindle (overhangs spindle).

Why we have overhang and offset tonearm or straight tonearm with offset headshell? It is a necessity for lowering the tracking error.

Because of fixed pivot, tonearm has to make an arc over record not a straight line. This causes tracking error and related distortion. In order to find a solution for lowering the error and distortion, many complex equations and calculations developed and related technical papers published.

The pioneers are, Lofgren, Baerwald and then Stevenson and all these names have their own tonearm geometry alignment equations according to their preferences.

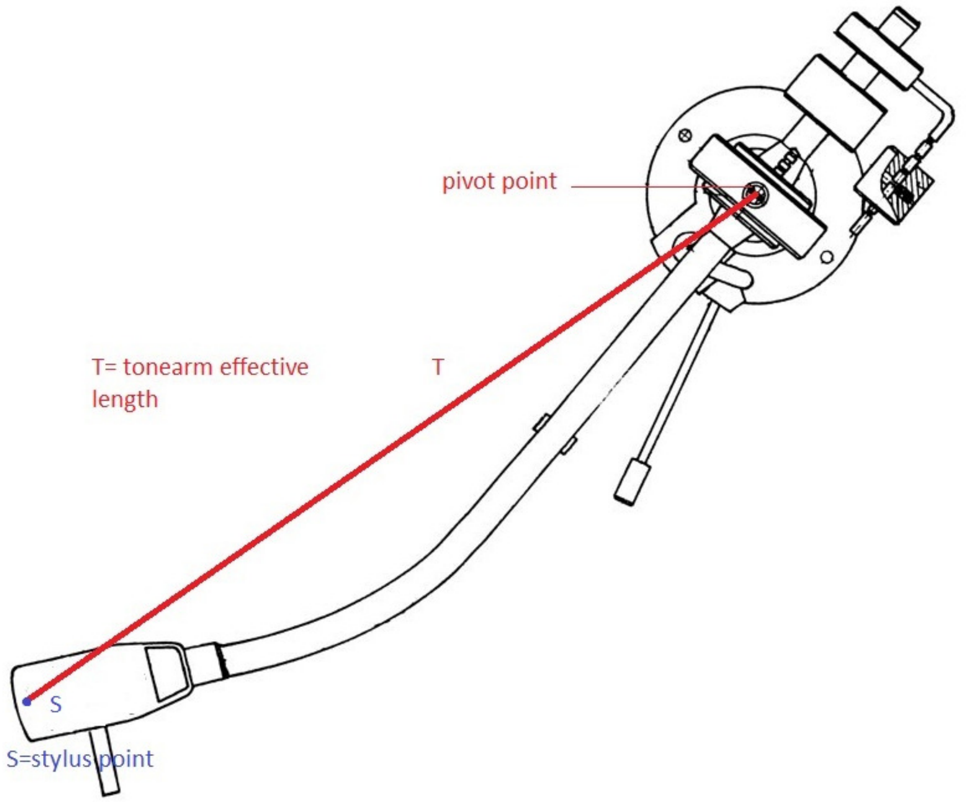
Nearly all pivoted tonearm designs with overhang either use one of these equations or their own equations derived from these, which means a pivoted tonearm should have an overhang and tonearm or headshell "offset".

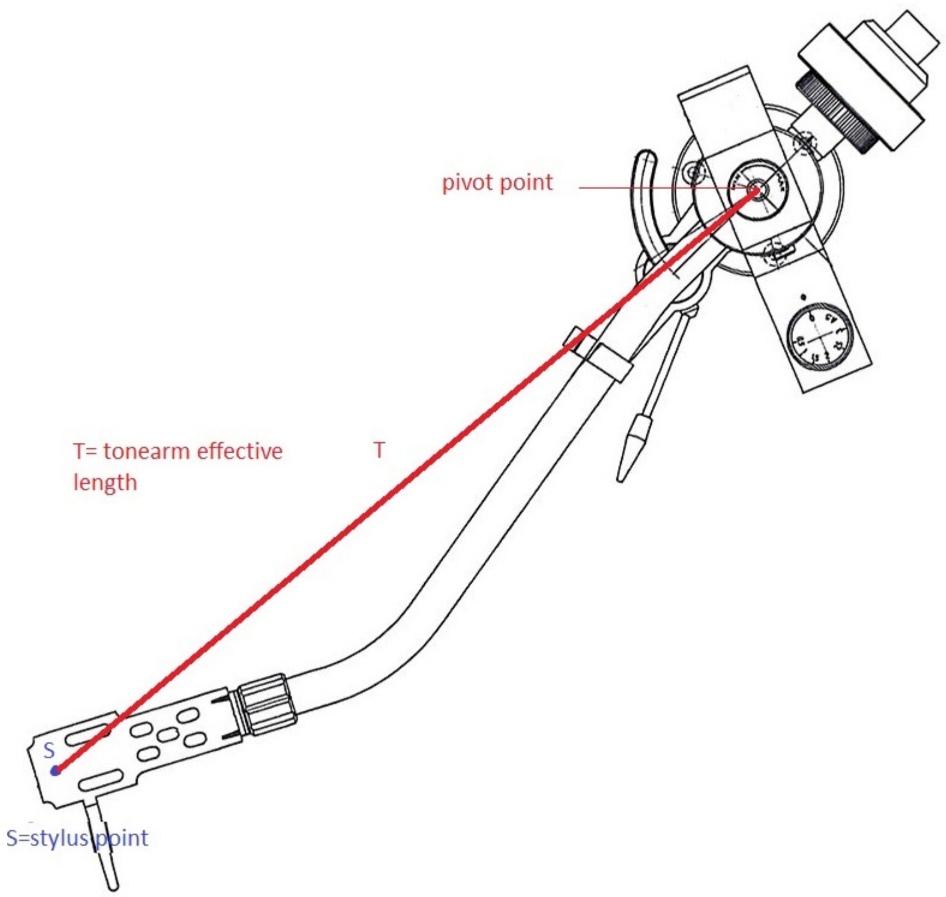
What does this tracking error compensation related "offset" do in the creation of side force (skating force), the answer is really it does nothing.

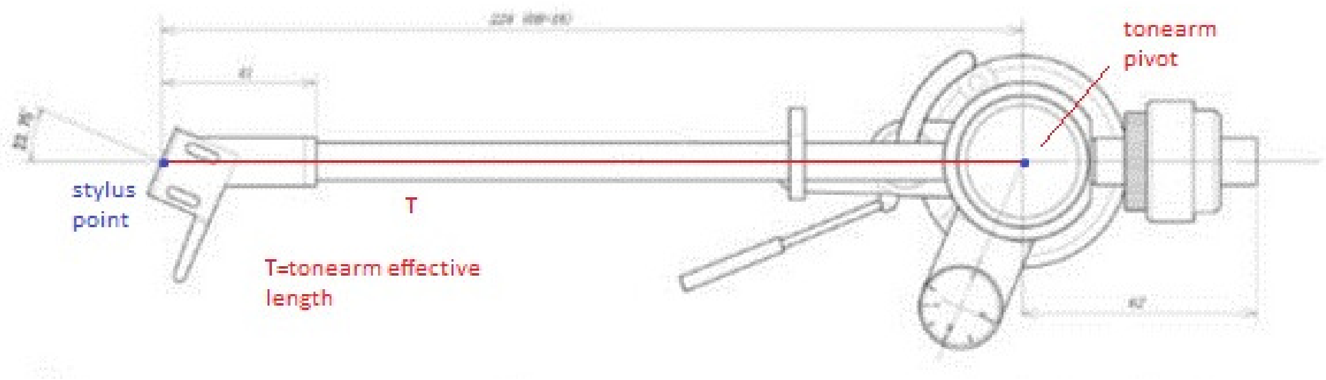
Because only the groove tangent line and the stylus to pivot axis is of use here and the angle between them determines the strength of the force.

When we think about stylus to pivot line, we can realize this is also what we called tonearm effective length.

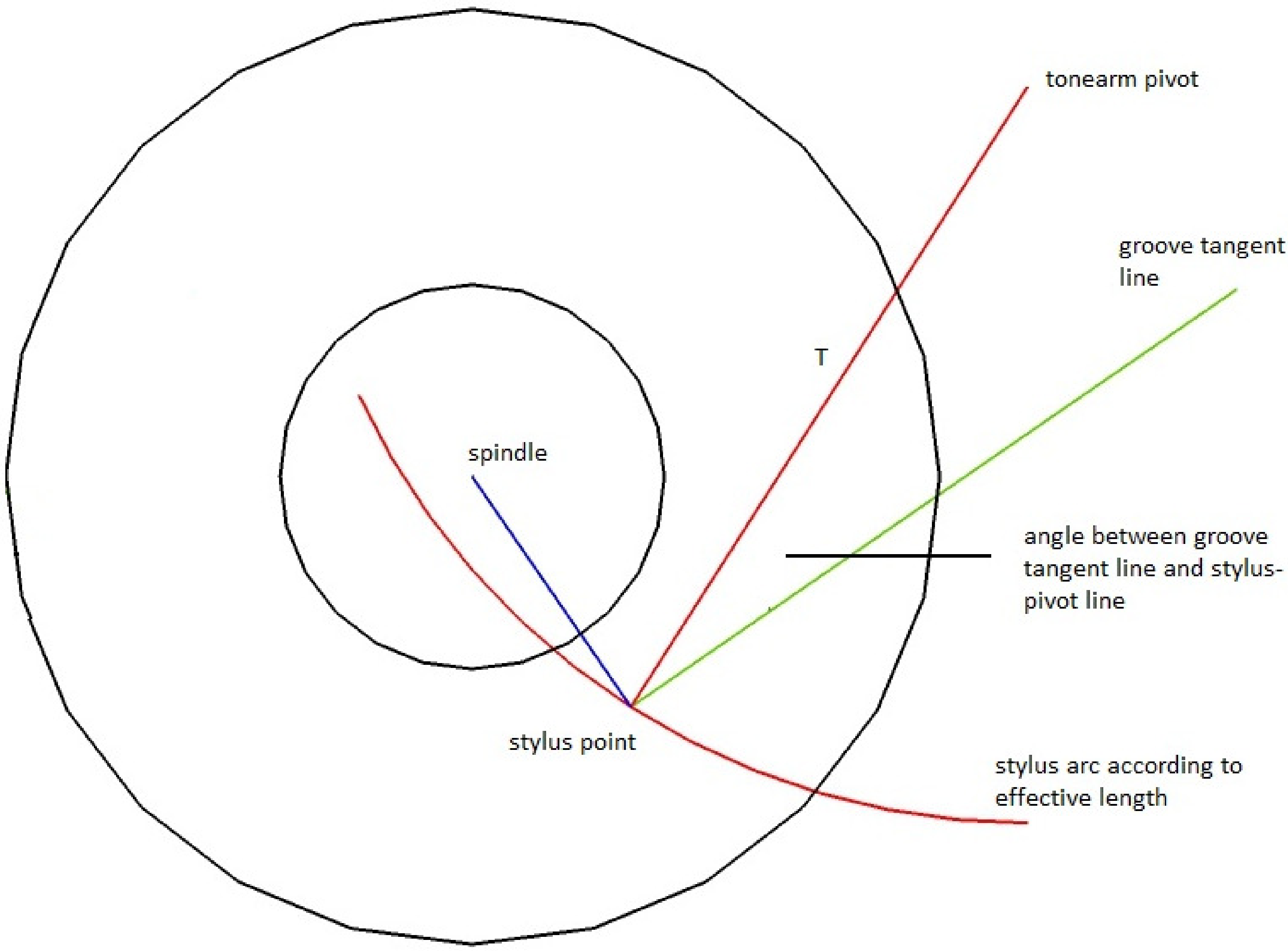
If any tonearm, be it a J shape or S shape or straight one with an offset headshell, has the same effective length and overhang, they will all share the same stylus arc and on that arc at the exact stylus position, they will all have the same stylus to pivot line. So tonearm or headshell offset has no work here.







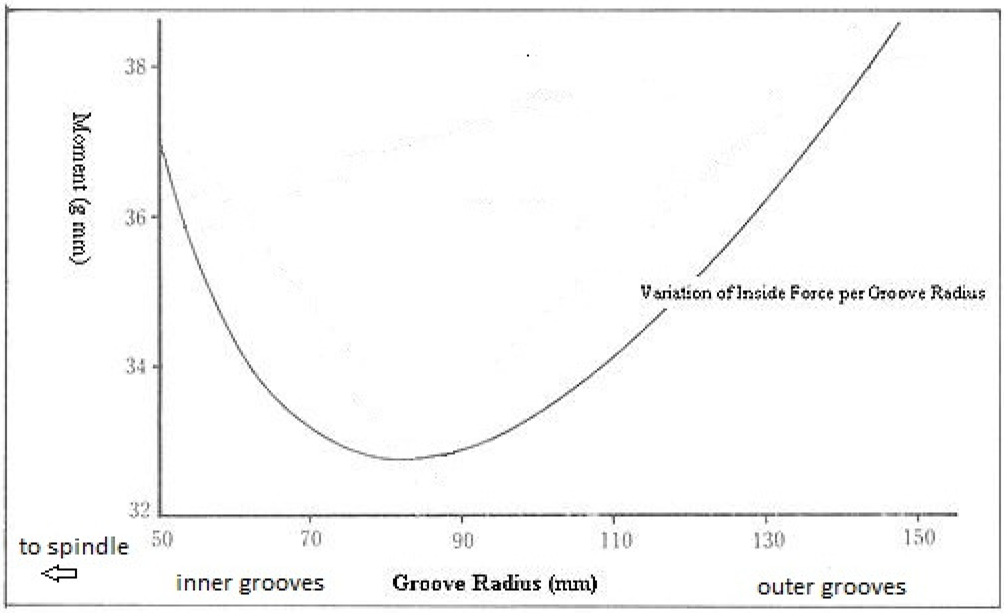
All these tonearms above, if they have the same overhang and same effective length, will have the same angle as below.



- Tonearm offset has no significant function on skating force but what about overhang?

Overhang is a very important parameter side-force-wise and it's proportional to skating force. The higher the overhang the more skating force, the lower the overhang the less skating force.

When we read technical papers about this subject we often see a graph like below;



It is a graph showing one tonearm example of a typical variation of side-force per groove radius in overhung tonearms.

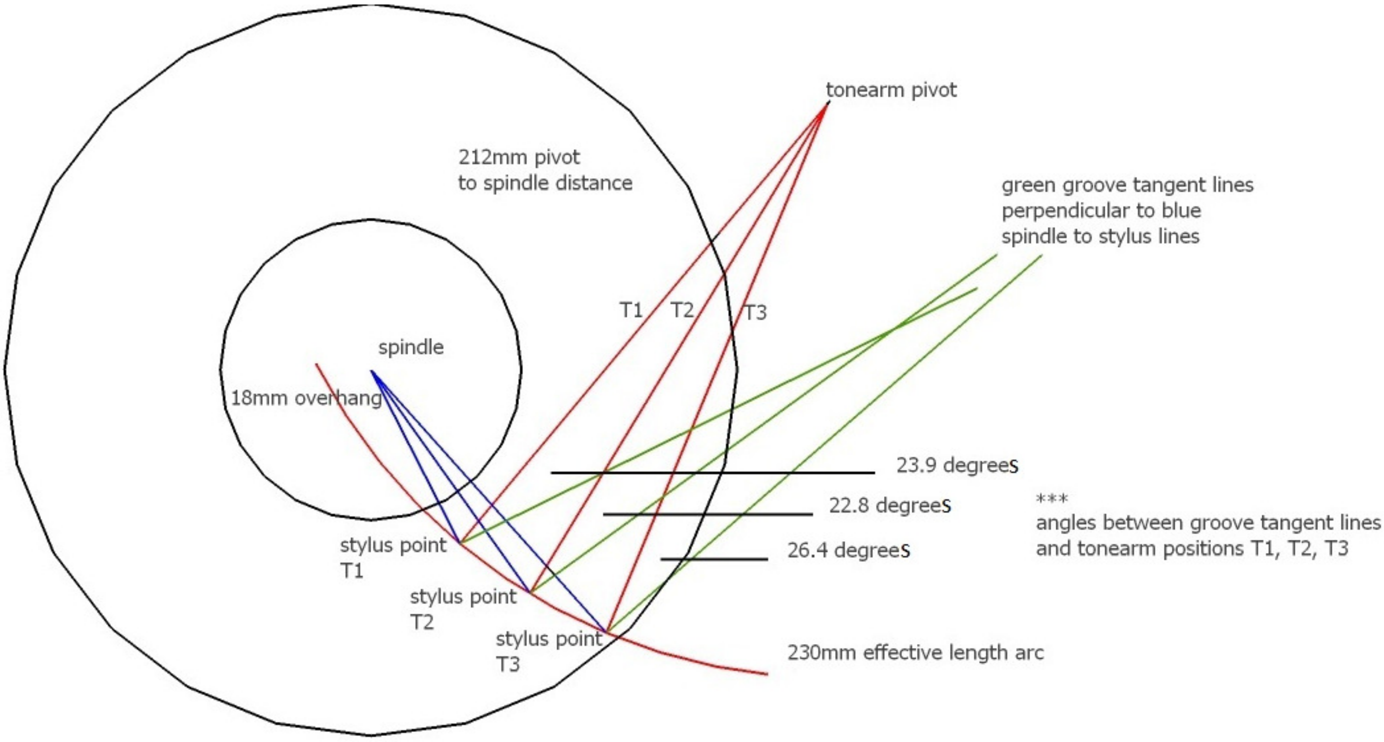
What can we learn from this picture?

a- First thing we can notice is **skating force is not constant** and **varies according to groove radius**.

b- We can easily see **at no point over record, skating force is never zero**. So there **is always positive skating force with overhung fixed pivot tonearm**.

c- The force at the **outer grooves (at the beginning of record) highest**, **gradually falls to minimum after passing the record's halfway of the groove area** then **gradually rises again at the inner grooves** but never high enough as at the outermost grooves.

Below we have the picture of a 9inch tonearm which has 230mm effective length, 212mm pivot to spindle distance and 18mm overhang.



It confirms again what we said before;

a- Side-force is not constant and varies related to groove radius (at different tonearm positions we have also different angles).

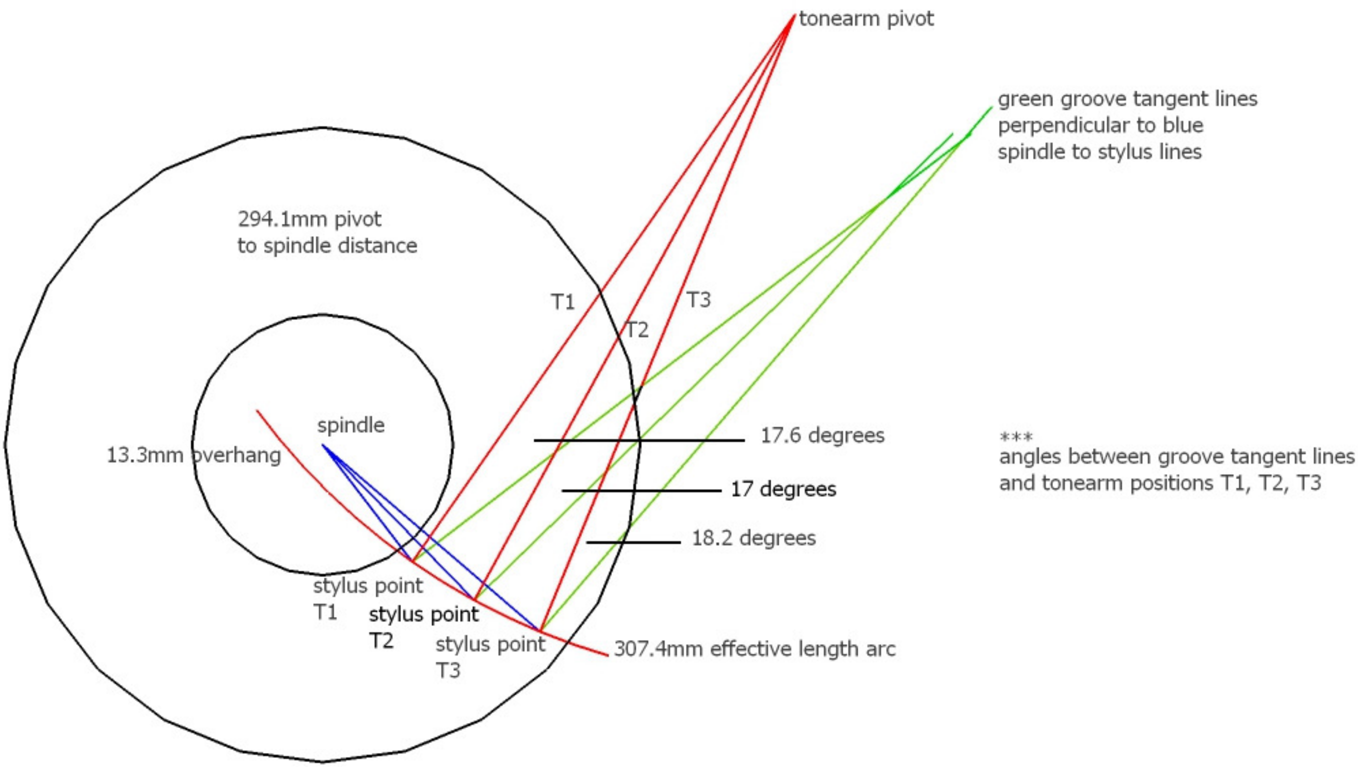
b- An overhung tonearm at no point would have zero side-force (skating force).

c- At the outer grooves the angle is 26.4 degrees which is highest.

At around middle parts the groove area side-force is lower than either beginning or end of the record. In this example angle is 22.8 degrees.

At the inner grooves side-force is high again but not as high as at outer grooves. Angle is 23.9 degrees.

Below we have the picture of a 12inch tonearm which has 307.4mm effective length, 294.1mm pivot to spindle distance and 13.3mm overhang.



Please compare these two 9 inch and 12 inch tonearms.

What we see is all a, b, c statements above are also true for the longer arm but there is one main difference which affects the skating force. It is overhang.

Longer arm has much lower overhang therefore has less skating force. All the angles in the longer effective length arm is smaller than (closer to our reference of 0 degrees where no side-force exist) its shorter sibling.

This also confirms what we said before about overhang.

Note: The longer arm already has an advantage over shorter one in regard to tracking error. Having also lower skating force is, it's another advantage.

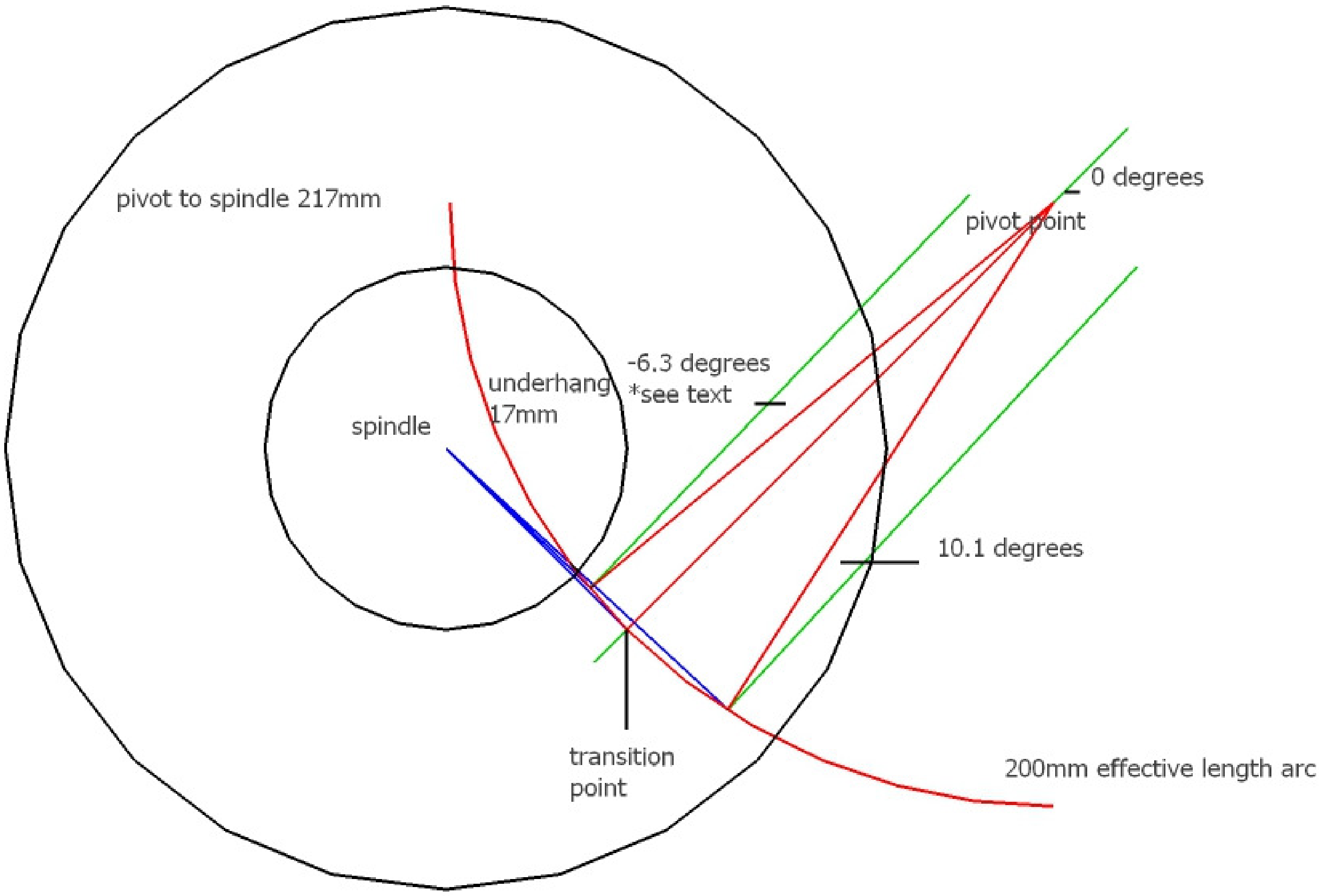
- **What about underhung tonearms?**

Probably you have read some of the info above here and there. But I think you can't find easily the info about side-force in underhung tonearms.

They are scarce, uncommon and always have way too much tracking error. They have the advantage of lower side-force because of not having overhang, instead underhang, but as you'll see their side-force are very different than overhung tonearms.

Below is a picture (probably you can't find anywhere) that explains a lot about skating force for the underhung tonearms.

Tonearm has 200mm effective length, 217mm pivot to spindle distance and 17mm underhang.



After first look we realize it doesn't look like a regular overhung tonearm.

If we highlight the differences;

a- It has much smaller angles which means much less skating force (side-force).
b- Contrary to overhung tonearm's always present skating force, underhung tonearm has at one tonearm position has no skating force.
This is where the angle between groove tangent line and stylus point to pivot line is 0 (zero) degrees.
I named this position Transition Point because after this no side-force point, tonearm again has a skating force but a different surprising one.
Surprise is; now there is a negative side-force which means skating force takes a reverse direction and causes tonearm skating outwards.

So with underhung tonearms;
- Beginning at the outer grooves, there is a positive and gradually decreasing side-force up to the Transition Point.
- No skating force at the Transition Point.
- Negative and gradually increasing skating force up to the end of inner groove area.

- Positive skating force means tonearm moves inwards as in regular tonearms with overhang.
- Negative skating force means tonearm moves outwards.

Why is this like that?

Look at the picture and you'll see after the Transition Point, the groove tangent lines (green line) begin to pass through inner side of the tonearm pivot.

This has force vector from reverse direction that causes tonearm skates outwards.

So we can say;

- If groove tangent line passes through outer side of tonearm pivot as in overhung tonearms, side-force moves tonearm inwards.
- If groove tangent line passes through inner side of tonearm pivot as in underhung tonearms after Transition Point, side-force moves tonearm outwards.
- If groove tangent line passes through tonearm pivot as in Transition Point here and in linear and moving pivot tangential tonearms, there is no side-force.

Now we have the knowledge of why this force exists and how it makes the tonearm behave in its presence.

Even though this force is small, (roughly 10% - 12% of vertical tracking force) it has some negative effects if not compensated.

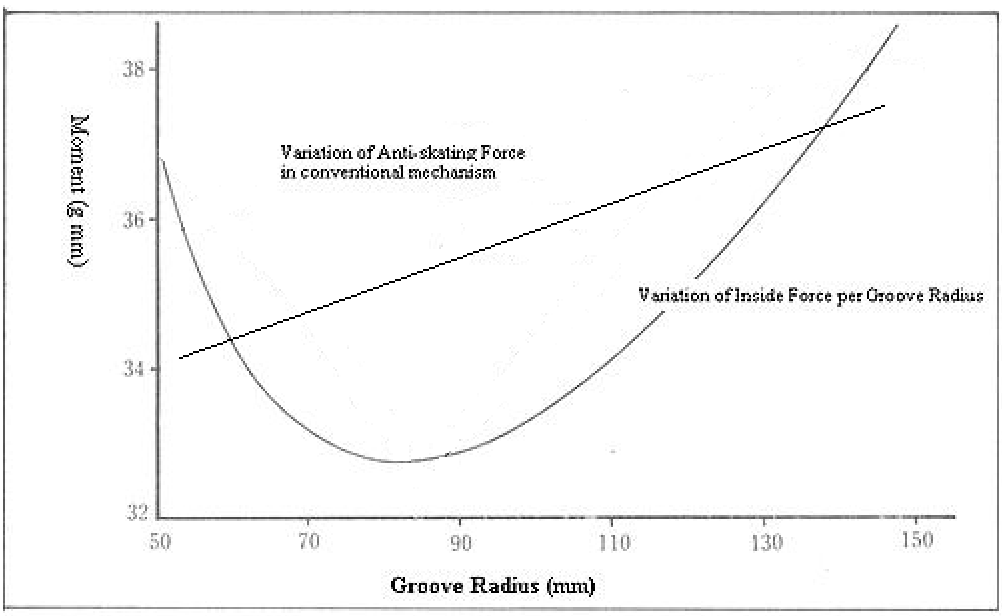
These may be; asymmetrical wear of record grooves and/or stylus in the long run, mistracking ,

harmed cantilever suspension.

According to Kogen, tests show skating force compensation improves tracking 20% - 25%. You may increase VTF if you have the margin but it will do no good to cartridge suspension and record/stylus wear.

For the tonearms we mostly use which are tonearms with overhang, a great majority of their designers and manufacturers add some mechanisms to counteract this side-force.

These solutions are not perfect but in practical use good enough so better to have them than not.



Most common solutions behave like above; highest anti-skate at outer grooves then gradually decrease until end of grooves.

Some of them have more complex mechanisms in order to follow "variation of inside force per groove radius" curve. For example Morsiani uses magnets and some Audio Technica models use weight loaded thread on eccentric body.

I don't want to debate anyone but in my opinion more complexity for relatively less important things is non-productive and especially for tonearms even can be detrimental on sound quality.

These anti-skate mechanisms in modern arms may apply;

- Magnets
- Weight loaded thread
- Weight loaded lever
- Springs or coils
- Twisted tonearm cables
- Electronic control

Or some combination of above.

Some people claim lower sound quality on their tonearms with anti-skate mechanism activated. This is a very subjective area and I can't say what people should do.

Personally, I prefer a little compensation than none and simpler non-resonant mechanisms.

Some people are after technical perfection, but it's an impossible goal to achieve. Because no matter what you do, even using some instrumentation setting anti-skating precisely, the curve of the skating force per groove radius will be intersected in two points at best.

Test records generally recorded with higher modulation levels so setting it using test records results higher than normal anti-skate during music listening.

A few words about setting anti-skate using grooveless blank record;

Here is a quote from an expert on the subject;

- "*On a grooveless record, this same angle exists because the frictional pull on the stylus from a spinning grooveless record occurs in the same direction as if the stylus were riding in a groove. In other words, the frictional force vector makes an angle with the pivot/stylus axis and creates skating force just as if the stylus were riding in a groove. The only difference would be in the amount of frictional force generated by a grooved surface versus a grooveless surface. However, the direction of the force vector would be exactly the same regardless of whether the stylus is riding in a groove or riding on a flat vinyl surface*". John Elison

Highly regarded tonearm designer Frank Schroder also suggests using blank part of the record near the end and Soundsmith's Peter Ledermann agrees with him.

- *"Make sure that the anti-skating is well set; there are many ways to tell, but this is a method suggested by Frank Schroder, with which we heartily agree. PLEASE NOTE – this will not agree or work with test records designed for higher amounts of anti-skating. The reasoning from Frank Schroder for this method and level of A-S skating is as follows: the level of antiskating used should create EQUAL forces on each groove wall for *most* of the record. Since this force is dependent on the level of recorded modulation (how loud the recorded music is on the disk) setting it for a "worst case" "loud music passage" level is totally inappropriate. Setting it where it provides equal force per groove wall for where music spend 80-90% of its time (30-40% modulation) makes FAR more sense, both from the standpoint of listening, and wear.*

  Procedure:

  When you have it adjusted right, the arm will track on the SURFACE of the record (not in the groove) at the end of the record on the un-pressed flat space where the run-out groove is – it should track SLOWLY INWARDS toward the center at a MUCH SLOWER RATE than IF IT WERE ACTUALLY in the end groove. If you do that, then the best average Anti-Skating is set correctly".

When you realize there is no perfect method for anti-skate adjustment, using grooveless record to set is as valid as any, even preferable.

Note: Skating force = side-force = side-thrust = bias force

I freely used skating force and side-force terms in place of each other.

References;

*Kogen, "The skating force phenomenon"

*Bauer, "Tracking angle in phonograph pickups"

Thanks to John Elison for his excellent contribution in audio forums on all things related to tonearm geometry, their working principles but especially for his instructive excel tonearm geometry spreadsheet. (His posts can be read at Audio Asylum vinyl forums)

Thanks to Yosh for his excellent work that can be seen on his website. Unfortunately main site is in Japanese but English site still has more than enough information. (http://www7a.biglobe.ne.jp/~yosh/sitemap.htm)

Thanks to Klaus Rampelmann for his work "Skating Force and Antiskating" document in vinylengine website. (https://www.vinylengine.com/turntable_forum/viewtopic.php?t=17293)

I hope this document can be helpful to many audiophile friends.

Hakan Agustos

My monikers at forums;

hagustos at audioasylum

tubehead at vinylengine

hagustos at diyaudio
