Abstract
We describe here the fundamental function of the spider, its limitations and the solution offered by Kartesian innovation.

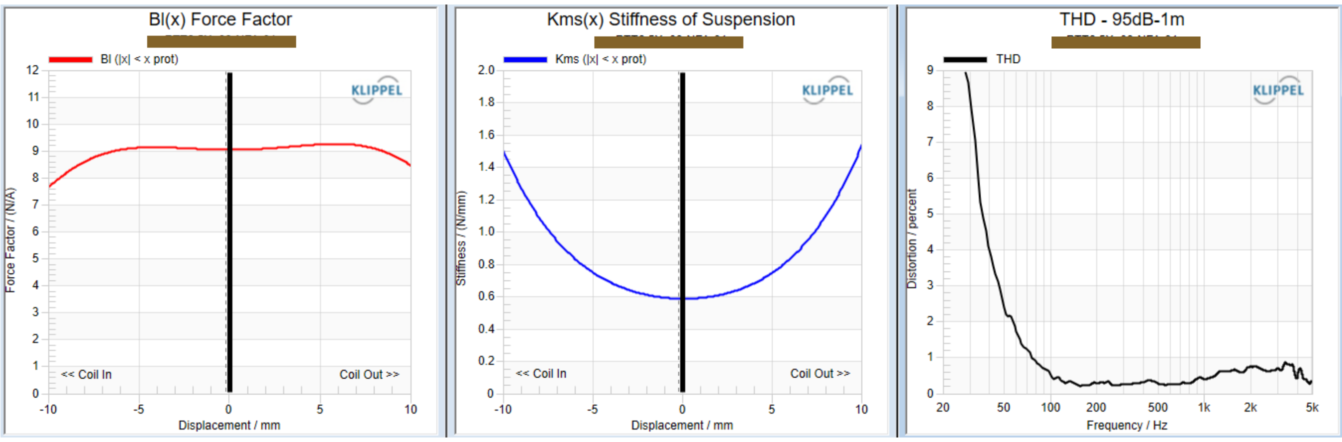
Context
Although the spider ensures 2 key functions of the electrodynamic loudspeaker, the spider is a neglected component:

1- **Keep the voice coil centered in the gap** (in association with the surround), up-to the largest excursion.
This feature provides the stability of the driver, avoiding rub & buzz between the voice coil and the pole pieces.

2- **Set the resonance frequency of the driver**.
Most of the time, the stiffness of the surround is significantly lower than the spider. As a consequence, the resonance frequency is mainly provided by the spider stiffness.

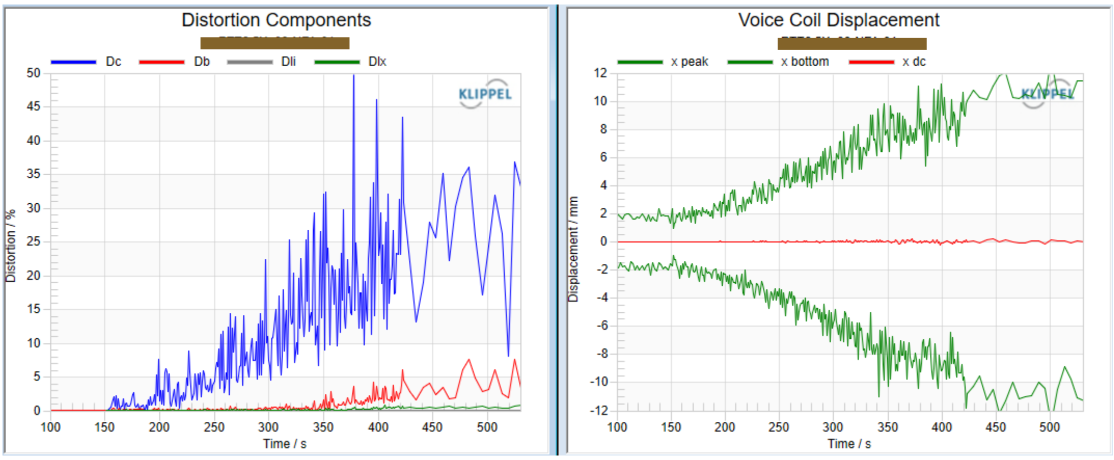
Regular design and limitation
During Kartesian R&D works, we did 2 reports about limitations of current spider state of the art:

1- Source of THD
Most of the time, the suspension stiffness is <u>the main root cause</u> of the THD in low frequency.
Here below, as example, an excellent woofer design, with extremely low THD in the mid-band (150 – 1000Hz).
Its force factor is very wide and constant over +/-8mm.
The inductance management is excellent, above any comment, not involved in any THD issue.
The suspension stiffness, is free from any asymmetry, and shows <u>usual Kms(X) increasing</u> according to the excursion.
This is a nowadays top of the art woofer, with the usual THD mainly located below 100Hz, with clearly audible ratio.



In this typical case, the root cause of the THD in low frequency is, by far, the suspension non-linearity.

On the measurement below, the signal amplitude increases continually, and the cone excursion as well.
We notice that from the smallest excursion (+/-3mm), the main THD root cause is the suspension non-linearity.
Next, from ~+/-11mm, which is the maximal possible excursion due to suspension mechanical limits, THD in low frequency reaches ~25%, due to suspension non-linearity.
The force factor makes only ~3% of THD, and as previously mentioned, the inductance is perfectly managed.



This physical phenomenon has been widely and brilliantly detailed in Klippel papers.

<u>We could summarize with:</u>

- Stiffness asymmetry increases pair harmonics (H2, H4, …)
- Stiffness variation according to excursion increases the overall THD in low frequency, including for small excursion.

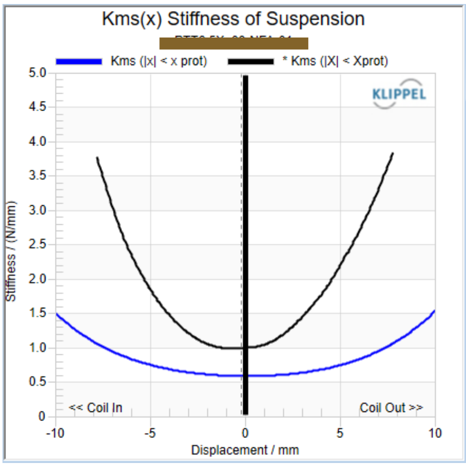
Speaker engineers (real engineer) are fully aware with these problems, and more and more loudspeakers are engineered with symmetric suspension stiffness, which solve a part of the issue.
Nevertheless, substantial efforts remain necessary to solve the main THD ratio caused by stiffness variation according to excursion.

<u>Conclusion:</u> Even for current top of the art woofer, the suspensions non-linearity is a topic which requires improvements.

2- T&S variation

When the stiffness increases according to the excursion, it slow-down the cone movement, and so, protecting the driver against unstable large excursion.

In pro-audio world, the spider stiffness is used as "mechanical limiter" integrated in the driver. Usually, these drivers have higher resonance frequency than "Hi-Fi woofer" with same diameter.

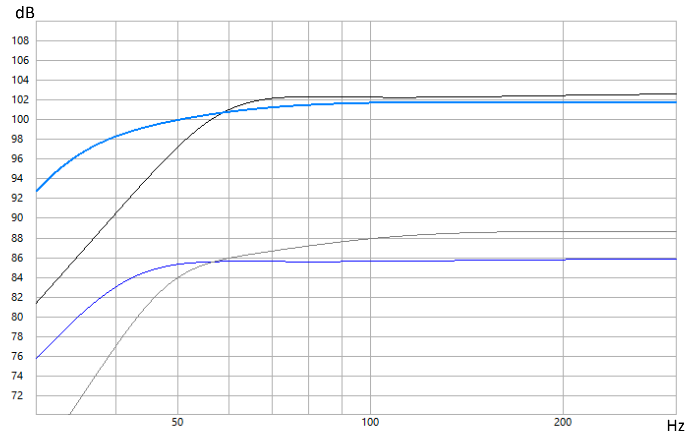


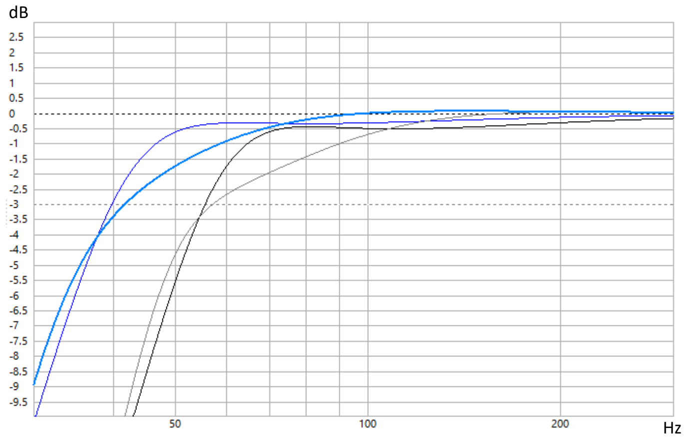
Here are 2 typical examples of (good) 6.5" -7" woofers.
The black curve is dedicated to pro-audio market (PA system) and the blue curve is designed for HiFi or monitoring studio purpose (same as previous chapter).

At the rest position, the suspension of the pro-audio are more than 2 times stiffer, and this value is doubled with only +/-5.5mm excursion.
For the "HiFi / monitoring studio" woofer, the nominal Kms value is double around +/-7mm excursion.

In both cases, by increasing the stiffness, the resonance frequency and Qts suffer some variation too.
Even we only consider the suspension stiffness variation (not the loss of force factor), for the "HiFi / monitoring studio" woofer, the Qts moves from 0.3 to 0.44. The Qts of the "pro audio" woofer increases from 0.32 to 0.5.

Only considering the suspension stiffness variation, with cone excursion of +/-7mm excursion, the modification of the T&S parameters changes the shape of the frequency response in low frequency.
Here below, the blue curve is the "HiFi / monitoring studio" woofer, the black curve is the "pro audio" woofer (dark = low excursion / light = +/-7mm).
We see the "HiFi / monitoring studio" woofer lost 1.5dB at 50Hz while its SPL has been increased by only 16dB.
The "pro audio" woofer lost 2dB at 70dB while its SPL has been increased by only 14dB.

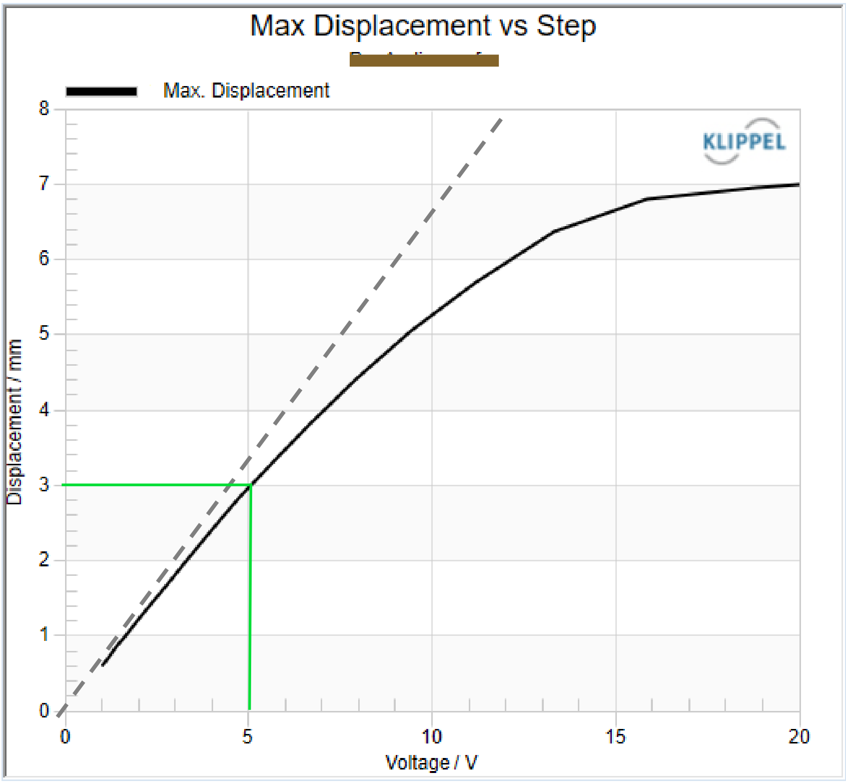




<u>Conclusion:</u> The T&S variations resulting from the suspensions stiffness variation isn't negligible.

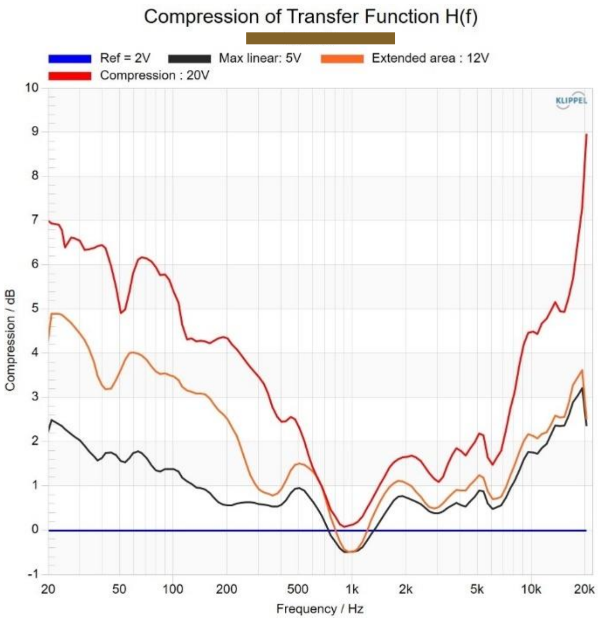
Dynamic compression

Another consequence of the increased stiffness according to the excursion, is to create a non-linear link between the input voltage and the cone excursion. This issue could also be the result of non-linear force factor, but in the example below, it is mainly due to suspension stiffness increasing according to excursion.



This pro audio woofer has linear function between input voltage and output displacement up-to 5V, which corresponds to +/-3mm excursion.
At +/-7mm, the physical limit of suspension deformation is reached.
Above 13V, there isn't any link between the input voltage and the cone excursion.
By adding more power, there is a significant risk of woofer damage.

Assuming that the force factor remains unchanged over the full excursion, the stiffness of the suspension limits the excursion.
If the motion forces involved in the cone movement changes according to the excursion, the cone movement isn't proportional with the input signal: This creates dynamic compression.



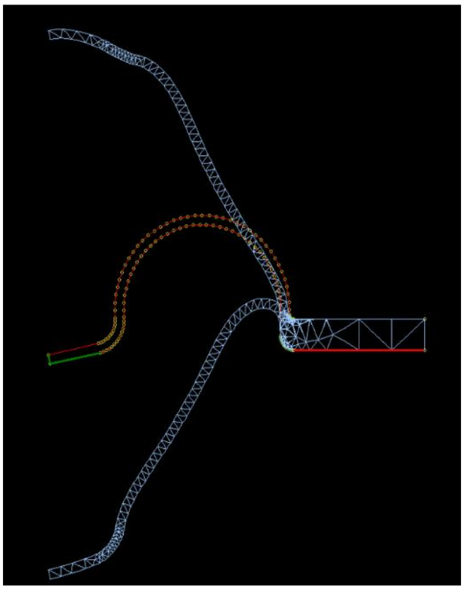
Conclusion: Spider (/surround) stiffness can be the root cause of dynamic compression.

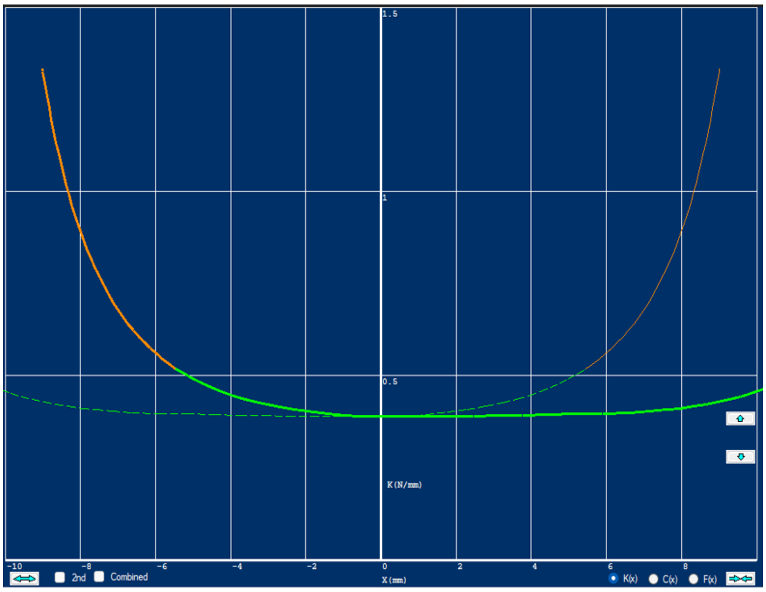
Spider / Surround stiffness matching

Usually, the surround is 2 to 5 times less stiff than the spider.
As a consequence, in many woofers design, the surround stiffness is neglected and the Fs[Hz] is mainly calculated with the spider stiffness.
Nevertheless, surround stiffness isn't linear neither.

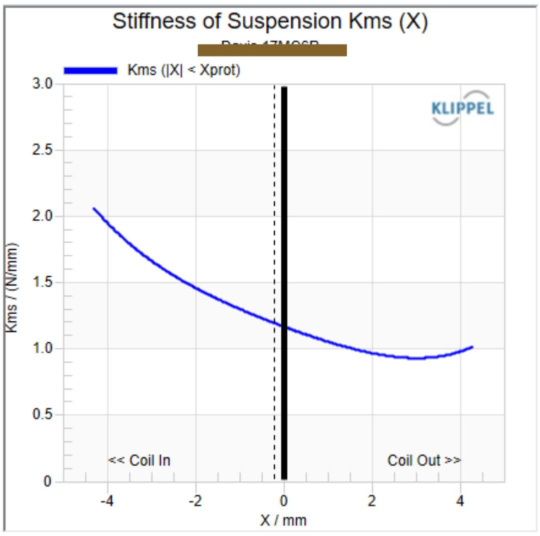
On the example bellow, a regular half roll rubber surround, supposed to be more linear than "M" shaped surround.

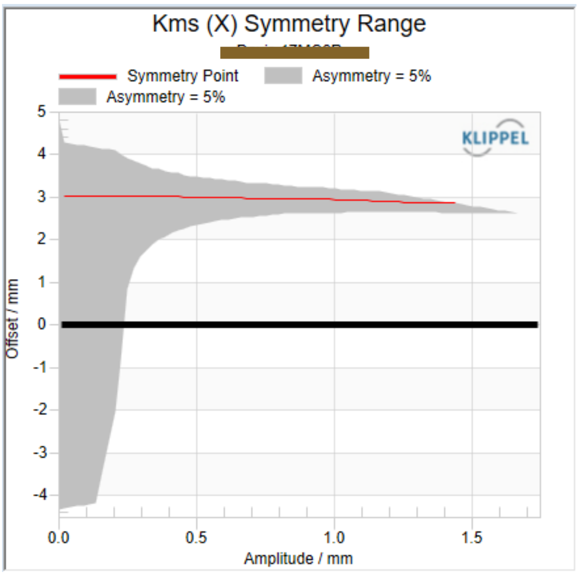
We notice this surround has a significant asymmetry, and it could be considered as "linear" only for excursion around +/-4mm, which isn't a good performance for high quality woofer.
At +/-8mm excursion, the surround stiffness increases up-to 0.8N/mm, 2 times its nominal value, which becomes comparable with the spider stiffness.



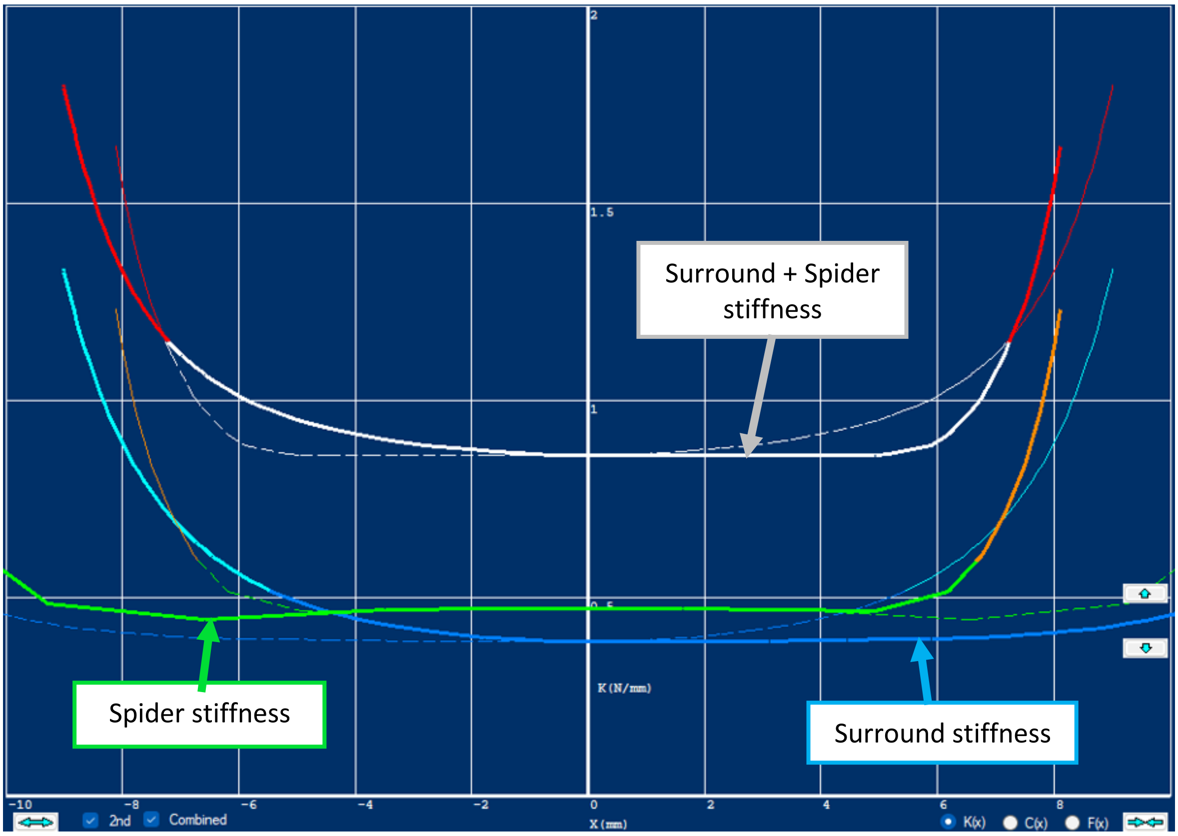


As a consequence, using a regular spider with its own asymmetry, this predictable offset is measured:

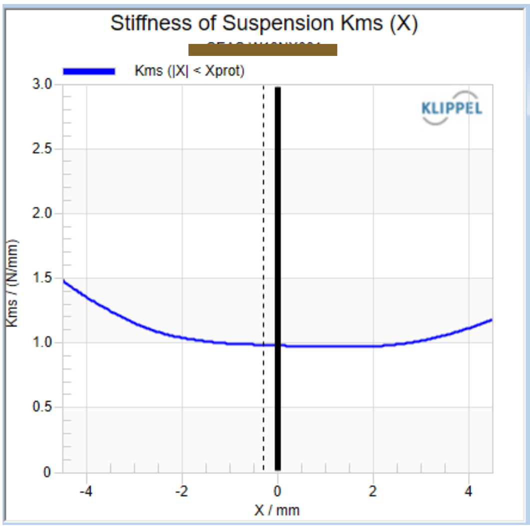


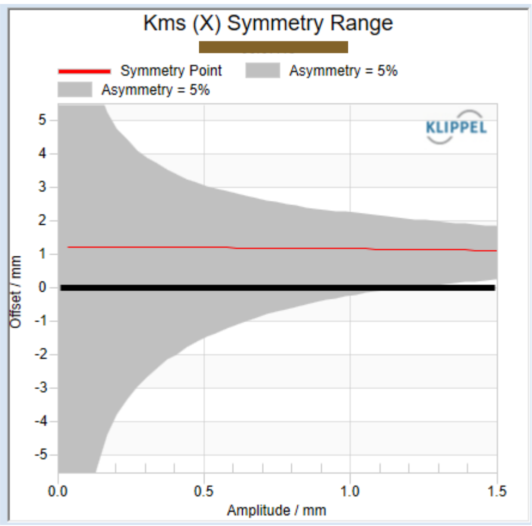


At this point, to avoid a strong offset, keeping the same surround, the only solution would be to design specific spider to compensate the surround issue:



The measurements show the offset is reduced from 3mm to 1mm, which is better, but the most important is the asymmetry area at 5% is much larger, ensuring more stable working.





The overall performances are far from excellence, with very limited linear excursion.

<u>Conclusion:</u> If the spider is designed to compensate the surround asymmetry, the woofer can only reach low linear excursion.

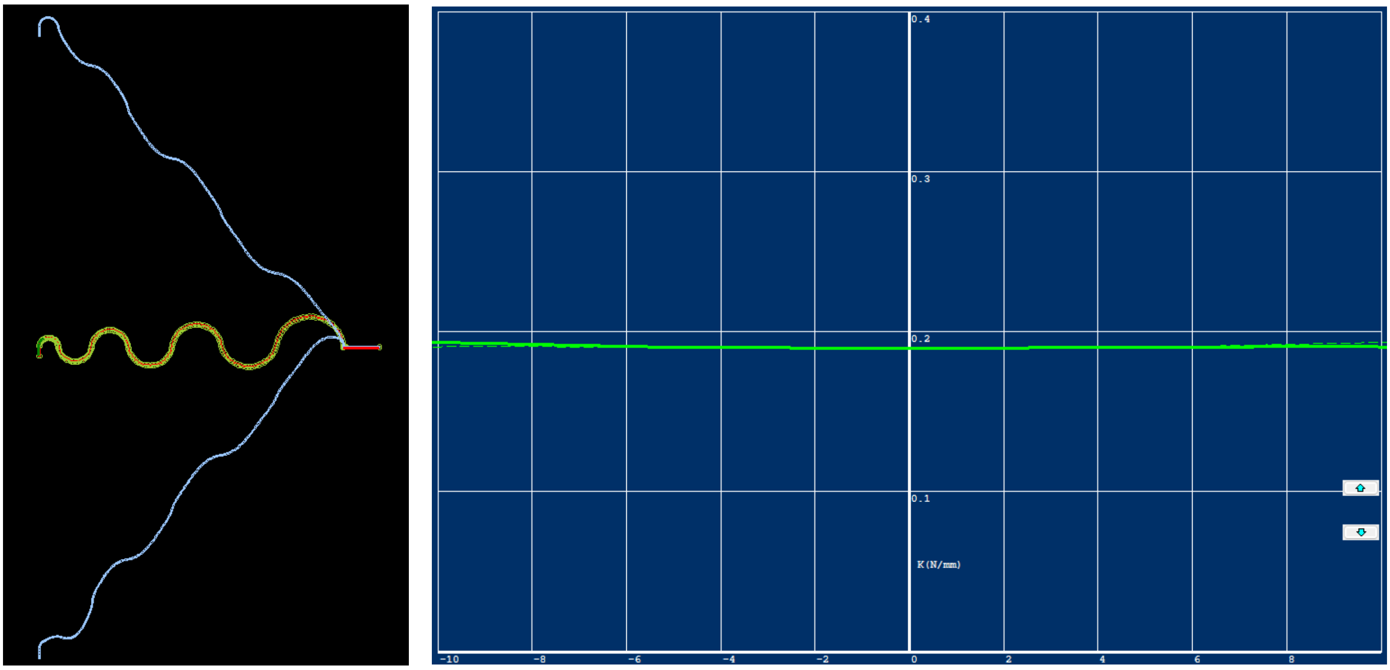
Kartesian spider design and results

1- Spider stiffness must be suitable to each product type

The perfect spider would have a constant stiffness over the full excursion.
In this way, the resonance frequency would remain unchanged, and others T&S parameters too.

1.1- dynamiK spider

To reach this target, we developed dynamiK spider.
As the stiffness is constant, there isn't any dynamic compression (due to spider) and the shape of the response in low frequency remains unchanged whatever the sound level (considering the Bl(X) is constant too).



dynamiK spider used on 185_vKi – Stiffness simulated over +/-10mm – Stiffness variation: 0.02N/mm

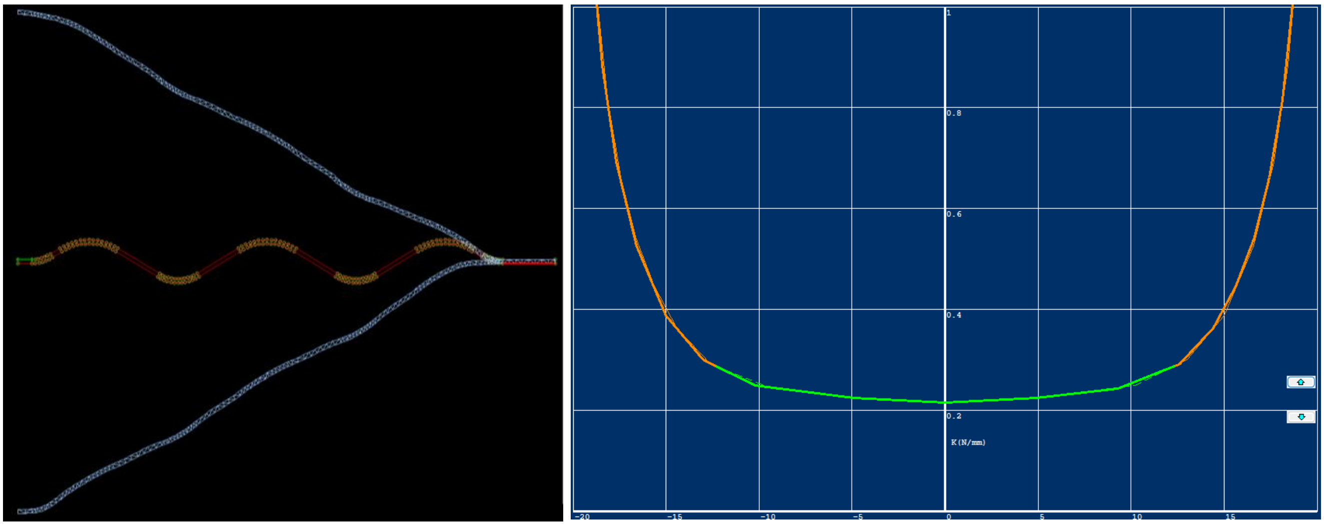
The drawback of the dynamiK spider is the lack of protection under the largest excursion.
Contrary to the pro audio example of previous chapter, with dynamiK spider, there isn't any "over stiffness" which protect the woofer.
It would be possible to damage to woofer with excessive input power causing voice coil heeling in the motor structure.
We highly recommend to the users of dynamiK spider to keep input signal under the woofer capability described in the datasheet, and if possible, use an active limiter above.

If you can handle these precautionary measures, dynamiK spider remains the best solution to get linear suspension.

Never try to check where the stiffness increases with dynamiK spider in _vKi drivers, you would reach +/-22mm excursion which is above the limits of the woofer.

1.2- pumaX spider

In order to overcome the drawback of dynamiK spider, we developed the pumaX spider.
The concept is to keep very linear stiffness over a wide excursion range, and make the stiffness increasing significantly in larger excursion to protect the woofer



pumaX spider – Stiffness simulated over +/-20mm – Stiffness variation: 0.2N/mm up-to +/-15mm

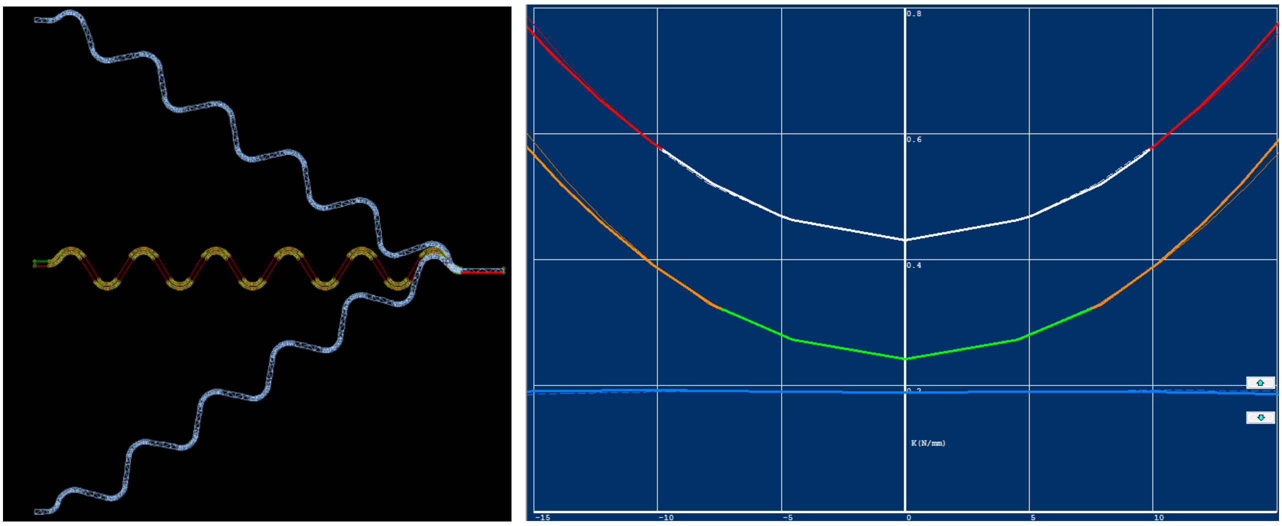
In this example, we notice the pumaX spider stiffness remains nearly constant over +/-10mm (+0.06N/mm).
Next, from +/-10mm to +/-15mm, the stiffness is doubled (+0.2N/mm).
Over +/-15mm, it starts the "protection area" with significant stiffness increase (+2N/mm with +2.5mm excursion).

Thanks to pumaX design, we call ally the benefits of constant spider stiffness on the useful excursion range, and protect the woofer above.
The only drawback of the pumaX design could be the transition from the "linear area" to the "protection area", which could be too sharp for some users.

1.3- progressive spider

The progressive spider is designed to work with dynamiK spider or pumaX spider.
Furthermore, dual spiders provide better voice coil guidance under large excursion, which is interesting for subwoofer application.

In association with dynamiK spider, it provides progressive stiffness variation and protection under large excursion.
It makes an interesting solution for those who need to balance Fs [Hz] shifting and driver protection.



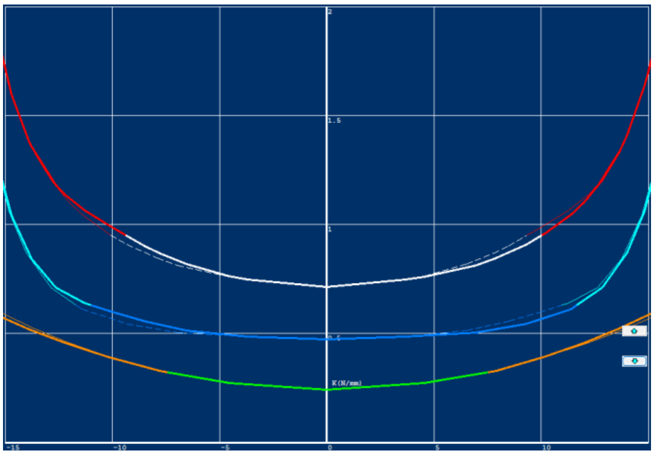
progressive + dynamiK - Stiffness simulated over +/-15mm – Stiffness variation: 0.3N/mm up-to +/-15mm
Used in Sub185_vKi

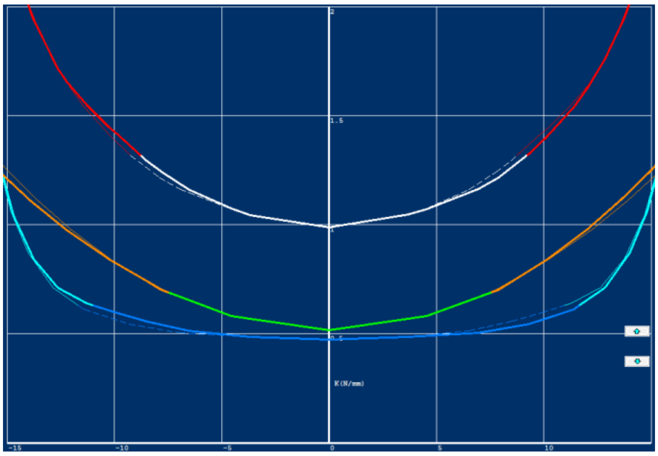
In association with pumaX spider, it allows to smooth the transition from the “linear area” to the “protection area”.
Thanks to progressive spider, the transition area of the pumaX spider can be adjusted with high accuracy.

On the left, the stiffness of progressive spider is set at 0.25N/mm, and pumaX stiffness is 0.5N/mm.
The result is nearly linear stiffness up-to +/-8mm and significant stiffness increase above +/-12mm.
The transition area from +/-8mm to +/-12mm is smoother than pumaX spider alone, but we still notice a step around +/-12mm.

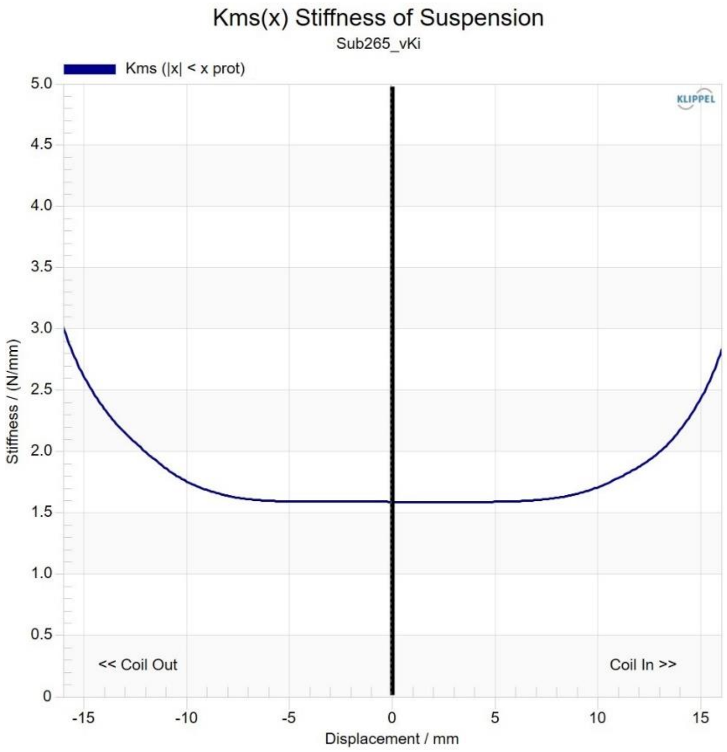
On the right, the stiffness of the progressive spider is set at 0. 5N/mm, and pumaX stiffness is 0.5N/mm too.
The result is a constant stiffness increase without noticeable step.

Any compromise between these two examples is possible in order to reach the required stiffness curve.





As concreate example, on Sub265_vKi-S, the pumaX spider is associated with progressive spider to reach a perfectly constant stiffness over +/-7mm, a smooth transition from +/-7mm to +/-11mm and next a light protection area.
The stiffness is nearly doubled from the rest position to the maximal excursion.

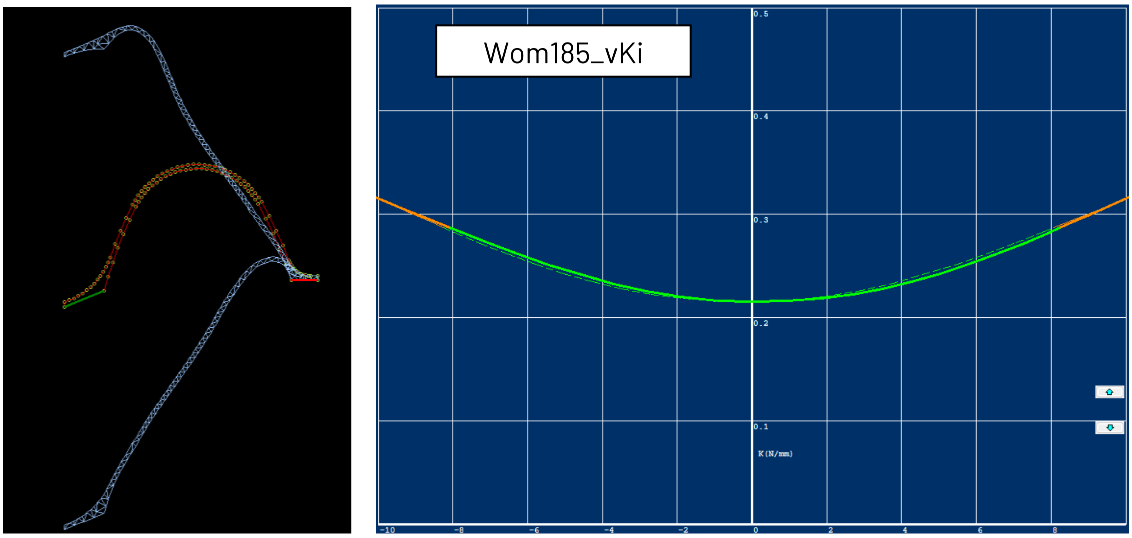


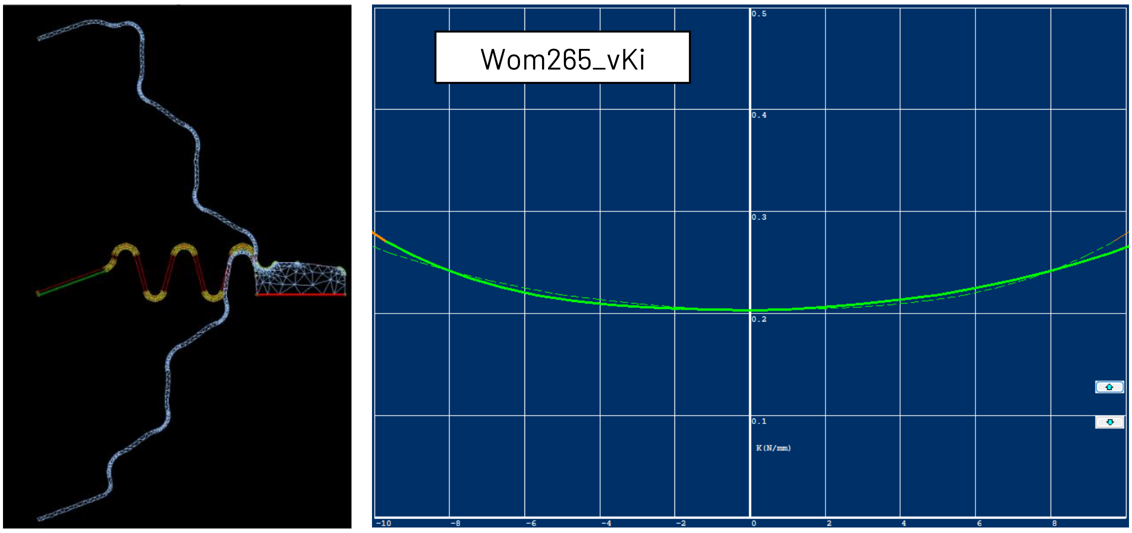
progressive + pumaX spiders - Used in Sub265_vKi-S

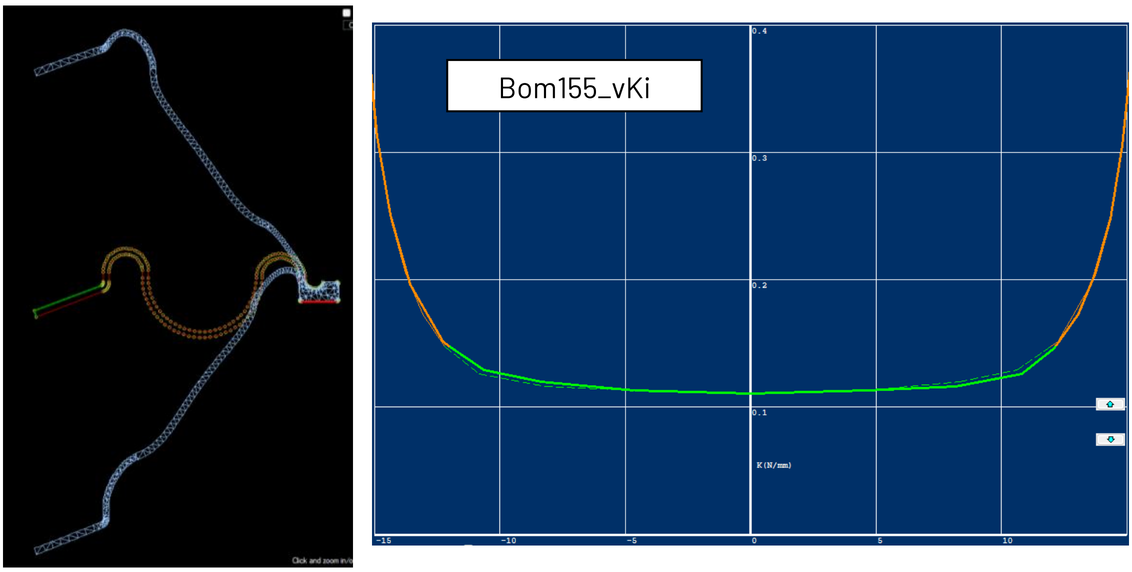
2- Design symmetric and linear suspension

In order to change the spider (stiffness and profile) according to customer requirements, we engineered suspensions with symmetric stiffness. The increased stiffness is the lowest which can be reached to ensure suitable mechanical coupling with the cone.

Here below are 3 examples of surround stiffness profile over +/-15mm excursion:





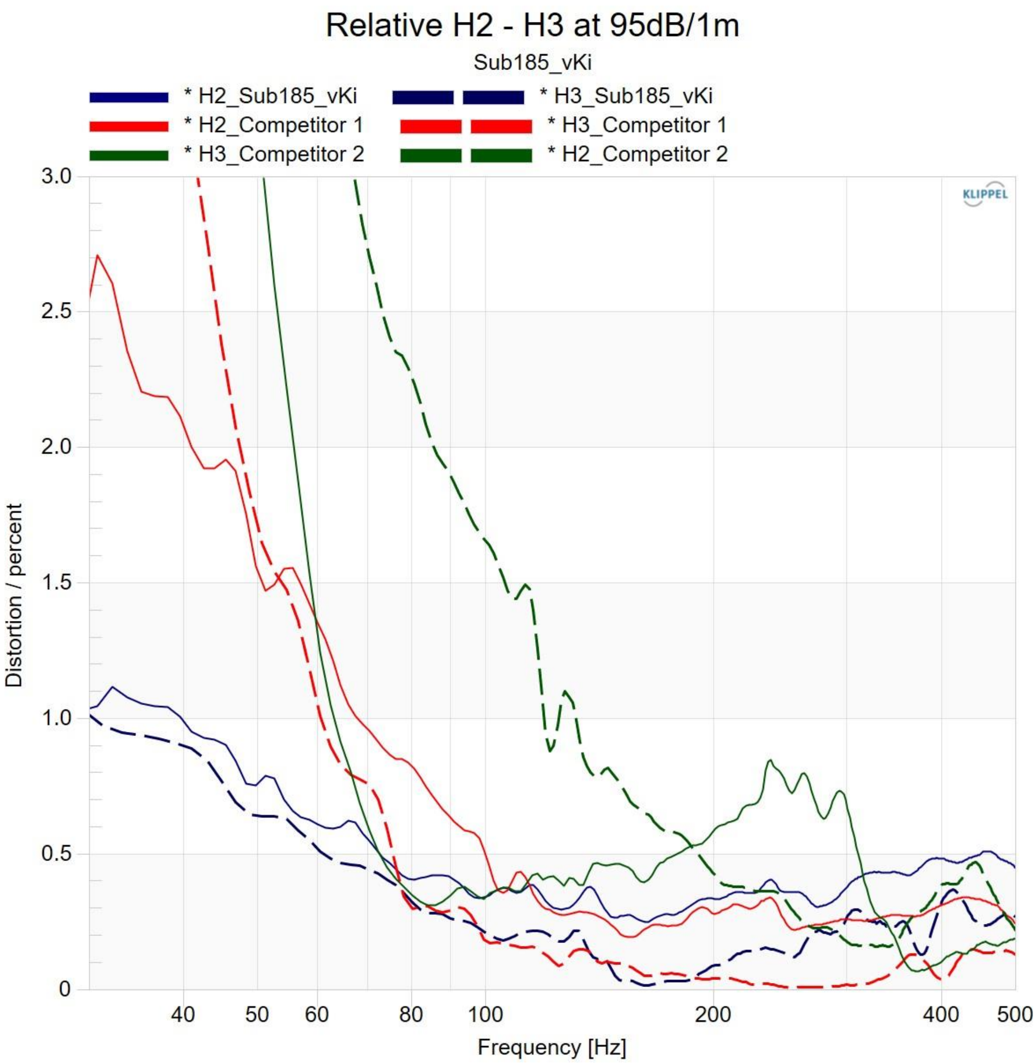


3- Lower THD in low frequency

By taking care of the suspension stiffness, it is possible to significantly decrease the THD in low frequency.
Here below, we compare the H2 and H3 of the Sub185_vKi with 2 competitors.

These competitors are top of the art woofers, with excellent performances, in a similar price range as 185_vki.
We notice the THD of competitor 1 is extremely low from~150Hz to 1000Hz, even better than any 185_vKi reference.
The competitor 2 has also very low THD in the midband, comparable with 185_vKi.
There isn't anything to blame with these woofers, they are very good drivers.

The purpose of this chapter is to show how the innovative suspension developed by Kartesian allows to significantly decrease THD below ~100Hz.
The gap at 40Hz is from 1.5% to 5% compared with regular high-quality woofers.



Keep in mind that 1.5% H3 at 50Hz means you generate 150Hz with an amplitude of 36dB below reference level.
Decrease it to 0.7% means you generate 150Hz with an amplitude of 43dB below reference level.
So, THD improvement in low frequency, from 1.5% to 0.7% means 9dB lower.

0,3% H2 at 400Hz means you generate 800Hz with an amplitude of 50dB below reference level.
0,5% H2 at 400Hz means you generate 800Hz with an amplitude of 46dB below reference level.
So, the THD improvement in the midband, from 0.5% to 0.3% means 4dB improvement.

As the consequence, the Kartesian engineering team is focus on THD improvement where it is the most important.
Considering the current state of the art, THD in low frequency seems to be the most relevant way of improvement.