Round-Robin-Test Pass-by Noise tracks Europe

Final report, 17th January 2017

Gregor Richartz, Porsche
Manuel Männel, Müller-BBM
Christoph Wibmer, Fakt motion GmbH
Dr. Herbert Finsterhölzl, Consultant

EXCERPT for GRBP Task Force on Measurement Uncertainties

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Review by Hans-Martin Gerhard, Porsche

VDA Verband der Automobilindustrie

Content

Why do we call the test Round-Robin ?

VDA

- The term round-robin denotes…
  …in computer science a process that computing processes allocates limited resources
  …in quality assurance, **a ring trial under identical conditions**
  …a tournament format, a round-robin tournament

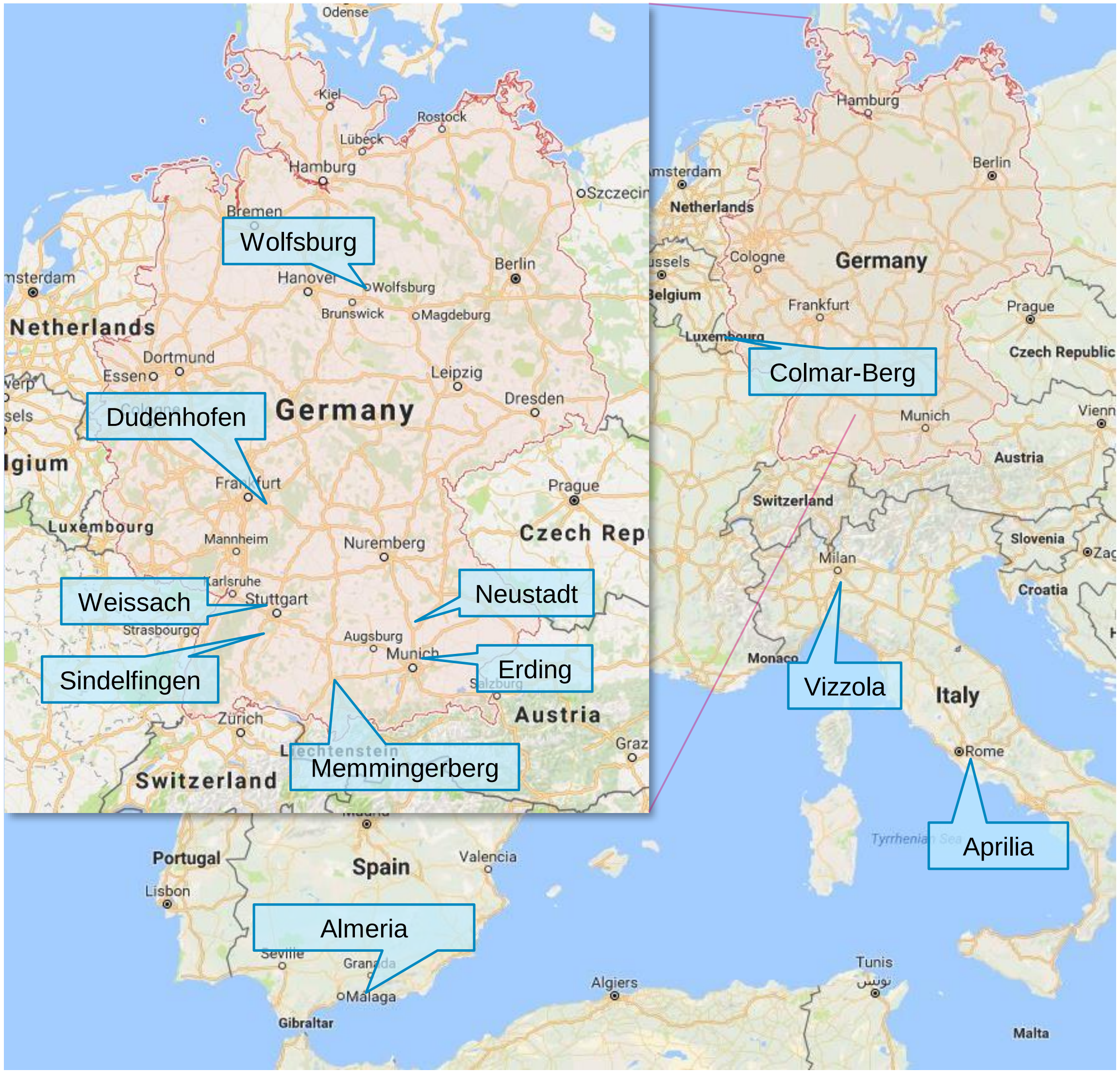
- The term dates from the **17th-century French ruban rond** (round ribbon). This described the practice of **signatories to petitions against authority** (usually Government officials petitioning the Crown) **appending their names** on a document **in a non-hierarchical circle** or **ribbon pattern** (and so disguising the order in which they have signed) so that none may be identified as a ringleader. This practice was adopted by sailors petitioning officers in the Royal Navy(first recorded 1731).

- First of all **French government officials** should practice the round robin, **by fixing tapes under their petitions in a circle** instead of sign with their name. This type of signature is in **French so called ruban rond** (literally translated to tape or **ribbon around**) what from in the Anglo-Saxon language area came to **round robin by oral tradition**.

Motivation and objectives

- Assessment of tyre road noise with OEM tires with regard to limit value reduction to 68dB (A) according to R540 / 2014 and upcoming review of the limits for tires according to GSR661 / 2009
- Gain experience with ISO10844:2014
- Comparative assessment of the track surface (eg diversification)
- Physical, acoustic description of the track surface (parameters, micro / macrogeometry)
- Evaluation of parameters
- Collect suggestions for future review of ISO-standard
- Comparison of track surfaces in Europe among themselves and compared to Chinese tracks

Tracks and participants



All tracks are build according to ISO10844-2014

Pictures of road surface

Test Track 1

Test Track 2

Test Track 4

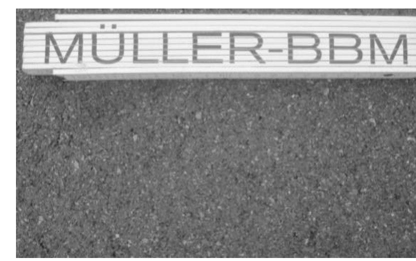
Test Track 5

Test Track 6

Test Track 7

Test Track 9

Test Track 10

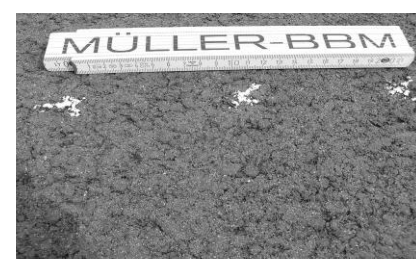


Test Track 11

Test Track 12

Test Track 13

Test Track 14



Tyres and test car

Tested tyres:

- Four different typical summer tyres by different manufactures, size 205/55 R16
- One typical summer tyre, size 245/40 R18
- One slick tyre (without negative profile), size 205/55 R16
- One SRTT (TIGER PAW M+S), size 225/60 R16

Test car:

- VW e-Golf VII
- Engine power: 85 kW
- Transmission: 1-gear-automatic
- 4 Doors

Measured values:

- Sound level left/right [dB(A)], Vehicle speed [km/h], Ambient sound level (before each run) [dB(A)], Air temperature [°C], Surface temperature [°C], Tyre temperature [°C], Air pressure [mbar], Humidity [%], Wind speed [m/s], Wind direction [deg]

Test conditions

Driving conditions:

• Rolling at different speeds from 40-80 km/h (in 10km/h-steps)	2 runs for each speed level
• Cruising 45/55/65km/h	2 runs for each speed level
• Cruising at 50km/h	6 runs
• Acceleration with 2m/s² as well 50km/h at line PP'	6 runs

Tolerances:

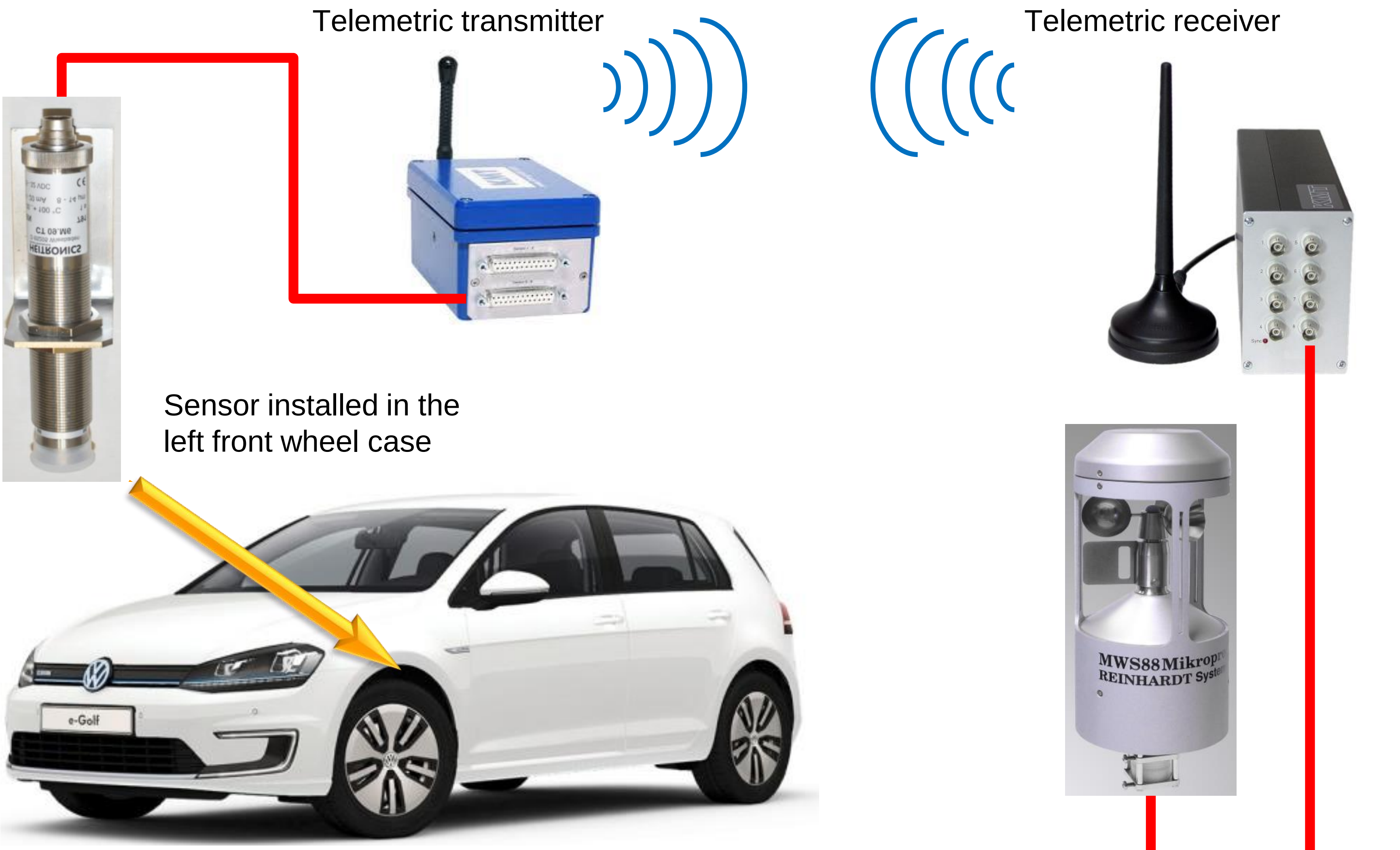
- Max. speed variation: ±0,5 km/h from target speed
- Max. level difference: left-right ≤ 0,6 dB for each run in the same direction

Ambient and weather conditions:

- low ambient noise: expected measured sound level minus 15 dB(A)
- Surface Temperature: 10°C – 40°C

Measurement system

Tyre temperature measurement system

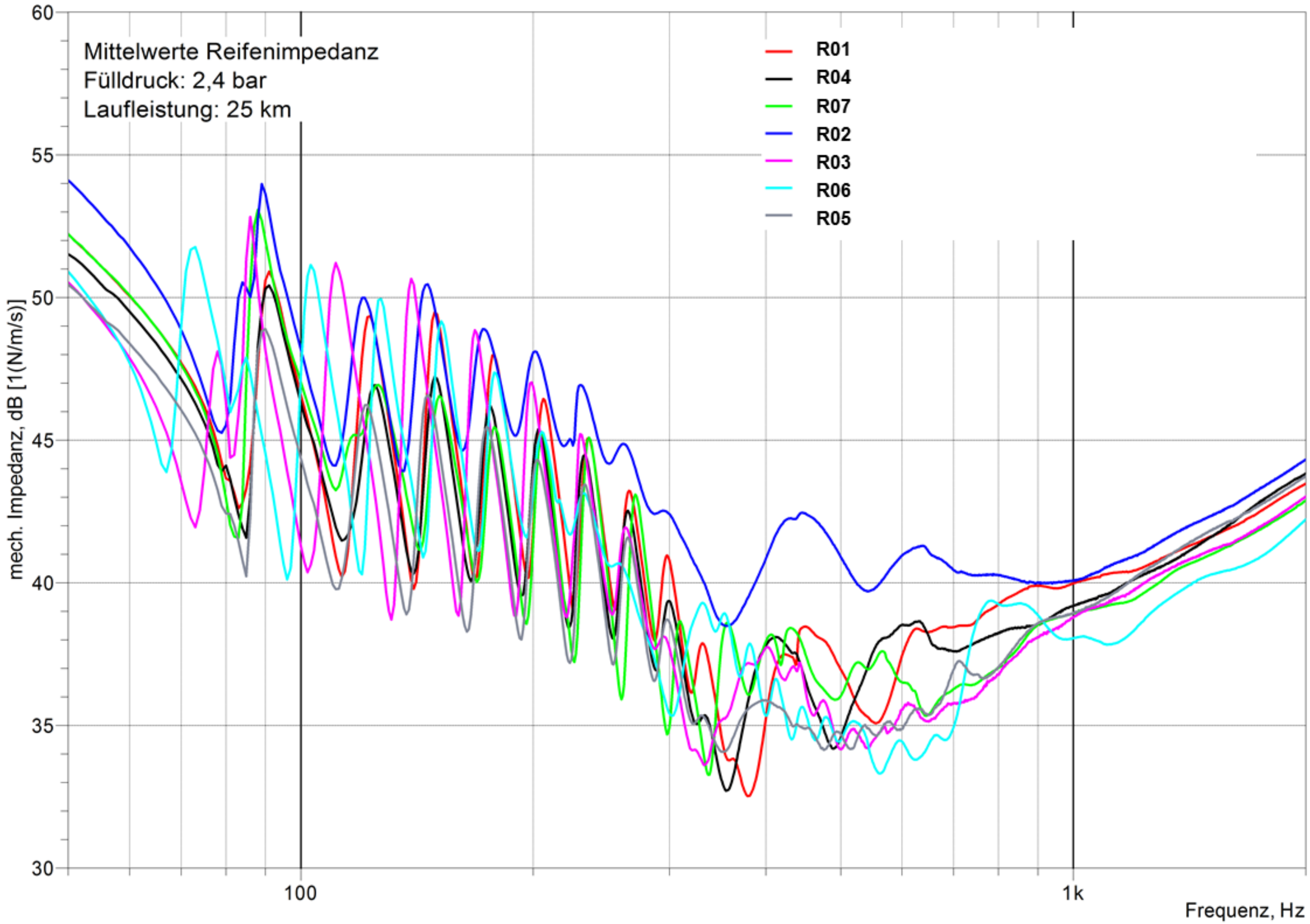


Quelle: Volkswagen

Tyre measurements

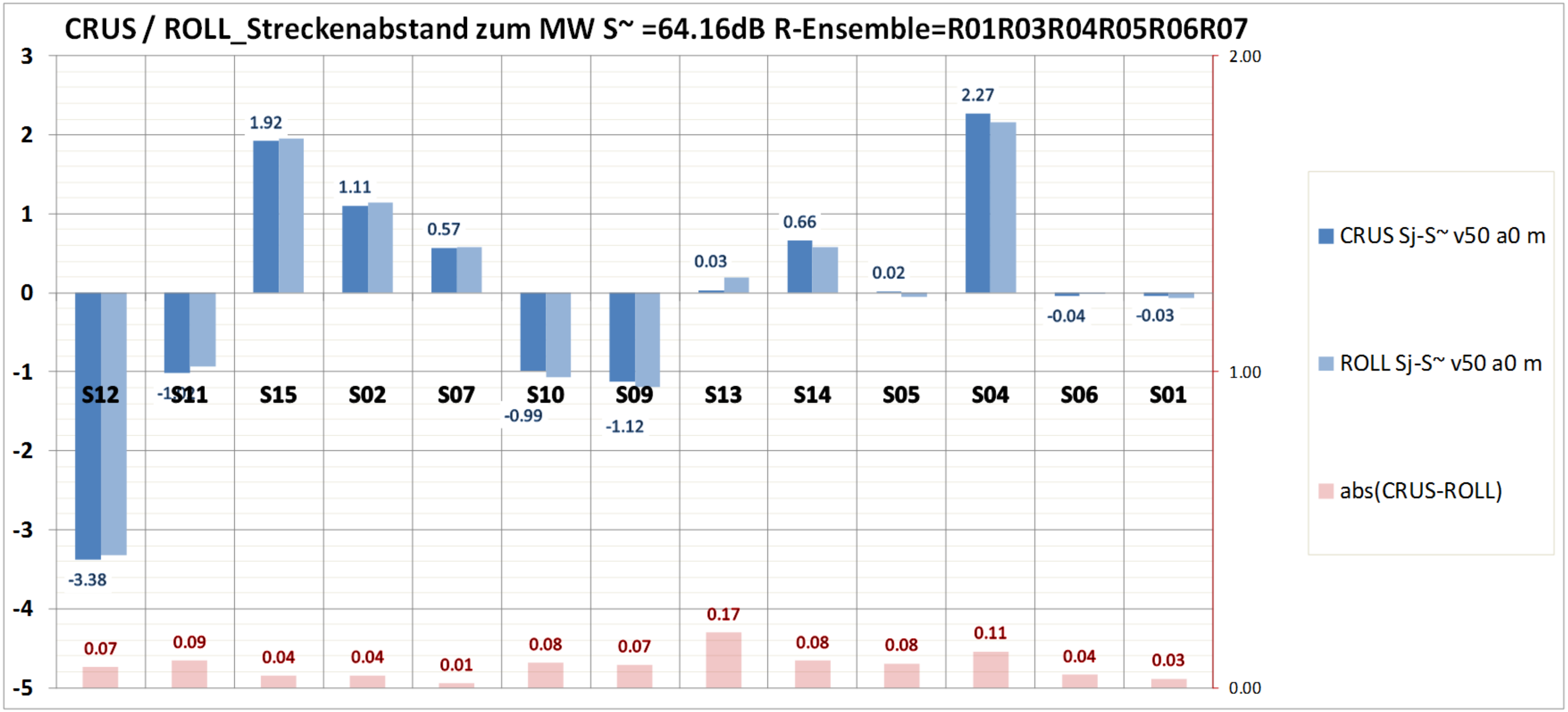
- Measurement of mechanical impedance of all 6 (4 driving, 2 backup) tyres of each type (42 tyres) at the beginning, in the middle and at the end of the pass-by measurements.

Tyre measurement results – mechanical impedance



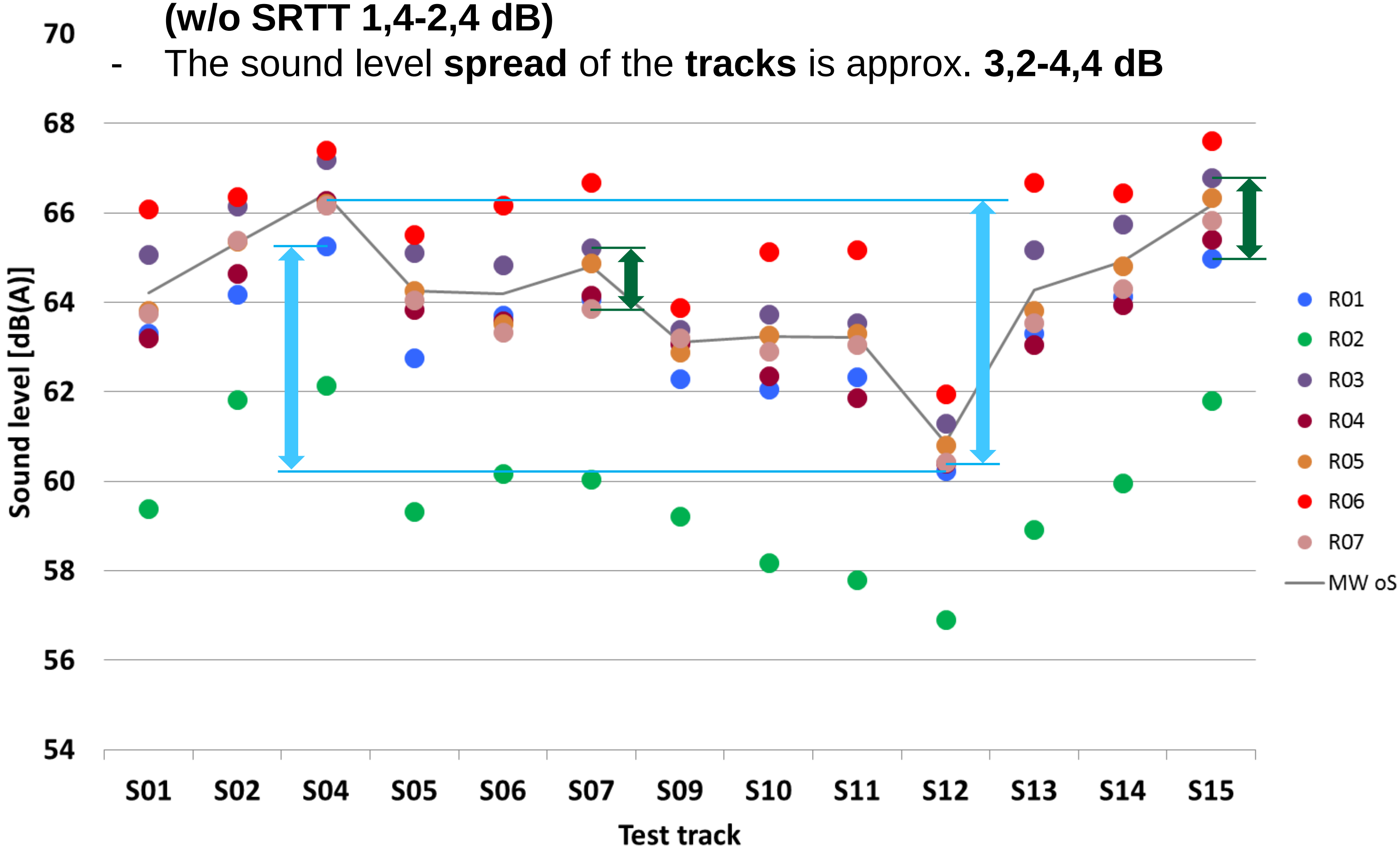
Comparison sound level cruising vs. rolling

VDA



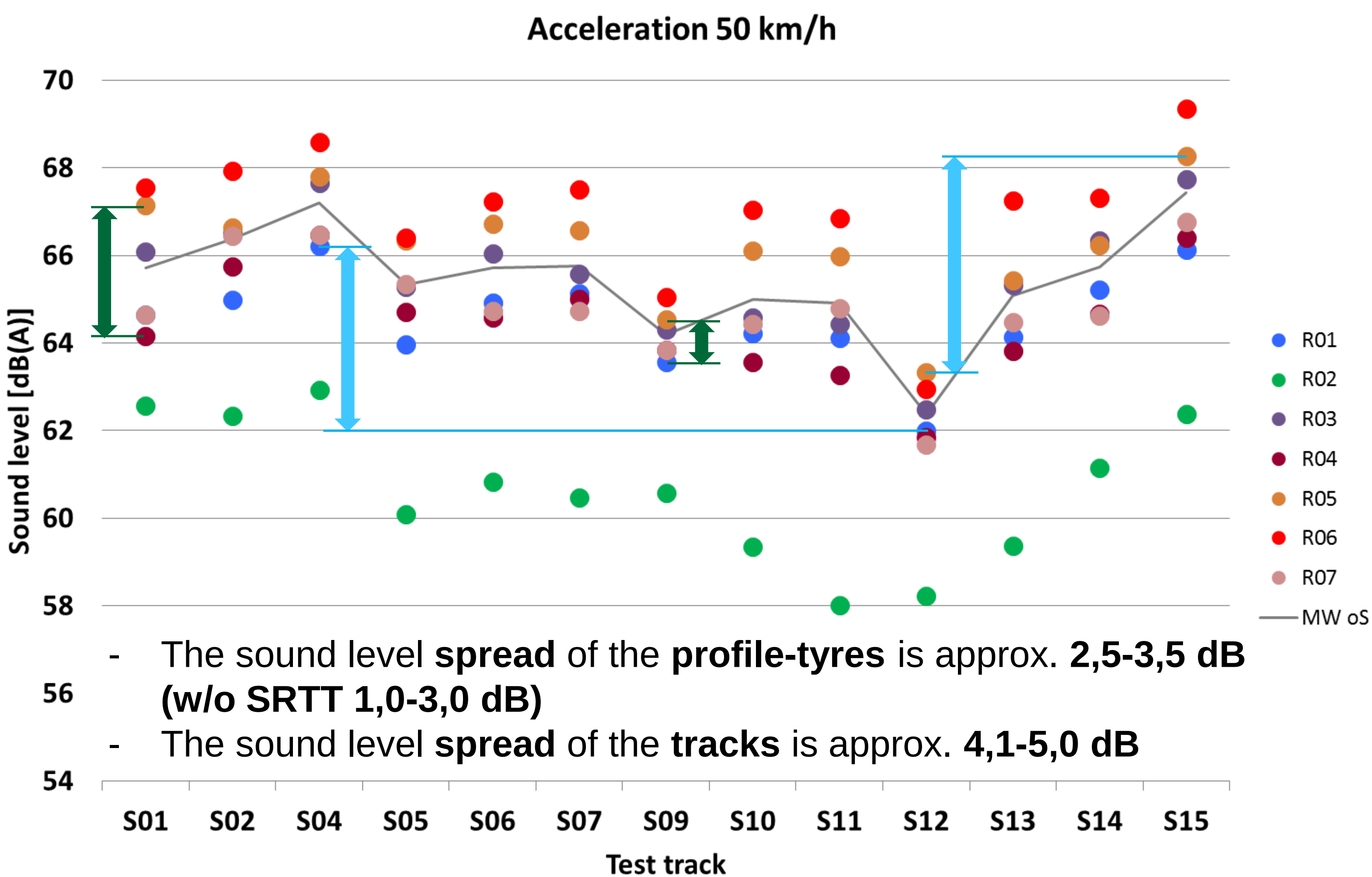
Comparison of test tracks and tyres
Cruising at 50 kph

- The sound level **spread** of the **profile-tyres** is approx. **1,6-3,6 dB (w/o SRTT 1,4-2,4 dB)**
- The sound level **spread** of the **tracks** is approx. **3,2-4,4 dB**



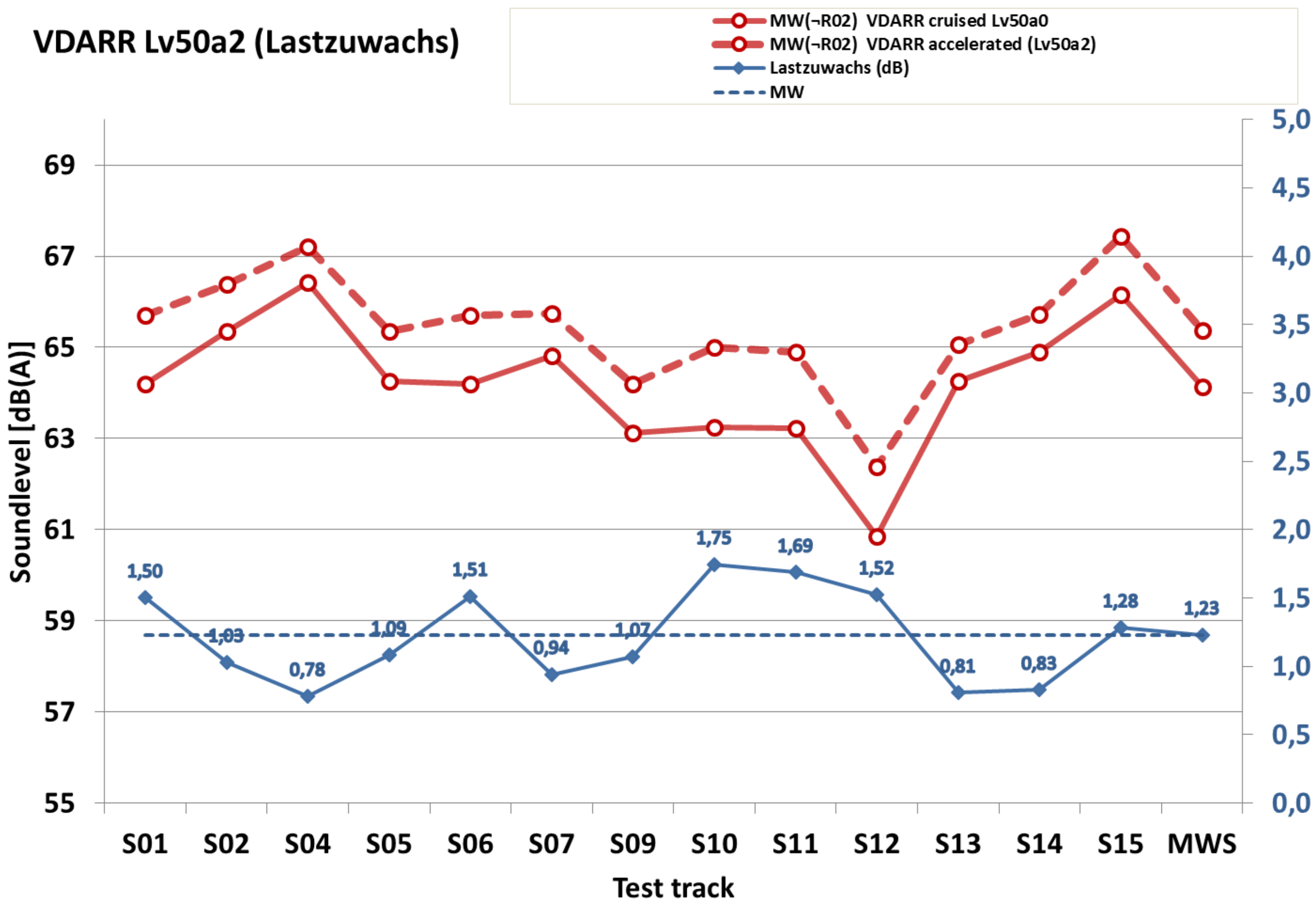
Comparison of test tracks and tyres
Accelerating at 50 kph

VDA



- The sound level **spread** of the **profile-tyres** is approx. **2,5-3,5 dB (w/o SRTT 1,0-3,0 dB)**
- The sound level **spread** of the **tracks** is approx. **4,1-5,0 dB**

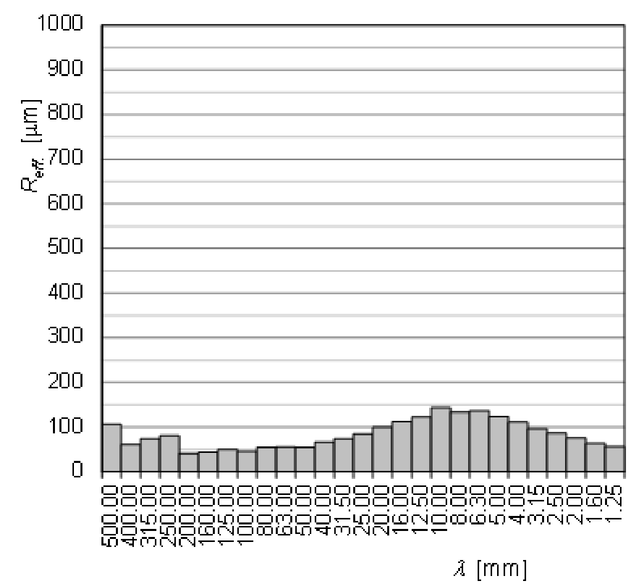
Comparison sound level cruise vs. accelerated



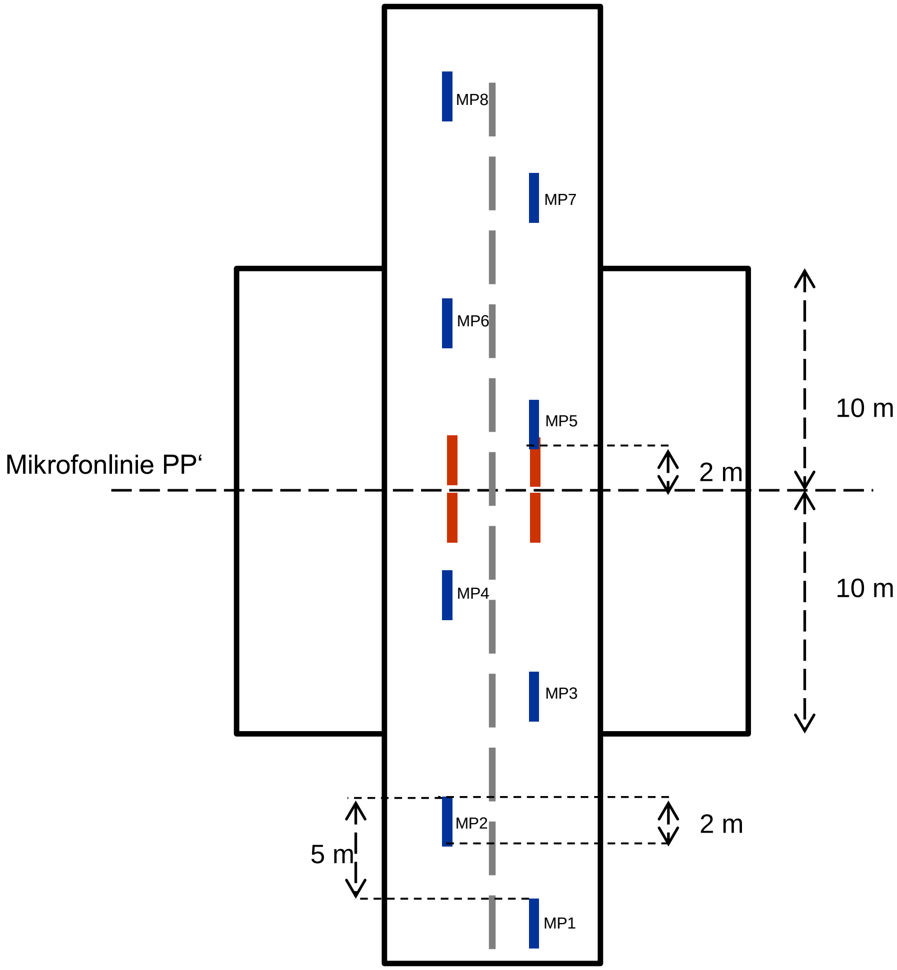
Content

Measurement methods - Texture

- Mean Profile Depth (*MPD*), according to ISO 13473-1
- Shape factor *g*
- Roughness spectrum



Measurement methods - Texture

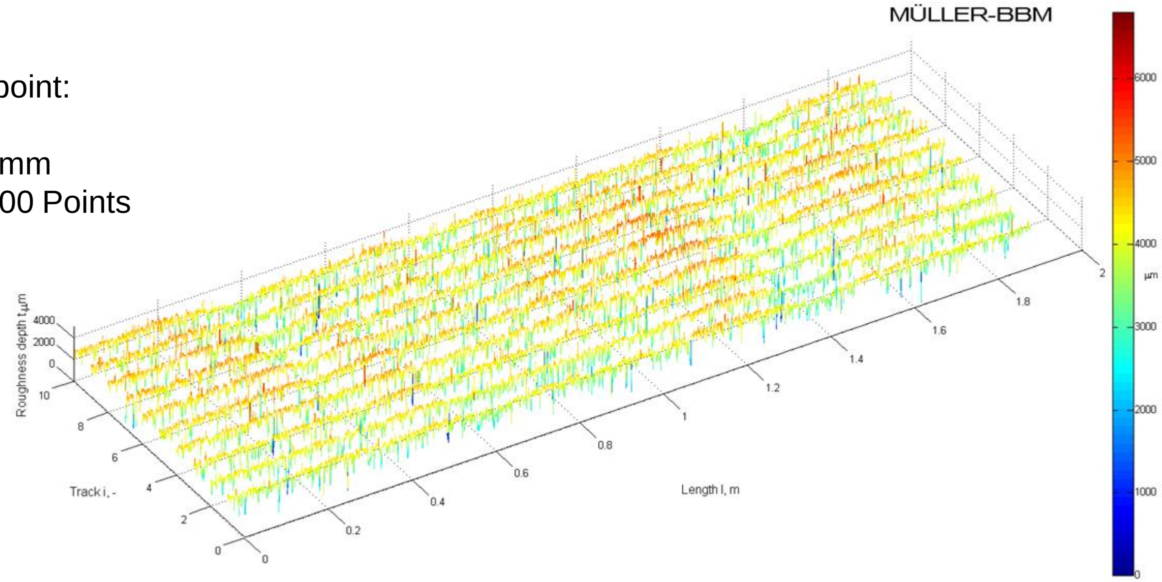


- 8 Measurement points according to ISO 10844:2014
  - 6 parallel profiles (distanced by 20 mm)
  - Scanning length: 2 m
  - Horizontal resolution: 0,2 mm
  - Vertical resolution: 8 µm

- Additionally 4 measurement points close to the PP'
  - 180 parallel profiles (distanced by 1mm)

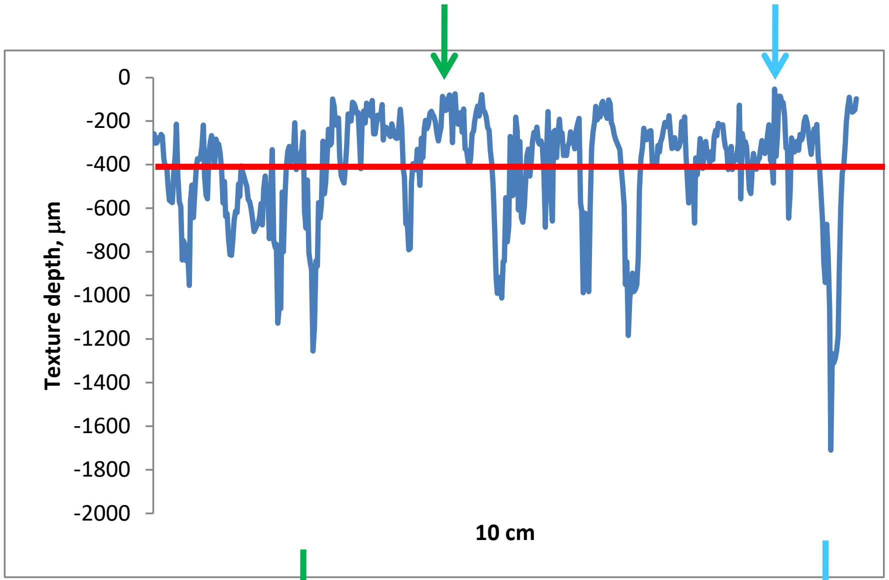
Textur evaluation for *MPD* and *g*

Raw data per ISO-measurement point:
6 profiles each 2 meters long
resolution in driving direction: 0.2 mm
→ 6*2*1/0.0002 = 60.000 Points



Apply high pass filter to reduce unevenness
Divide each profile in segements of 10 cm
Calculate *MPD* and *g* for each 10 cm segment
→ 2m / 10 cm * 6 Profiles/measurement point =
= 120 *MPD* and *g* values per measurement point

Principle – evaluation of *MPD* value



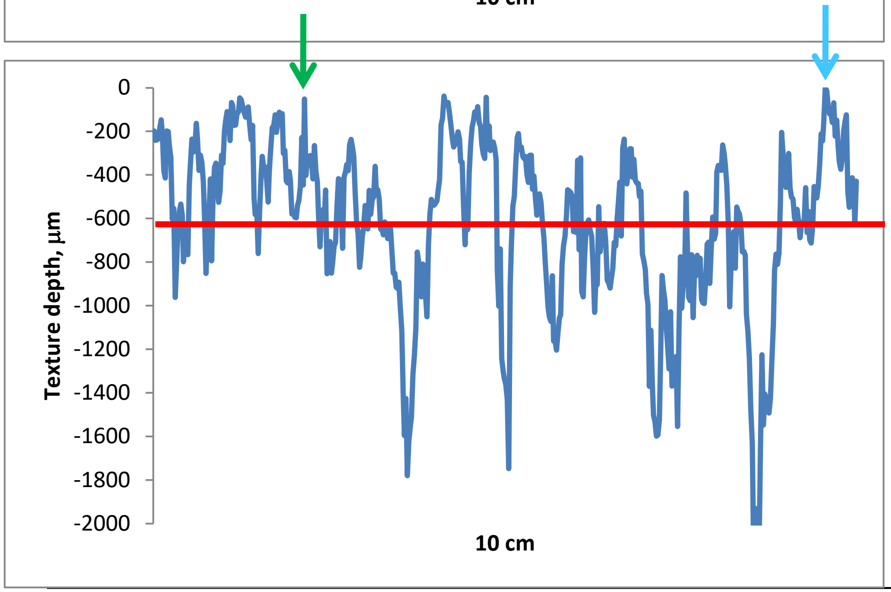
Mean value = -407 µm

Max height 1st half of the segment = -74 µm

Max height 2nd half of the segment = -52 µm

MPD = (-74 µm - 52µm)/2 + 407µm = 344 µm

= 0,34 mm



Mean value = -613 µm

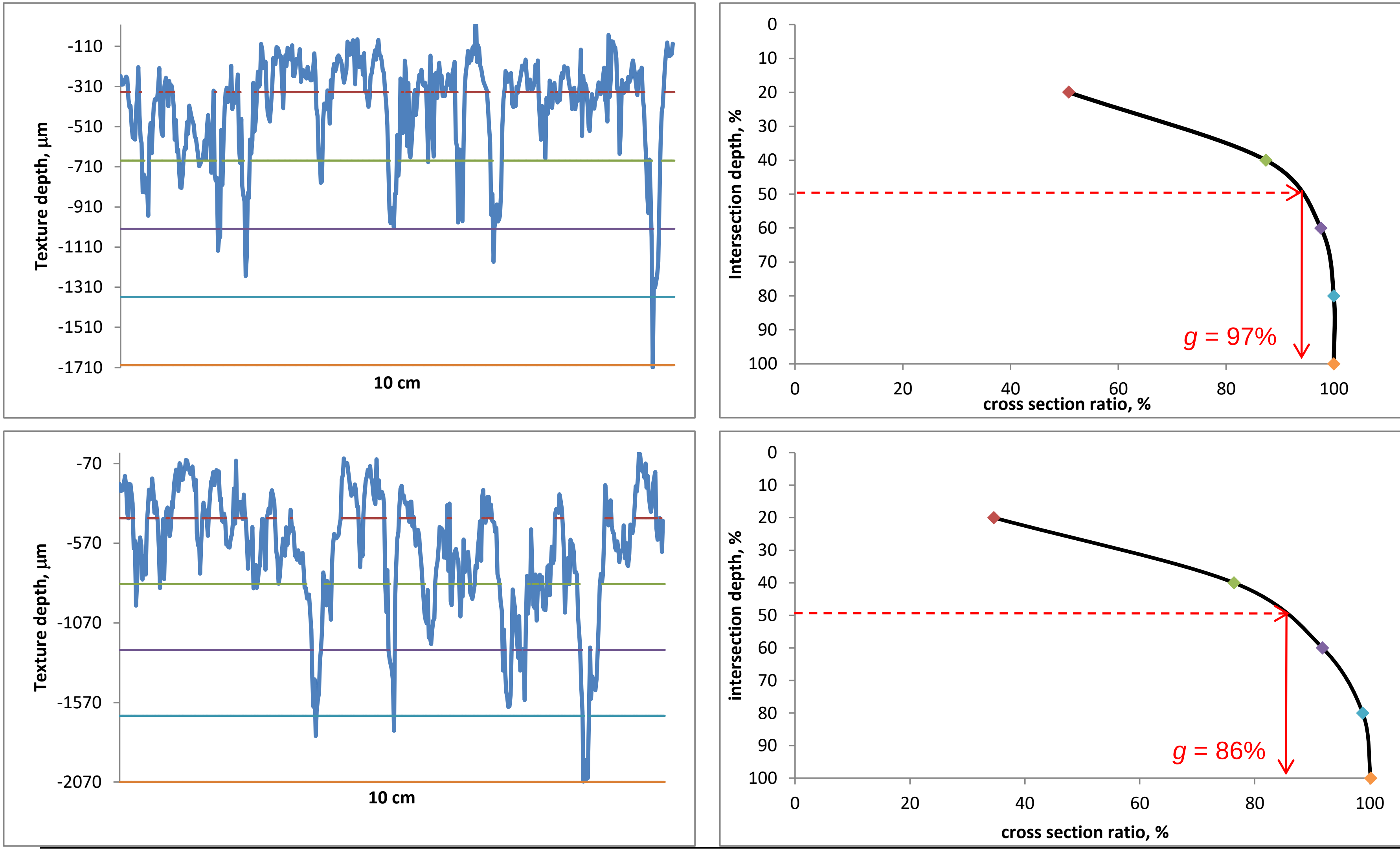
Max height 1st half of the segment = -38 µm

Max height 2nd half of the segment = -8 µm

MPD = (-38 µm - 8µm)/2 + 613µm = 590 µm

= 0,59 mm

Principle – evaluation of shape factor *g*



Measurement methods – Acoustic Absorption

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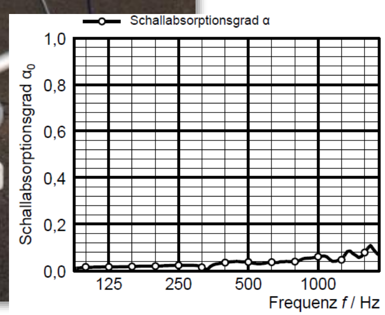
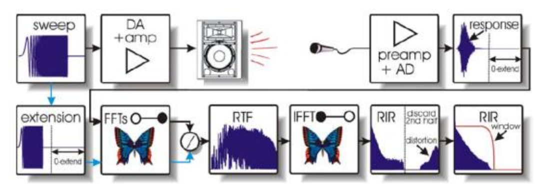
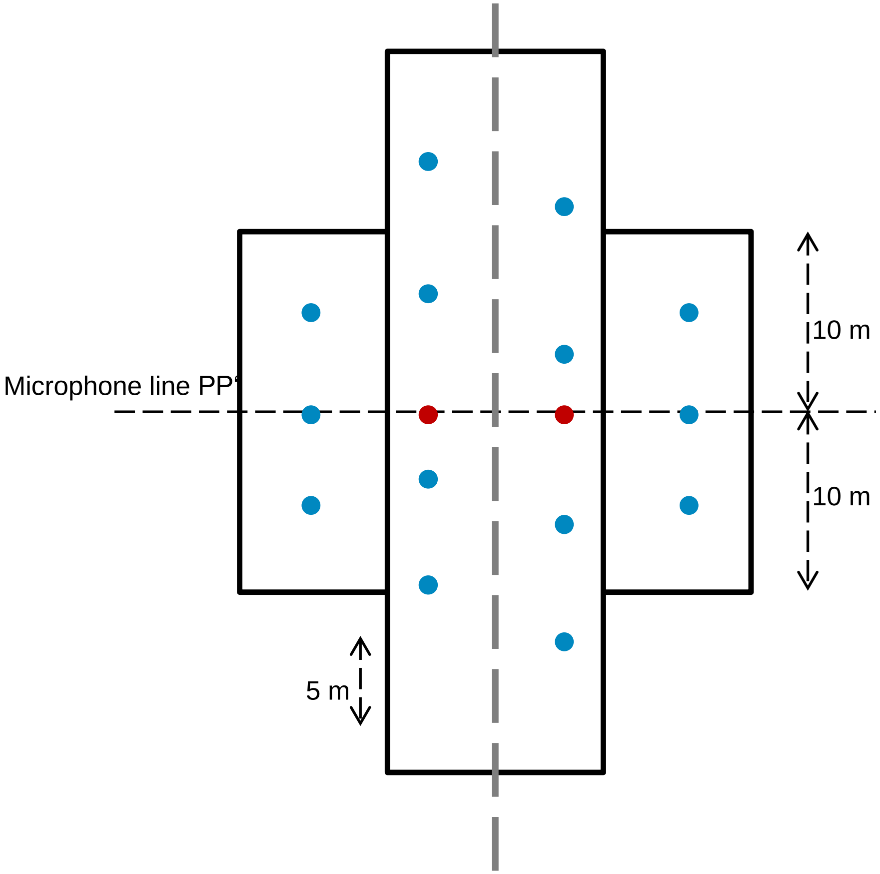
- Measurement of the transfer function (sound pressure level and velocity, including reflections);
- Calculation of the surface impedance;
- Derivation of the Acoustic Absorption coefficient





Measurement methods – Acoustic Absorption



- 8 Measurement points according to ISO 10844:2014 on the track +

  6 measurement points on the propagation area

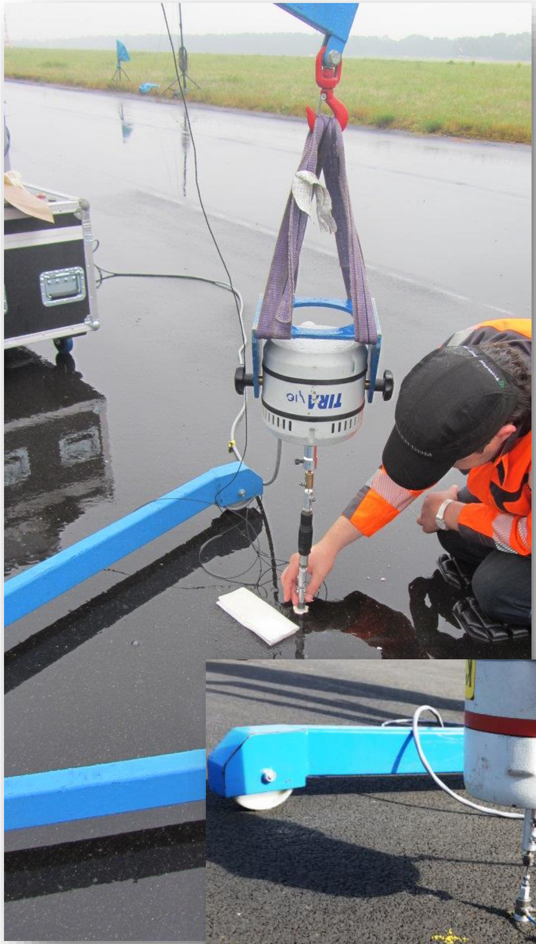
- 2 additional measurements with the p-u probe near the P-P' line

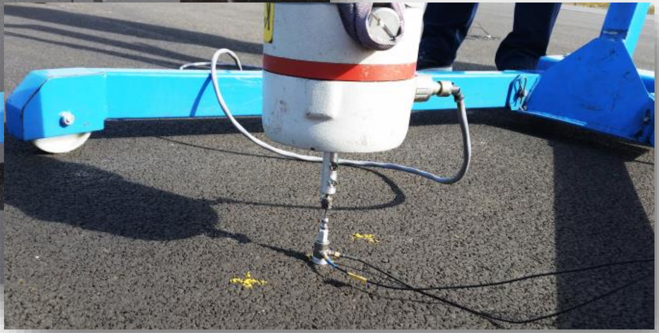
  Spherical sound field

  Measurements in 4 angles (90°, 75°, 60°, 45°)

Measurement methods – Mechanical Impedance

Road Surface

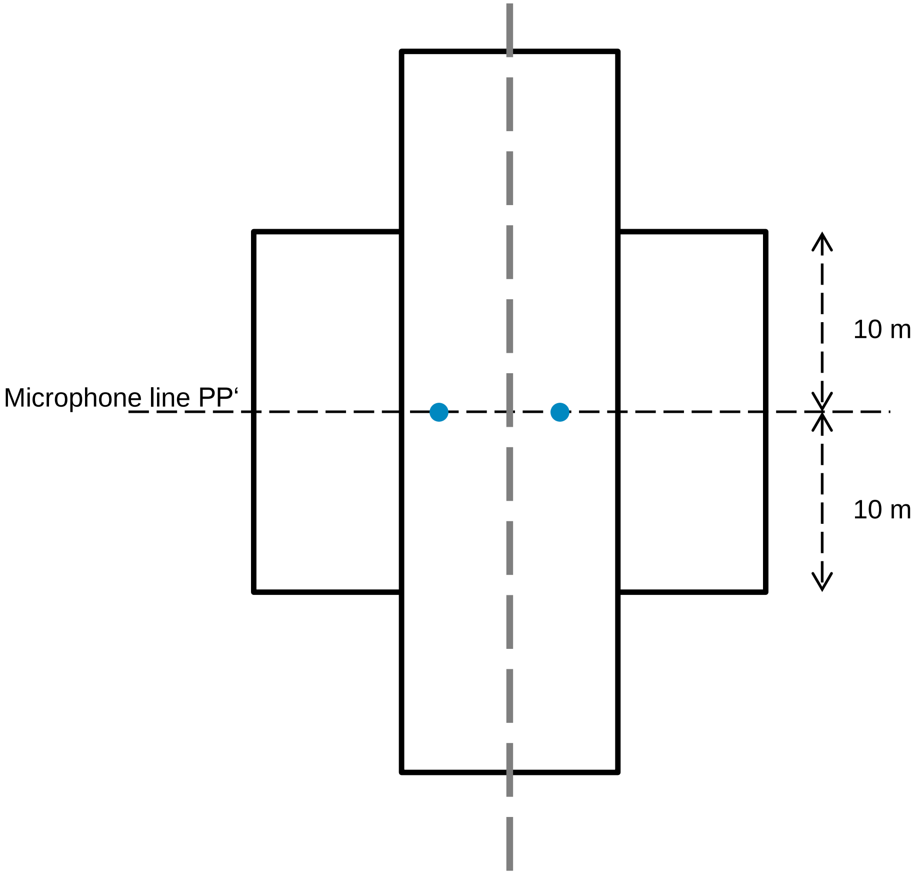




Tyres

$$Z_{mech} = \frac{\vec{F}}{\vec{v}} = \vec{F} \cdot \frac{1}{\int a\, dt}$$

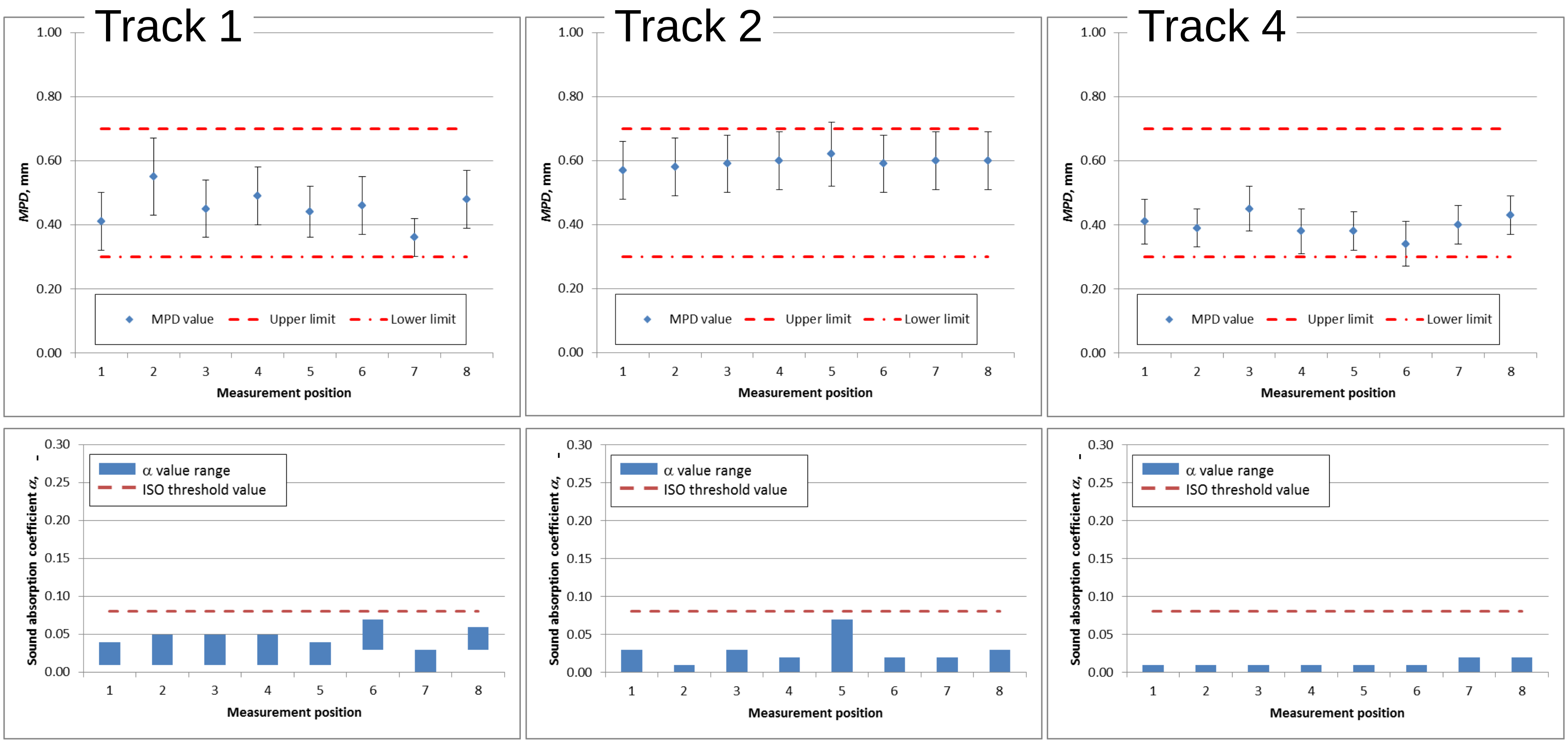
Measurement methods – Mechanical Impedance



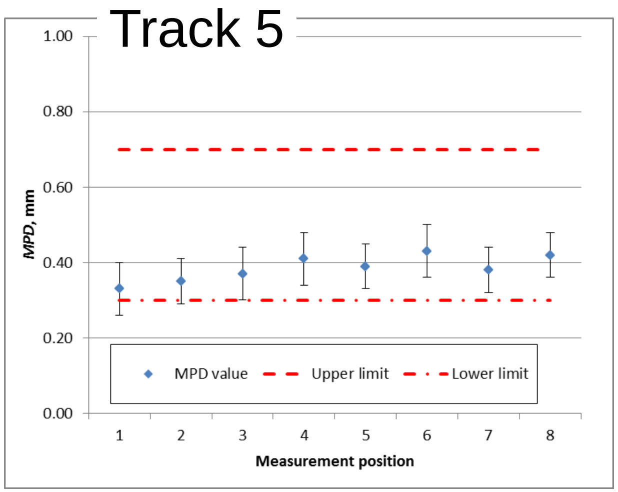
- Measurements at both lanes
  Average of 3 measurements
  very close to each other

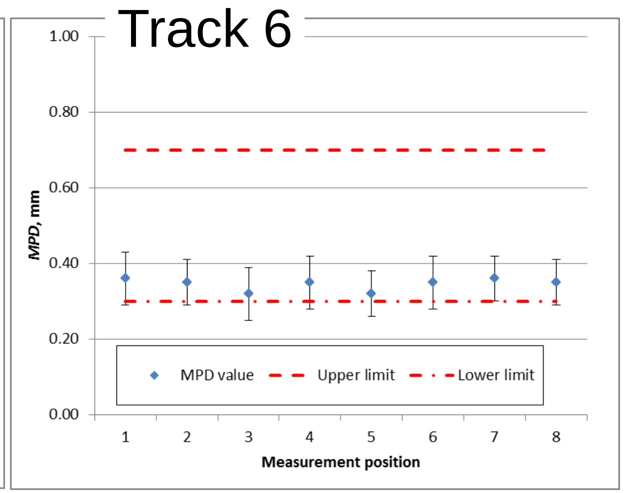
Evaluation of MPD and α as standard parameters

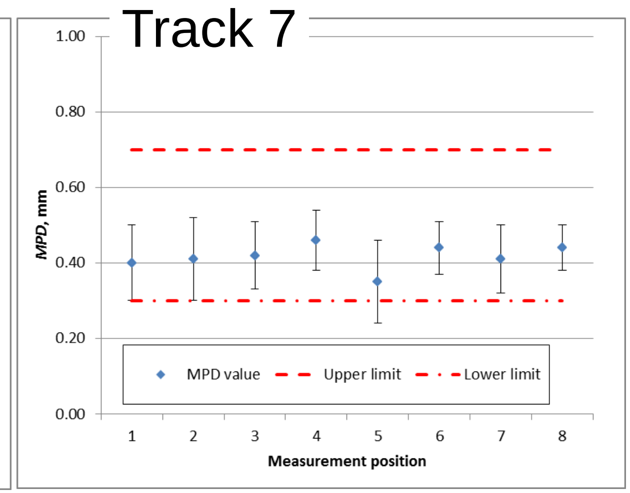
VDA

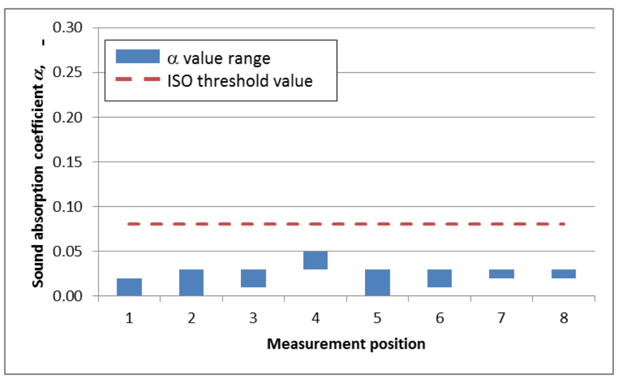


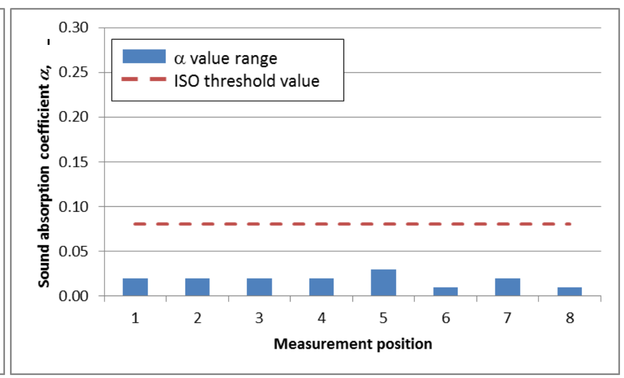
Evaluation of MPD and α as standard parameters

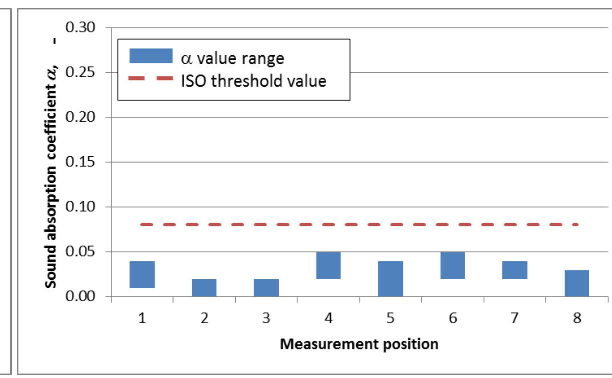




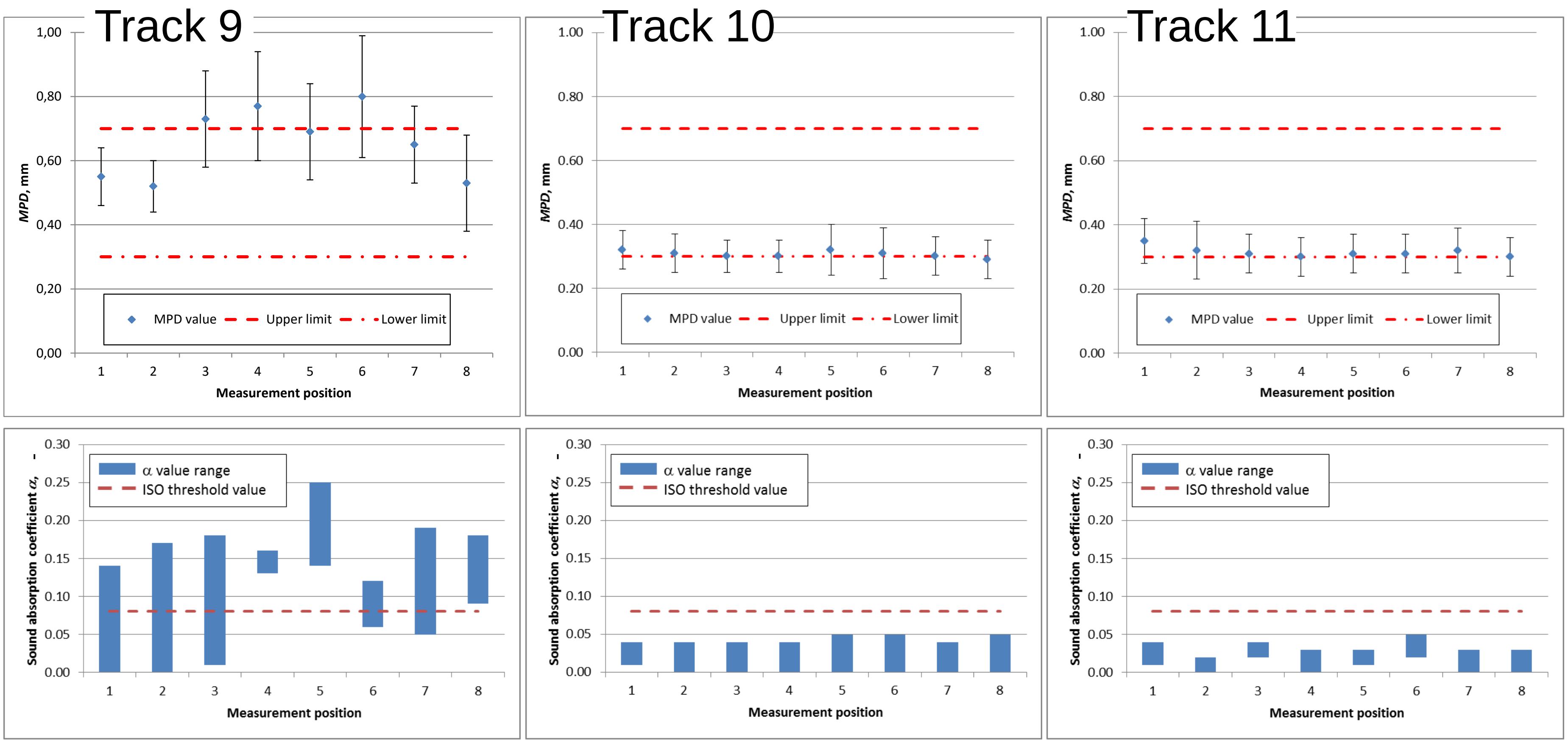




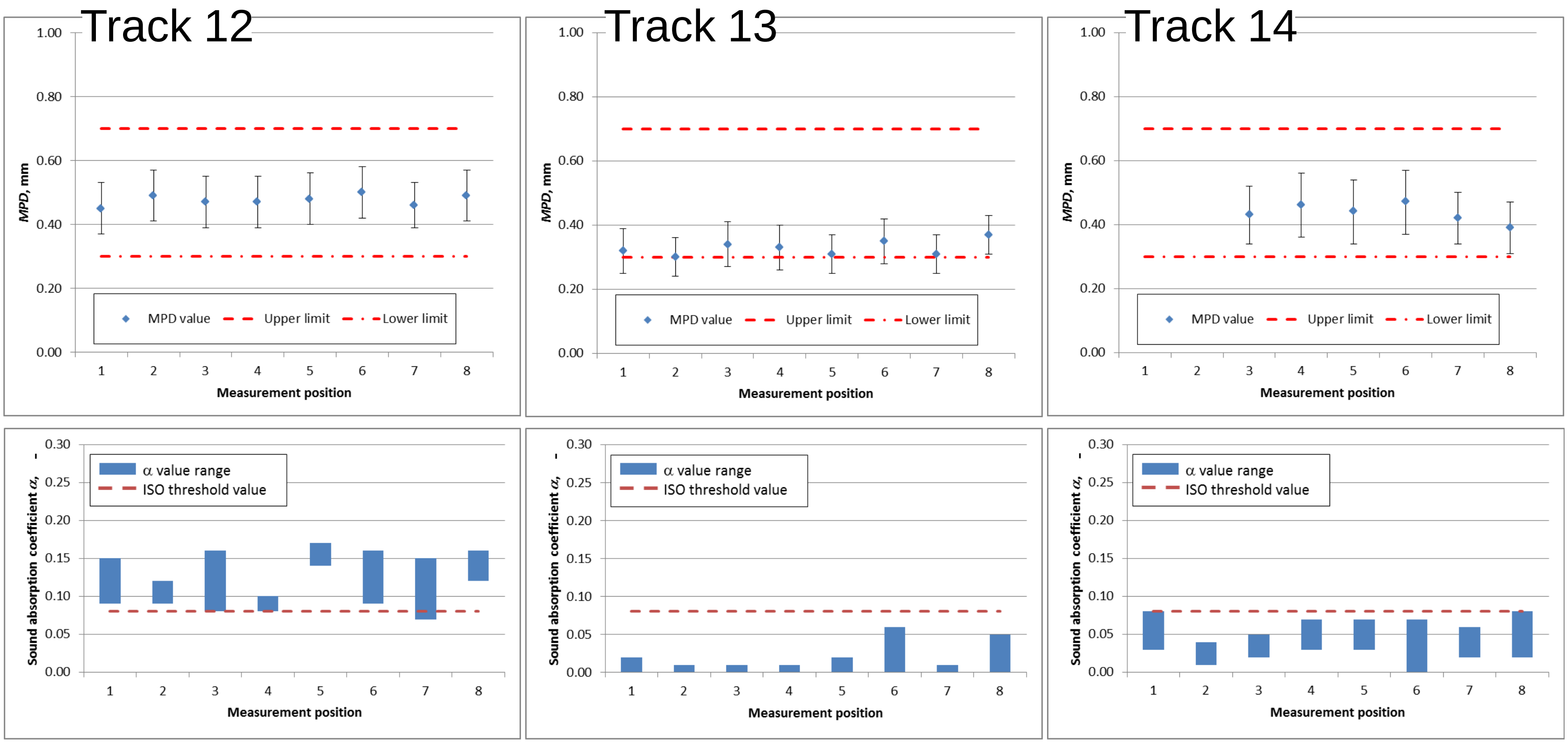




Evaluation of MPD and α as standard parameters

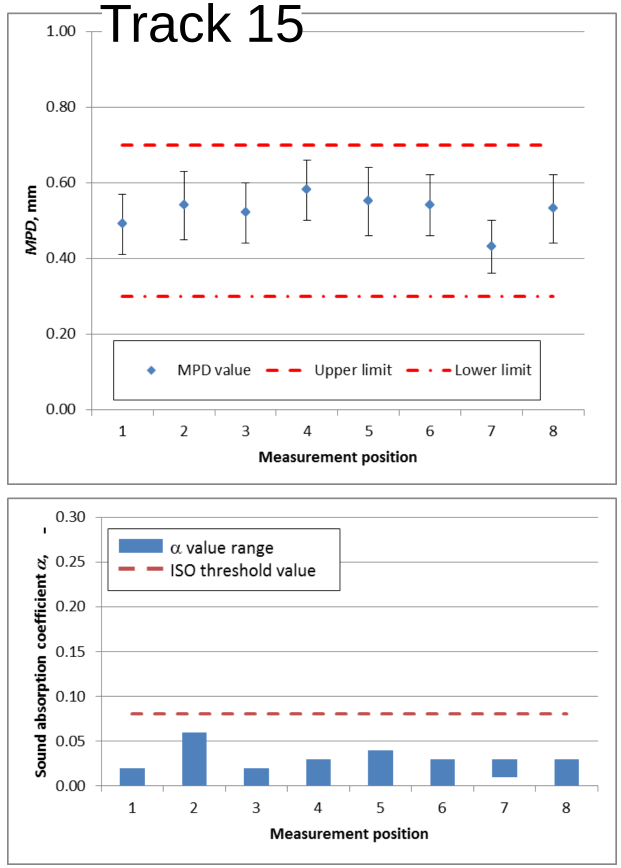


Evaluation of MPD and α as standard parameters

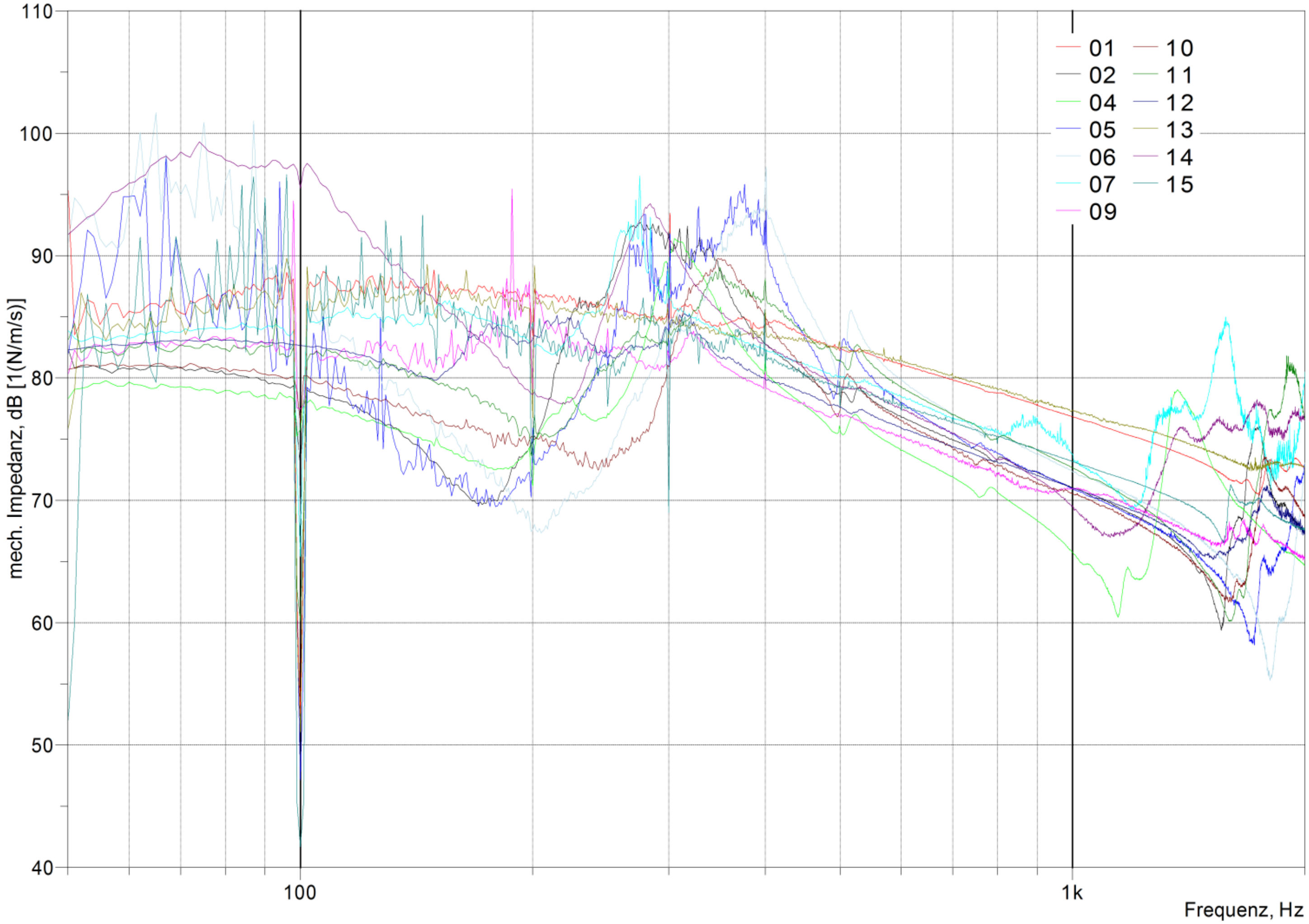


Evaluation of MPD and α as standard parameters

Track 15



Evaluation of mechanical impedance – Road Surface



Content

Pass-by noise vs. surface parameters

Influence of surface properties (MPD, shape factor, sound absorption)

Present knowledge

- **Increasing profile depth increases pass-by noise**: the higher the profile depth is, the deeper the rubber is penetrated by the road surface irregularities;
- **Increasing shape factor decreases pass-by noise**: the lower the shape factor is, the less contact area is available in the tyre-road-contact;
- **Increasing sound absorption decreases pass-by noise**: Horn effect is reduced and propagation damping takes place.

- **BUT: all of these parameters depend on each other, in granular media, e.g. no sound absorption if there are no irregularities!**

Pass-by noise vs. surface parameters

VDA

Bringing data together

Mean profile depth *MPD*

VDA number	measurement position 1	2	3	4	5	6	7	8
1	0,41	0,55	0,45	0,49	0,44	0,46	0,36	0,48
2	0,57	0,58	0,59	0,60	0,62	0,59	0,60	0,60
4	0,41	0,39	0,45	0,38	0,38	0,34	0,40	0,43
5	0,33	0,35	0,37	0,41	0,39	0,43	0,38	0,42
6	0,36	0,35	0,32	0,35	0,32	0,35	0,36	0,35
7	0,40	0,41	0,42	0,46	0,35	0,44	0,41	0,44
9	0,55	0,52	0,73	0,77	0,69	0,80	0,65	0,53
10	0,32	0,31	0,30	0,30	0,32	0,31	0,30	0,29
11	0,35	0,32	0,31	0,30	0,31	0,31	0,32	0,30
12	0,45	0,49	0,47	0,47	0,48	0,50	0,46	0,49
13	0,32	0,30	0,34	0,33	0,31	0,35	0,31	0,37
14	x	x	0,43	0,46	0,44	0,47	0,42	0,39
15	0,49	0,54	0,52	0,58	0,55	0,54	0,43	0,53

Shape factor, *g*

VDA number	measurement position 1	2	3	4	5	6	7	8
1	89,5	89,9	90,3	89,8	90,6	89,5	91,1	90,0
2	81,2	81,9	81,6	81,1	81,7	80,9	80,8	82,6
4	78,8	79,0	79,2	80,9	77,8	78,2	80,6	79,9
5	87,8	87,5	88,4	89,6	88,3	88,5	88,8	88,9
6	88,3	88,5	89,1	88,5	88,8	88,6	88,3	88,6
7	88,5	89,0	89,4	89,2	90,4	89,9	88,8	88,9
9	79,5	79,8	68,6	72,9	68,2	71,3	72,3	80,8
10	84,6	85,5	84,6	83,6	81,4	83,0	87,6	86,8
11	87,5	86,9	89,2	88,7	88,3	88,9	87,6	90,0
12	87,8	88,0	87,0	87,8	85,9	87,1	88,0	86,6
13	89,9	88,4	88,4	89,1	88,1	88,6	90,1	87,6
14	x	x	90,2	89,8	88,9	89,9	89,7	90,5
15	86,5	83,9	84,5	83,6	84,1	84,7	84,3	83,7

Mechanical Impedance Z_{surf}

VDA_Number	MechImp630lin
1	80,7
2	76,2
4	73,4
5	77,1
6	78,9
7	78,1
9	74,7
10	75,7
11	78,5
12	75,5
13	80,9
14	76,7
15	77,3

Sound absorption $\alpha_{mean, Points\ 3-6}$

VDA number	*f* in Hz 315	400	500	630	800	1000	1250	1600
1	0,02	0,02	0,03	0,04	0,03	0,05	0,05	0,03
2	0,02	0,03	0,03	0,04	0,04	0,04	0,05	0,04
4	0,01	0,00	0,00	0,00	0,01	0,01	0,00	0,00
5	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,02
6	0,01	0,00	0,00	0,02	0,01	0,01	0,01	0,01
7	0,02	0,03	0,02	0,03	0,02	0,02	0,04	0,02
9	0,17	0,15	0,13	0,14	0,13	0,13	0,13	0,11
10	0,01	0,01	0,02	0,04	0,02	0,02	0,03	0,01
11	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,02
12	0,11	0,12	0,12	0,15	0,14	0,13	0,14	0,10
13	0,00	0,01	0,01	0,02	0,01	0,01	0,02	0,00
14	0,03	0,02	0,03	0,05	0,04	0,04	0,06	0,05
15	0,01	0,02	0,01	0,01	0,01	0,02	0,00	0,01

Pass-By noise $L_{cruise50,\ alltyres\ ex.\ slick}$

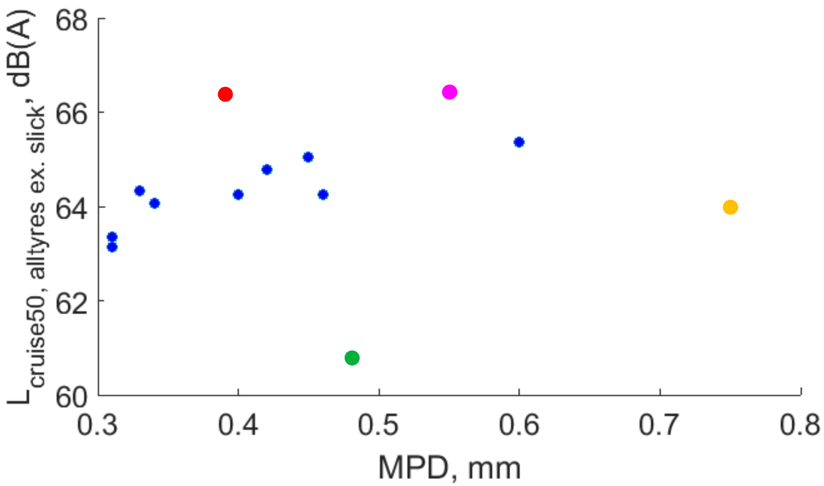
VDA_Number	$L_{cruise50,\ alltyres\ ex.\ Slick}$
1	64,25
2	65,37
4	66,37
5	64,26
6	64,06
7	64,79
9	63,95
10	63,15
11	63,36
12	60,80
13	64,32
14	65,05
15	66,39

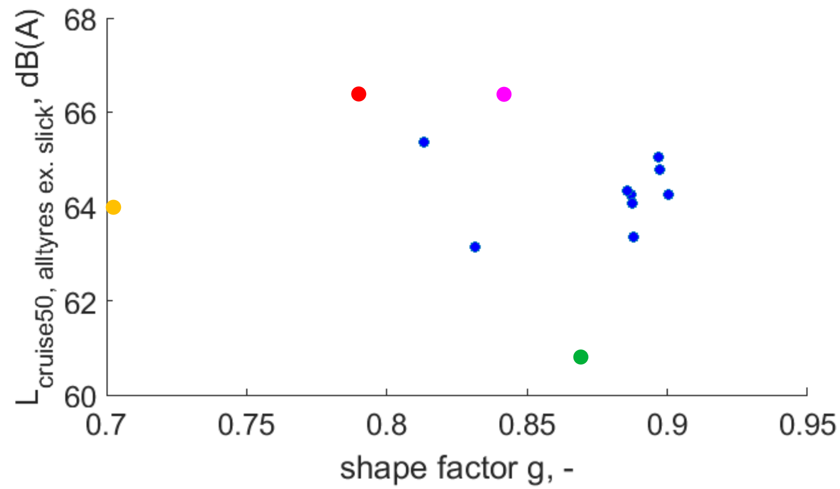
Pass-by noise vs. surface parameters

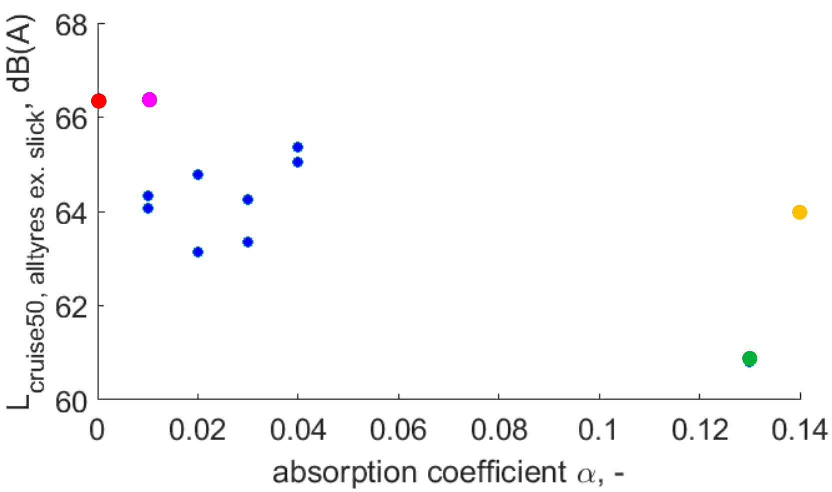
VDA

Influence of single parameters

Examples: S04, S15, S12, S09





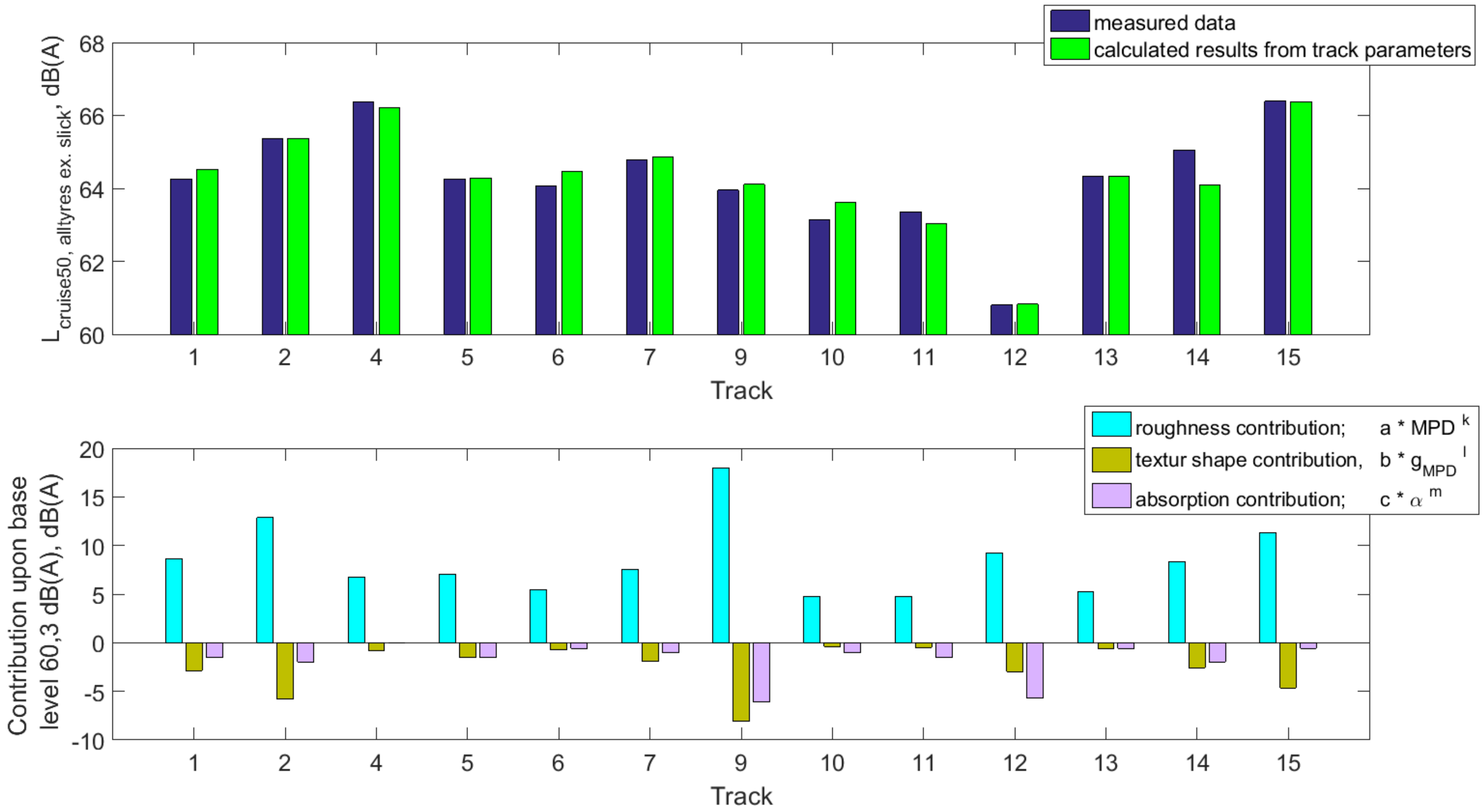


Analysis of a single parameter does not show significant trends, but taking all 3 parameter into account explains pass-by levels qualitatively.

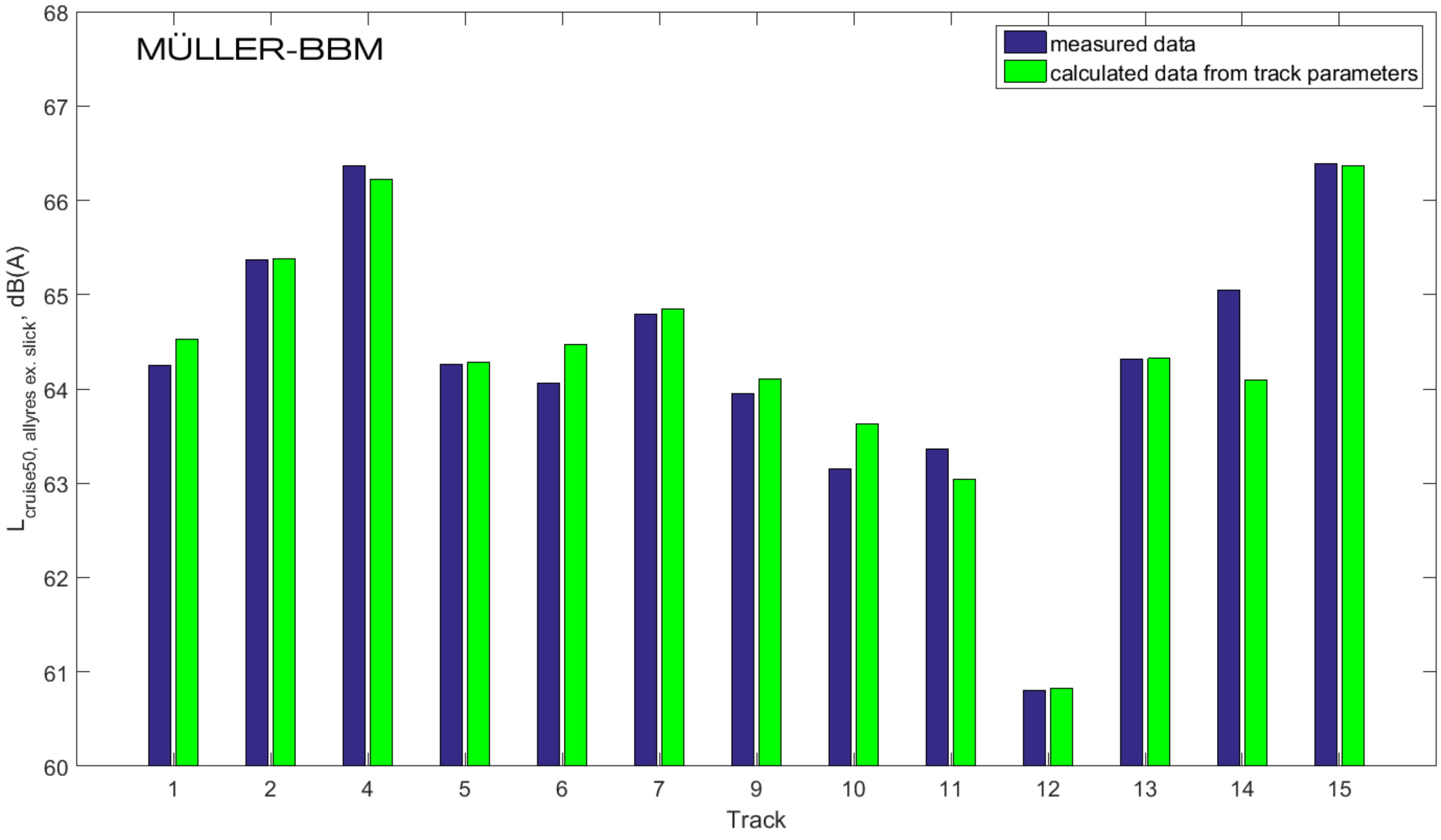
A combined data analysis is necessary for quantitative analysis!

Pass-by noise vs. surface parameters

Contribution analysis



Pass-by noise vs. surface parameters



$$L_{P,cruise50} = 60{,}3 + 27{,}7 \cdot MPD^{1{,}5} - 126 \cdot g_{MPD}{}^{4{,}3} - 36 \cdot \alpha^{0{,}9}\ dB(A)$$

Pass-by noise vs. surface parameters

First conclusions for combined data analysis and next steps

The result of the combined data analysis gives a statistically good and physically reasonable solution.

- It can be used to characterize ISO-tracks based on surface properties!
- It can be used to do a contribution analysis.
- It can also be used to test the influence of further parameters.

Summary and conclusions

- The **average differences** between **test tracks** approved according to **ISO10844:2014** are between **3,2-4,4 dB(A)** for **cruising** and between **4,1-5,0 dB(A)** for **accelerated** measurements.
- For a **single tyre**, the **spread is up to 5,6 dB(A)** for cruising and an **additional 1 dB(A) must be added in case of accelerated measurements.**
- The result of the combined data analysis gives a statistically good and physically reasonable solution.
  - It can be used to characterize ISO-tracks based on surface properties.
  - It can be used to do a contribution analysis.
  - It can also be used to test the influence of further parameters.
- Based on pass-by and surface measurements a simulation model for sound level forecast for an average tyre was developed.
- Different **acoustical performance** between ISO10844-2014 tracks are not only **explainable** by **Mean Profile Depth, shape factor, absorption and mean peak shape (skewness), t**he **sound level** of a track can be **quantified** and **simulated** with an accuracy of < 0,2 dB by a mathematic model.

Important measurement facts

• **Test facilities:**	**11**
• **Countries:**	**4**
• **Traveling Kilometers:**	**15.372 km**
• **Measurement Kilometers:**	**5.481 km**
• **Runs:**	**11.001**
• **Measurement hours:**	**165 h**
• **Beers:**	**a lot**

Thank you very much for your attention!