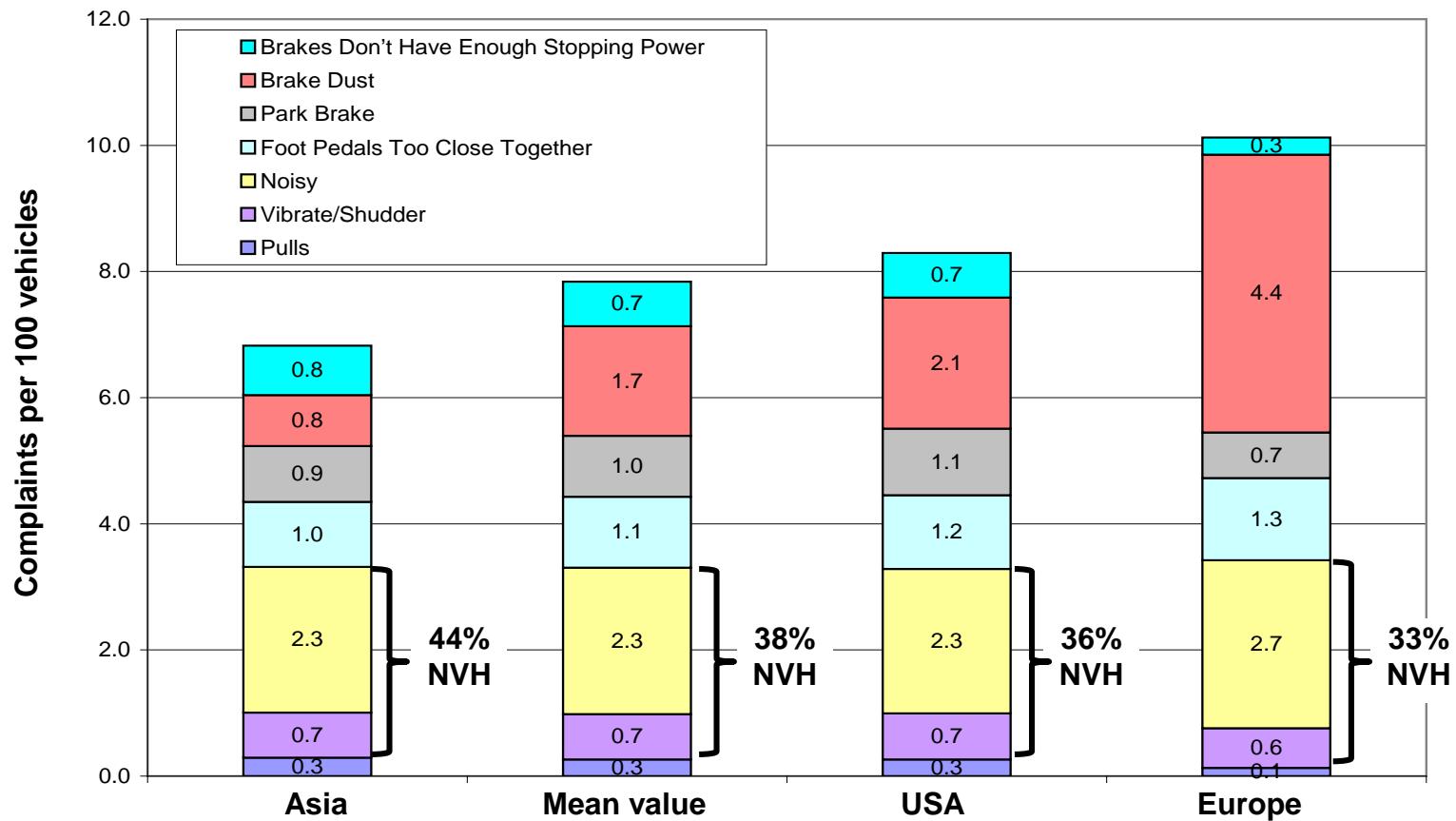


PHYSICAL ATTRIBUTES OF FRICTION MATERIALS WITH RESPECT TO NVH PERFORMANCE

Ralf Gross, Nils Perzborn, Joachim Noack, Philipp Luckhardt, Jeff Shaya
ZF Friedrichshafen



J.D. Power Survey Brake and Handling (2006)

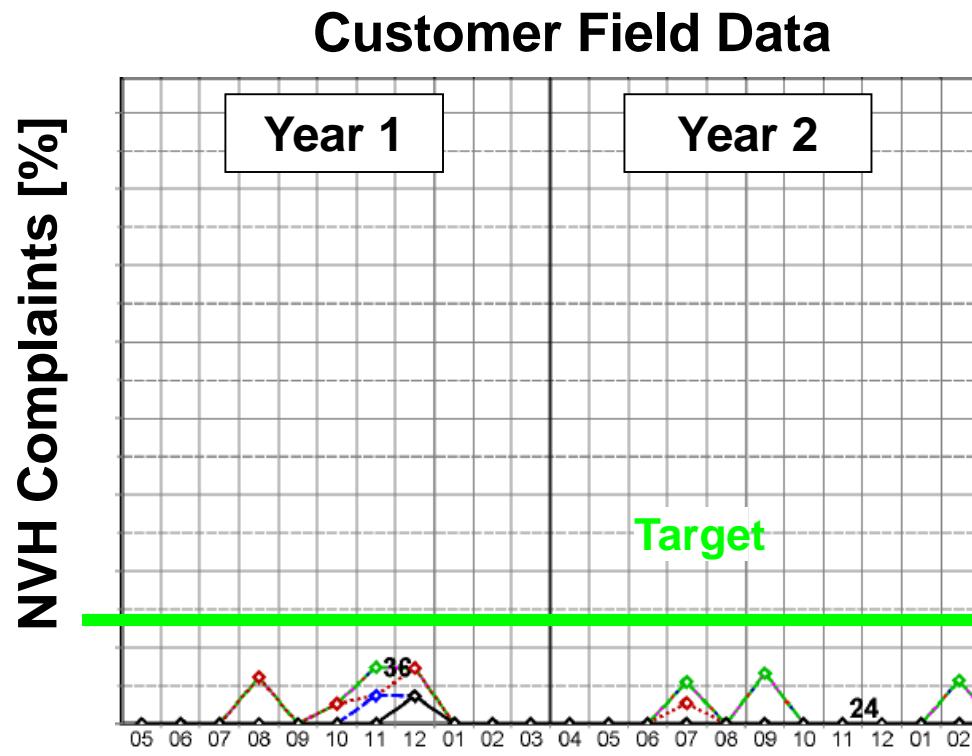


- Comfort is one major indicator for passenger vehicle quality
- NVH behavior of calipers is very important to achieve quality targets

Introduction/Background

- A substantial part of noise is caused by friction induced vibrations from the disc/pad contact
 - Brake pads are a key factor for robust noise behavior.
- But, today no clear identification of “good” and “bad” linings by measurable physical parameters
- However, this is required to:
- a) develop robust caliper systems
 - b) define limits and perform quality monitoring

What is NVH Quality?



Year 1 & 2: NVH performance acceptable

Year 3: Non acceptable peak indicates quality issue

Warranty costs, Bad reputation, Business loss

What Is Critical to Quality?

NVH Quality = F (pad material, caliper, disc, knuckle, ...)

- **X1: Pad material:**

Lining data, process data, eigenfrequencies

ZF + Pad Supplier

- **X2: Carrier:**

Geometries, material properties, eigenfrequencies

ZF + Casting Supplier

- **X3: Housing:**

Geometries, material properties, eigenfrequencies

- **X4: Disc:**

Material properties, geometries, eigenfrequencies

OEM, Supplier

- **X5: Knuckle:**

Geometries, material properties, eigenfrequencies

What Is The Issue?

- All components have tolerances in production
- The number of prototypes in development is limited
- Statistically significant populations are available late -> NVH robustness issues are often found too late
- Later changes in the supply chain can cause new noise issues (e.g. casting transfers, localisations, etc.)

Three Steps to Frustration (@SAE 2015)

FROM FINGERPOINTING TO FINGERFOOD

Dr. Torsten Treyde, Joachim Noack ZF TRW,

Panel: Another Look at Pad Characterization for NVH

SAE Brake Colloquium & Exhibition -
33rd Annual

2015, Charleston, South Carolina, USA



**WE expect YOU
to solve YOUR
problem**

**Let's look
at data**

**All values in
spec.**



**Friction
Supplier**

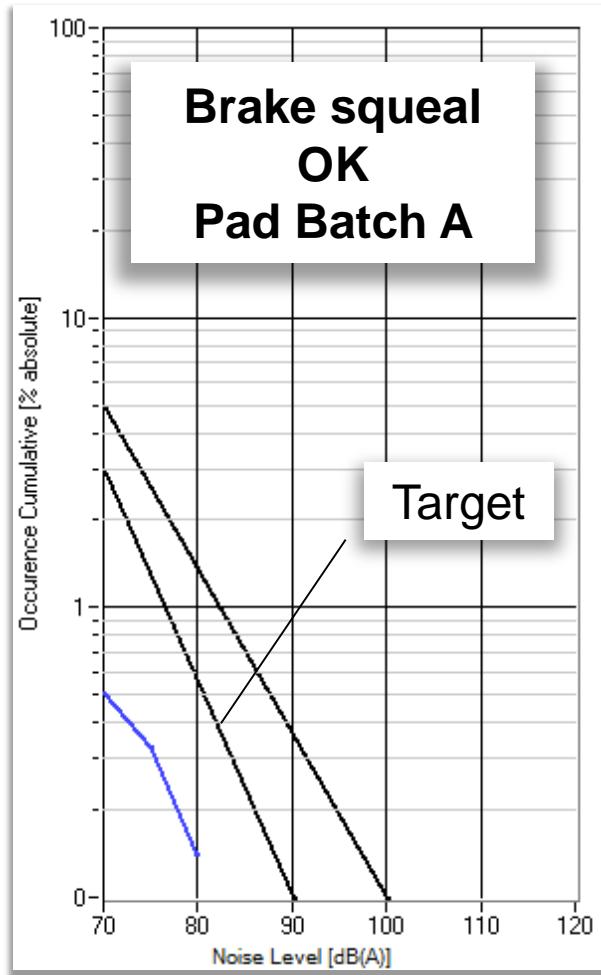
**WE expect YOU
to show it's not
YOUR problem**

**All values in
spec.**

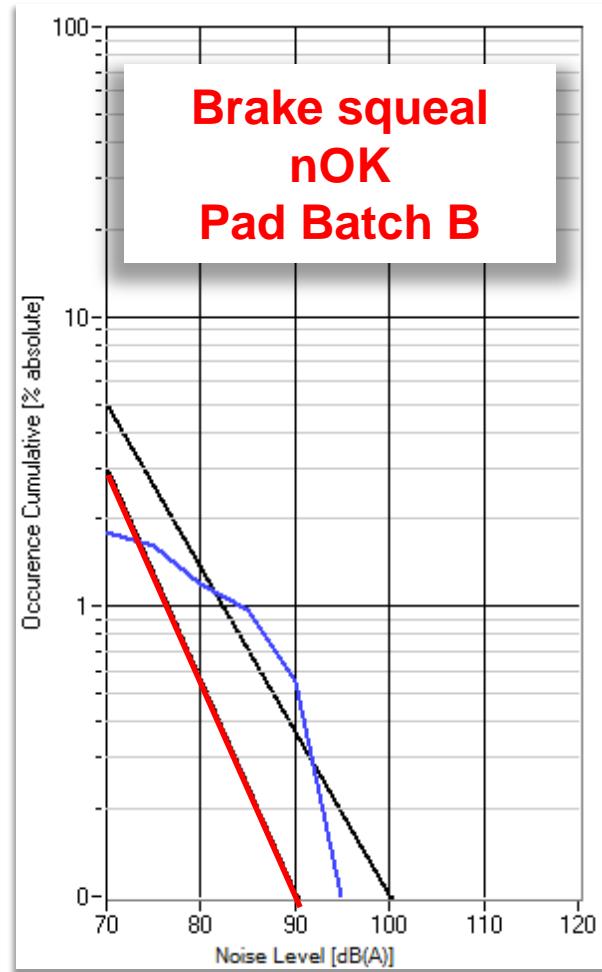
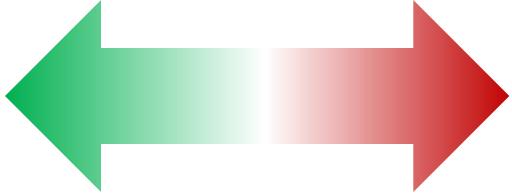
- Common problem understanding
- Fair data exchange
- Appropriate resources
- **New Measurements**



Example I: TRW Noise criteria



Same dyno, fixture,
caliper, rotor -
But different pads!

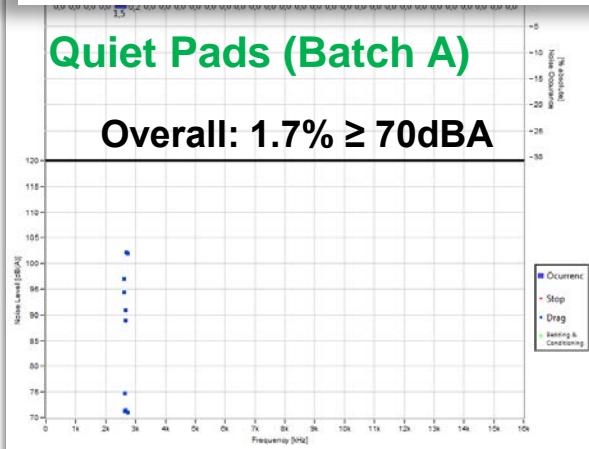


Example II: ZF TRW Cold Procedure (Short)

Tests run in Koblenz

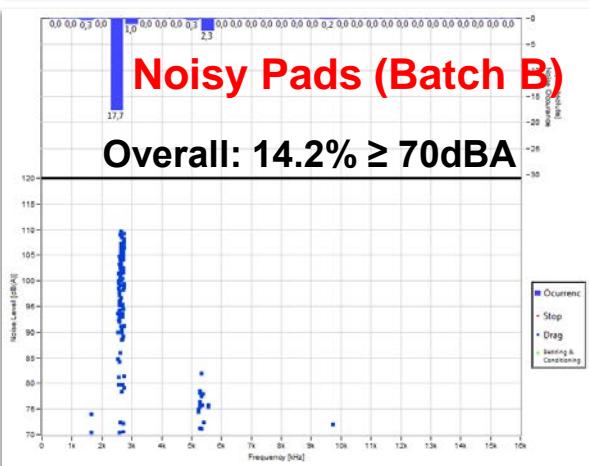
Quiet Pads (Batch A)

Overall: 1.7% \geq 70dBA



Noisy Pads (Batch B)

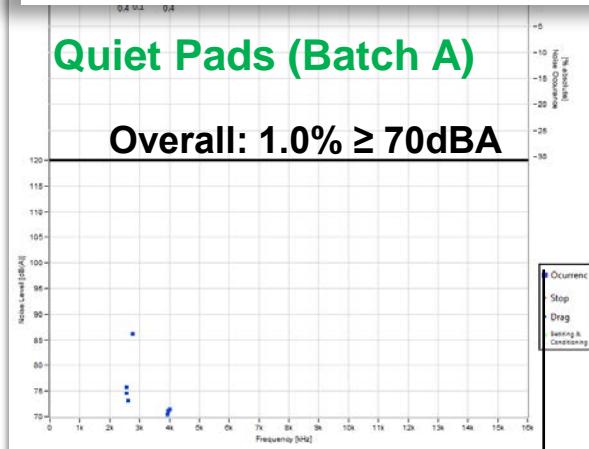
Overall: 14.2% \geq 70dBA



Tests run in Livonia

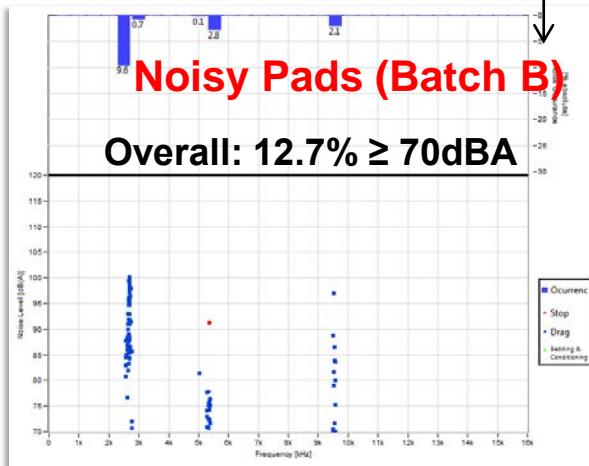
Quiet Pads (Batch A)

Overall: 1.0% \geq 70dBA



Noisy Pads (Batch B)

Overall: 12.7% \geq 70dBA



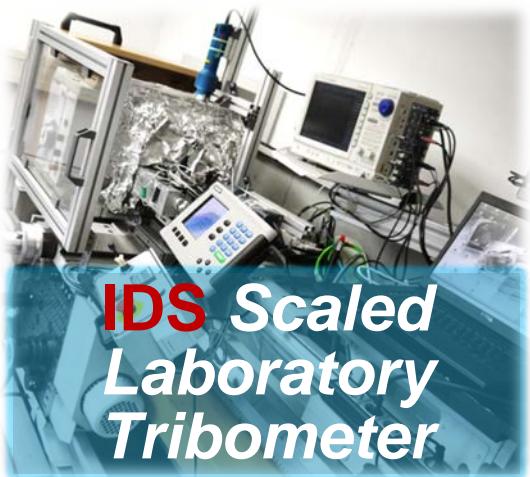
Same pads but
different dyno,
fixture, caliper,
rotor!



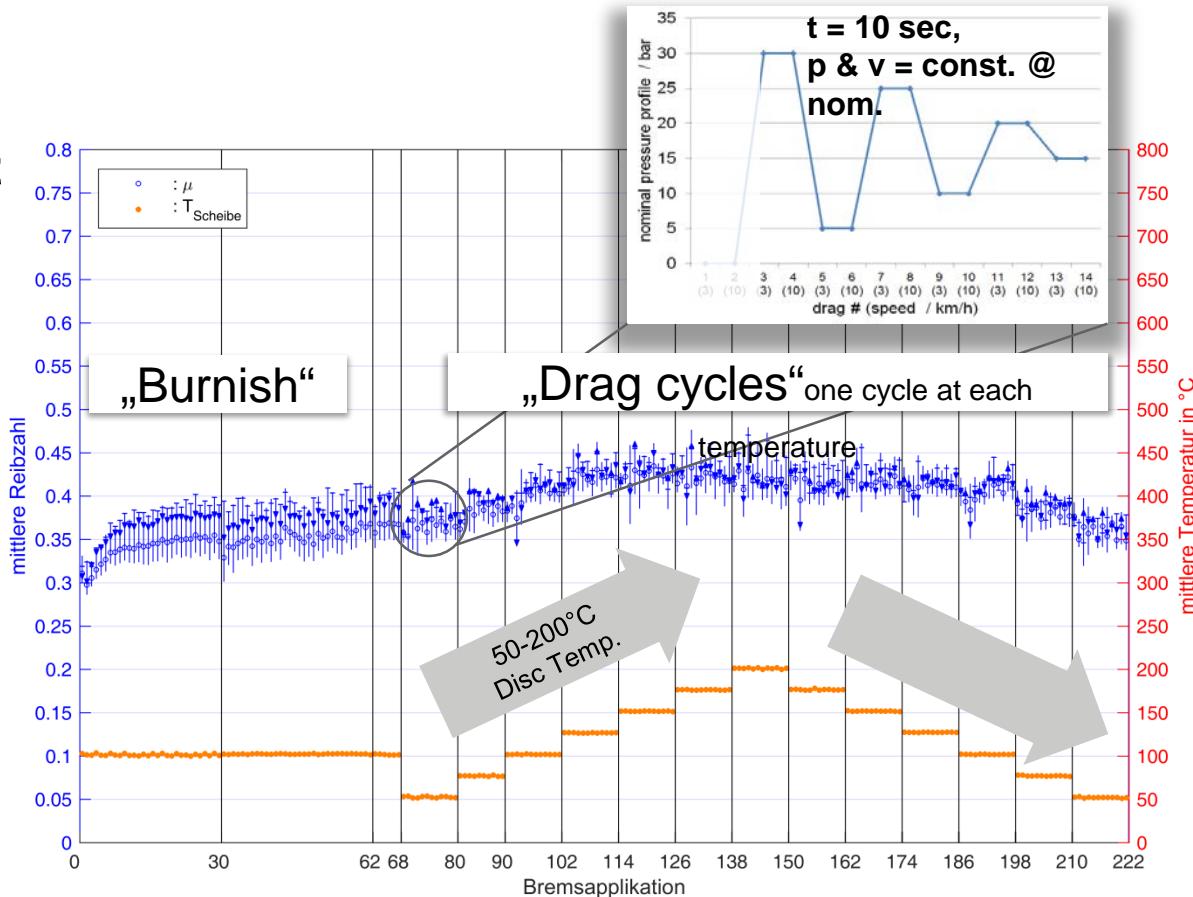
Clear influence of brake pads - good" and "bad" linings are "existing"

Friction Procedure acc. to SAE J2521

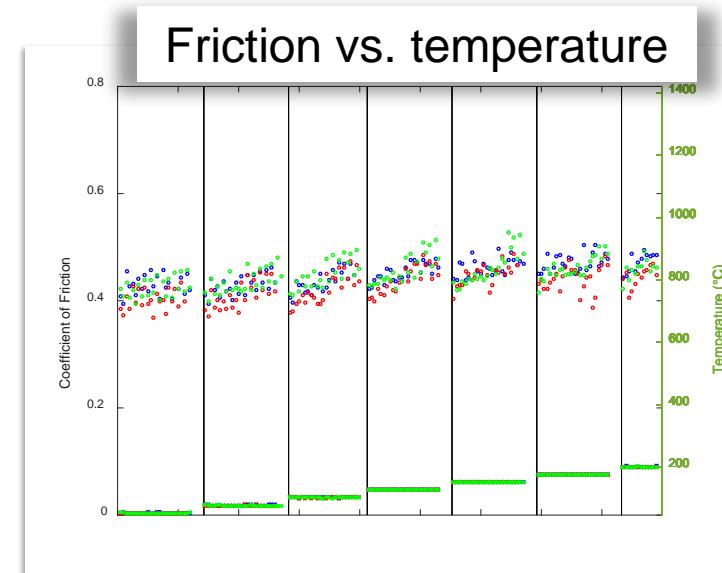
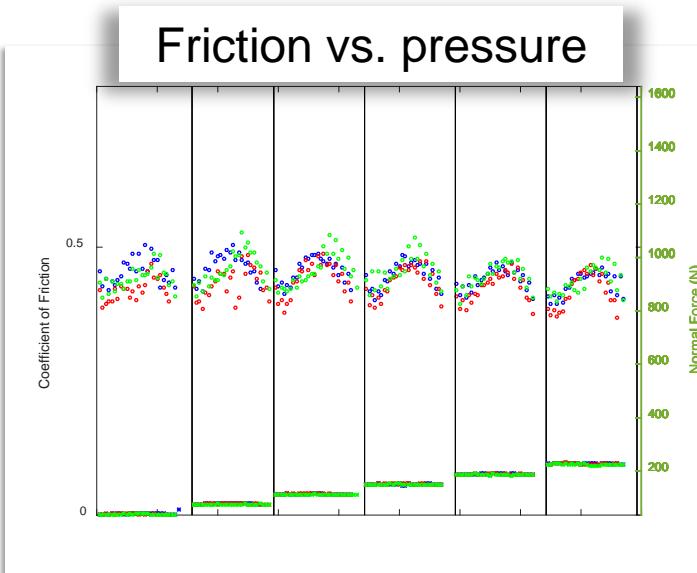
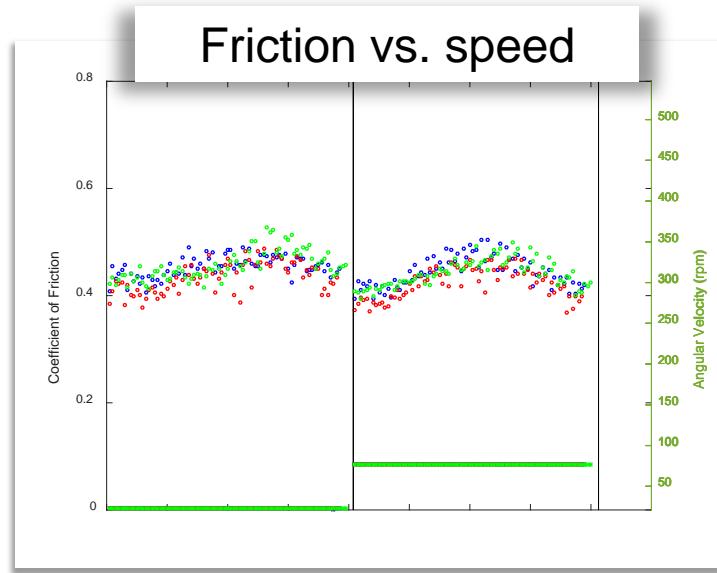
Friction Measurement & Brake Applications



G.-P. Ostermeyer and N. Perzborn,
*Dynamic Friction Measurements,
Especially for High Power.* SAE
Technical Paper 2011-01-2373, 2011, doi:
10.4271/2011-01-2373.



Example I, Friction Measurements @TU Braunschweig/IDS

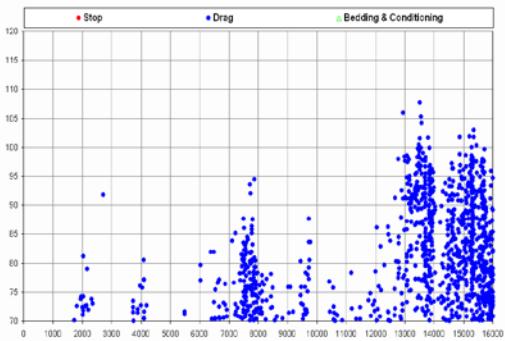


NOK vs.
OK **OK**

- ▶ No significant correlation between friction characteristics and NVH results

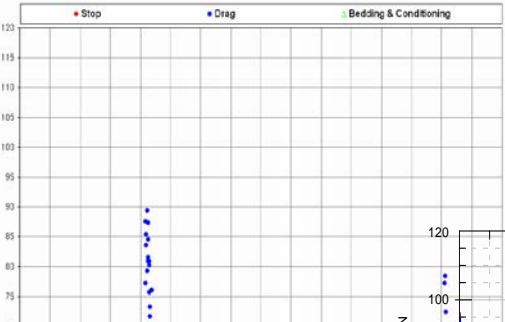
Example I, Eigenfrequency

Noisy pads: Compressibility: 117/120

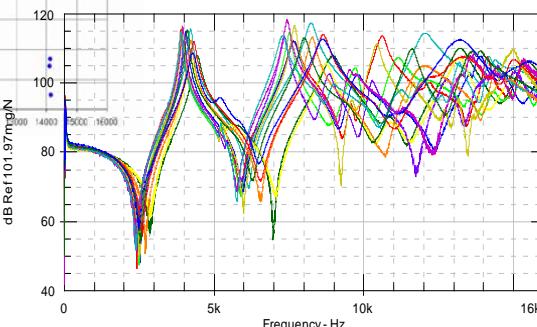


37% NOK

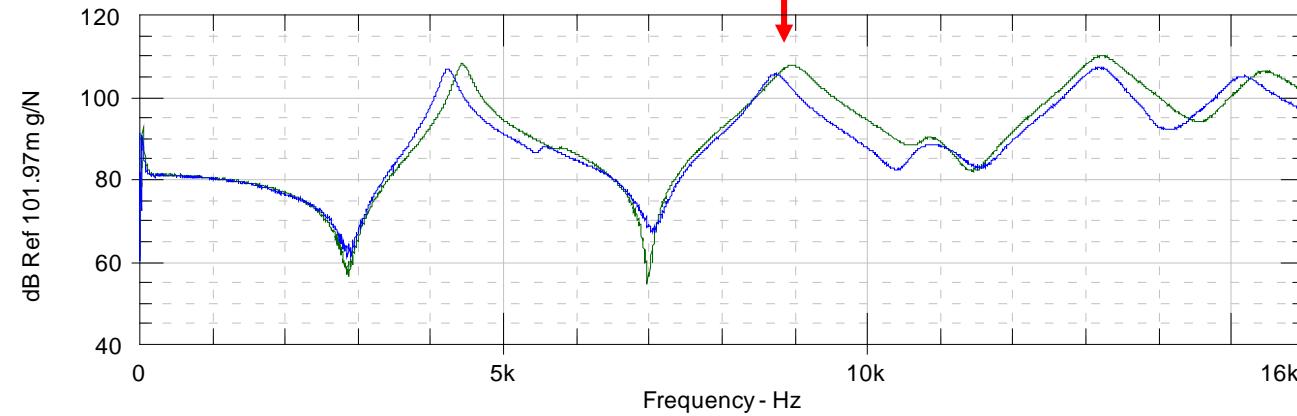
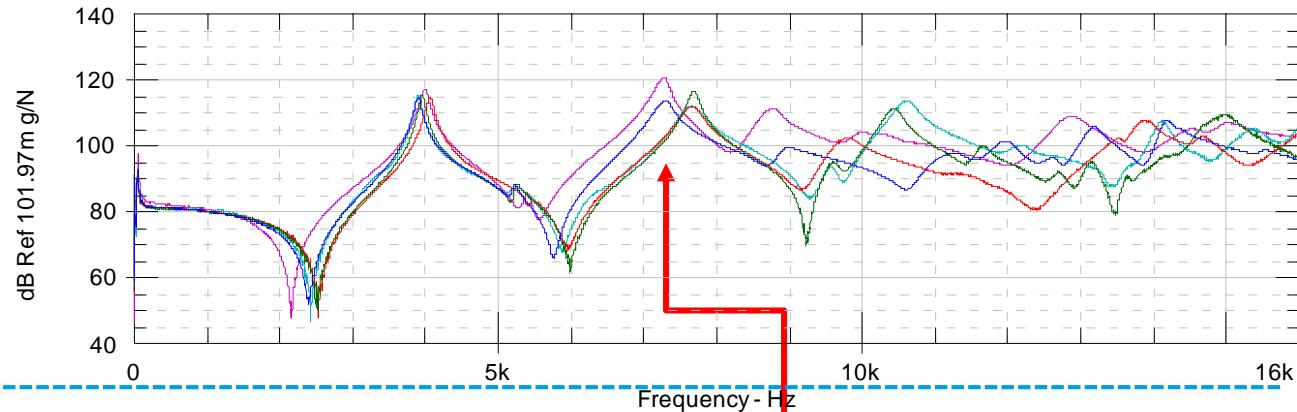
Quiet pads: Compressibility: 119/120



1.5 % OK



FRF of Inner Pads Batch 2



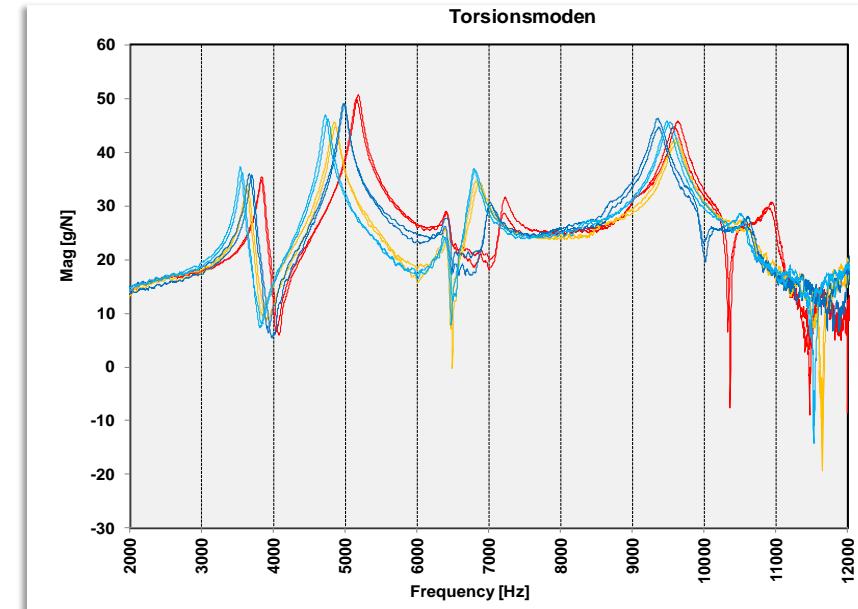
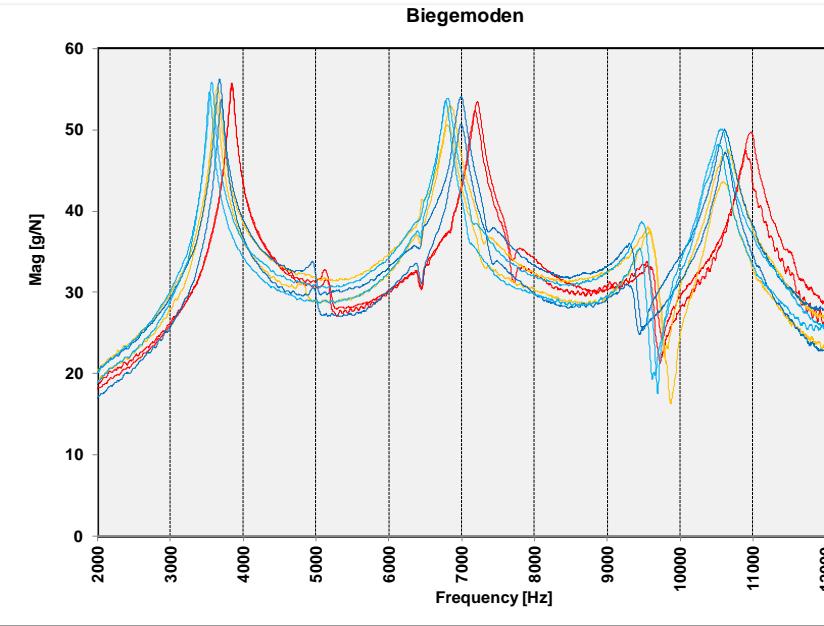
Noisy pads show lower eigenfrequencies & variation

Example II, Eigenfrequency

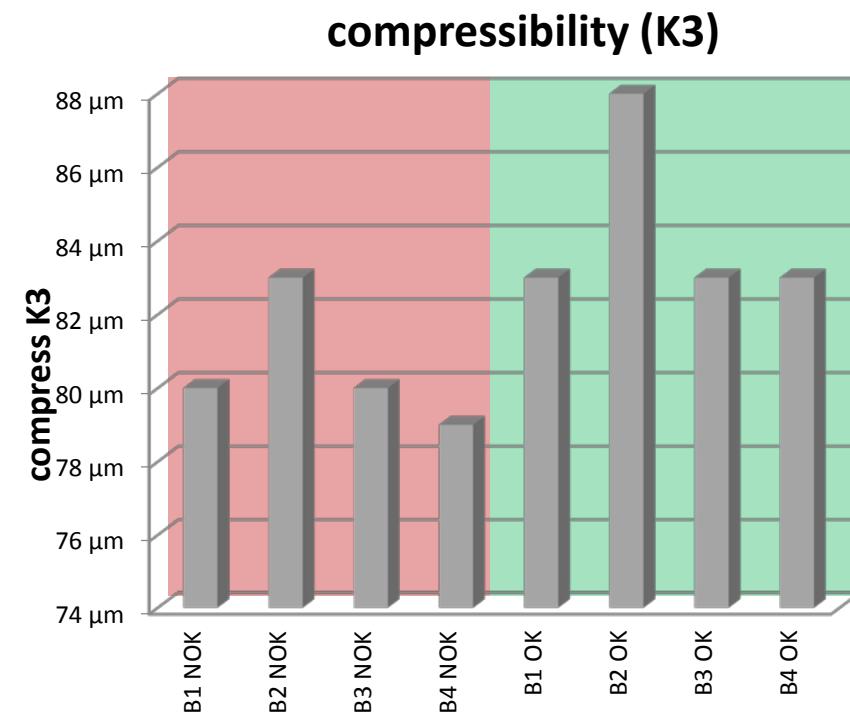
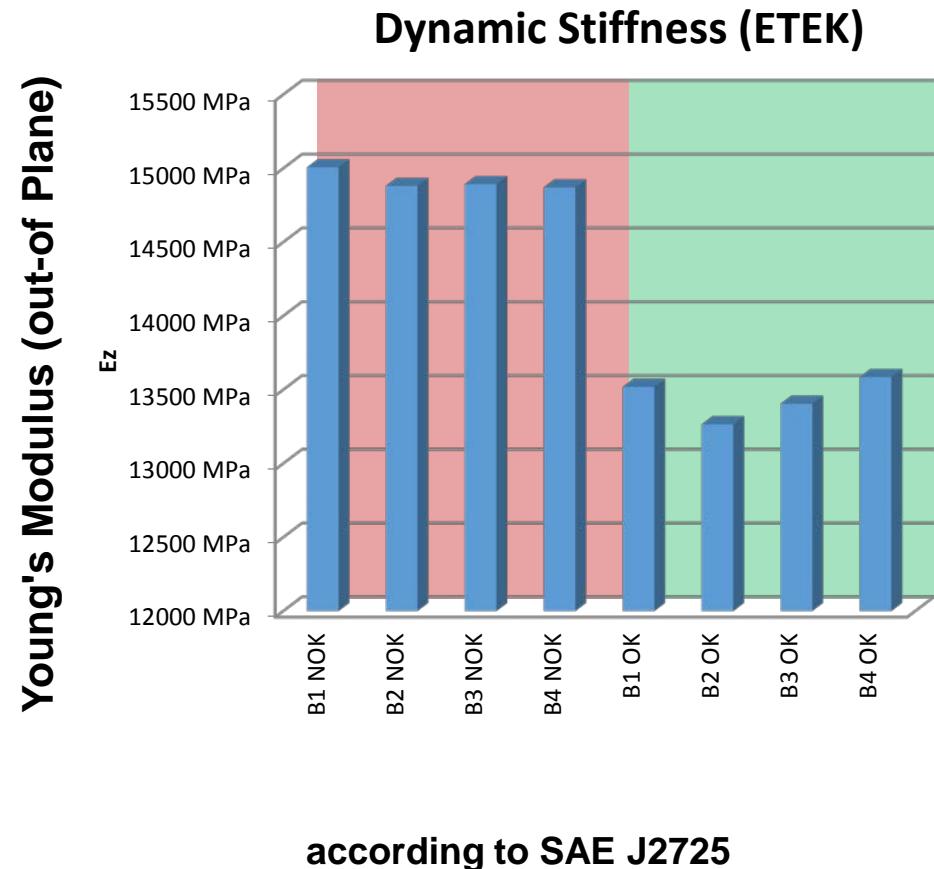
Batch	Belag	K3	Gewicht	Biegung						Torsion			
				Mode 1		Mode 2		Mode 3		Mode 1		Mode 2	
				Frequenz	Dämpf. [%]								
009-14	Aussenbelag	79	347.7	3847	0.93	7219	0.88	10981	0.75	5181	0.92	9634	0.90
009-14	Aussenbelag	80	346.7	3844	0.96	7188	0.96	10903	0.79	5156	1.00	9591	1.04
009-14	Kolbenbelag	83	338.5	3631	1.20	6800	1.26	10606	1.27	4850	1.16	9603	1.07
009-14	Kolbenbelag	83	339.2	3644	1.19	6844	1.21	10656	1.27	4862	1.12	9609	1.07
012-14	Aussenbelag	83	347.0	3700	0.99	6991	0.97	10619	0.84	4987	0.88	9363	0.93
012-14	Aussenbelag	82	345.3	3656	0.98	6953	0.99	10569	0.91	4956	0.89	9325	0.99
012-14	Kolbenbelag	83	338.2	3553	0.98	6769	1.02	10531	0.96	4728	0.94	9478	0.90
012-14	Kolbenbelag	83	337.2	3538	0.99	6778	0.81	10519	0.88	4722	0.95	9478	0.83

NOK

OK

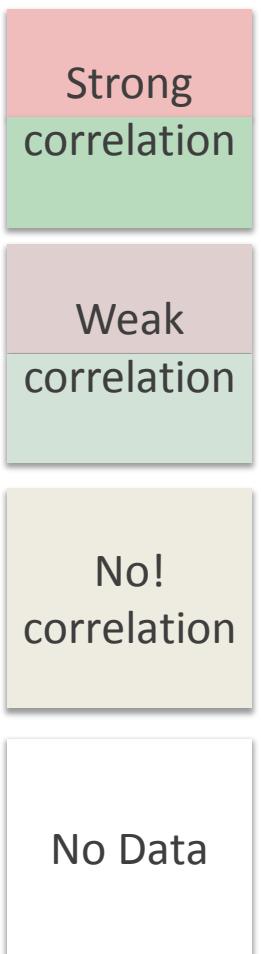


Elastic Parameters, Example I



Correlation chart

				ETEK (GPa)	K3 (µm)	f1 (kHz)	f2 (torsion) (kHz)	f3 (kHz)	Flatness	CoF
CII 38HE-8/10	ECE	4.6kHz 8.8kHz 12 kHz	OK							
			NOK							
PC43HE 17"	ECE	5.9 kHz 8.9kHz	OK							
			NOK							
CII 45	NAO	5.7 kHz 6.3 kHz	OK							
			NOK							
PC43HE-24/11 (320x24)	ECE	2.7 kHz	OK							
			NOK							
PC45+48 VA 17"	ECE	3 kHz 6 kHz 9 kHz	OK							
			NOK							
PC60-24/12 (17"- 330x24)	NAO	1.5 kHz 2.4 kHz 3.5 kHz	OK							
			NOK							
PC45HR 22/11 (294x22)	NAO	1.8 kHz								

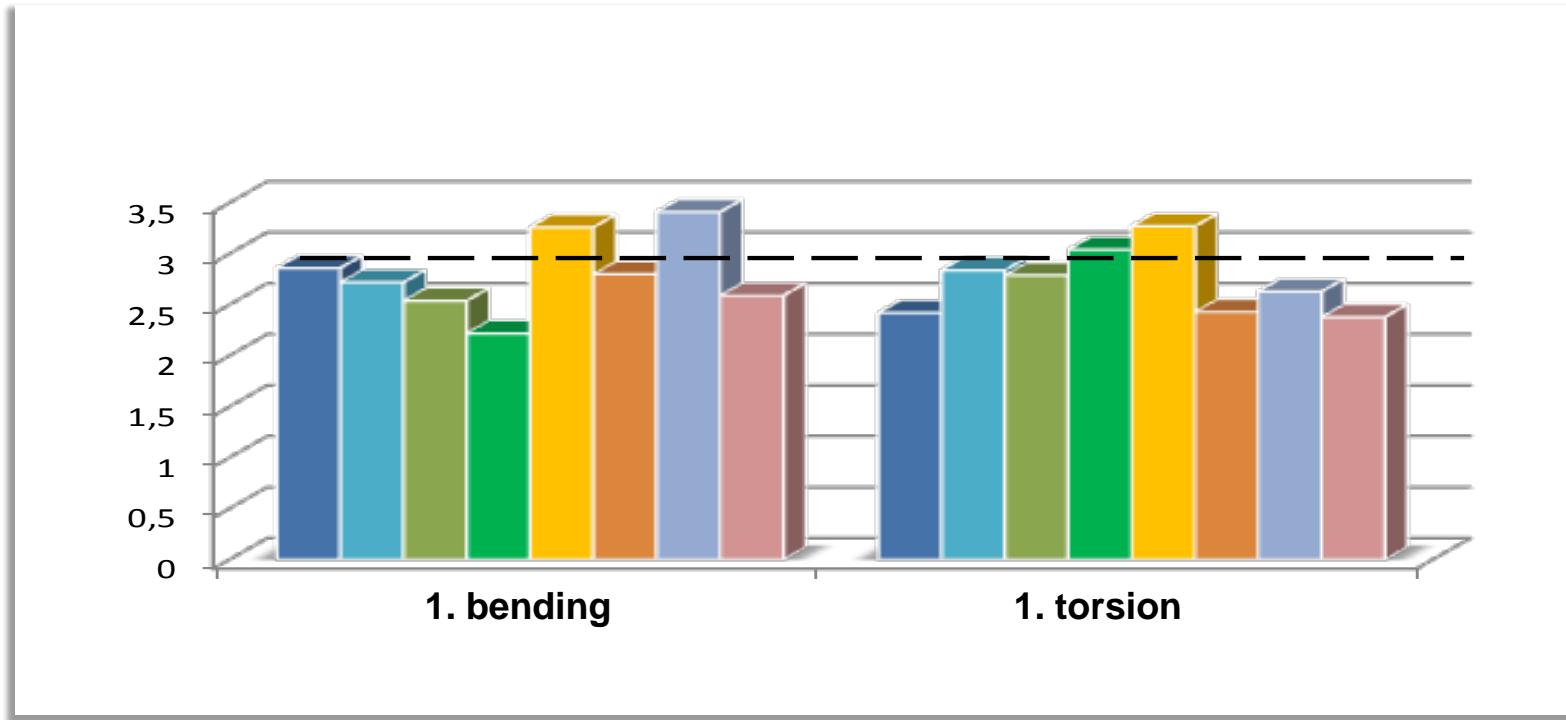


- Influence of brake pads on NVH is “existing”
- So far no clear identification (besides NVH rig tests) is visible by physical parameters
 - But this is required for quality monitoring, robustness, limit definition, ...
- Up to now *eigenfrequency* (torsion modes) and *dynamic stiffness* seems to be the most potential “identifier”

Which further physical parameter could have an influence on the NVH behavior?

Let's think about inconstant behaviors

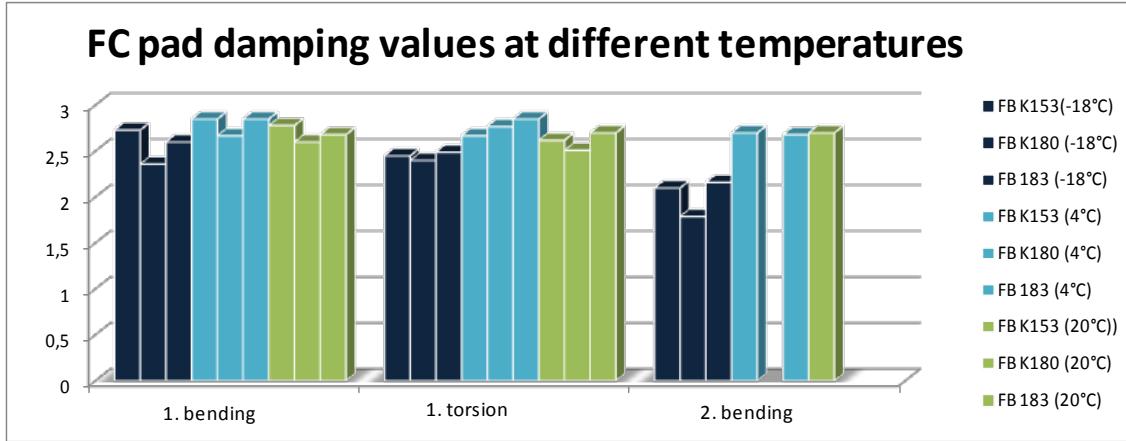
Damping values of various lining qualities



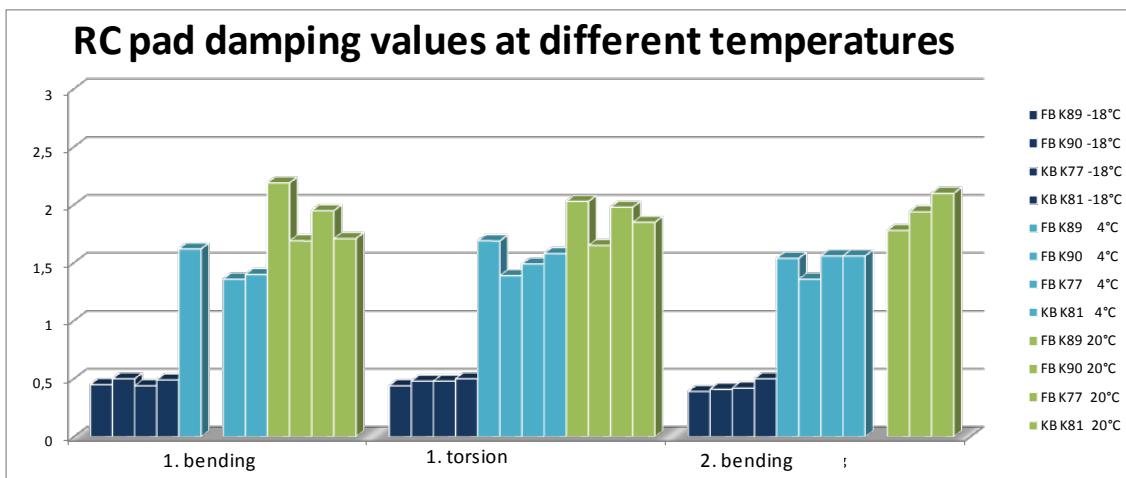
The mean value of damping is 2.75% over all variants.

*Setup partly with Shim / with Chamfer

Impact of Temperature on Damping



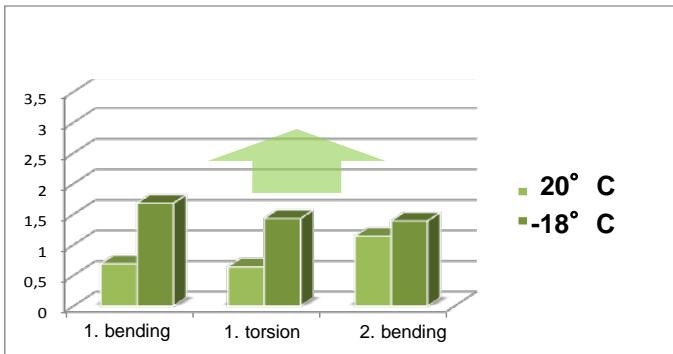
Damping values are very stable.



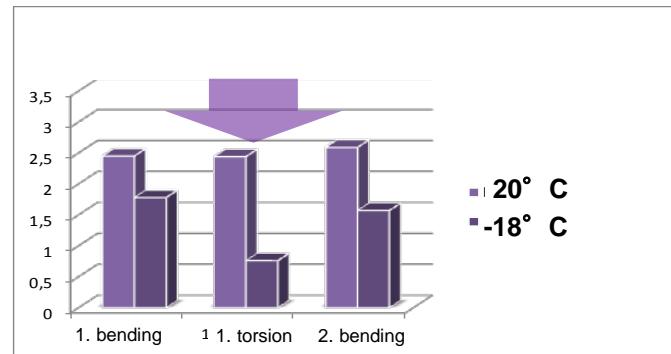
The damping values not stable and temperature-sensitive.

Damping comparison at 20° C and -18° C pads without / with underlayer in 2mm / 4mm size

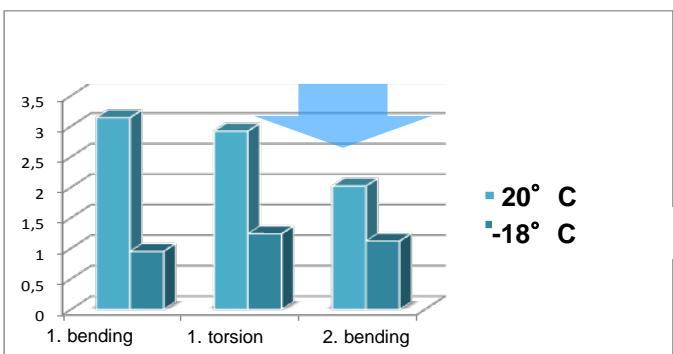
B1: without UL



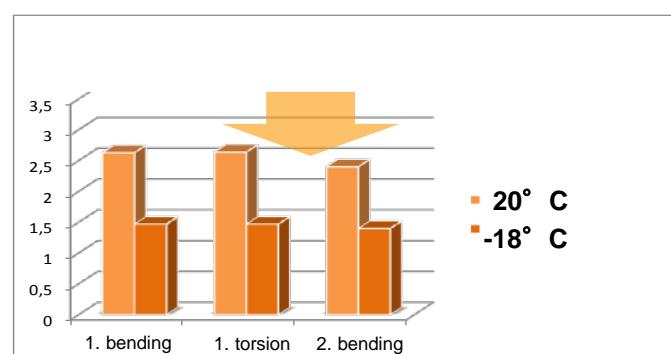
B2: with std. UL, 2mm size



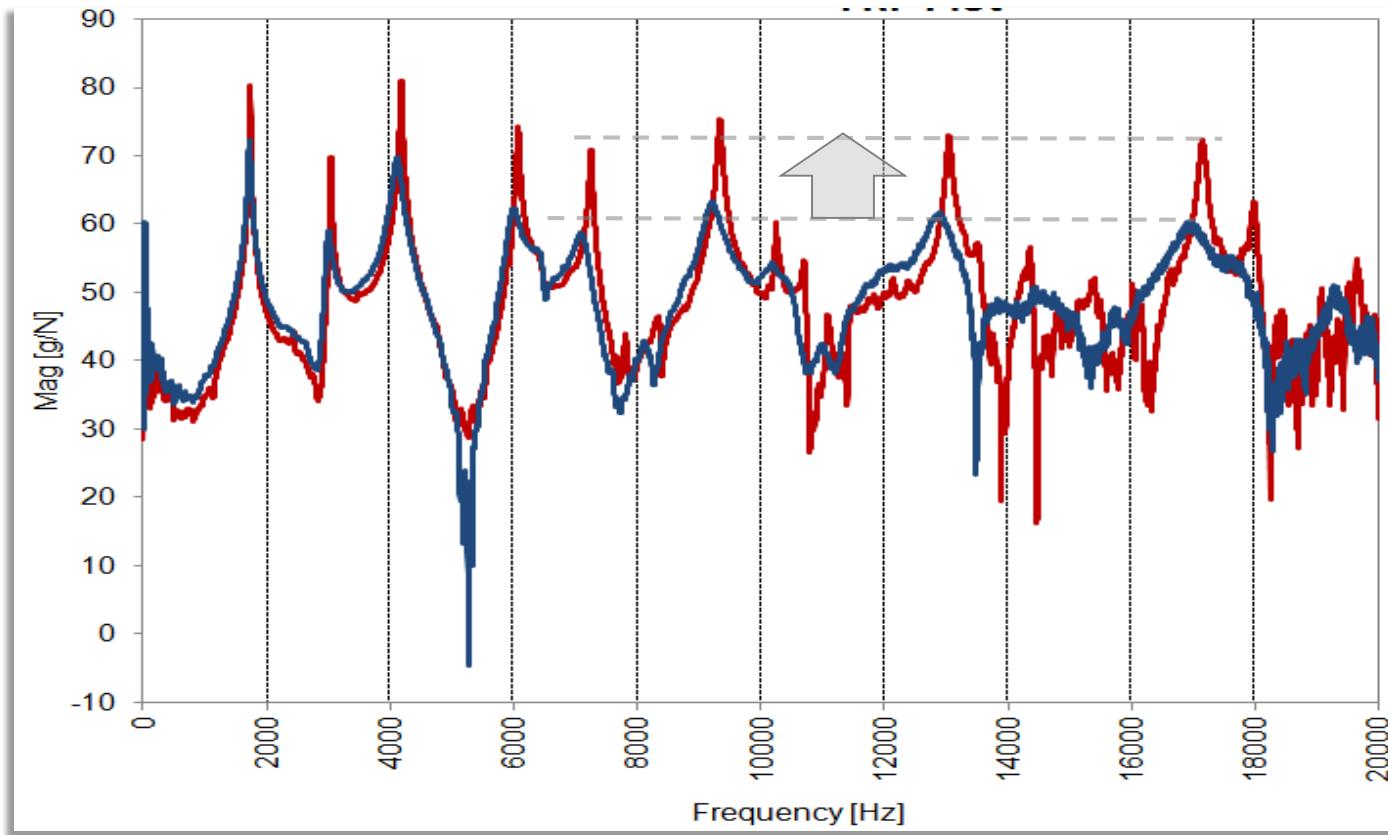
B3: with std. UL, 4mm



B4: with std. UL, 2mm; different batch



Damping Loss after high temperature impact



New-Pad (50%)

Pad (50%) after 2h in oven (300° C)

Summary

- ▶ Noise behavior important to achieve customers' quality targets and substantial part of noise is caused by friction induced vibrations from the disc-pad contact.
- ▶ There is clearly an influence of the brake pad on the NVH behavior! – “good” and “bad” linings are existing!
- Up to now *eigenfrequency* (torsion modes) and *dynamic stiffness* seems to be the most potential “identifier” → but are not robust parameters to clearly separate “good” and “bad” linings
- ***Temperature behavior of the lining material and especially thermal stress resistance tend to be very relevant parameters.***
 - But a final understanding of what exactly leads to worsening of the results under temperature influence is still under investigation.
 - Here *damping* and particularly *damping-loss* play an important role but are not the only reason
- Also strong indications that the *hygroscopic behavior* of lining materials have an influence on NVH.

Thank you

- Dr. Ralf Gross
- ZF Friedrichshafen, Division A, Braking
- Carl-Spaeter-Strasse 8, 56070 Koblenz, Germany
- ++49 261 895 2935
- ralf.gross@zf.com