Quiet machine design: Motivation, classical methods, and novel approaches

Joachim Bös, Technische Universität Darmstadt, Germany

TECHNISCHE UNIVERSITÄT DARMSTADT

Symposium

Buy Quiet

25 August 2016

Hamburg, Germany

SzM

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction of the research group SzM
- Examples for successful noise reduction measures
- (Potential) reasons why companies contact us for support
- Classical methods for noise control engineering
- Novel approaches for noise control engineering

Introduction of the research group SzM

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- research group “System Reliability and Machine Acoustics SzM”, TU Darmstadt, Germany
- activities started in the 1960s (Prof. H.W. Müller)
- technical acoustics with focus on gearboxes, axial piston pumps, motors, ball bearings → term “machine acoustics” was coined
- in the 1970s: “fundamental equation of machine acoustics”
- soon: “System Reliability, Adaptive Systems, and Machine Acoustics SAM” (Prof. Tobias Melz)
- special/new topics: structural intensity, inequidistant gearings, scaling laws using sensitivity analyses, psychoacoustic aspects, electret and piezoelectret energy harvesters, active systems, …
- student education (classes), research projects, and industry contract research and services

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Examples for successful noise reduction measures

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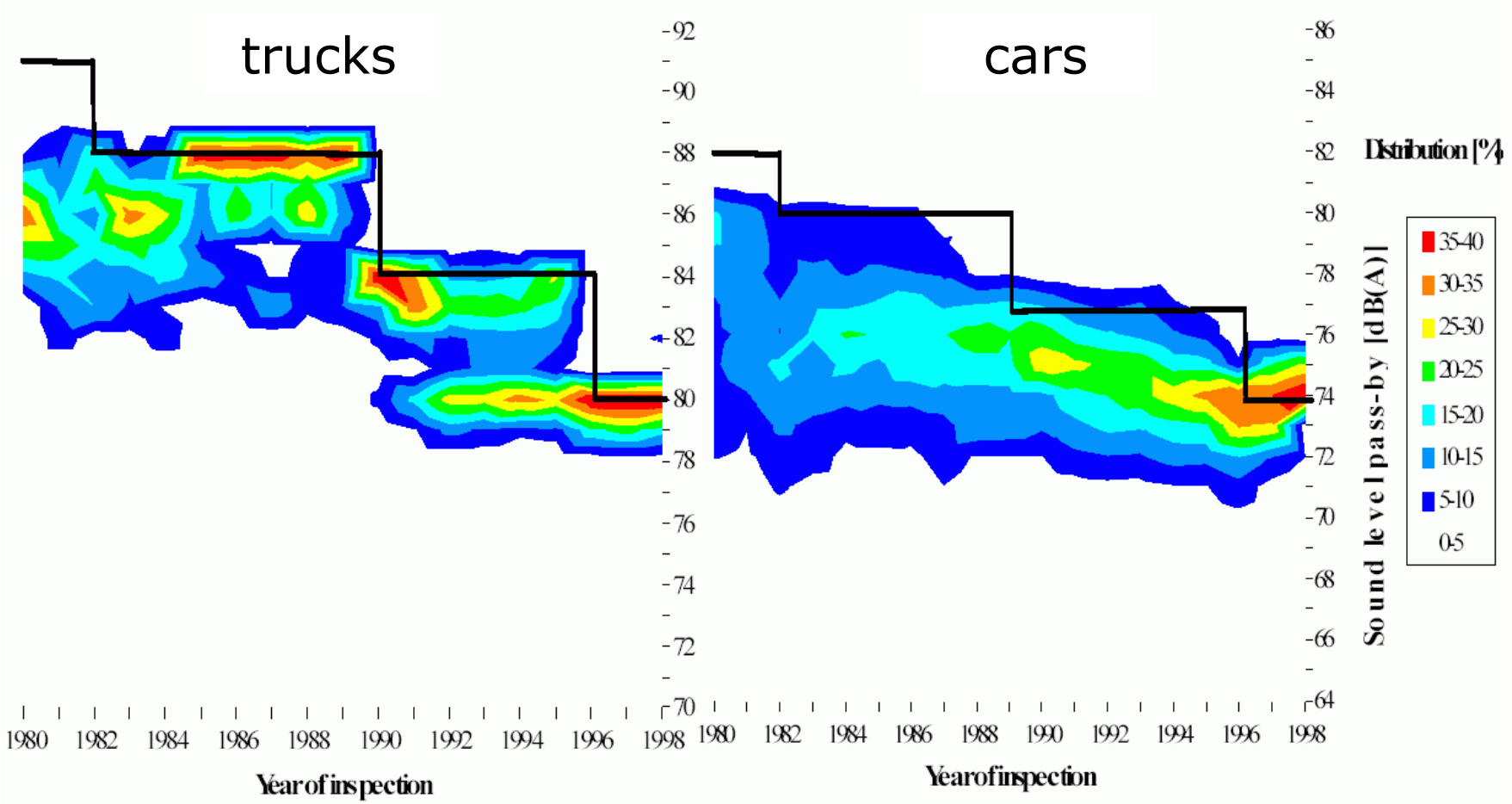
Traffic noise: legal noise limits and reality



source: Müller-BBM, Statusseminar „Leiser Verkehr", 2003

Examples for successful noise reduction measures

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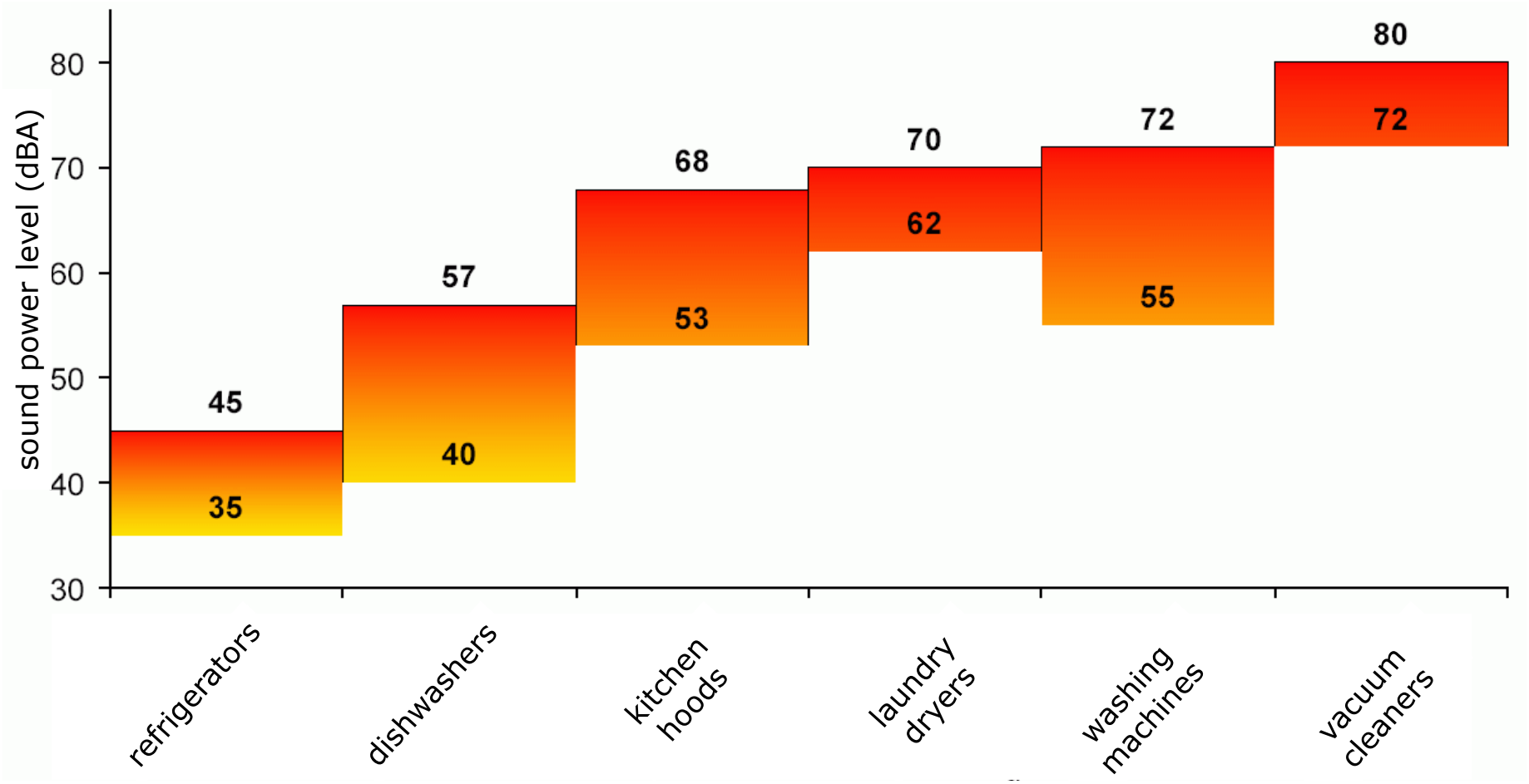
Sound power levels of various household appliances



source: BSH, OTTI-Seminar „Entwicklung geräuscharmer Geräte“, 2007

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Examples for successful noise reduction measures

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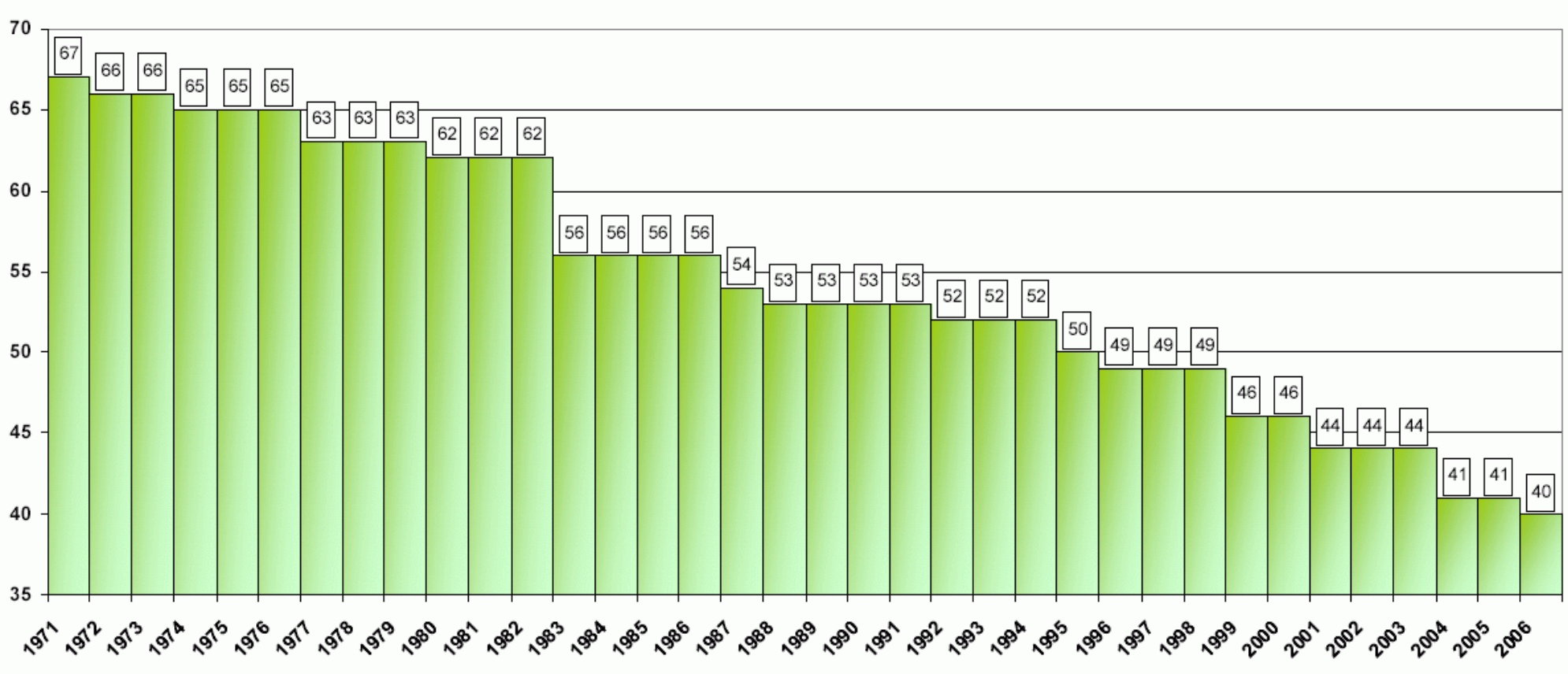
Temporal development of the noise emission of dishwashers



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(Potential) reasons why companies contact us for support

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Scenario 1: problems with regulations or customers

1.1 statutory or stipulated noise limits are actually exceeded and company is forced to act (approvals, permits, or orders might be revoked)

Project example for scenario 1.1

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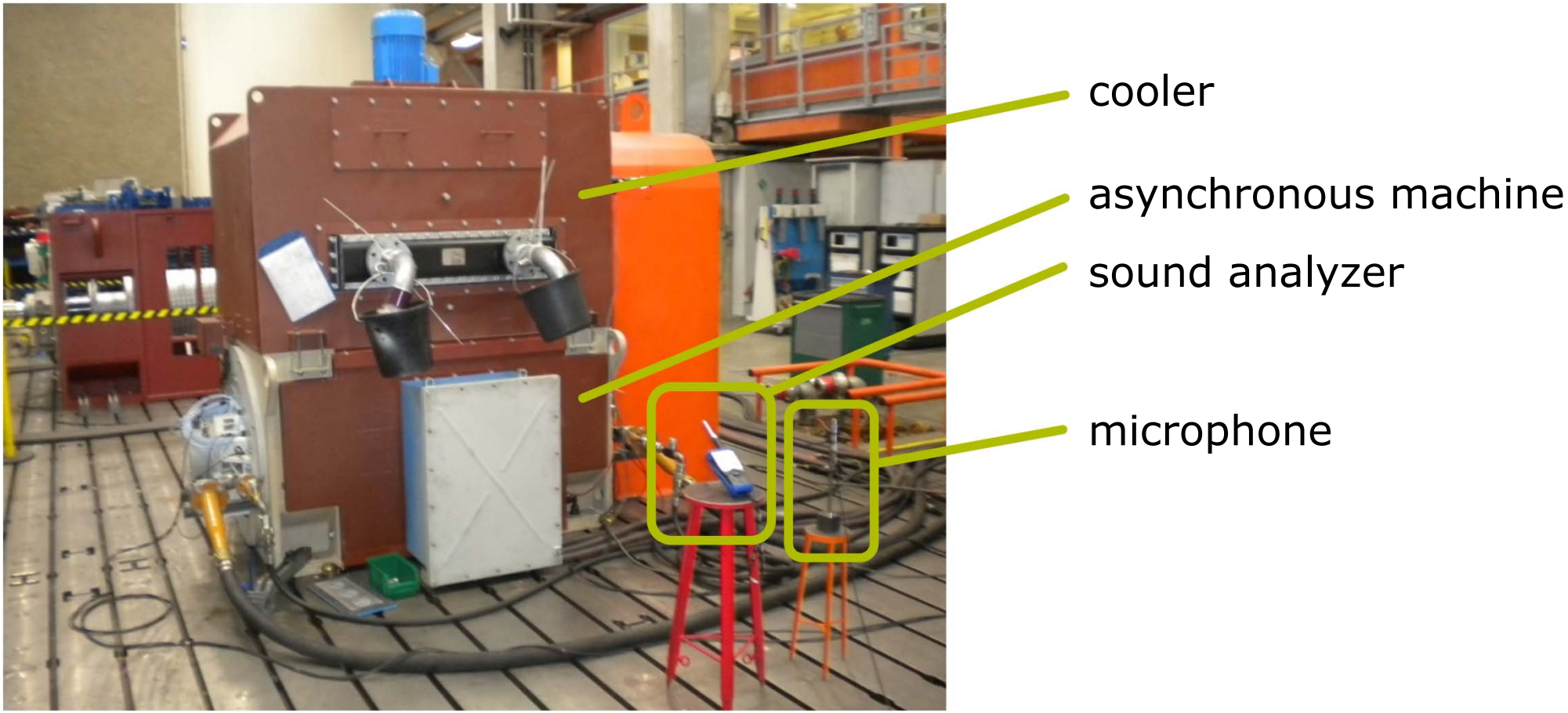
Large asynchronous machine with cooler
(airborne and structure-borne sound measurements)



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Project example for scenario 1.1

Large asynchronous machine with cooler
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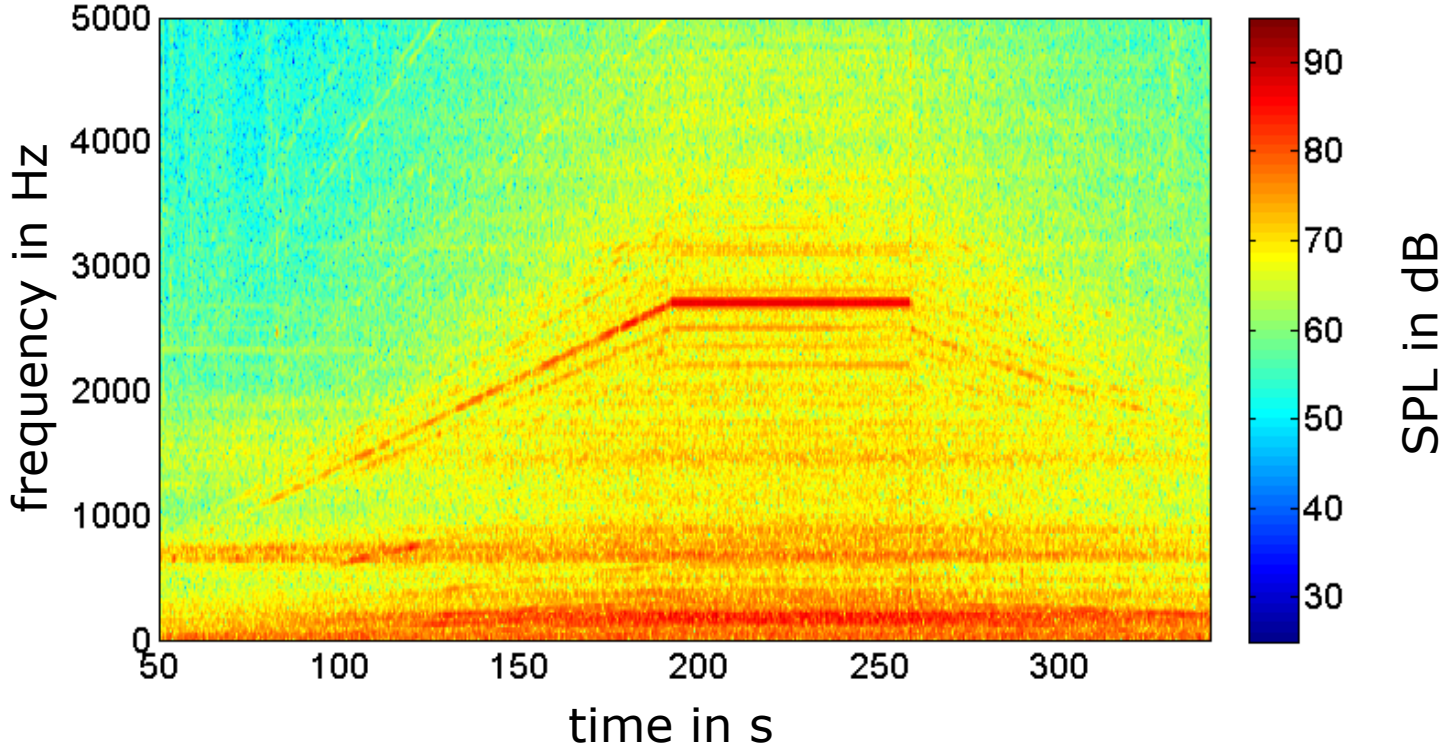

SPL close to certain openings: up to 120 dB!
reason: excitation of the 6th mode shape of the stator

(Potential) reasons why companies contact us for support

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1.2 statutory or stipulated noise limits are not exceeded, but customer complains nonetheless (product is “too loud”)

Project example for scenario 1.2

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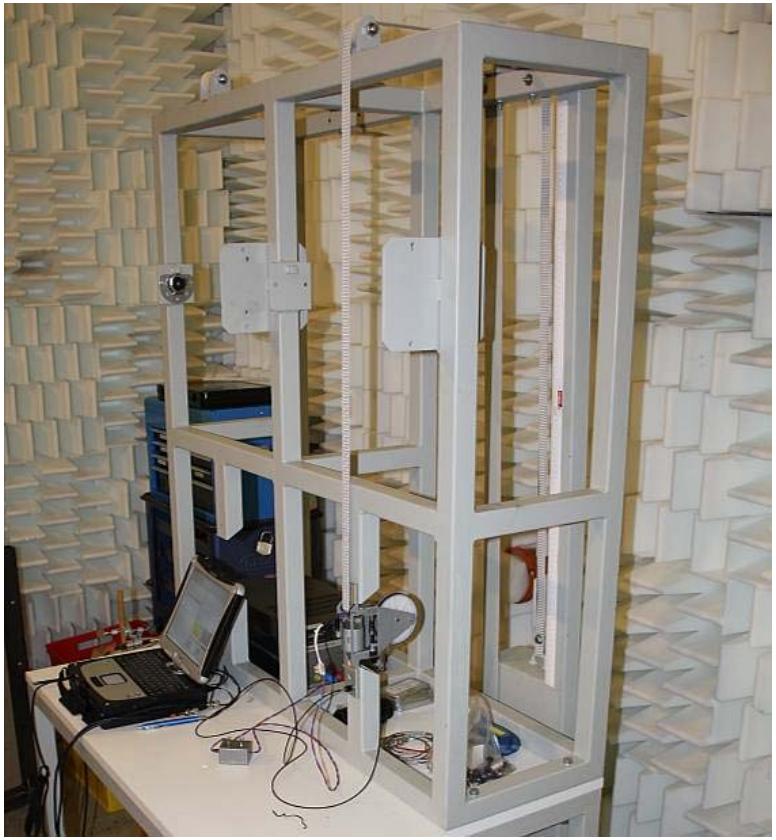
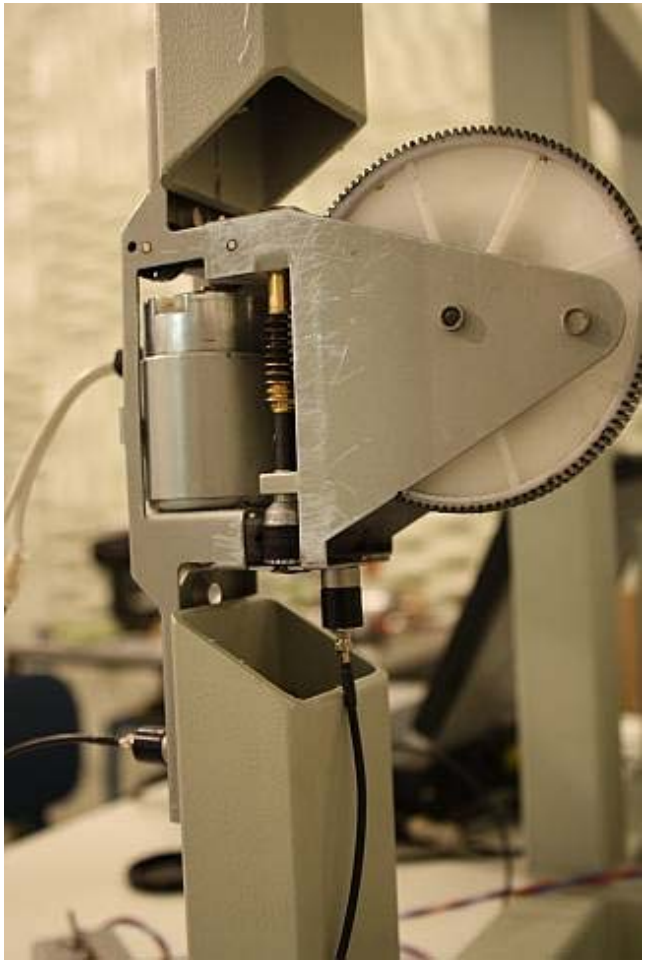
Acoustic analysis of a rolling shutter motor





Project example for scenario 1.2

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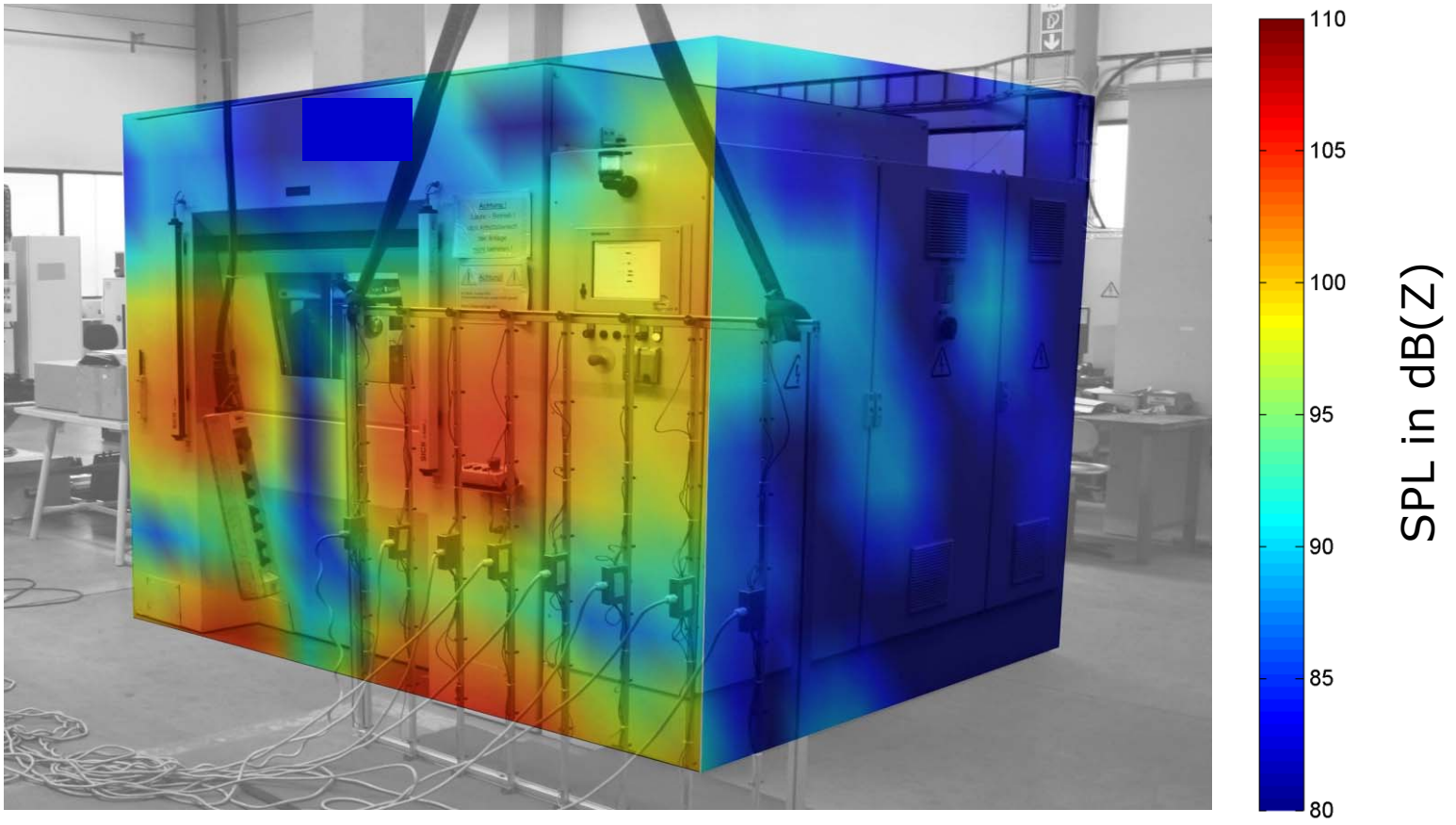
SPL distribution around a vibration welding machine (≈ 240 Hz)



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(Potential) reasons why companies contact us for support

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1.3 there are no problems yet, but company fears potential problems as described above

Project example for scenario 1.3

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Acoustic analysis and improvement of a wellness couch for spas

Project example for scenario 1.3

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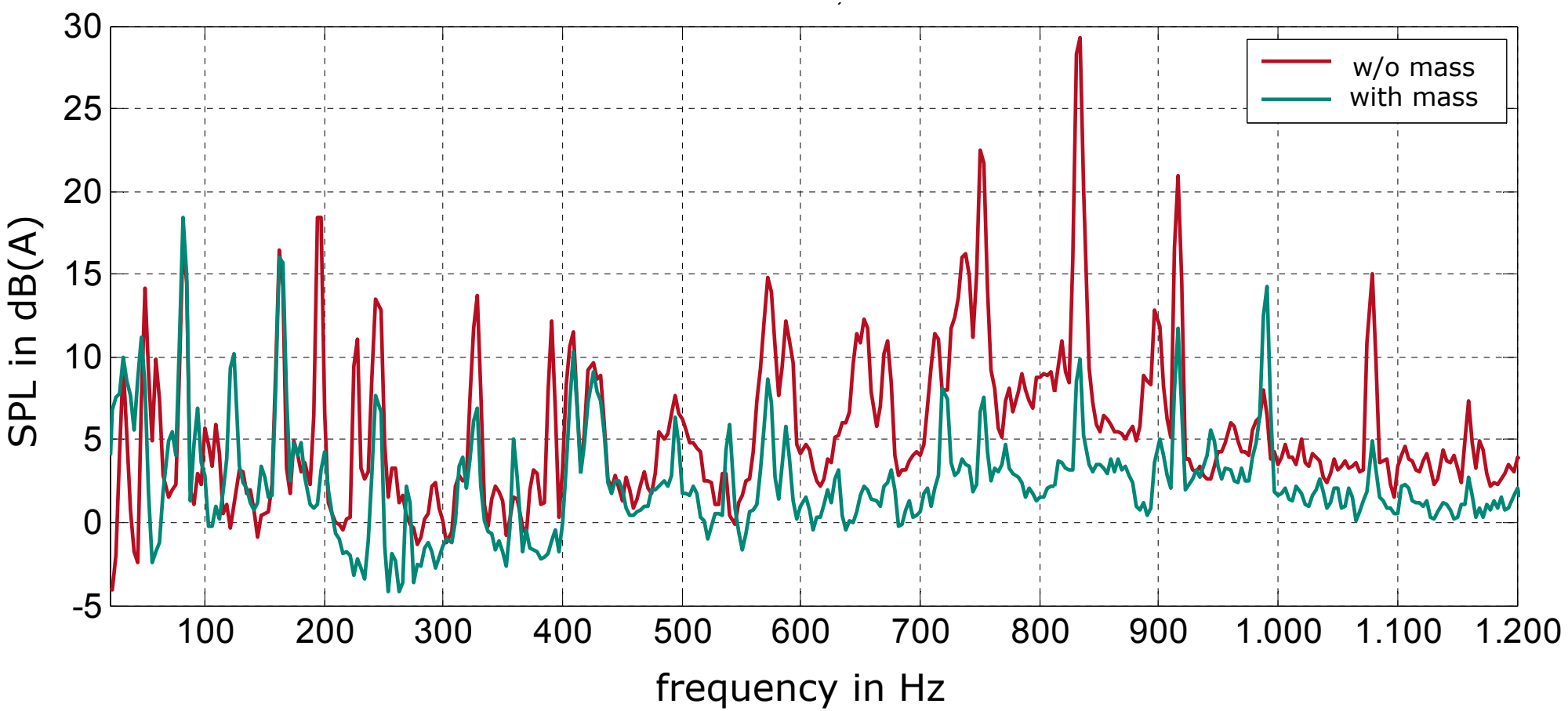

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Project example for scenario 1.3

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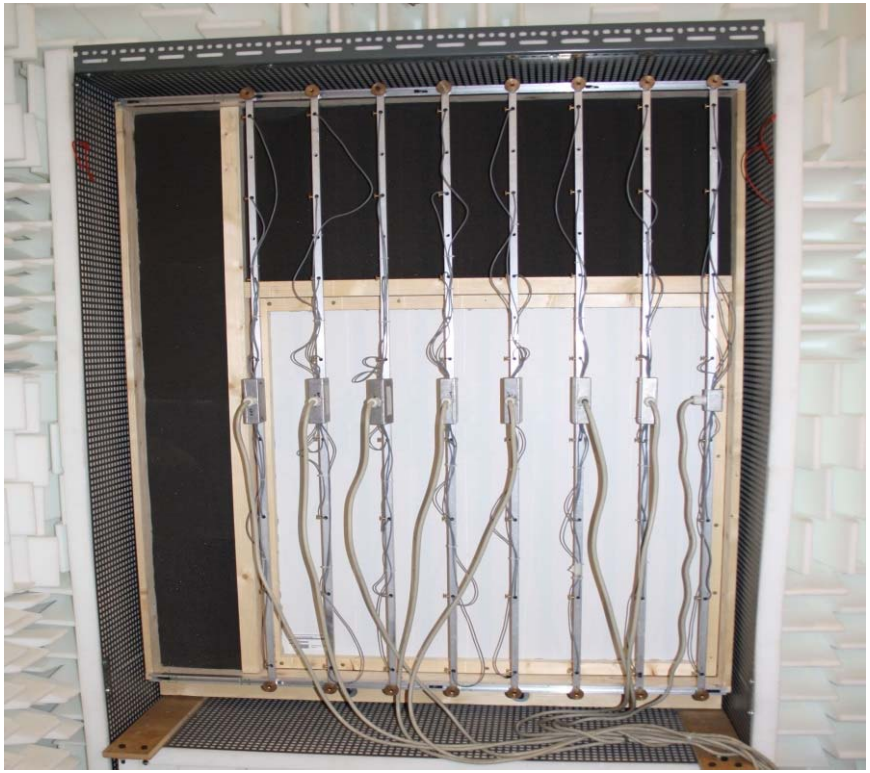
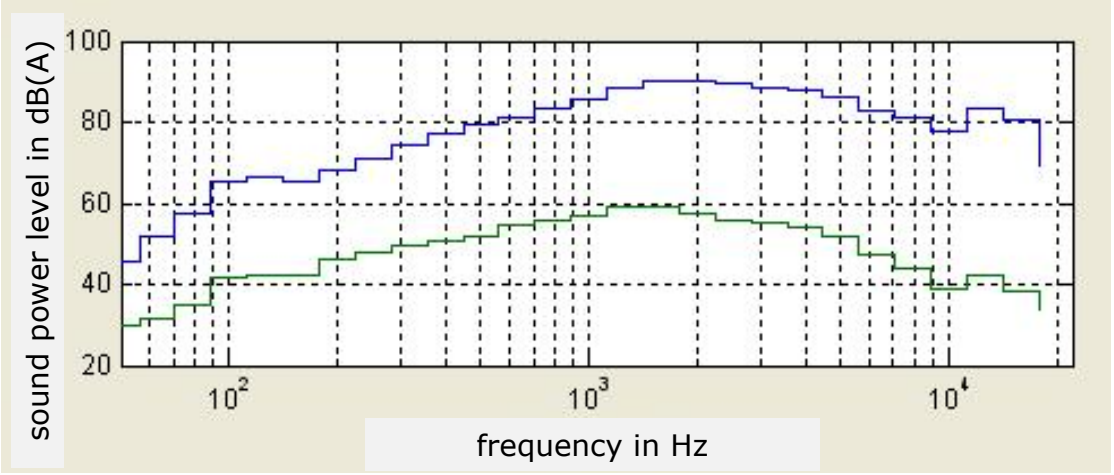
Sound transmission measurements for aircraft parts (sandwich panels used for the floor)





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1.4 statutory or stipulated noise limits are not exceeded yet, but these limits will be tightened soon so the company must act

Project example for scenario 1.4

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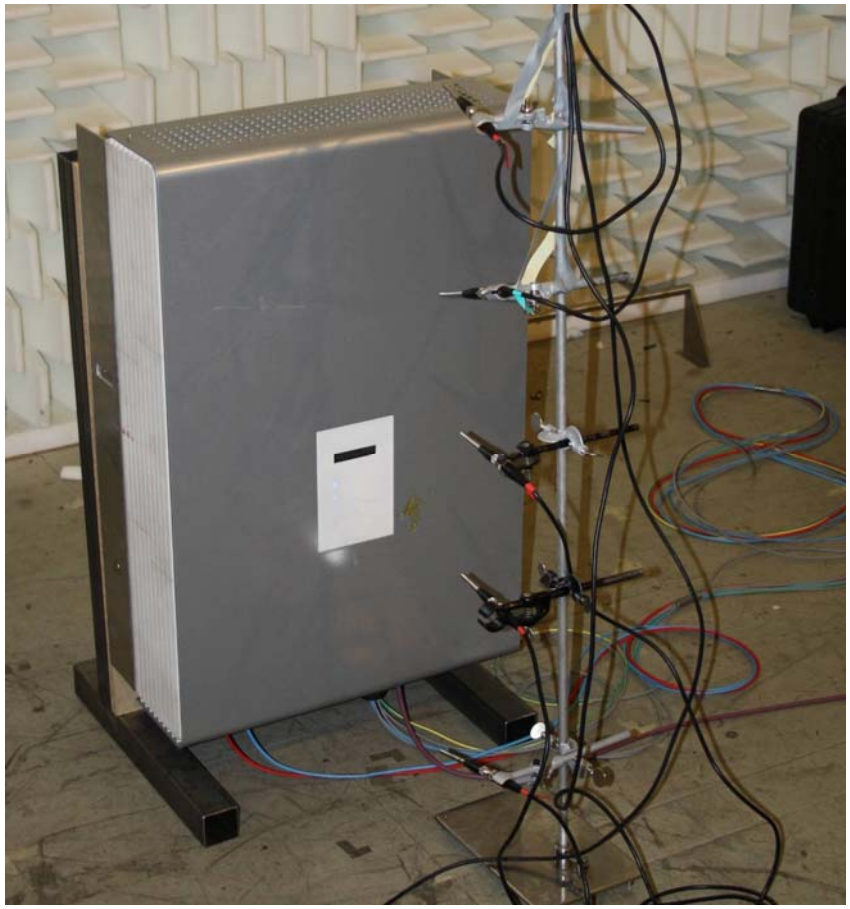
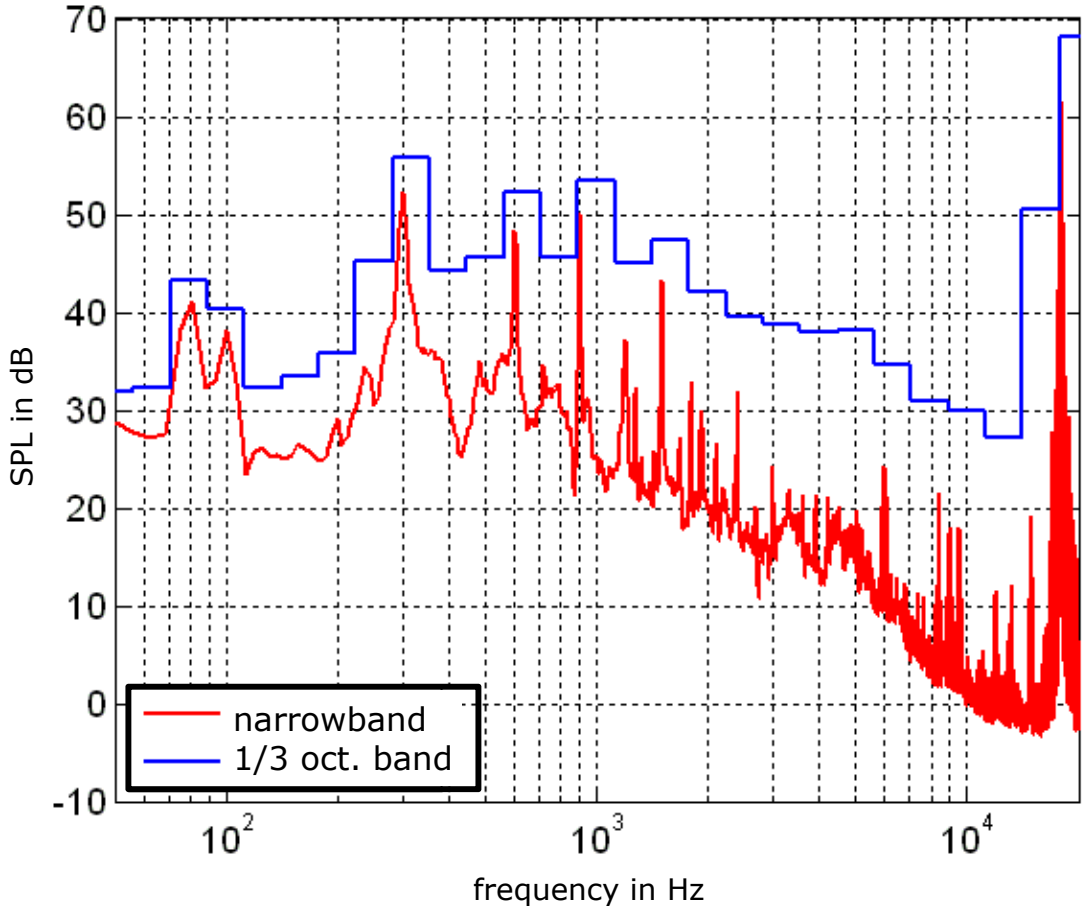
Acoustic analysis of photovoltaic inverters





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1.5 noise limits were stipulated but company does not have a clue about acoustics → consulting

Project example for scenario 1.5

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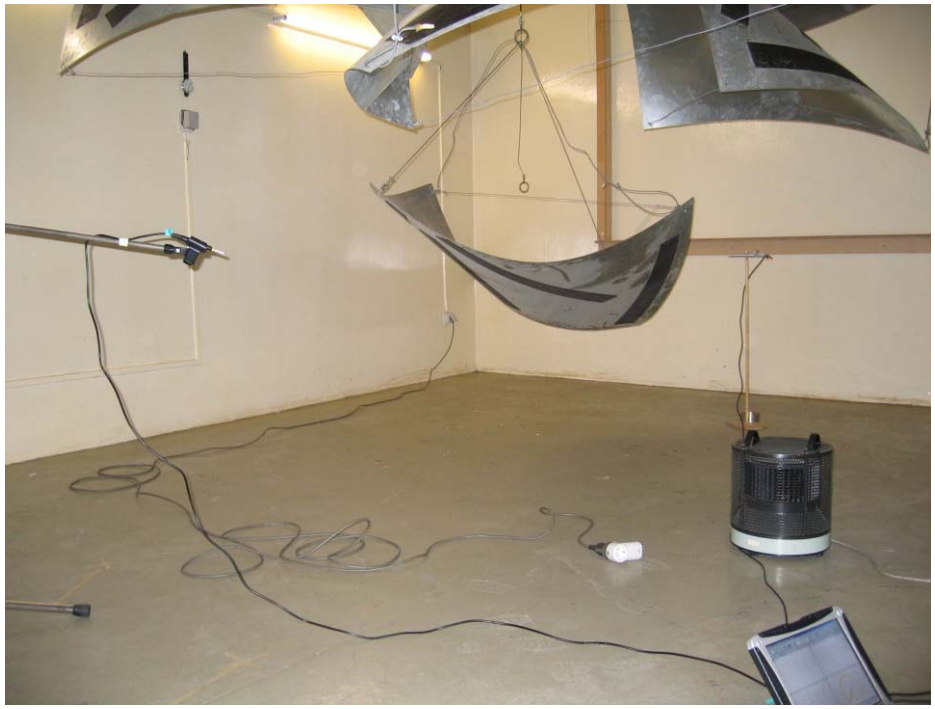
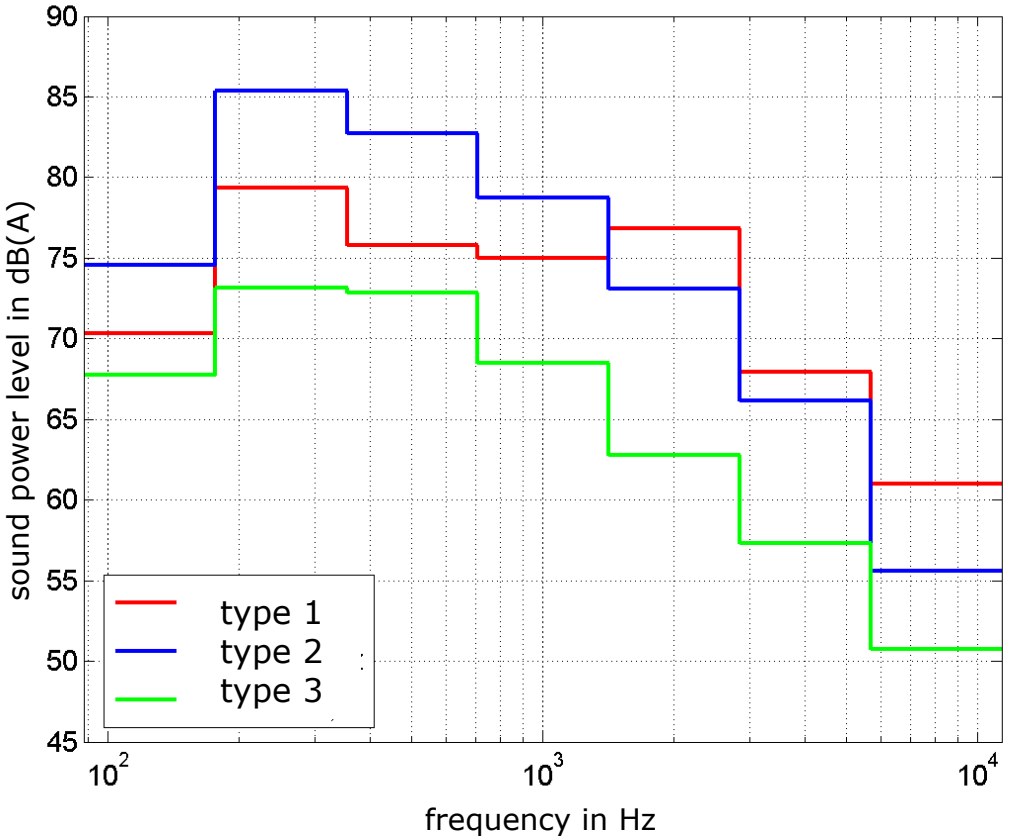
Sound power measurements of several prototypes of a grinding machine for dental laboratories





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(Potential) reasons why companies contact us for support

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Scenario 2: health and productivity of employees

2.1 company does not want to improve its products, but its own production facilities because noise limits are exceeded

Project example for scenario 2.1

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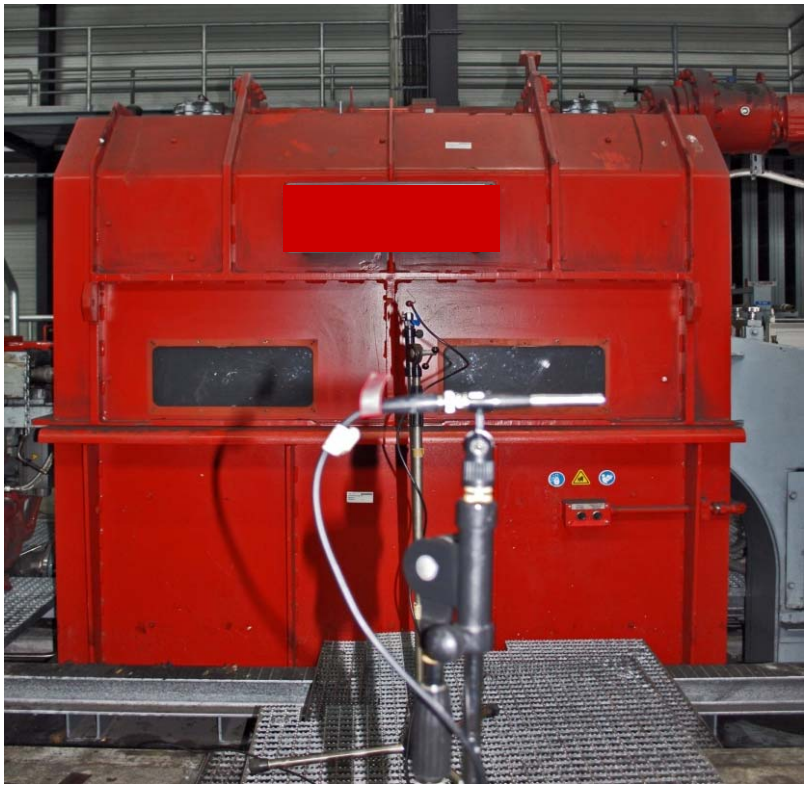
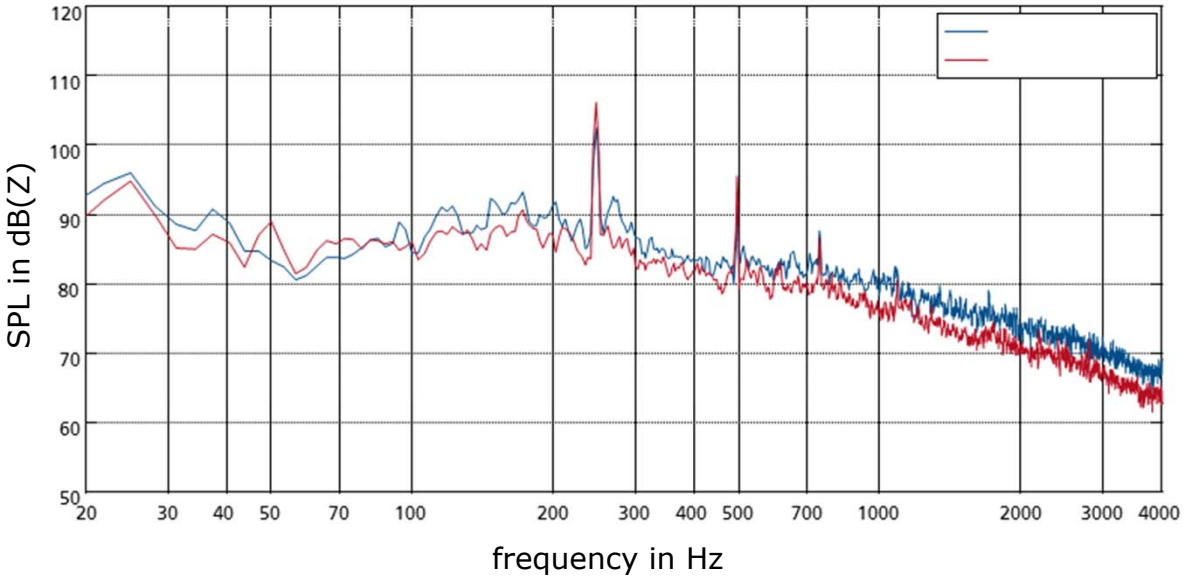
Several high-speed metal shredders in a steel plant





overall SPL: 114,2 dB(Z)!!

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(Potential) reasons why companies contact us for support

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Scenario 2: health and productivity of employees

2.1 company does not want to improve its products, but its own production facilities because noise limits are exceeded

2.2 company wants to improve its own production facilities although noise limits are not exceeded – but employees complain about noise nonetheless

Project example for scenario 2.2

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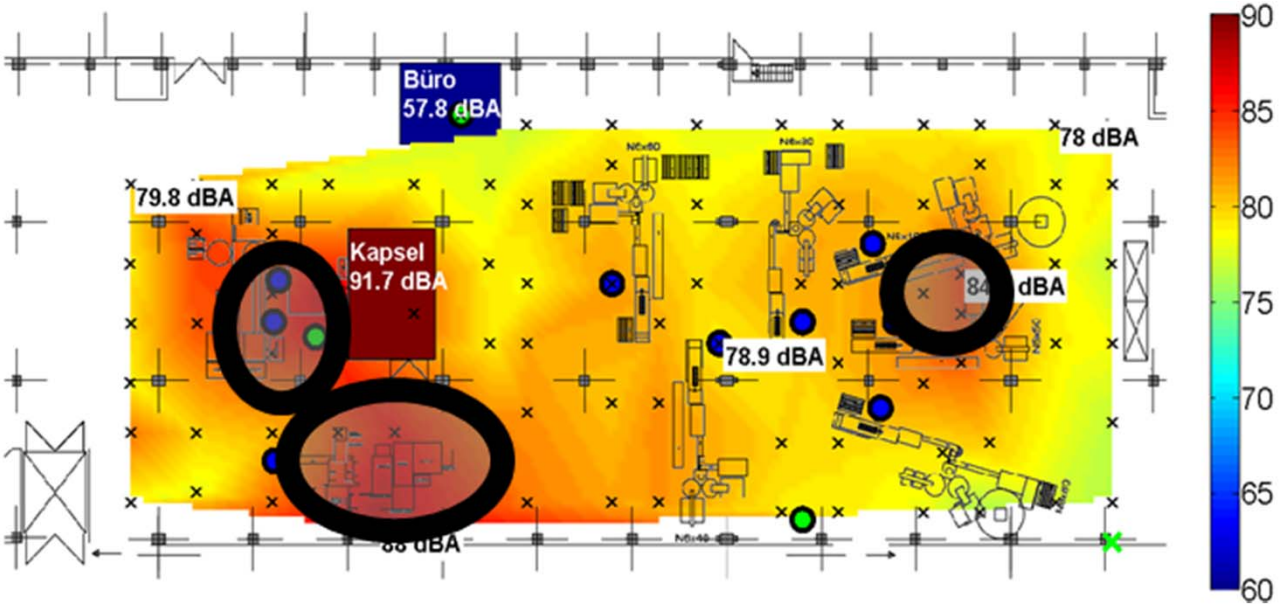
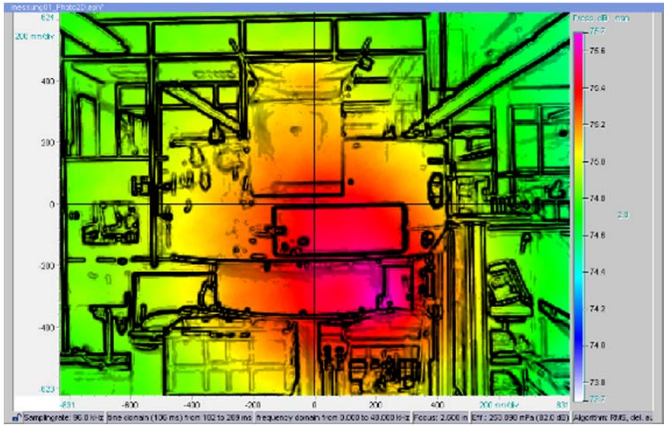
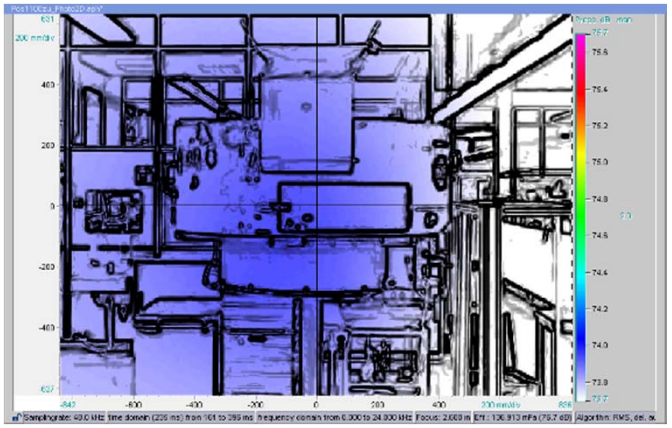
Noise maps and noise reduction at a production plant for plastic screw anchors







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2.3 company wants to preventively improve its own production facilities although noise limits are not exceeded and employees have not complained yet (→ productivity)

Project example for scenario 2.3

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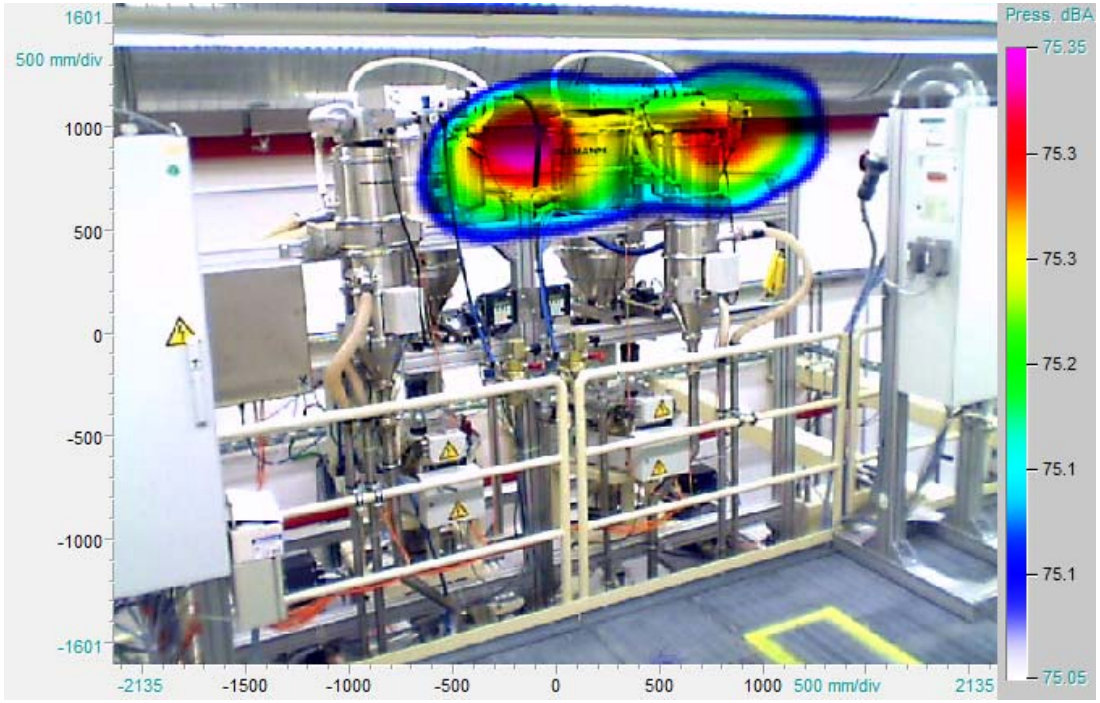
Acoustic analysis of a prototyping machine for diaper production



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2.3 company wants to preventively improve its own production facilities although noise limits are not exceeded and employees have not complained yet (→ productivity)

2.4 company does not know if noise limits are exceeded in its production facilities or not and commissions us to find out

Project example for scenario 2.4

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Sound measurements in a production plant for electrical parts

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(Potential) reasons why companies contact us for support

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Scenario 3: (possible, potential, ...) problems in the future

3.1 products are advanced already – but others are catching up and are threatening this competitive edge

Project example for scenario 3.1

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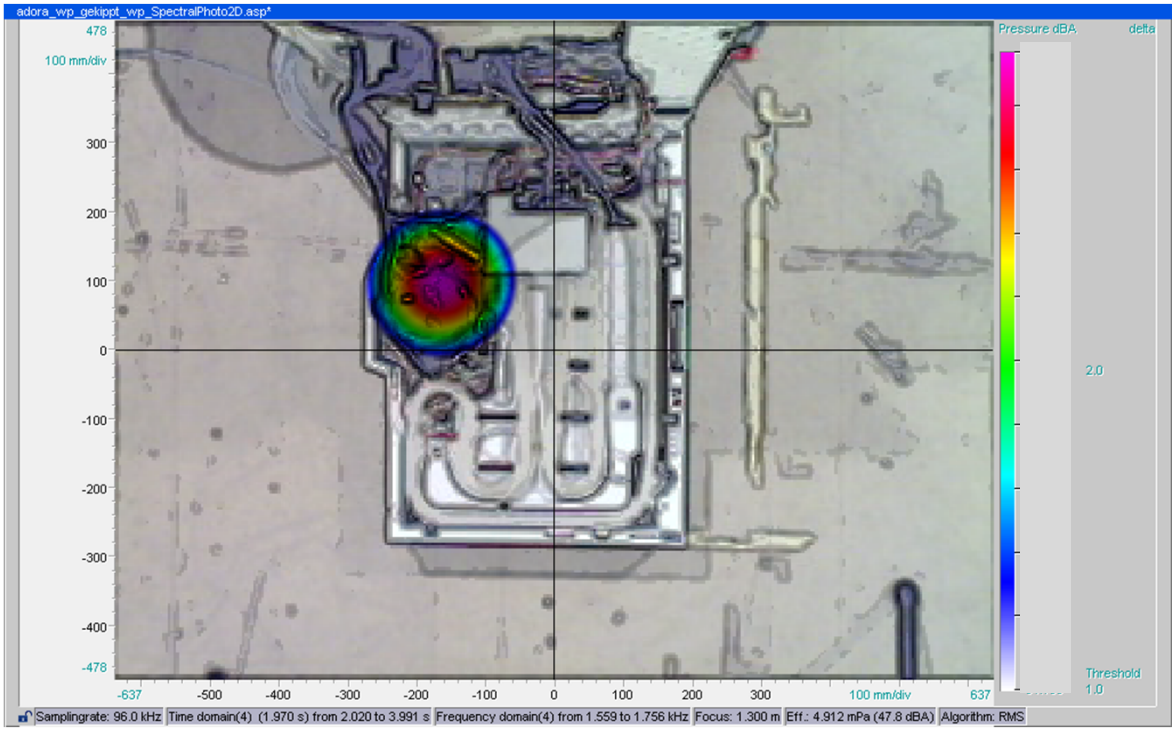
Acoustic analysis of a novel approach for a dishwasher



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(Potential) reasons why companies contact us for support

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Scenario 3: (possible, potential, ...) problems in the future

3.1 products are advanced already – but others are catching up and are threatening this competitive edge

3.2 products are advanced already – and company wants preventively to keep or even further improve that status

Project example for scenario 3.2

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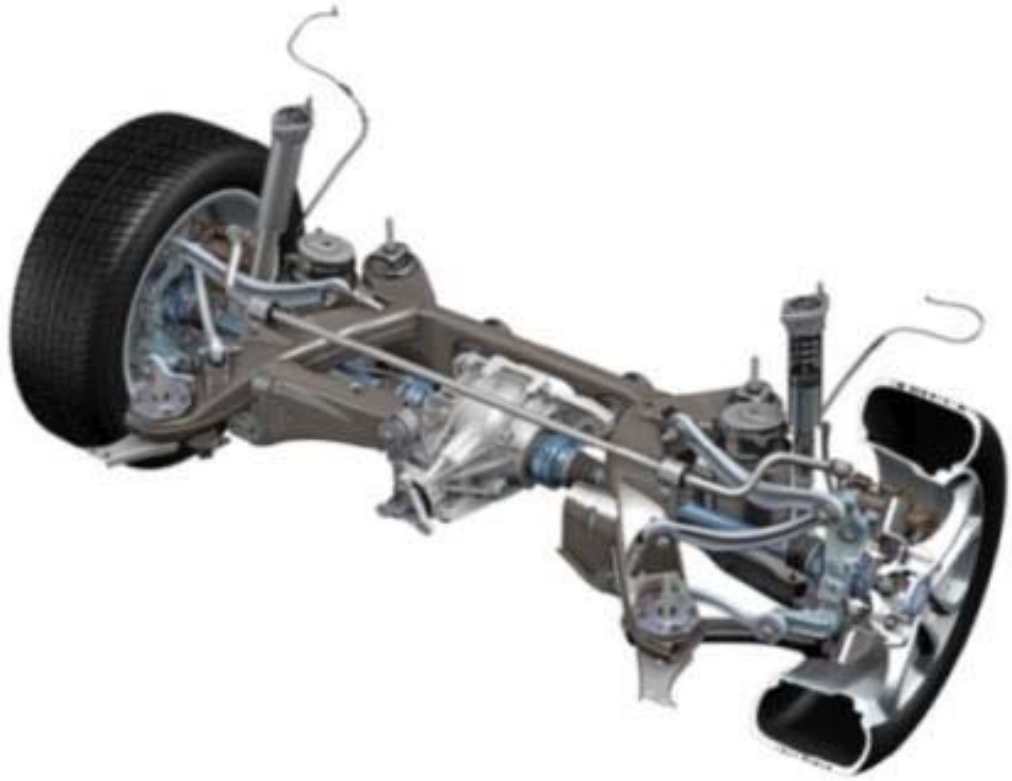
Modal analysis of the rear axle of a sporty car



(Potential) reasons why companies contact us for support

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Scenario 3: (possible, potential, ...) problems in the future

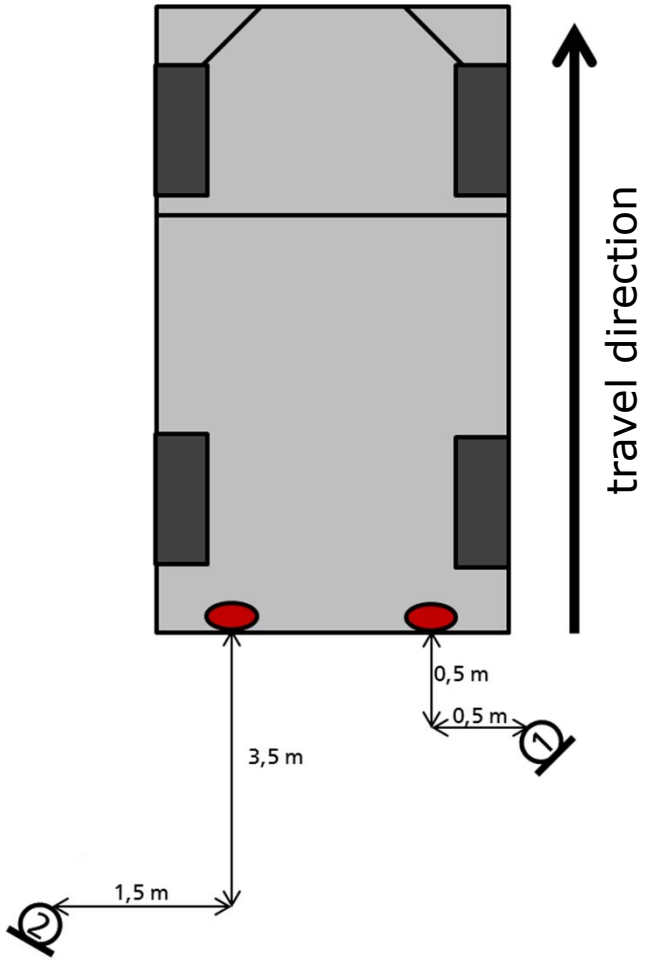
3.1 products are advanced already – but others are catching up and are threatening this competitive edge

3.2 products are advanced already – and company wants preventively to keep or even further improve that status

3.3 products are advanced already – but company aims at becoming the market leader

Project example for scenario 3.3

Acoustic analysis of the exhaust noise of a sporty car



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- **Classical methods for noise control engineering**
- Novel approaches for noise control engineering

Classical methods for noise control engineering

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often based on the “fundamental equation of machine acoustics”:

$$P(f) = \overline{\tilde{v}^2}(f) \cdot S \cdot \sigma(f) \cdot Z'_{medium}$$

$$P(f) = \tilde{F}^2(f) \cdot \frac{T_v^2(f)}{Z_E^2(f)} \cdot S \cdot \sigma(f) \cdot Z'_{medium}$$

Classical methods for noise control engineering

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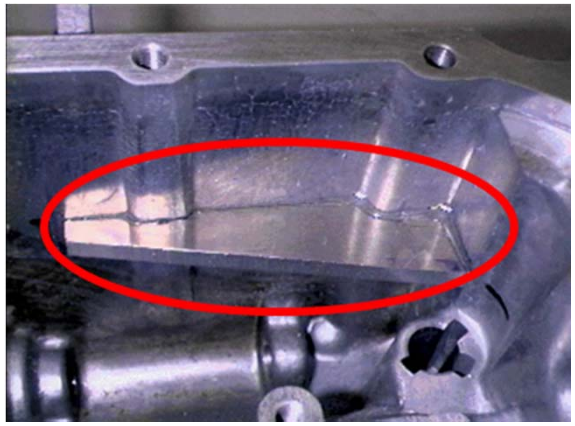
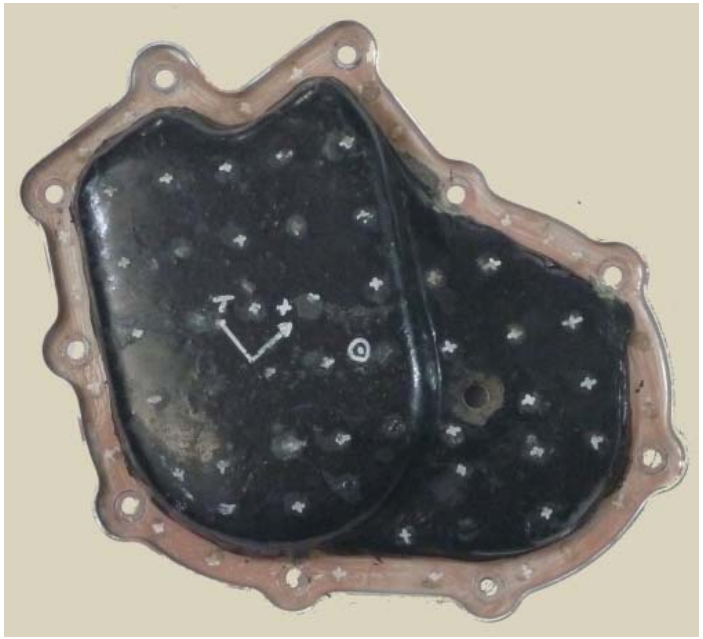
e.g., applying stiffening ribs or damping material, increasing the input impedance by applying a lumped mass at the excitation point, changing the radiation efficiency, or detuning the structure





Classical methods for noise control engineering

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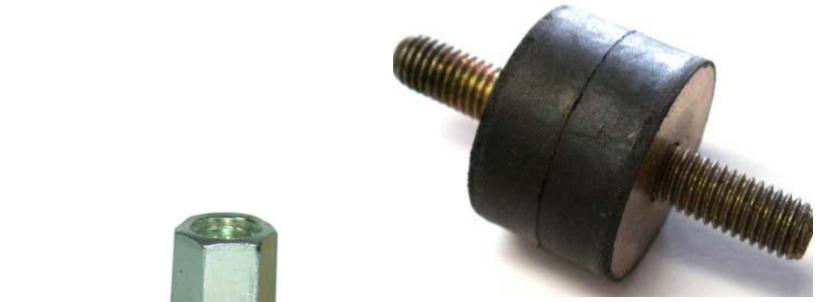
also: mufflers, encapsulations, vibration absorbers, etc.



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Novel approaches for noise control engineering

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Structural intensity (STI):

- describes the paths and magnitude of the vibratory energy flux within a vibrating structure (similar to the airborne sound intensity)
- analysis tool and for potential manipulation/optimization
- theory published in the 1970s and 1980s, but “real life” applications just start to emerge
- obtained from numerical simulations and (to a lesser extent) from measurements

Novel approaches for noise control engineering

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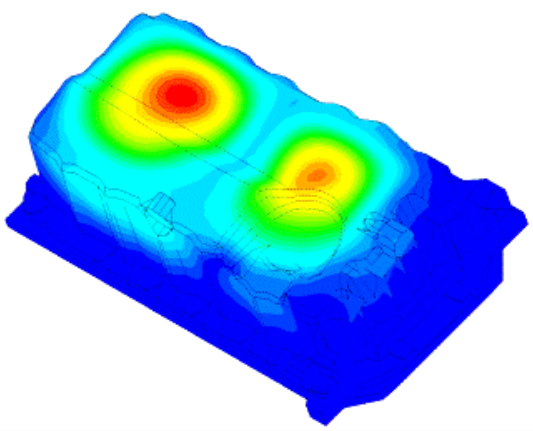
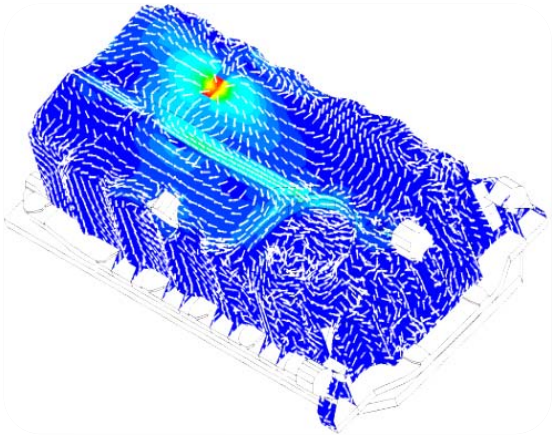
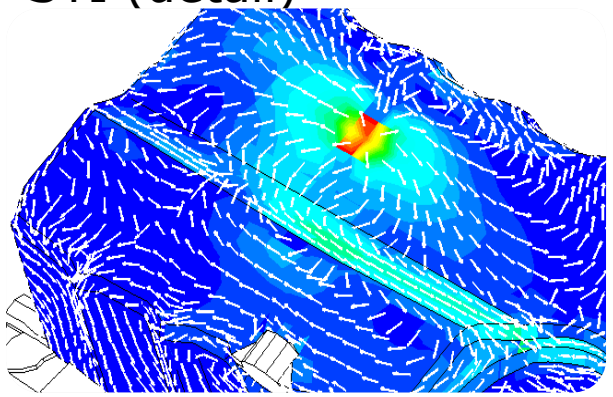
surface velocity



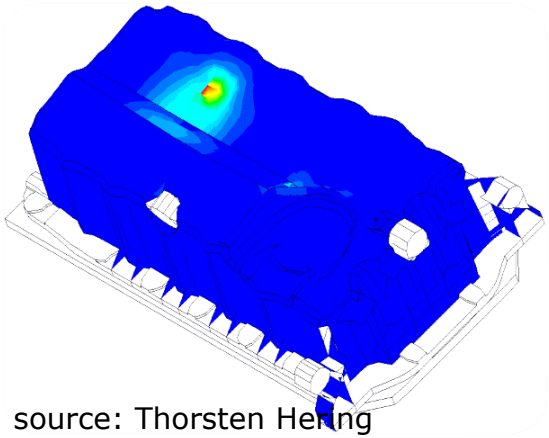
STI



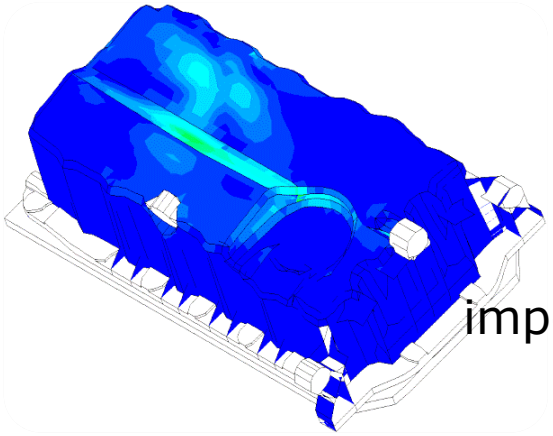
STI (detail)

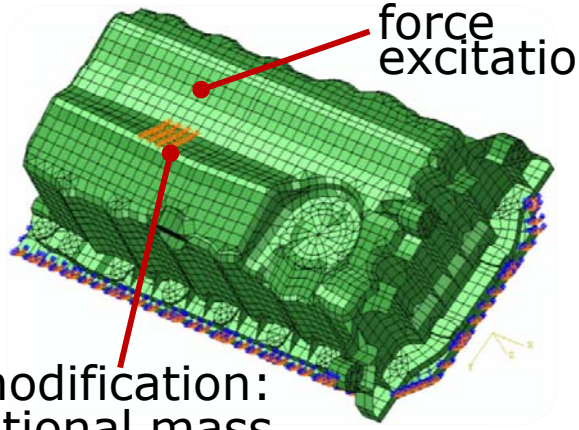


STI, out-of-plane



STI, in-plane



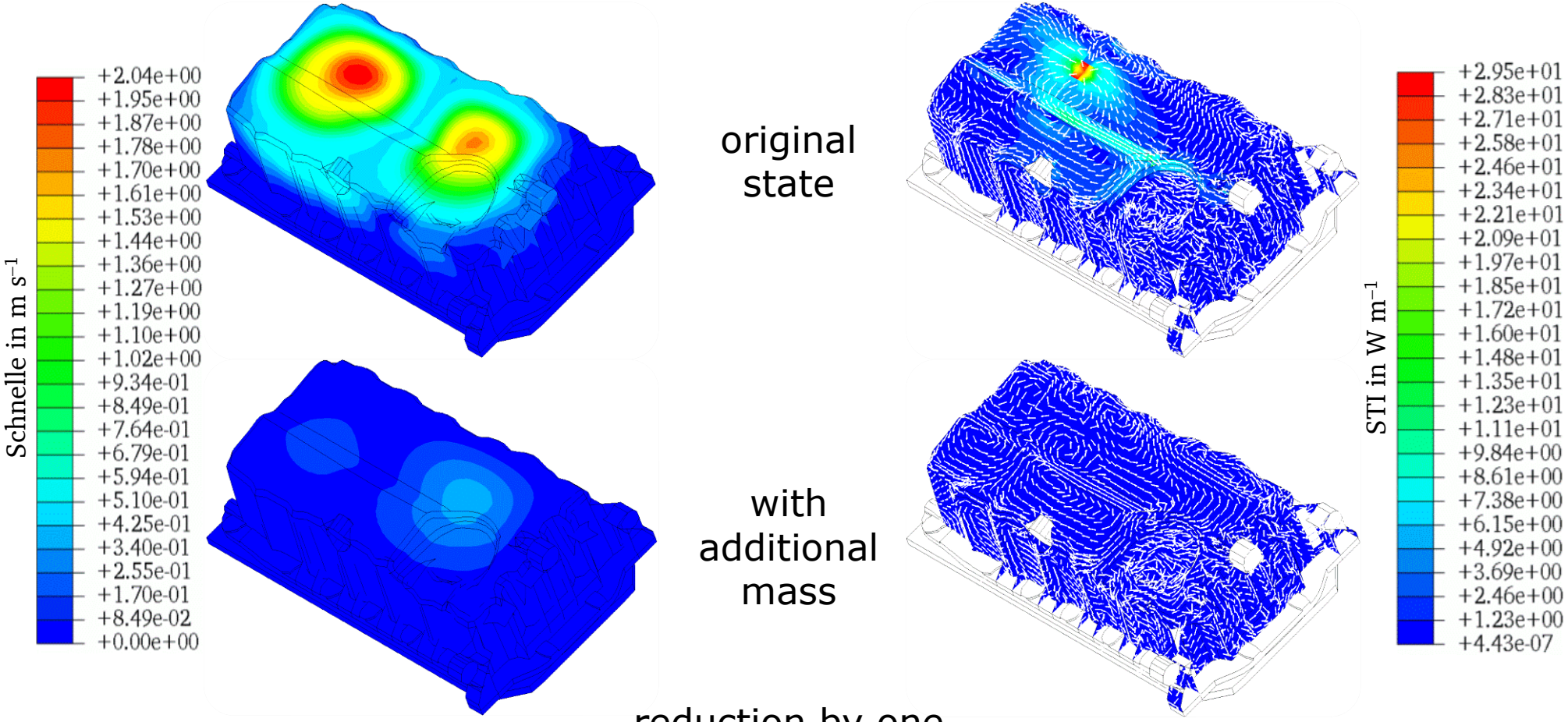


impedance modification:
additional mass
(from 5,5 to 5,6 kg)

source: Thorsten Hering

SzM

Novel approaches for noise control engineering



reduction by one order of magnitude

source: Thorsten Hering

(Quelle: [11])

Novel approaches for noise control engineering

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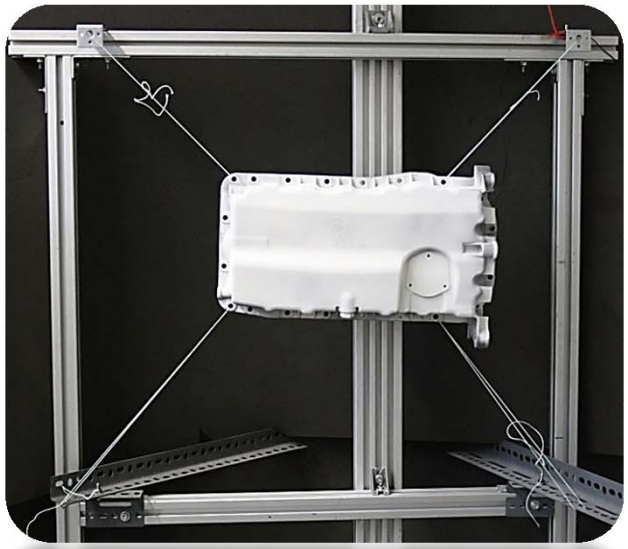
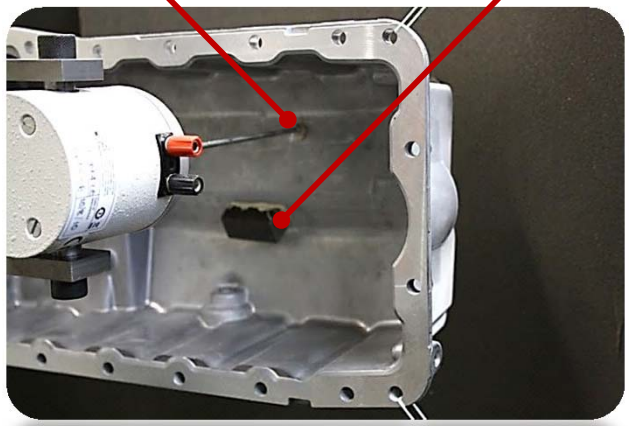
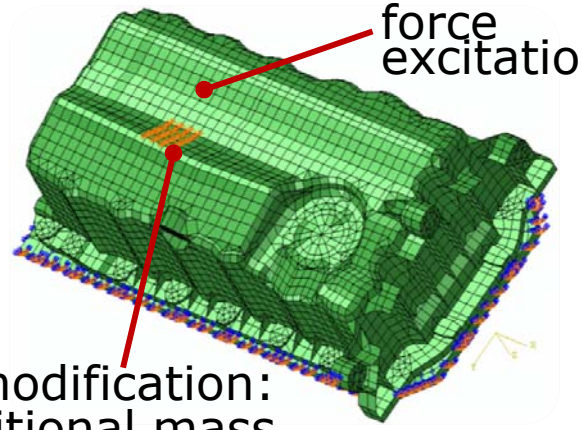
test rig







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Novel approaches for noise control engineering

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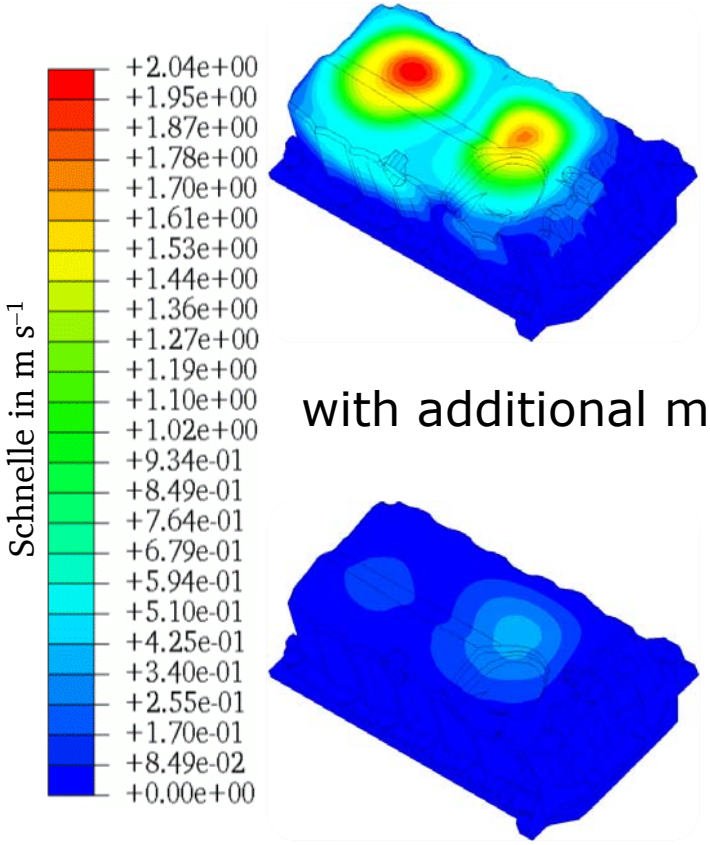
numerical simulation

original state:

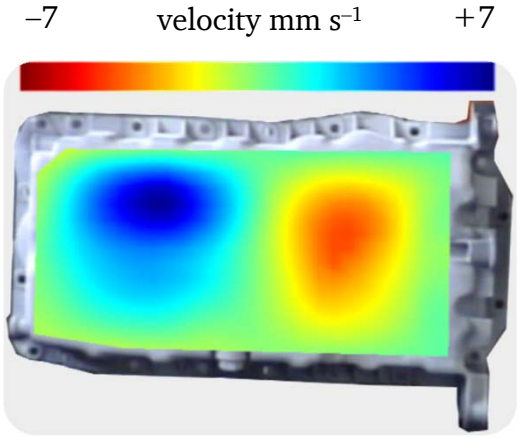


with additional mass:

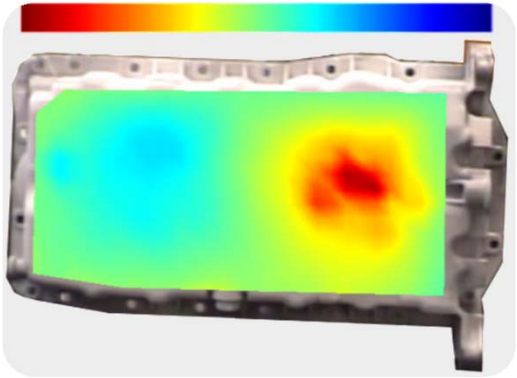
reduction by one order of magnitude

experimental simulation

original state:



with additional mass:



source: Thorsten Hering

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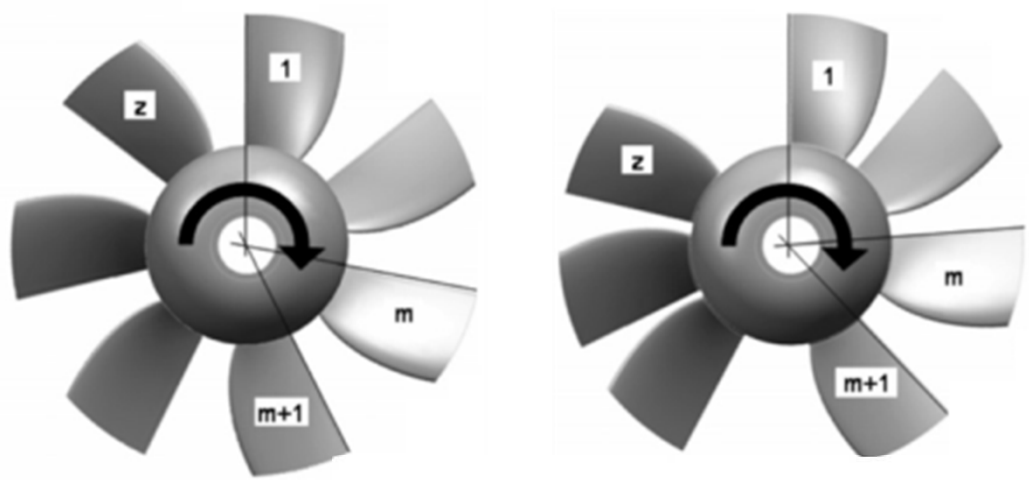
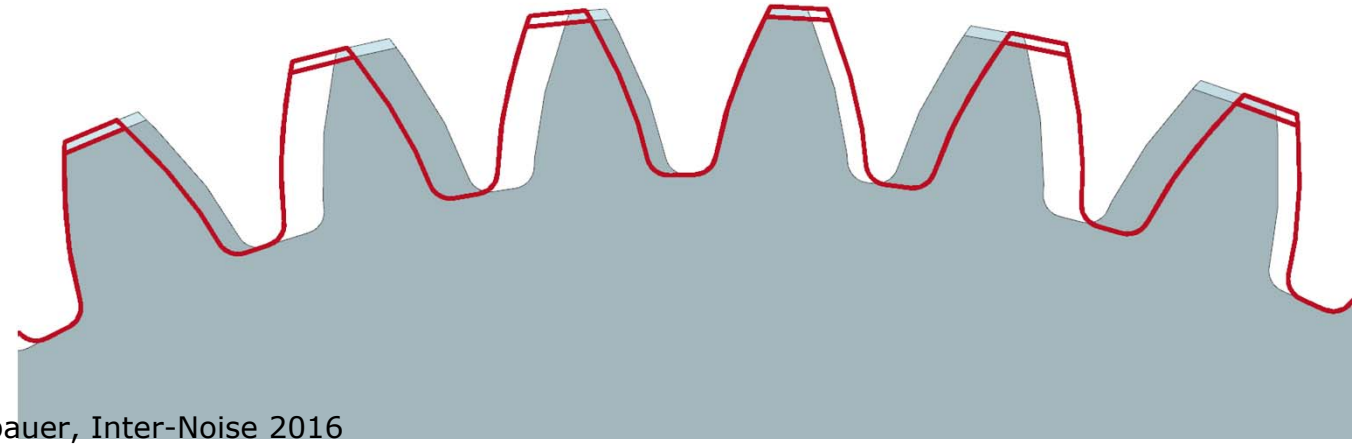
Inequidistant gearings



→ reduction of tonal noise
→ broadband noise character
→ less annoying



source: Philipp Neubauer, Inter-Noise 2016

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source: Philipp Neubauer, Inter-Noise 2016

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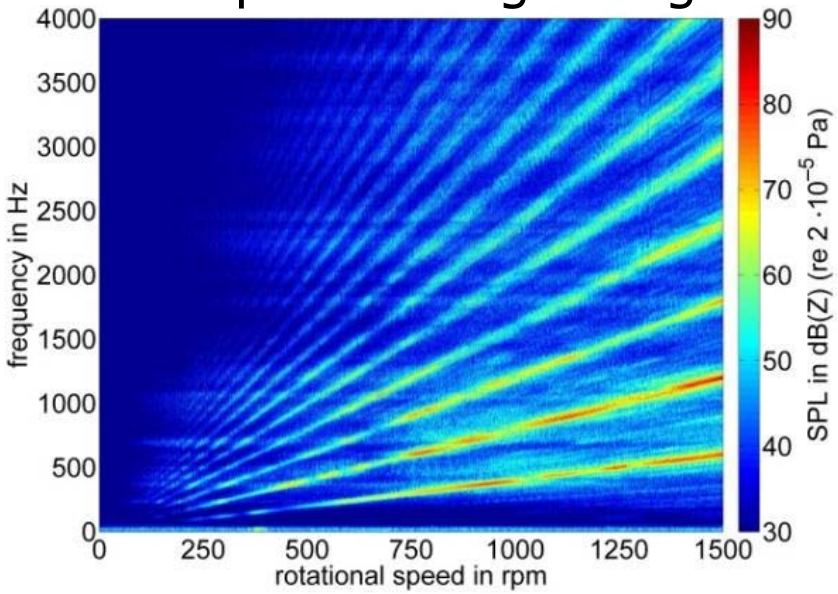
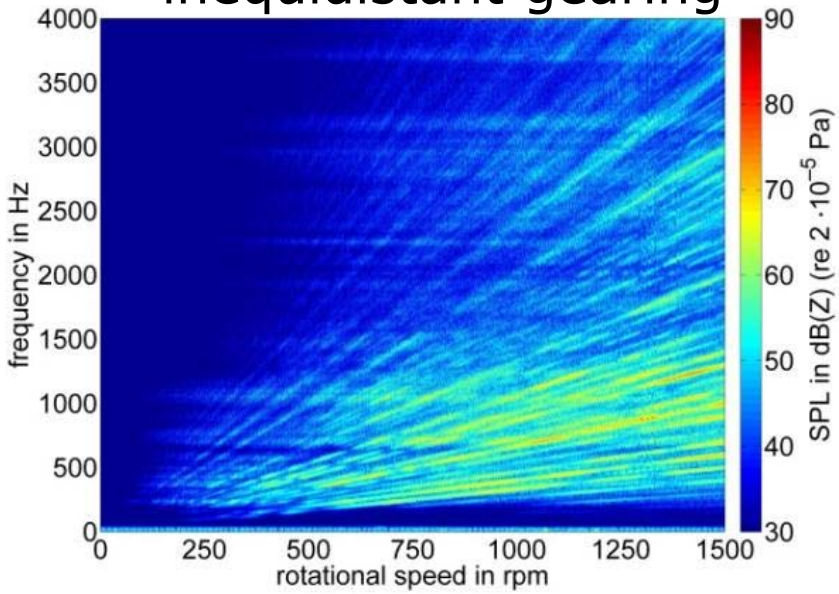
Inequidistant gearings

equidistant gearing



inequidistant gearing



source: Philipp Neubauer, Inter-Noise 2016

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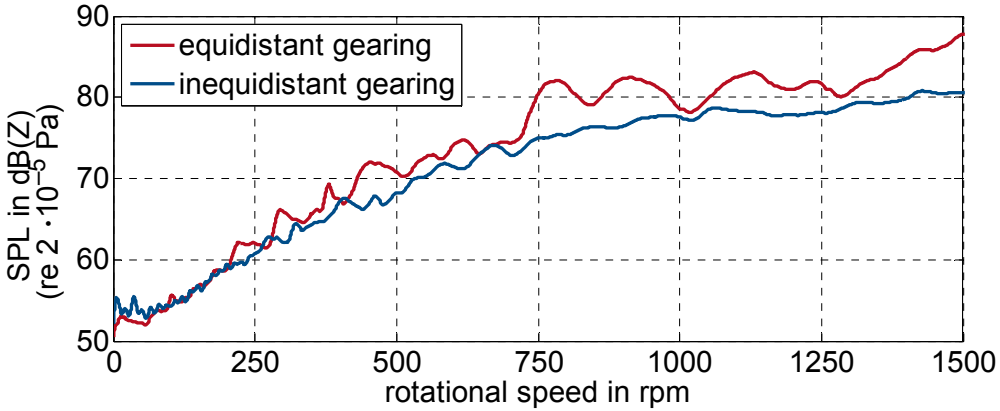
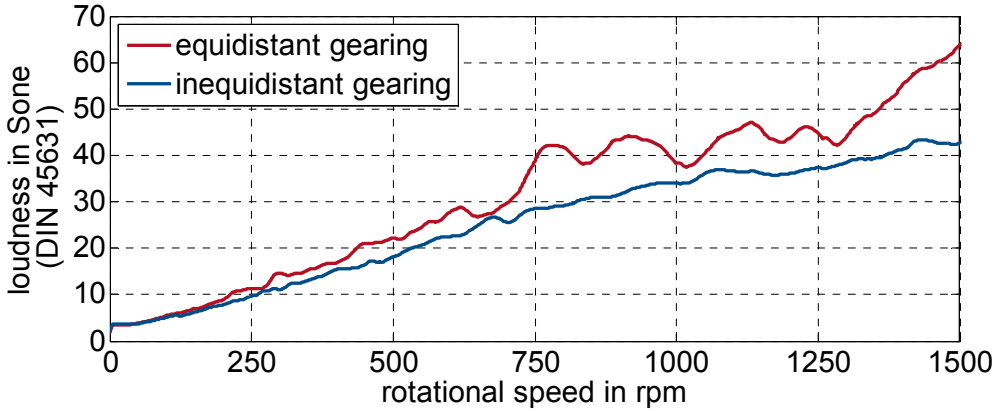
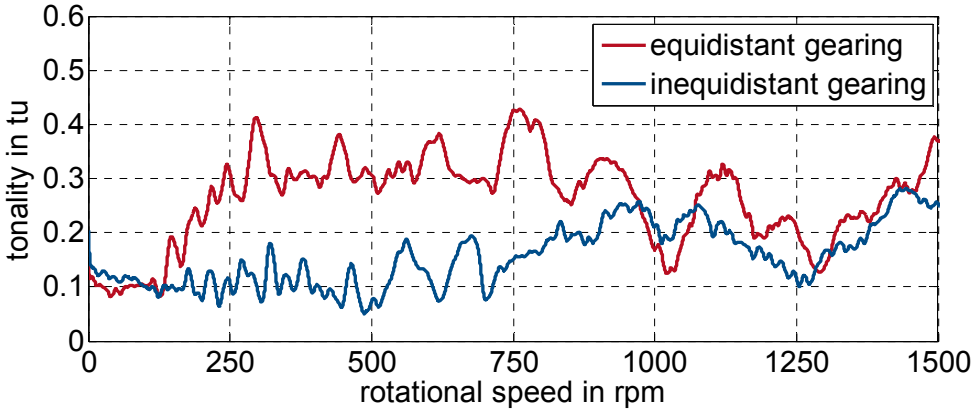
total sound pressure level



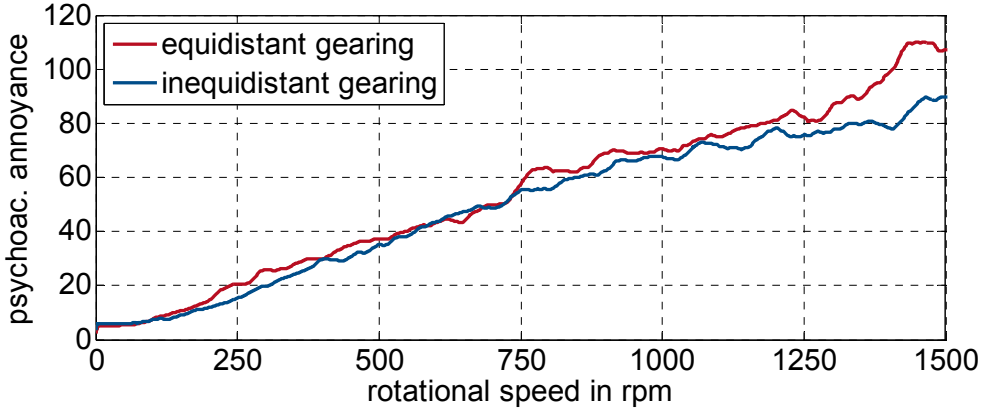
psychoacoustic loudness



tonality



psychoacoustic annoyance



source: Philipp Neubauer, Inter-Noise 2016

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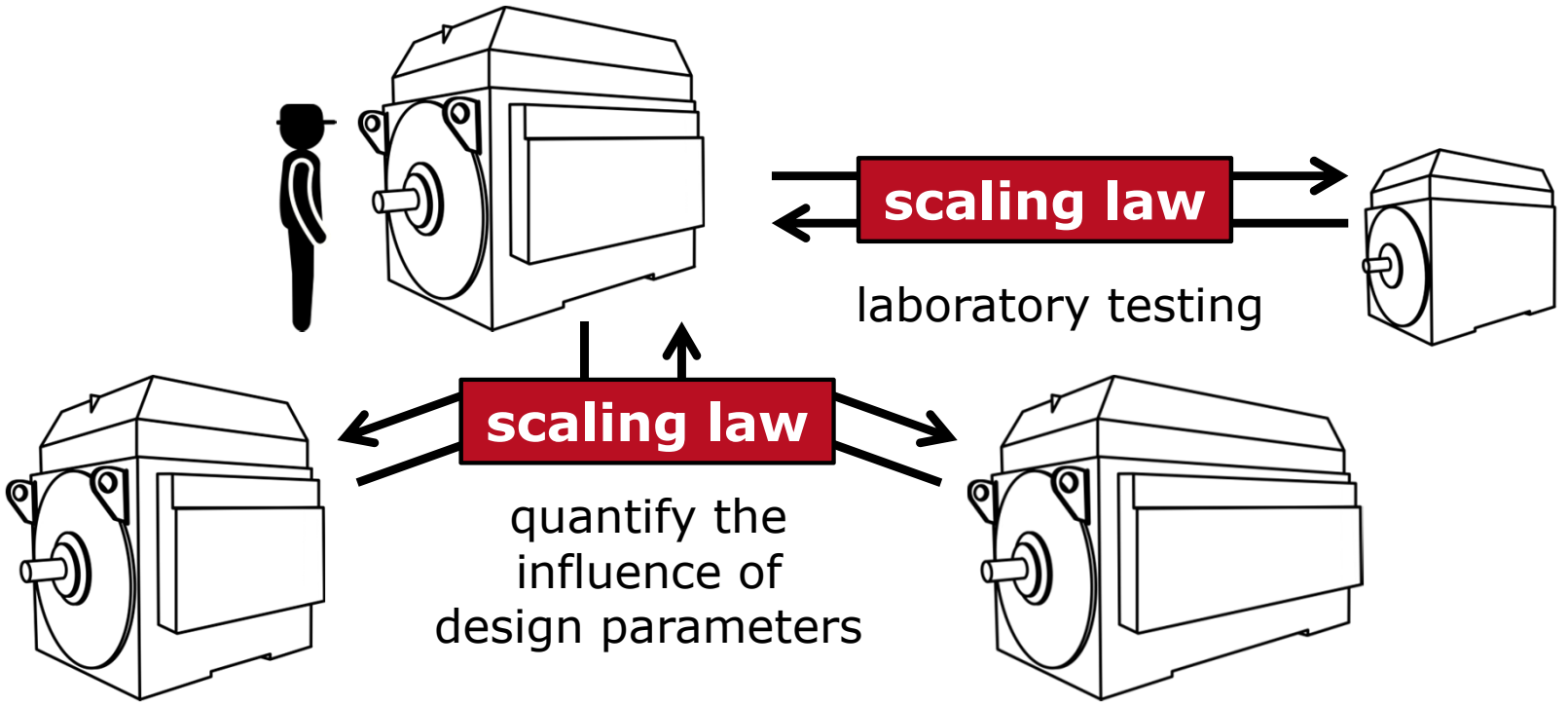
Scaling laws using sensitivity analyses



source: Christian Adams, Inter-Noise 2016

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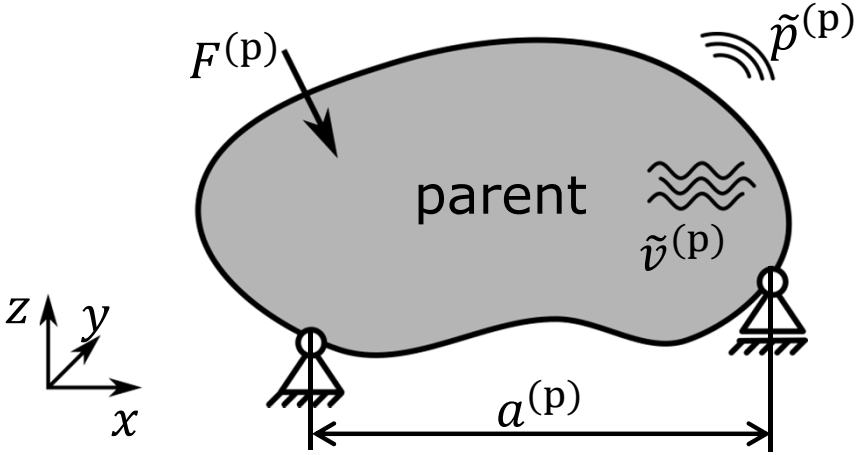

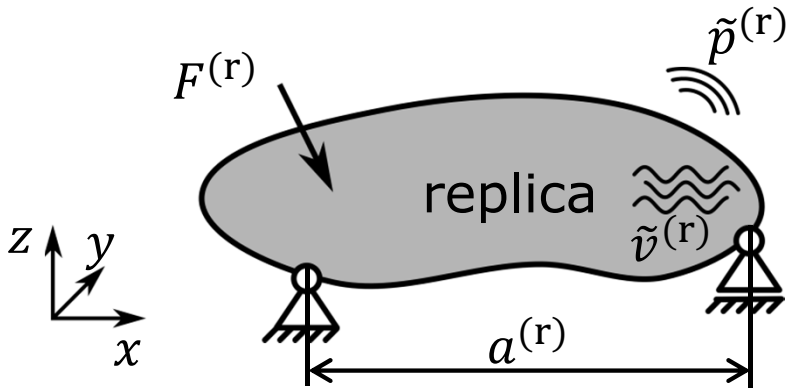

design parameters $X_j^{(\mathrm{p})}$

- $F^{(\mathrm{p})}$, $a^{(\mathrm{p})}$, etc.

vibroacoustic responses $Y^{(\mathrm{p})}$

- $\tilde{v}^{(\mathrm{p})}$, $\tilde{p}^{(\mathrm{p})}$, etc.

scaling law

design parameters $X_j^{(\mathrm{r})}$

- $F^{(\mathrm{r})}$, $a^{(\mathrm{r})}$, etc.

vibroacoustic responses $Y^{(\mathrm{r})}$

- $\tilde{v}^{(\mathrm{r})}$, $\tilde{p}^{(\mathrm{p})}$, etc.

source: Christian Adams, Inter-Noise 2016

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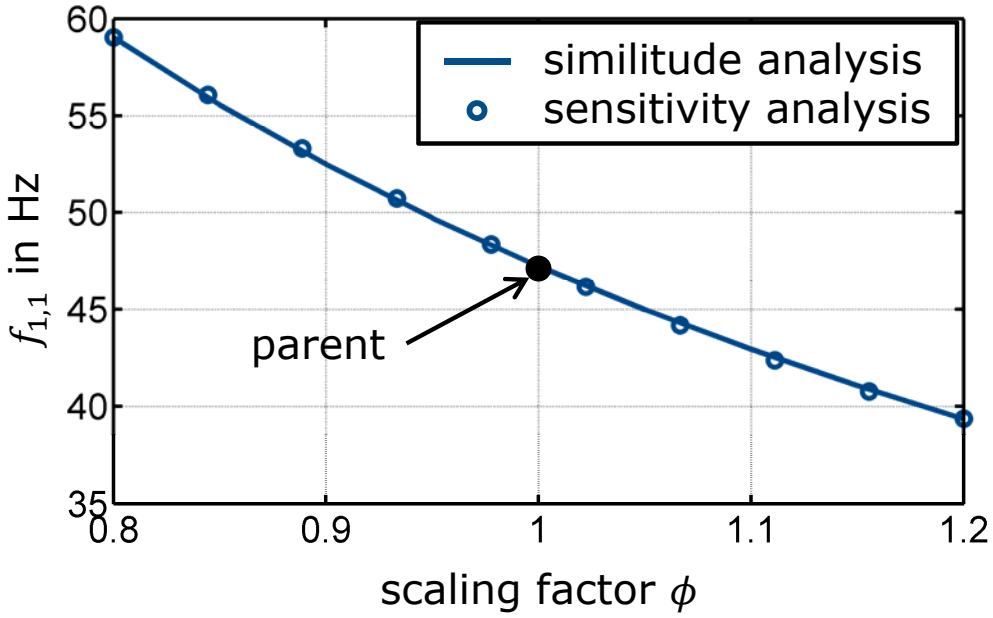
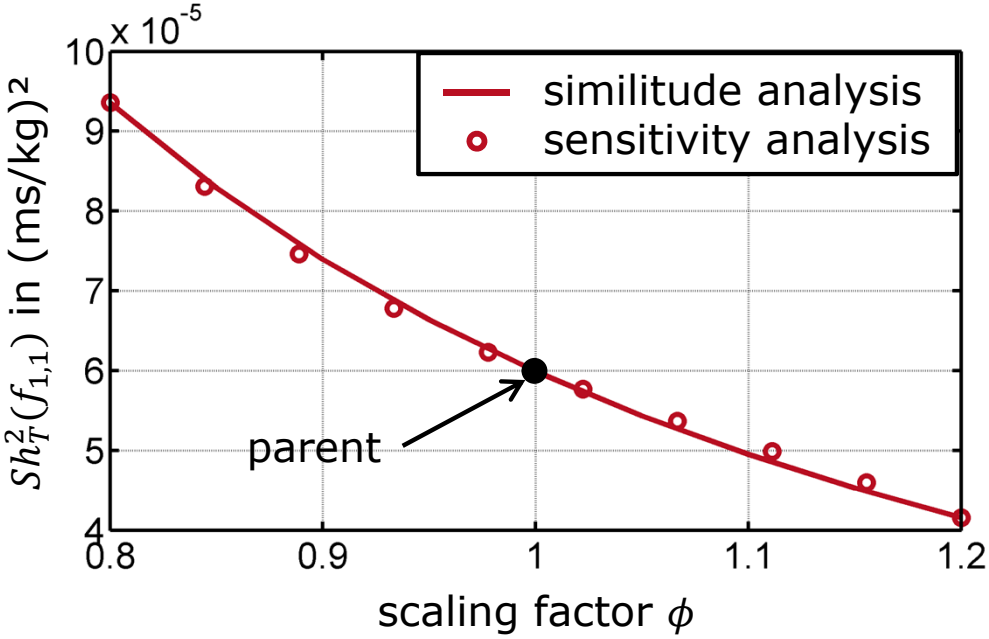
case: $\phi_l = \phi_h = \phi$, results for the fundamental frequency





source: Christian Adams, Inter-Noise 2016

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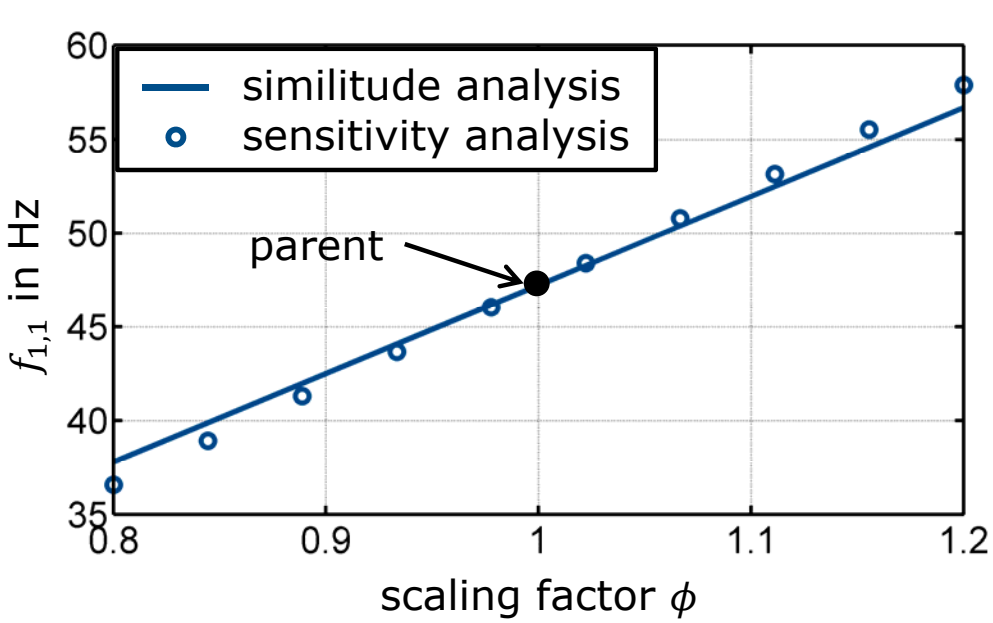
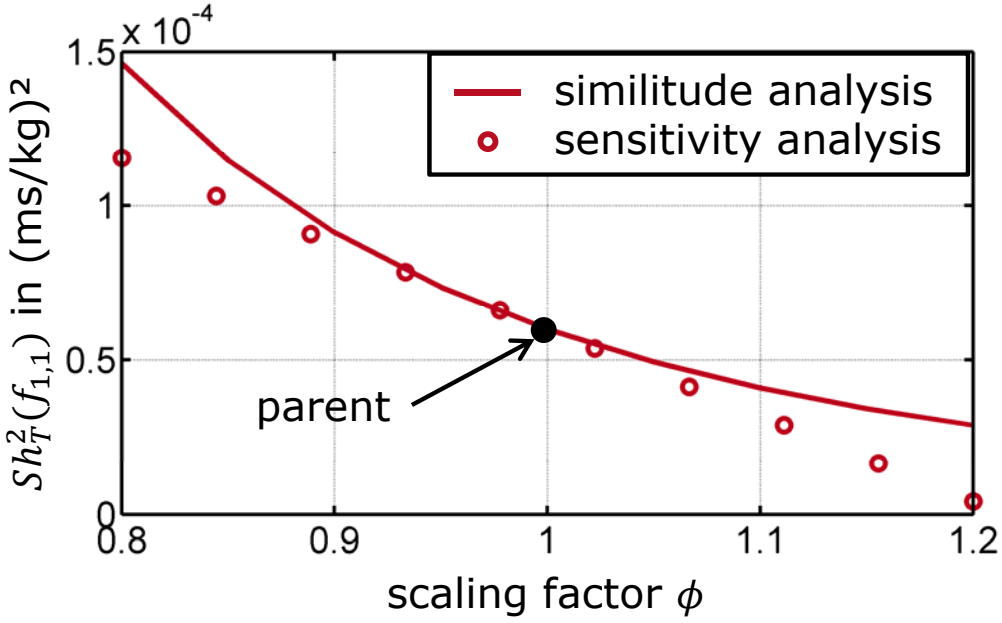
case: $\phi_l = 1,\ \phi_h = 0.8 \ldots 1.2$, results for the fundamental frequency





source: Christian Adams, Inter-Noise 2016

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Quiet machine design: Motivation, classical methods, and novel approaches

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Thank you for your attention!

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