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E-LASS seminar #16, 13/09/2022

Noise and vibration reduction with vibroacoustic metamaterials

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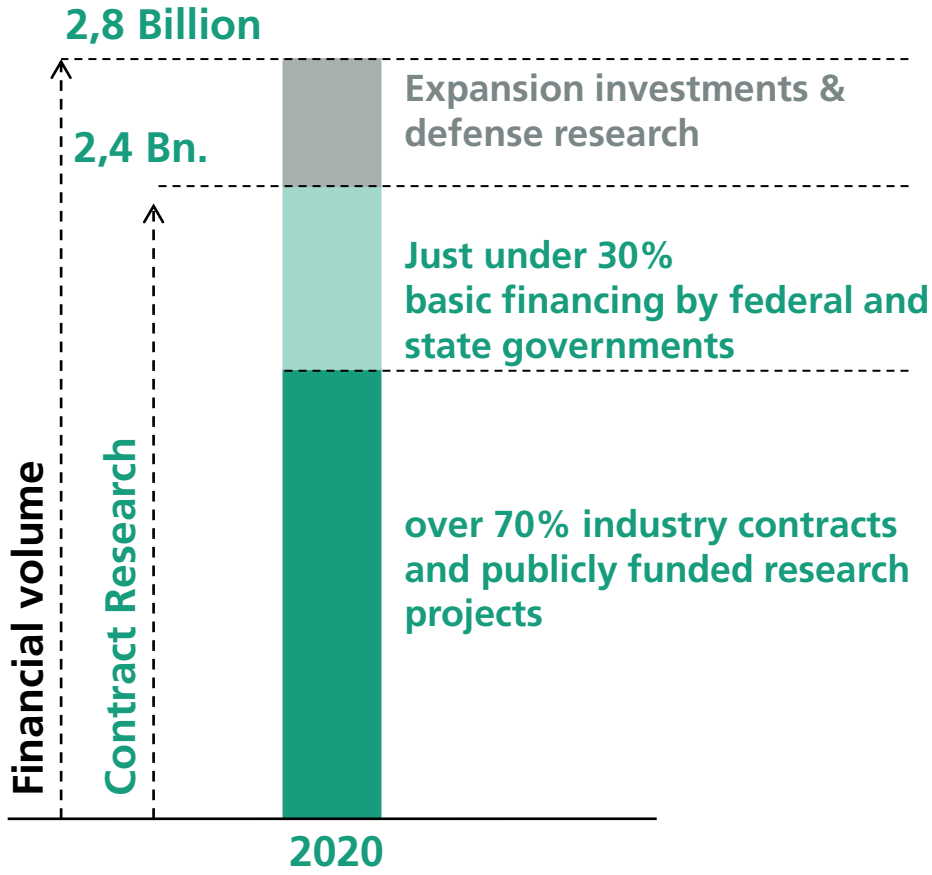
Fraunhofer-Gesellschaft

29 000 Employees

75 Institutes and research facilities



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Facts and figures

Employees	Facilities	Budget
■ 373 at the Fraunhofer LBF	■ Office: approx. 6,300 m²	■ Operating budget 2020: € 28 million
■ 40 at the TU Darmstadt	■ Lab: approx. 17,900 m²	■ Revenue share economy: 32.2%

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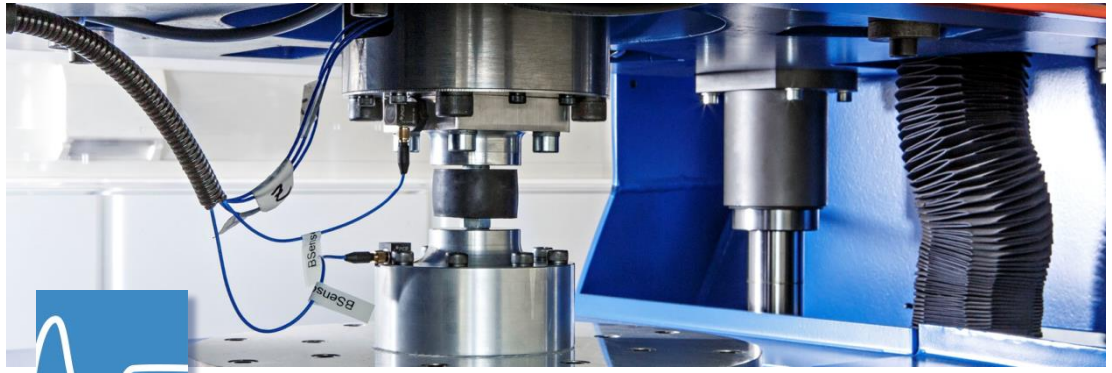
Research areas



Vibration Technology

Plastics

System Reliability

Lightweighting

Our markets

Automotive and supplier industry

Rail vehicle industry

Aviation industry

Shipbuilding

Mechanical and plant engineering

Special machine construction

Power engineering

Chemical industry

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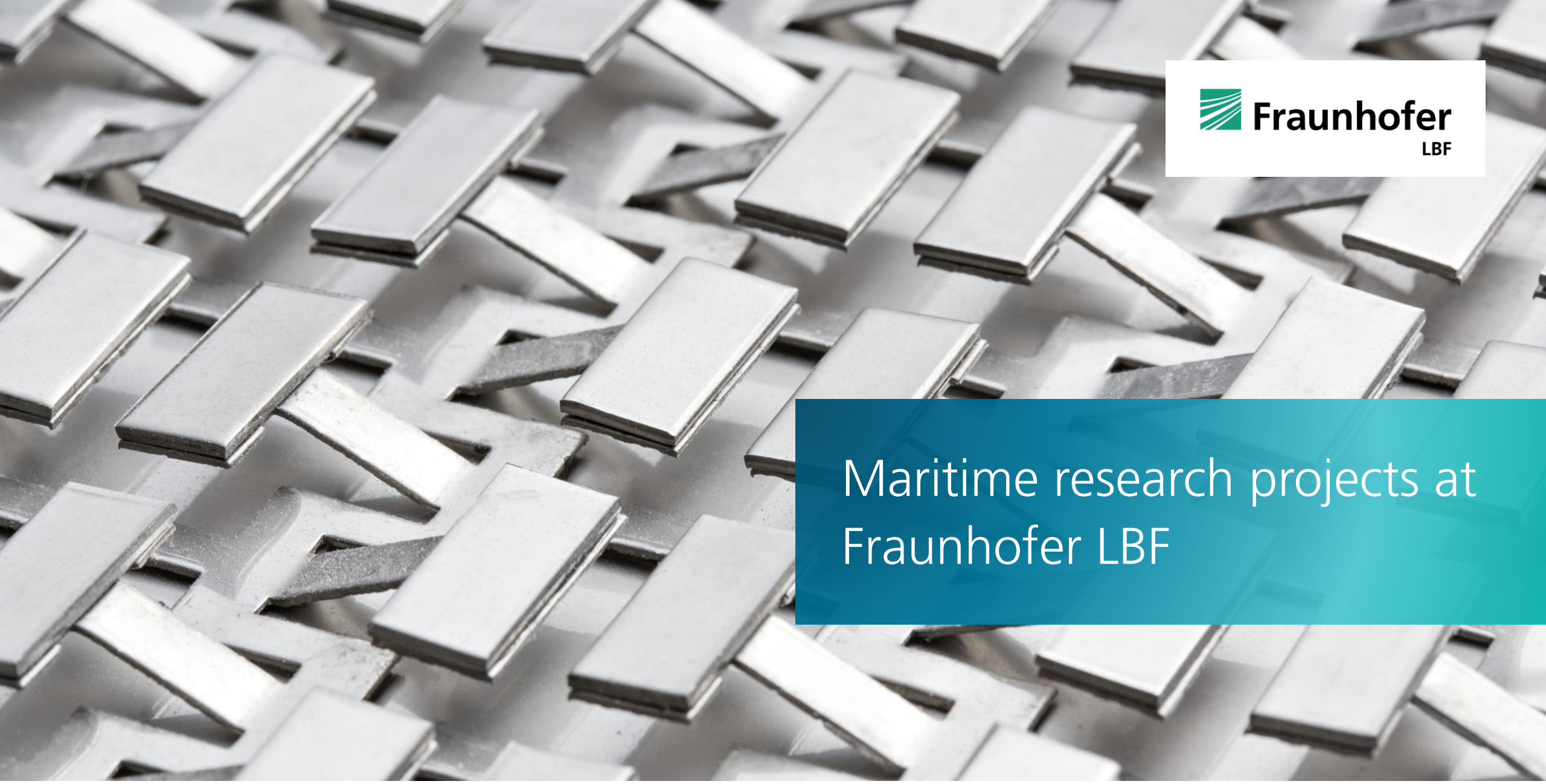
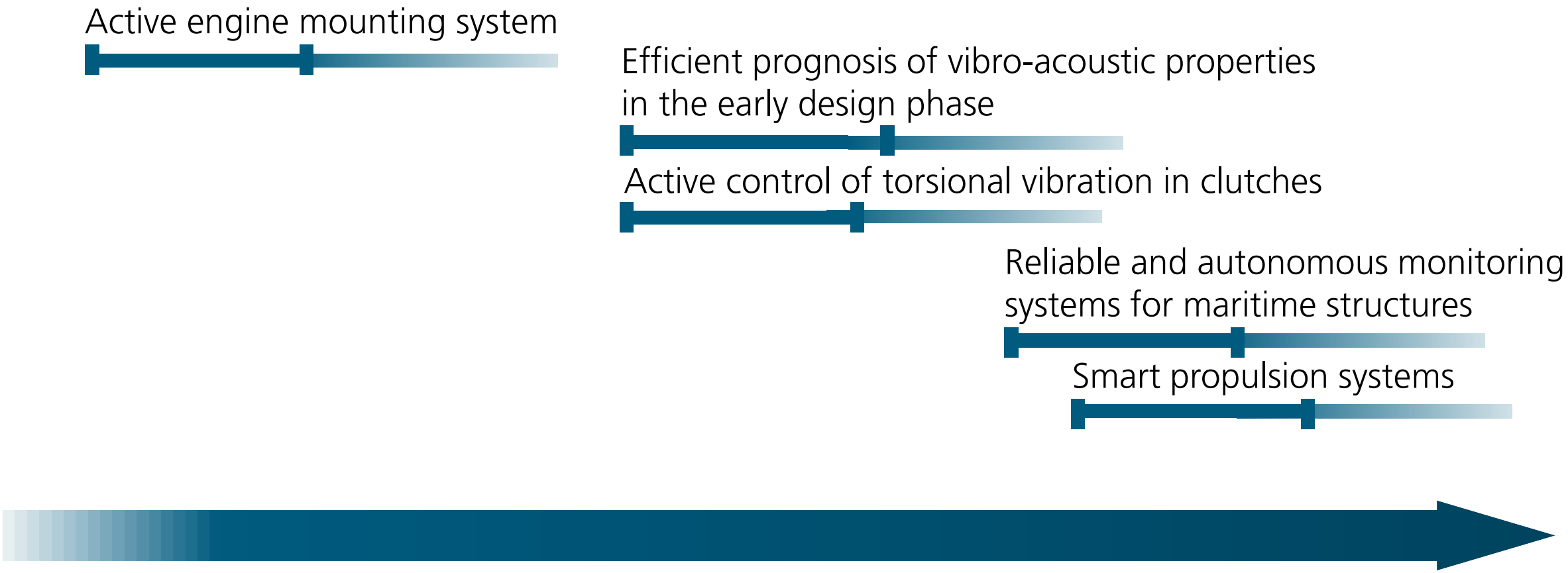


Maritime research projects at Fraunhofer LBF

BMWi funded maritime research projects at the LBF

Passive / active vibration and noise reduction, load analysis and monitoring systems, structural dynamics

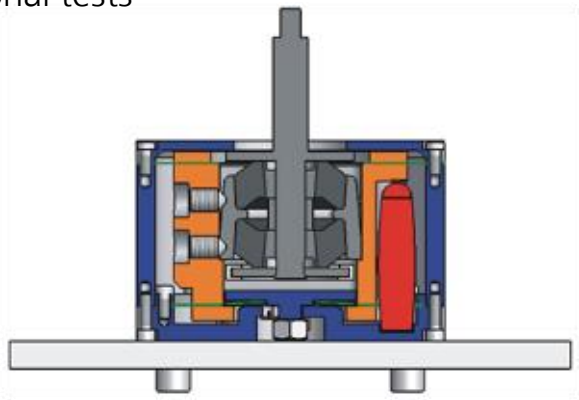


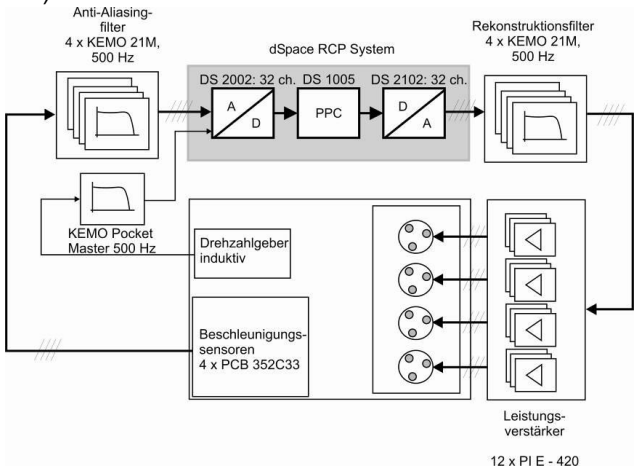
Active engine support for a rescue boat

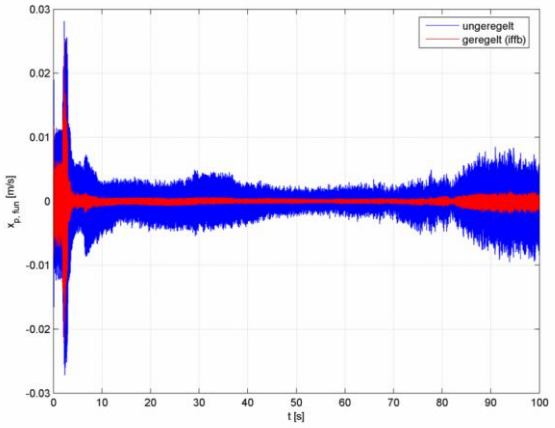
BMWi – AAL

Development of active mounts based on piezoceramic actuators to isolate the main drive engine in a ship

- System analyses und operational measurements
- System simulation in order to parameterize the active engine support
- Design of the active engine support (4x4)
- Evaluation of adaptive control approaches
- Implementation of the active engine support and lab test at LBF (full-scale)
- System integration and operational tests



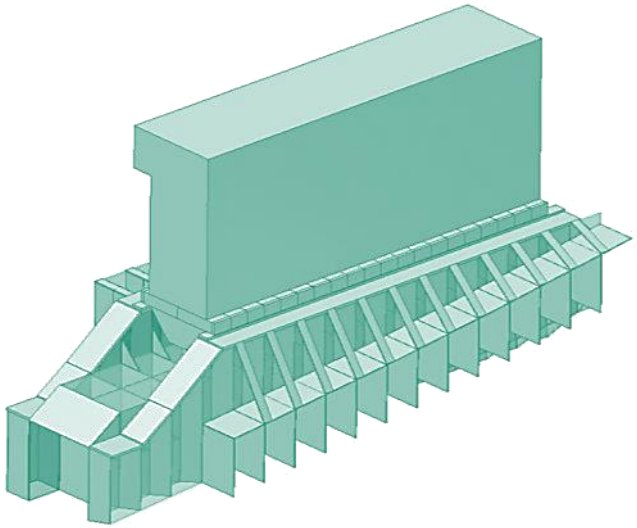


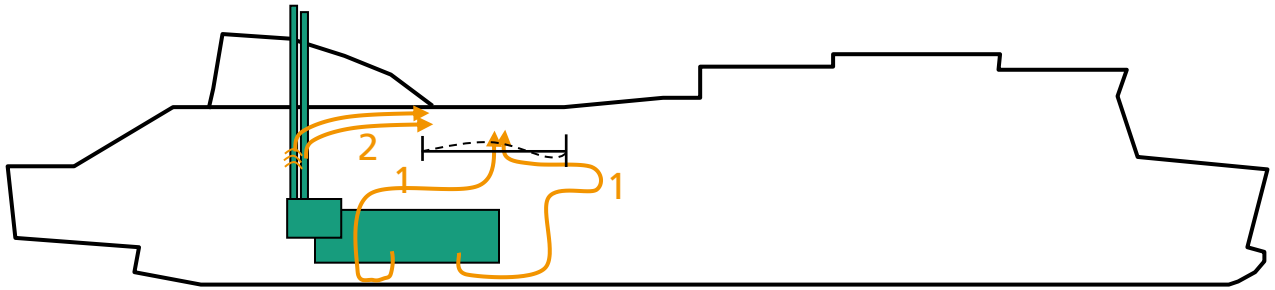


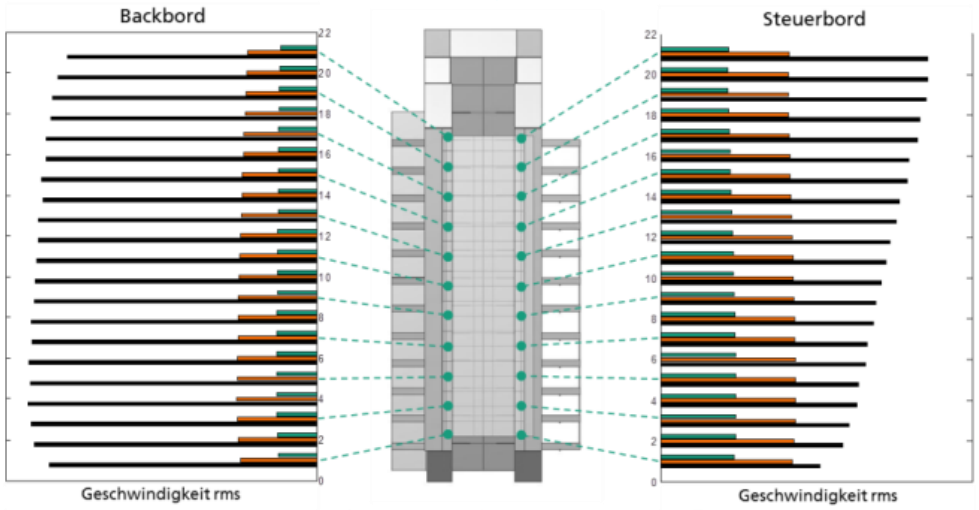
Vibration reduction by networks of tuned absorbers

Reduction of disturbing vibration in the passenger spaces of a RoPax-Ferry

- Vibrations from the main engines leads to annoying noise in some compartments of a RoPax-Ferry
- Investigations during the operation of the ship have shown two possible transfer paths between the source and the decks:
  - the ship structure (1)
  - the exhaust system (2)
- concepts of vibration neutraliser to install at the engine mounts were developed, numerical simulations have shown the potential of improvement







Ausgangszustand, 20 Tonnen Tilgermasse, 40 Tonnen Tilgermasse

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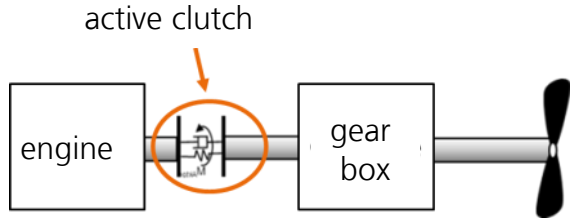
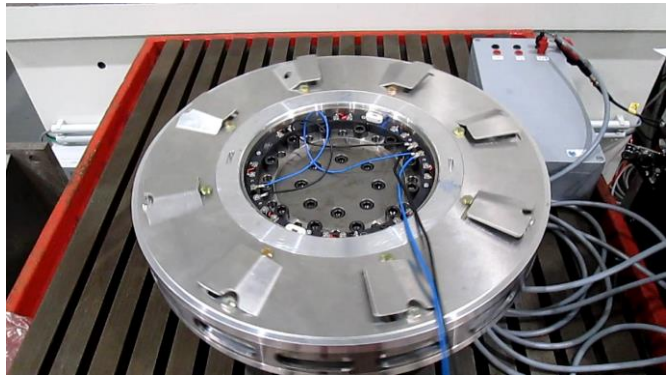
Active Vibration Control in powertrains - AkTos

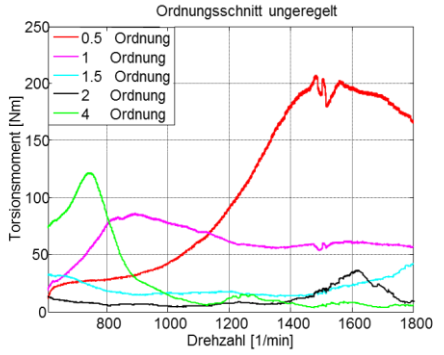
BMWi – AkTos

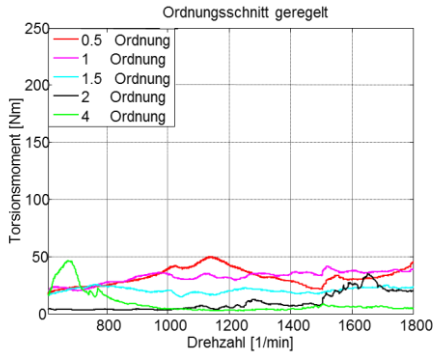
Development of an active clutch system to reduce torsional vibrations in a powertrain

- Investigation of different approaches for the reduction of torsional vibrations.
- Validation and implementation of the active system with rotary vibration actuator in a
  - small scale test stand
  - full scale powertrain test stand
- System integration and field tests









Vibroacoustic metamaterials

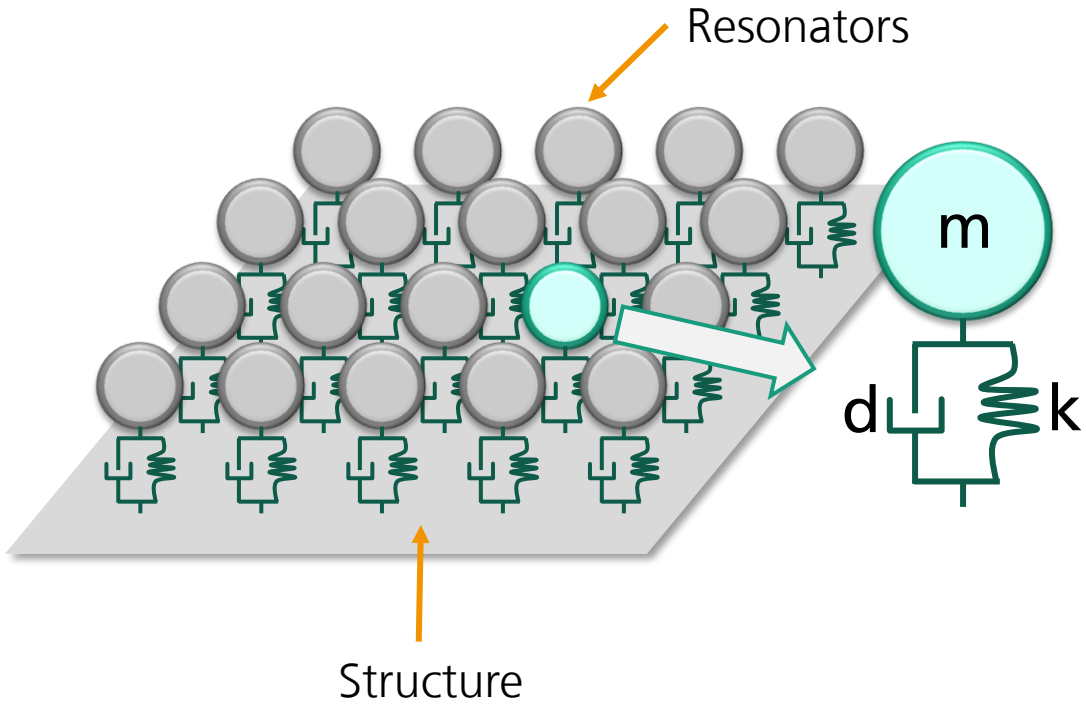
VAMM based on resonance effect

Definition (I)

Vibroacoustic metamaterials: artificially produced structures which, due to the specific design of periodically arranged unit cells, have **beneficial properties in terms of dynamic behavior** than conventional materials. Each unit cell represents an acoustic or structure-dynamic resonator (spring-mass system). In the figure, each (structure-dynamic) resonator is represented as a spring (dark green) and mass (grey).

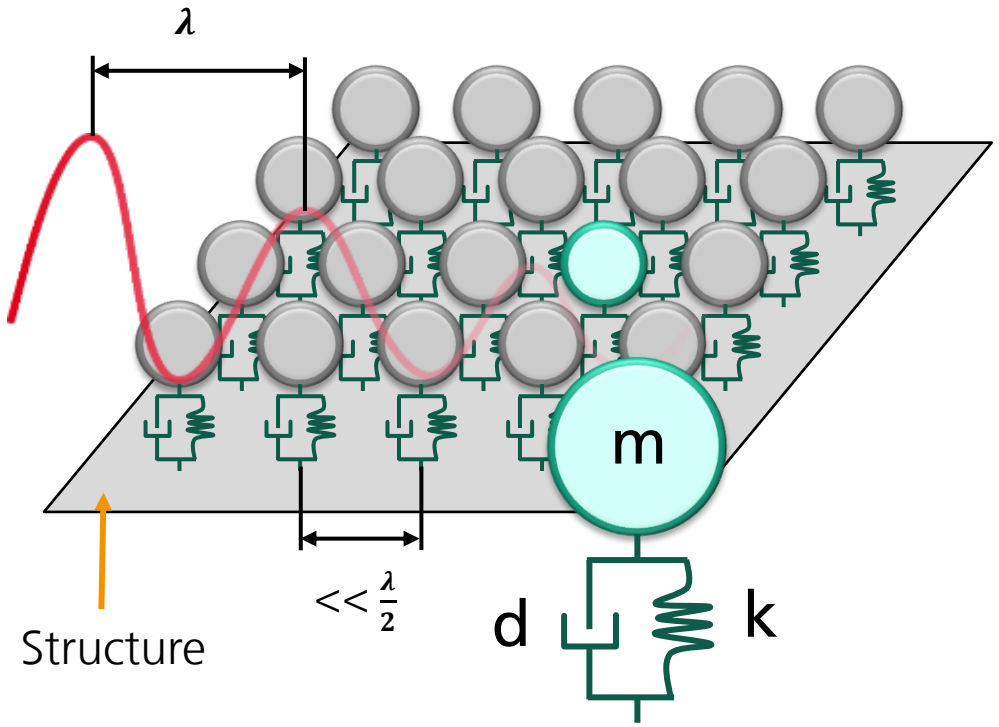
Pros:

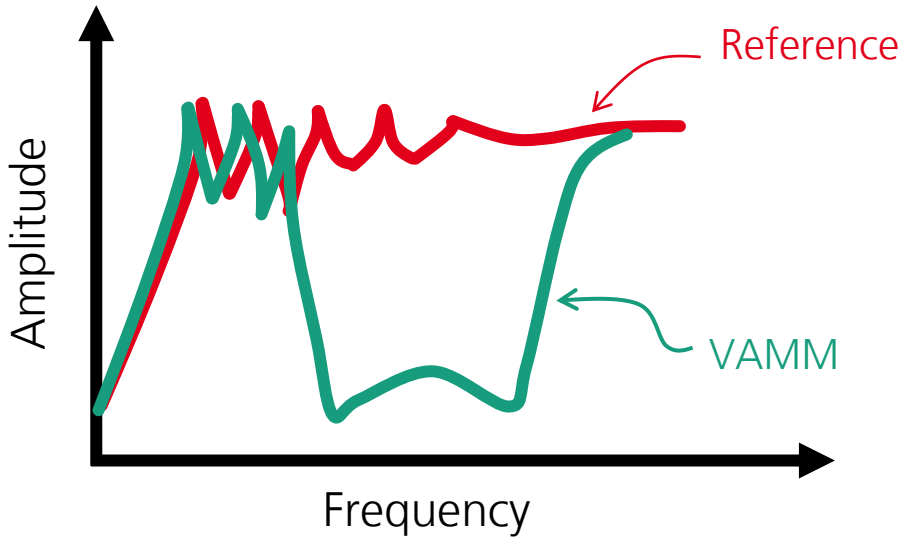
- ✓ Flexible and compact design
- ✓ High lightweight potential
- ✓ Broadband effect



VAMM based on resonance effect

Definition (II)



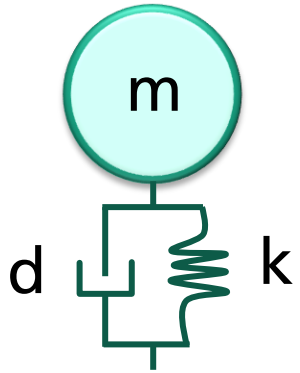


VAMM-structure consists of base structure with attached local resonance structures

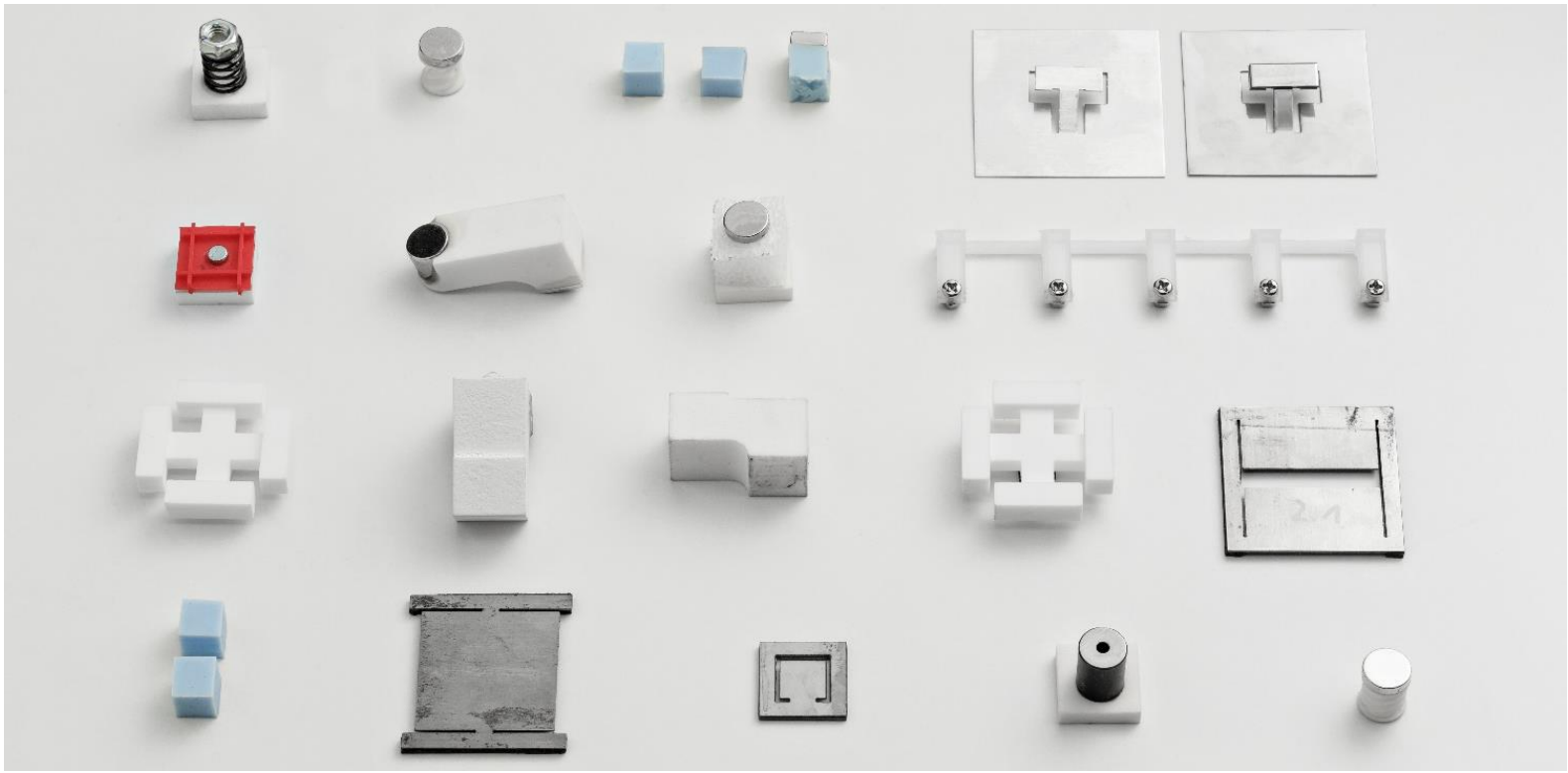
Stop band leads to strong wave attenuation in tunable frequency range

VAMM based on resonance effect

Design of locals resonators (I)

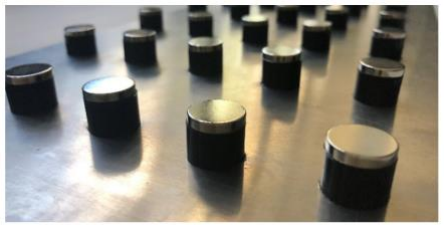
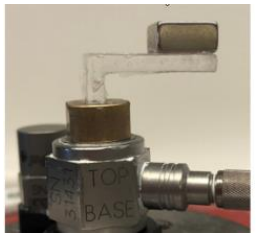
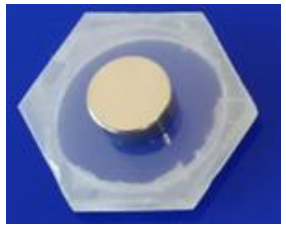


Individual resonators can be made in different geometries and from different materials

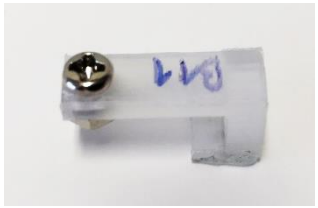
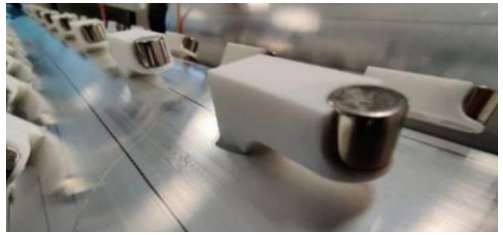


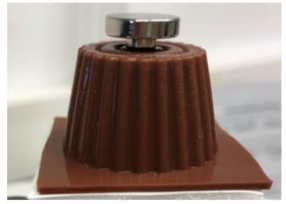
VAMM based on resonance effect

Design of locals resonators (II)

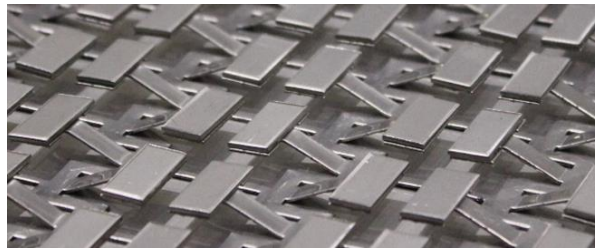








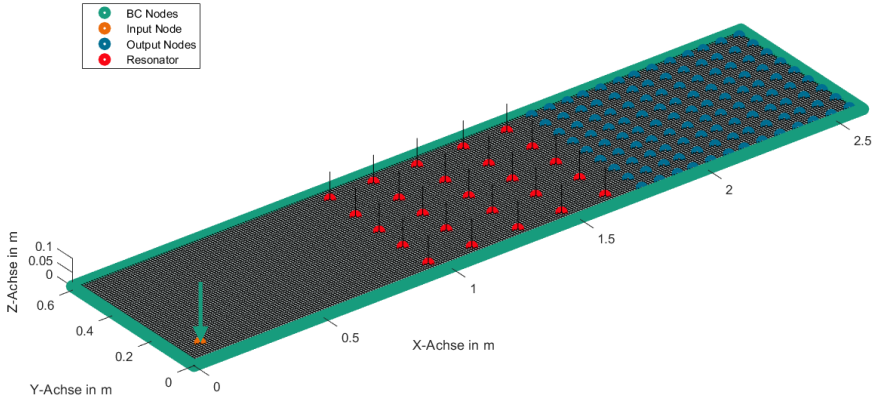


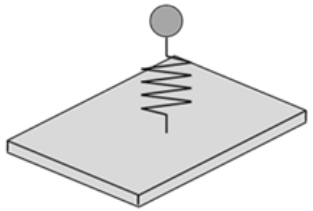
VAMM based on resonance effect

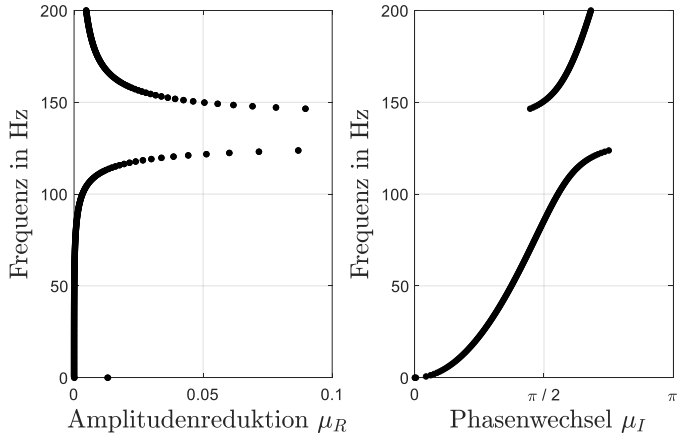
Dynamic effect of a VAMM structure (I)

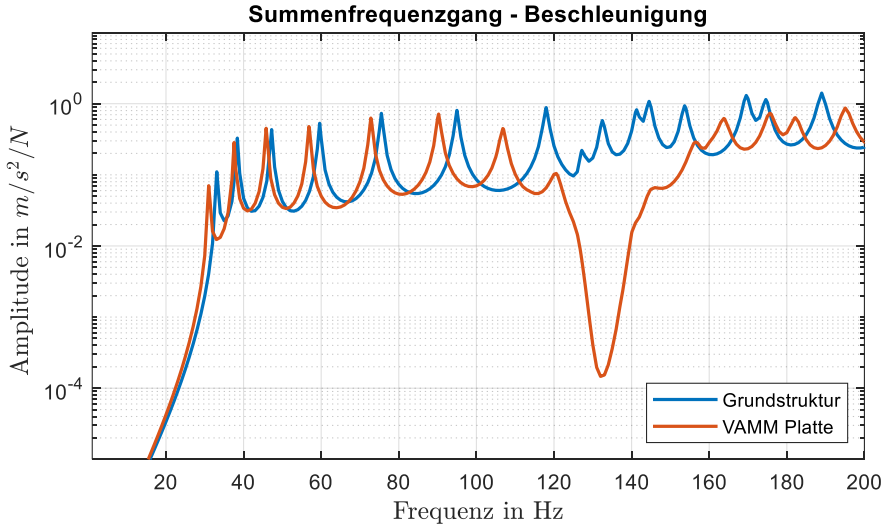
- 5x5 Resonators on plate
  - Resonance frequency: 130 Hz
  - Additional mass: 7 %
  - Damping ratio: 1 %

→ Stop band at approx. 125-150 Hz









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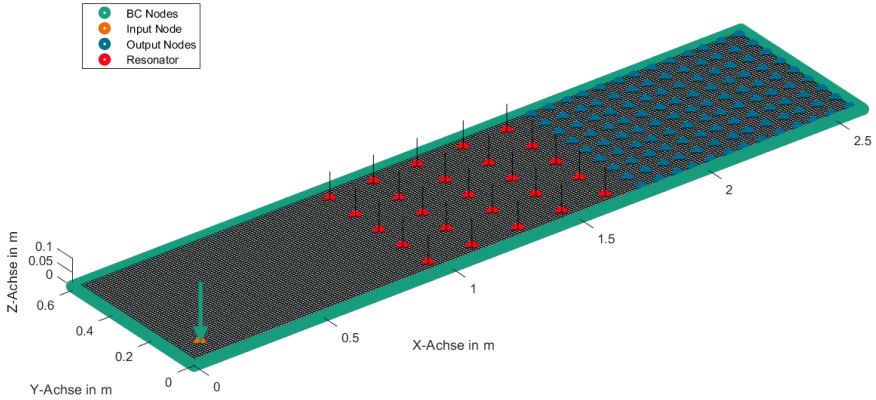
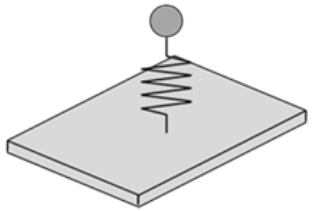
VAMM based on resonance effect

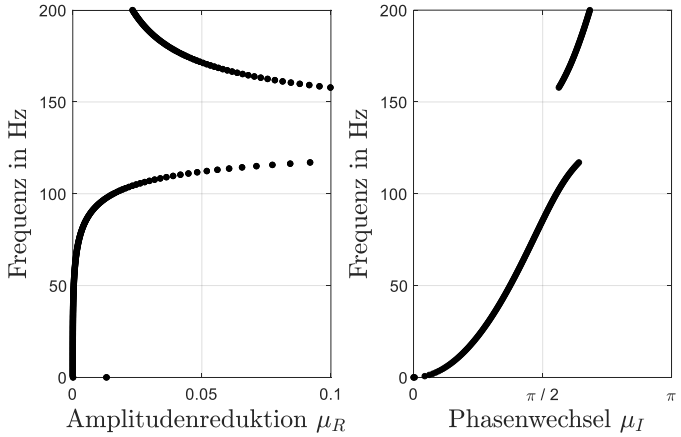
Dynamic effect of a VAMM structure (II)

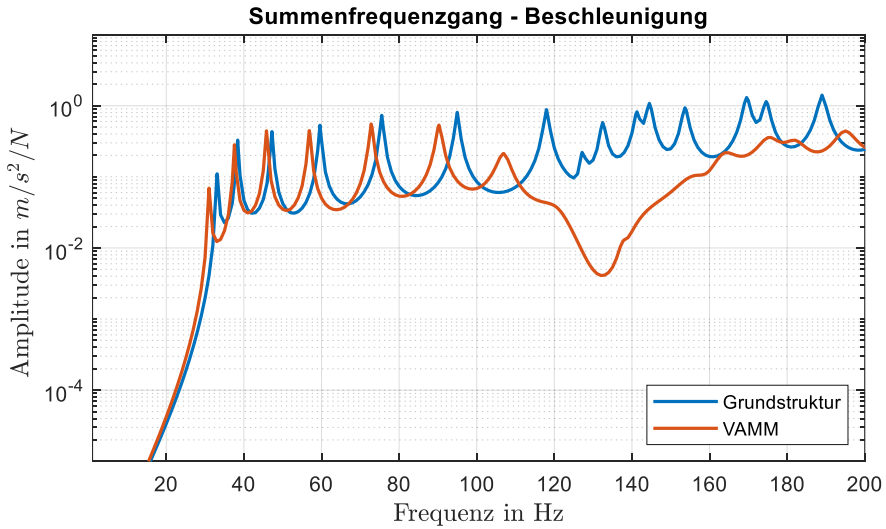
- 5x5 Resonators on plate
  - Resonance frequency: 130 Hz
  - Additional mass: 7 %
  - Damping ratio: 5 %

→ Stop band at approx. 115-160 Hz







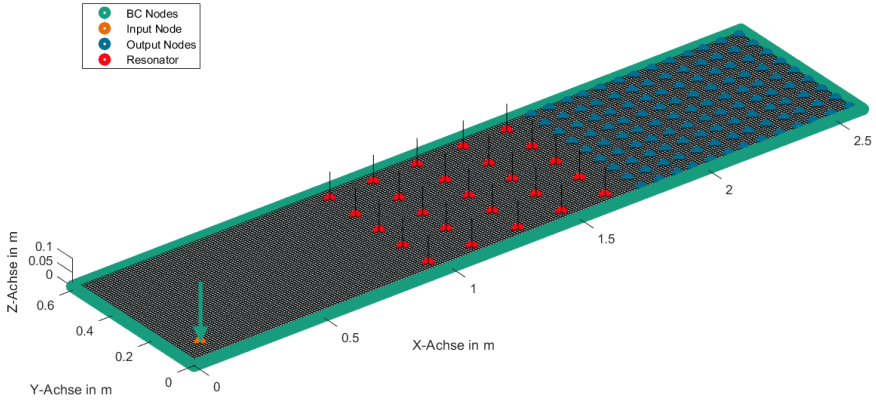


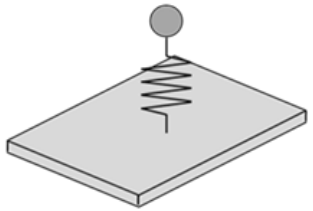
VAMM based on resonance effect

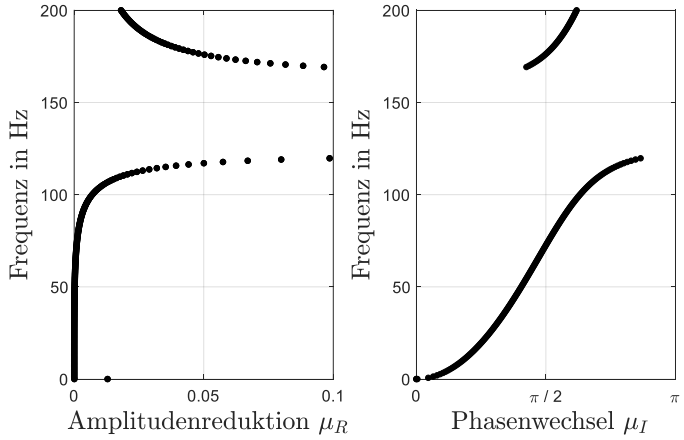
Dynamic effect of a VAMM structure (III)

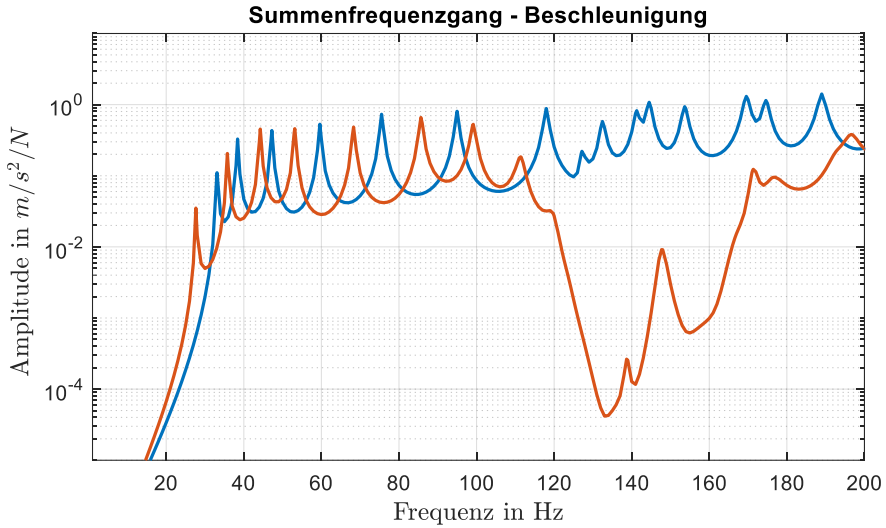
- 5x5 Resonators on plate
  - Resonance frequency: 130 Hz
  - Additional mass: 20 %
  - Damping ratio: 1 %

→ Stop band at approx. 125-150 Hz









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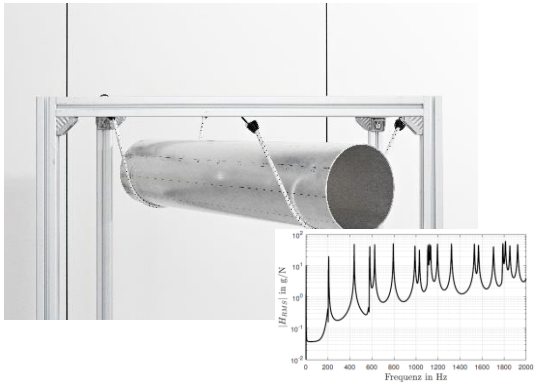
VAMM based on resonance effect

Workflow for design and validation of VAMM

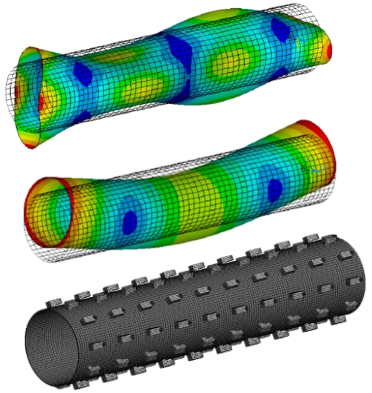
Experimental Investigation / Definition of Problem

- Frequency range of interest?
- Which parts are crucial?



Numerical investigations and design of VAMM parameters

- Design VAMM parameters (resonance frequency, effective mass, damping)
- Evaluation of effectiveness



Conceptual development / experimental Validation of Resonator

- Development of VAMM concept
- Manufacturing and experimental Validation

Testing VAMM in operation

- Validation of VAMM

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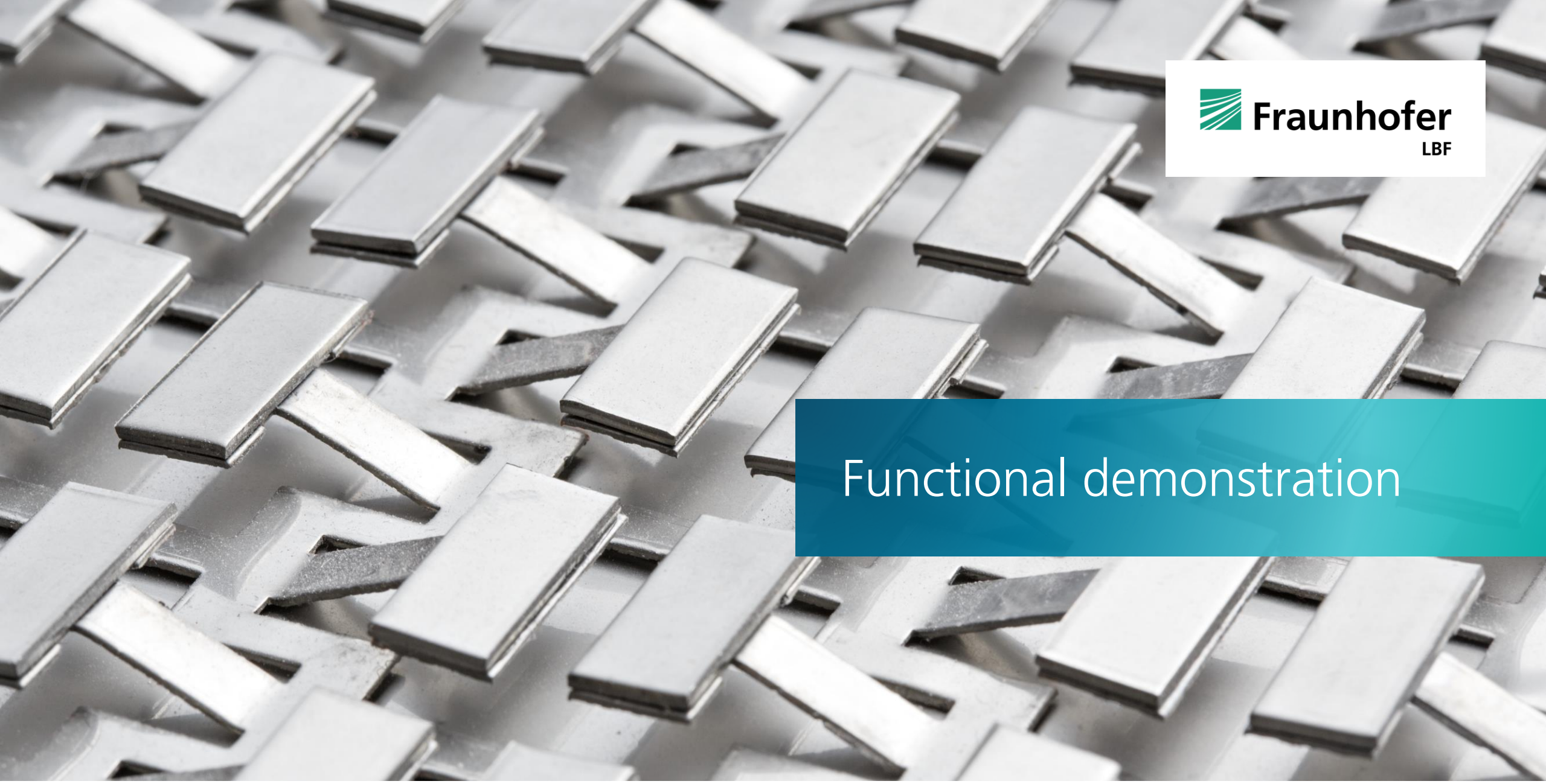
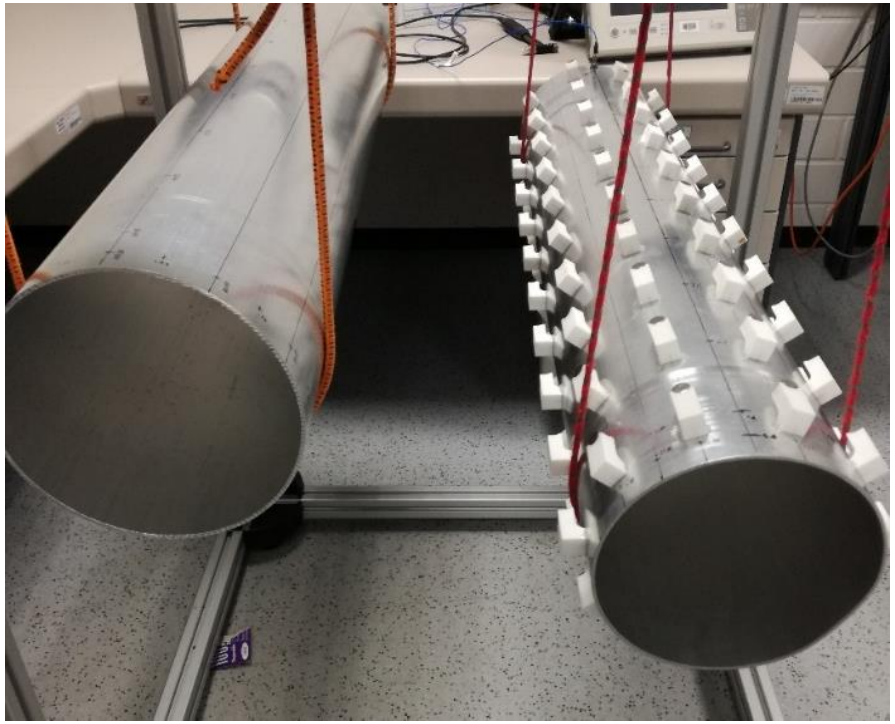


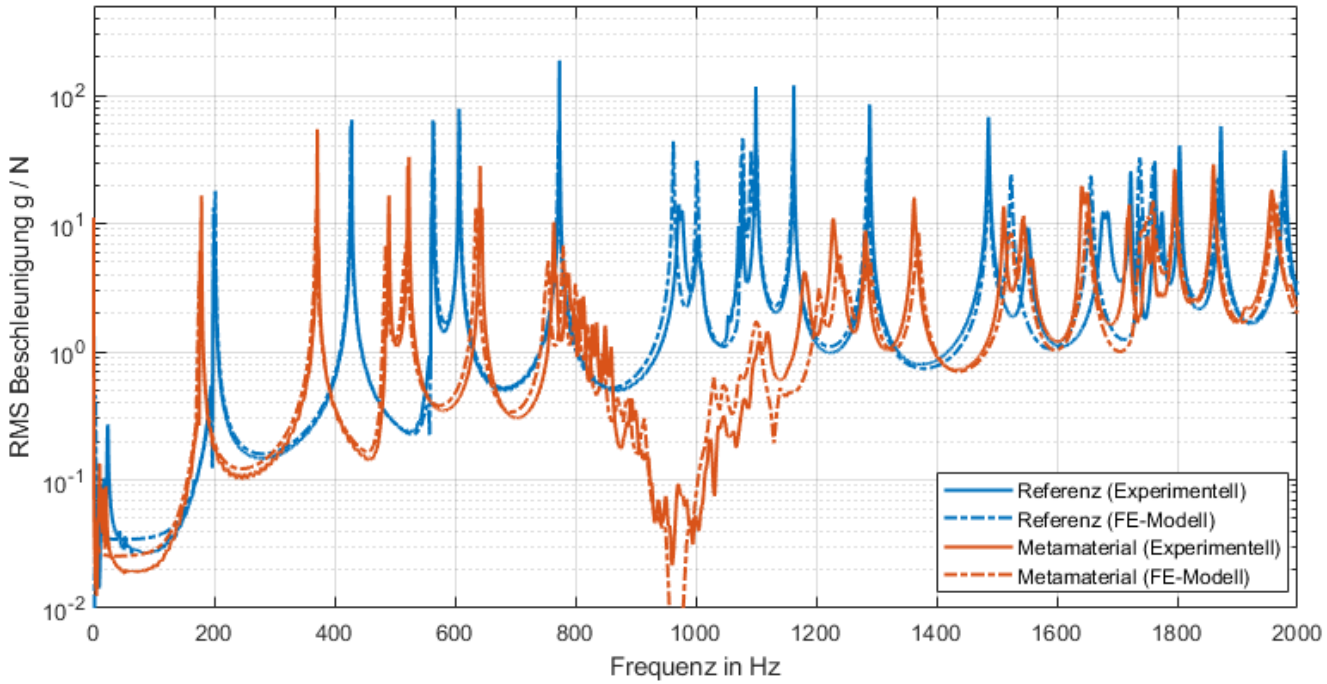
Functional demonstration

VAMM based on resonance effect

Demonstrators: Metalic cylinder

Experimental analysis of final applications: Validation of predicted behavior

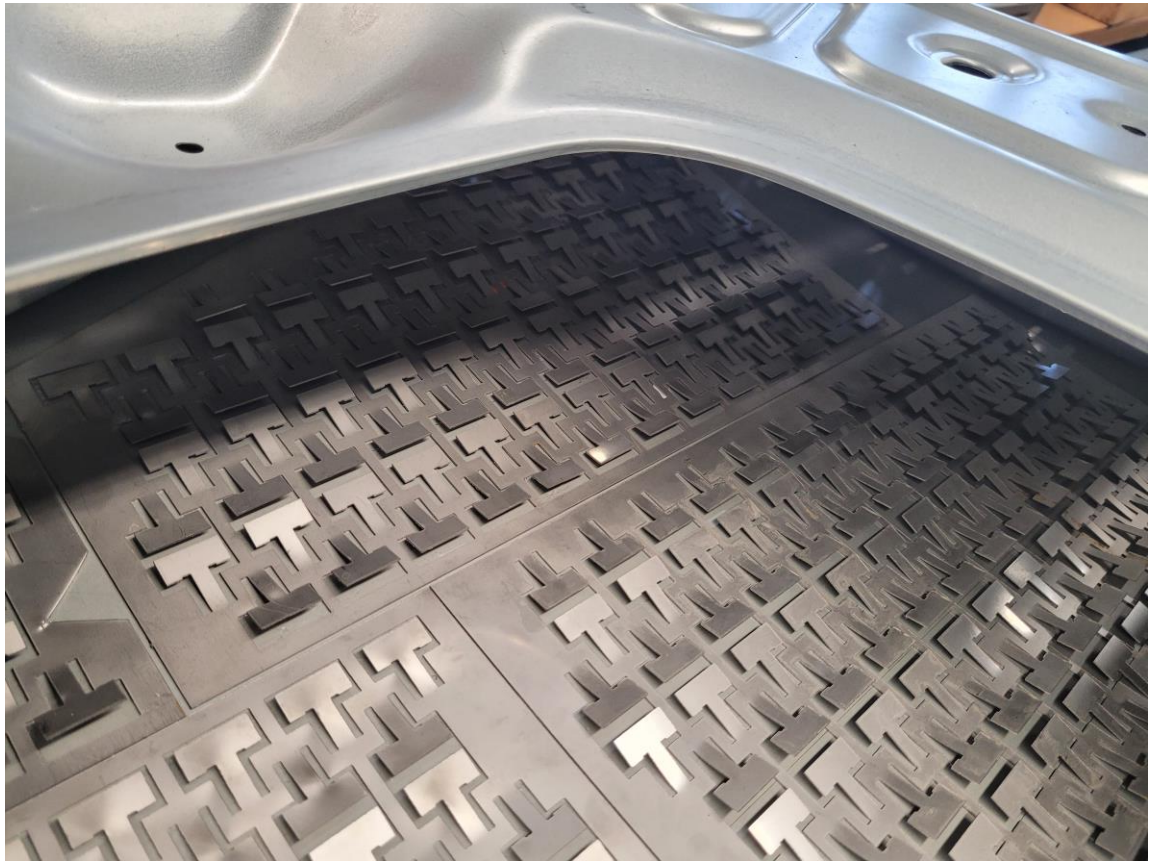




Vibroacoustic metamaterials for structural vibration reduction

Use-Case Vehicle Door: Implementation

Car door with vibroacoustic metamaterials



Compounds of beam-type resonators

Maritime applications

Potential of vibroacoustic metamaterials

Application scenario 1 - Ship structure with stiffeners

Application scenario

Excitation by machine vibrations and structure-borne sound propagation in ship structure

Radiation into air leads to unwanted noise in quiet areas

Reference model and evaluation

Simplified generic ship structure
1.85m x 1.60m x 0.3m (10 mm steel sheets)

Force excitation within the structure

Evaluation of structure-borne sound (sum frequency response) and radiated sound power (LPM)

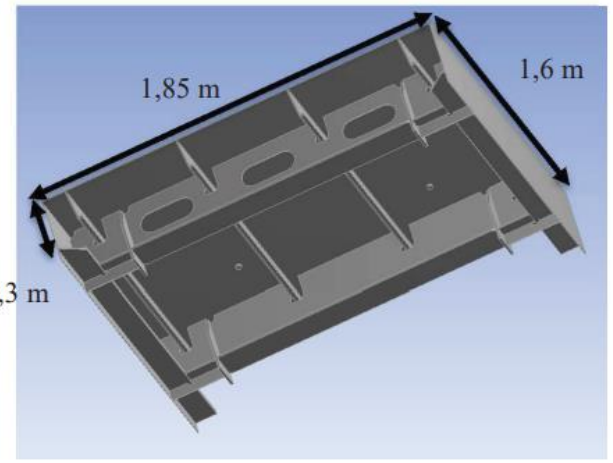
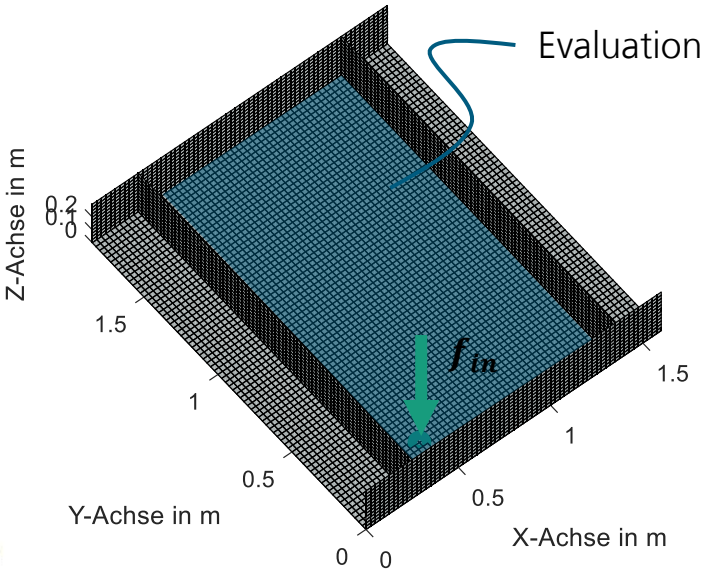
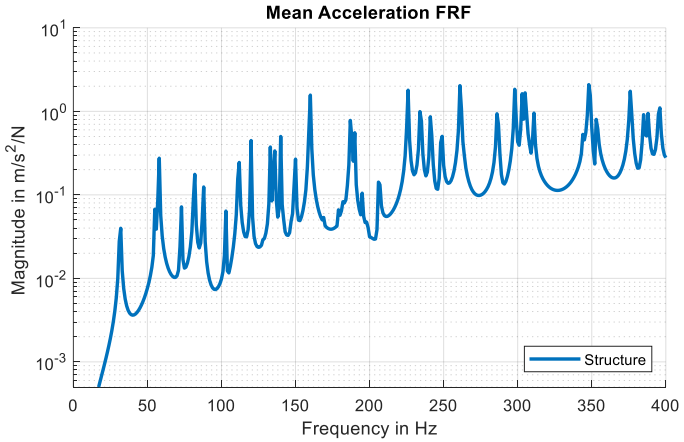
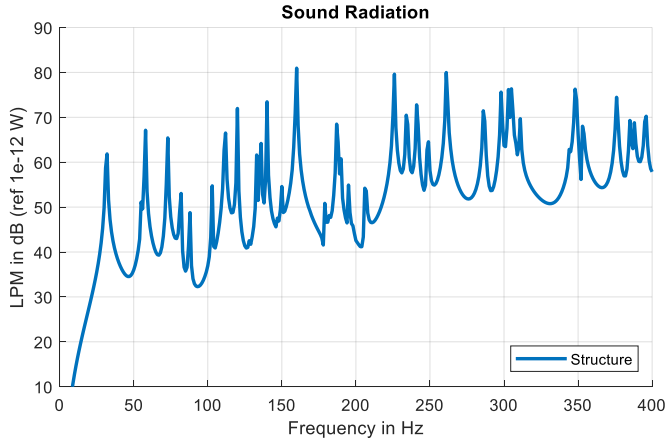


Abbildung 1: Untersuchte Schiffsstruktur, die mit Trägern und Hollandprofilen versteift ist.







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Potential of vibroacoustic metamaterials

Application scenario 1 - Ship structure with stiffeners

Solution - Vibroacoustic metamaterial.

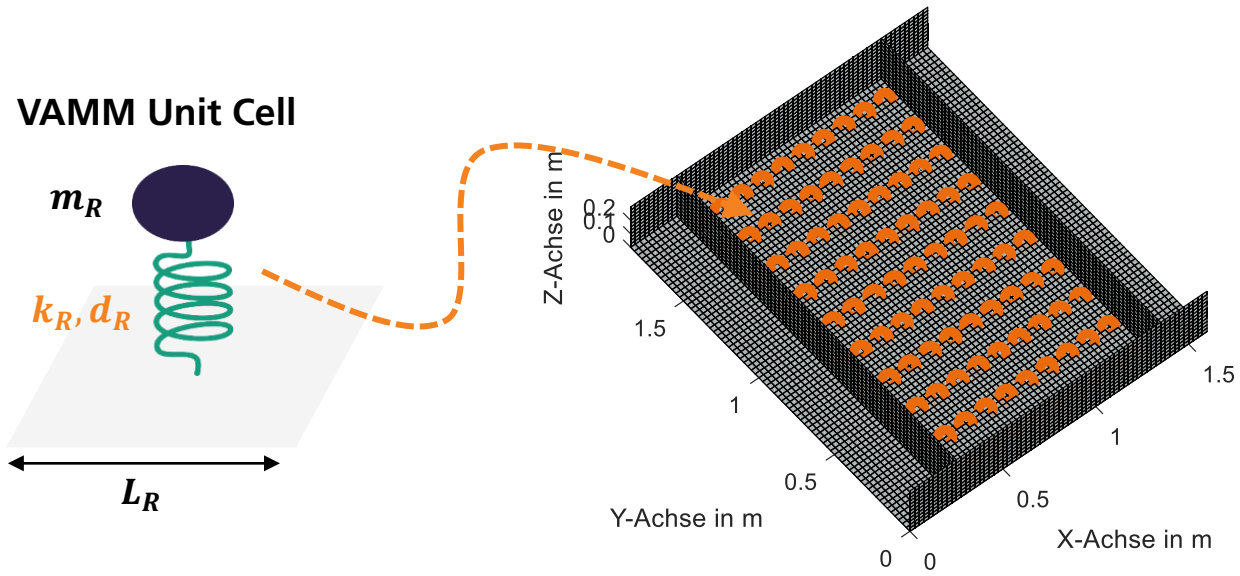
Insertion of discrete resonators to generate an adjustable stop band in the target frequency range

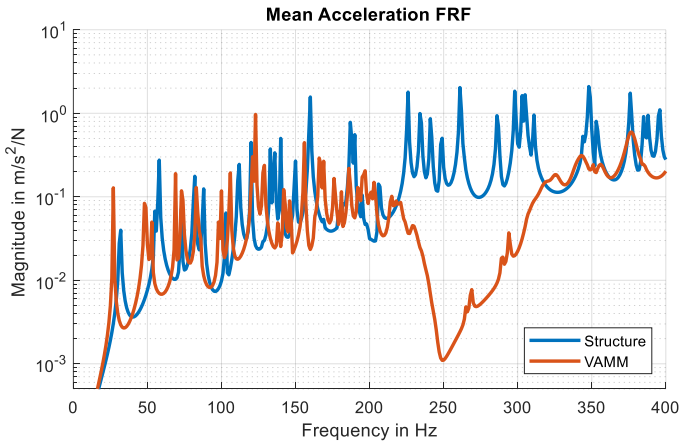
Reduction of structure-borne sound propagation and sound radiation

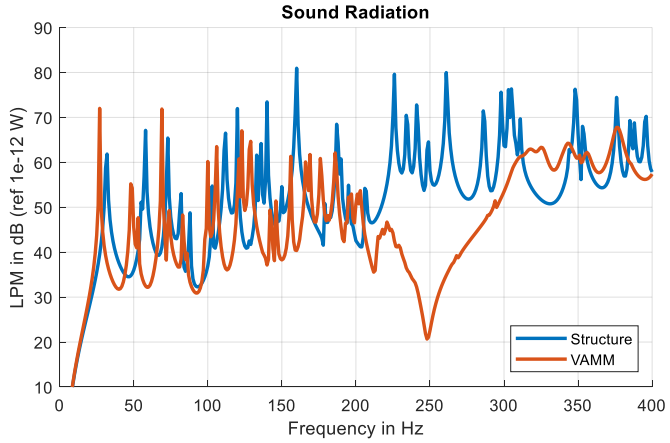
Parameters of the VAMM

Additional mass: 20% (~750 g per resonator)
Resonant frequency: 250 Hz
Damping ratio: 1%
Number of resonators: 10x10
Unit cell size: ~ 150 mm

Stop band: 220 - 320 Hz







Potential of vibroacoustic metamaterials

Application scenario 1 - Ship structure with stiffeners

Solution - Vibroacoustic metamaterial.

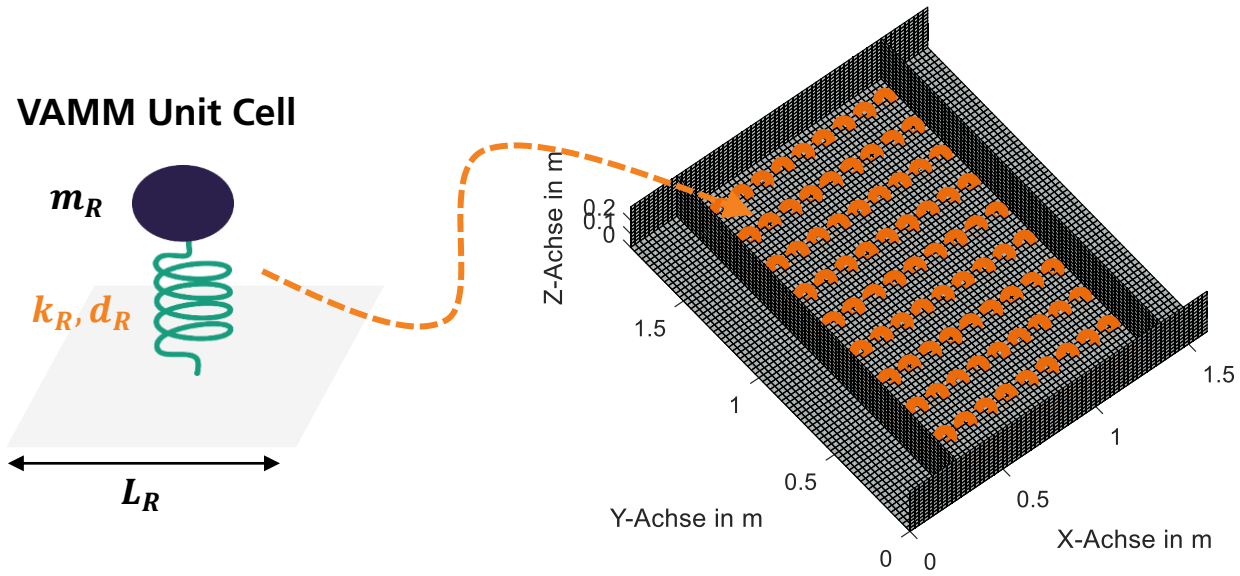
Insertion of discrete resonators to generate an adjustable stop band in the target frequency range

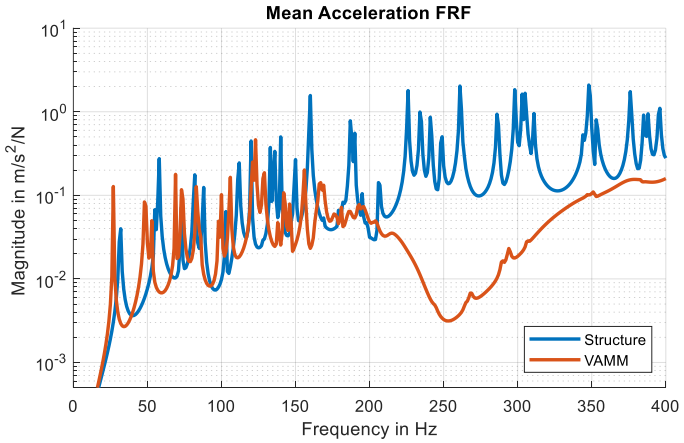
Reduction of structure-borne sound propagation and sound radiation

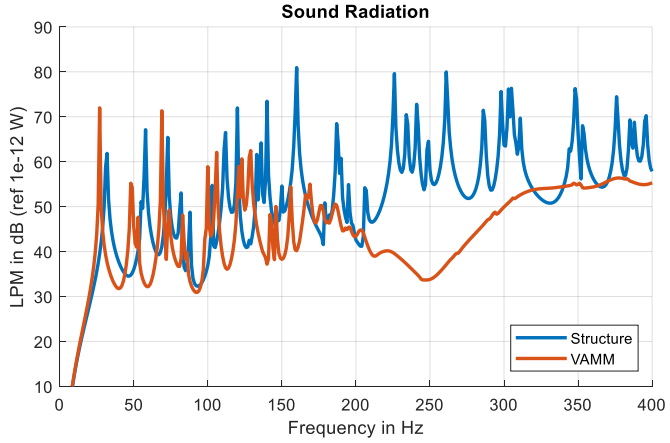
Parameters of the VAMM

Additional mass: 20% (~750 g per resonator)
Resonant frequency: 250 Hz
Damping ratio: **5%**
Number of resonators: 10x10
Unit cell size: ~ 150 mm

Stop band: 220 - 320 Hz







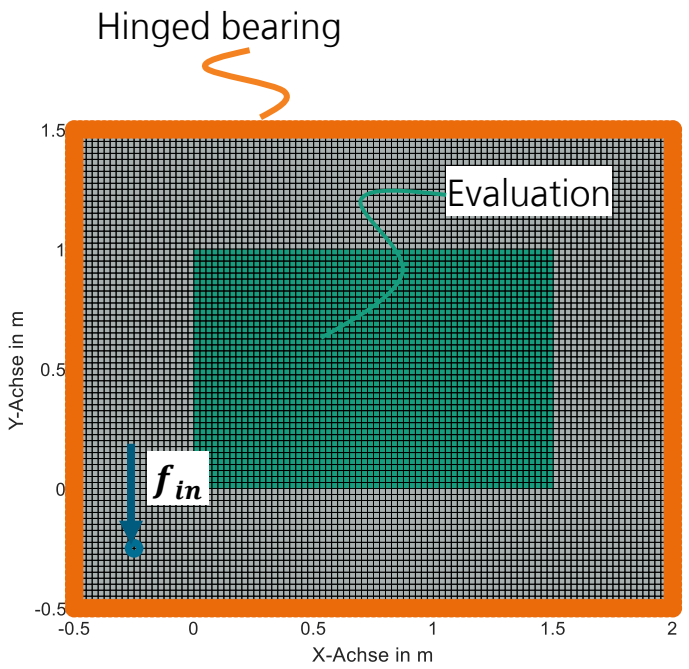
Potential of vibroacoustic metamaterials

Application scenario 2 - Sound radiation window

Application scenario

Vibration excitation of windows due to structure-borne sound propagation in ship structure

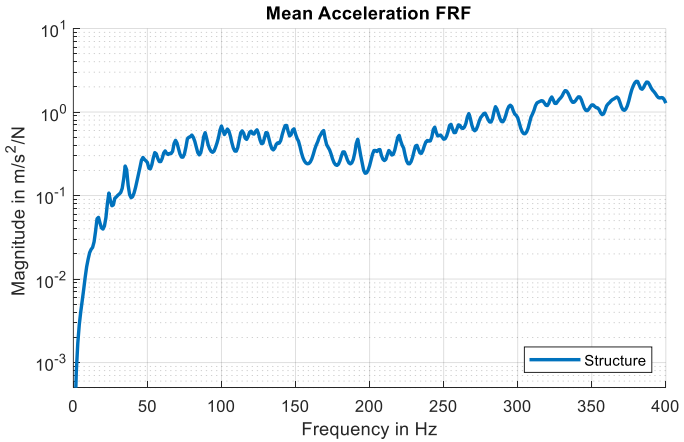
Sound radiation from windows leads to unwanted noise in quiet areas

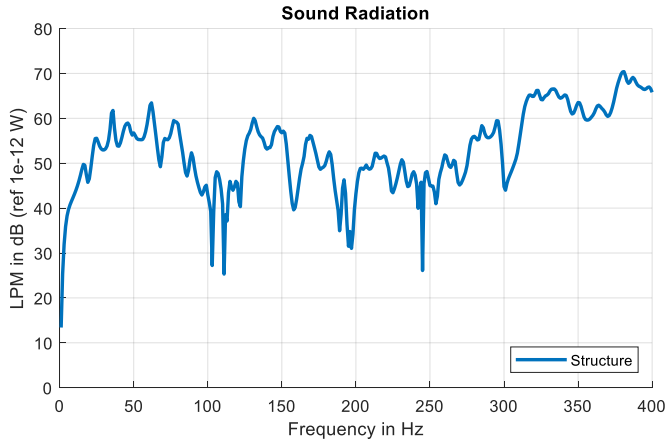


Reference model and evaluation

Window (1.5m x 1m, 10 mm acrylic glass) integrated into steel frame (0.5 m wide, 4 mm thick), hinged, Force excitation within the steel frame

Evaluation of the structure-borne sound (sum frequency response) and the radiated sound power (LPM) of the window





Potential of vibroacoustic metamaterials

Application scenario 2 - Sound radiation window

Solution - Vibroacoustic metamaterial.

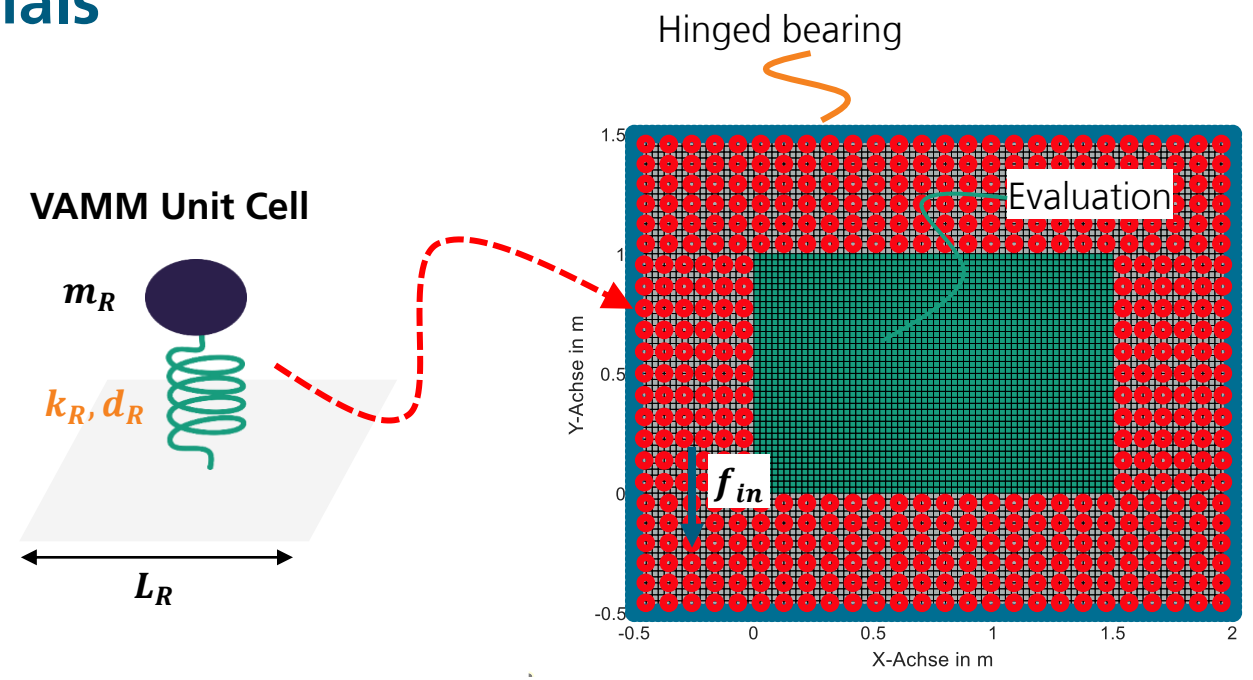
Insertion of discrete resonators into steel frames to create an adjustable stop band

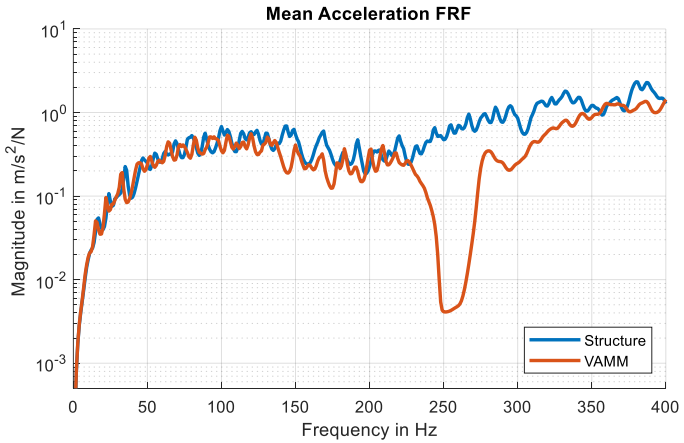
Reduction of structure-borne sound propagation and sound radiation

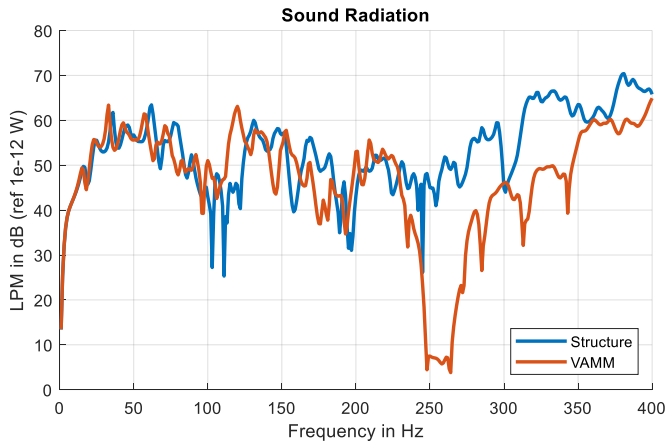
Parameters of the VAMM

Additional mass: 20% (~50 g per resonator)
Resonant frequency: 250 Hz
Damping ratio: 1%
Number of resonators: ~ 400
Unit cell size: ~ 100 mm

Stop band: 230 -300 Hz





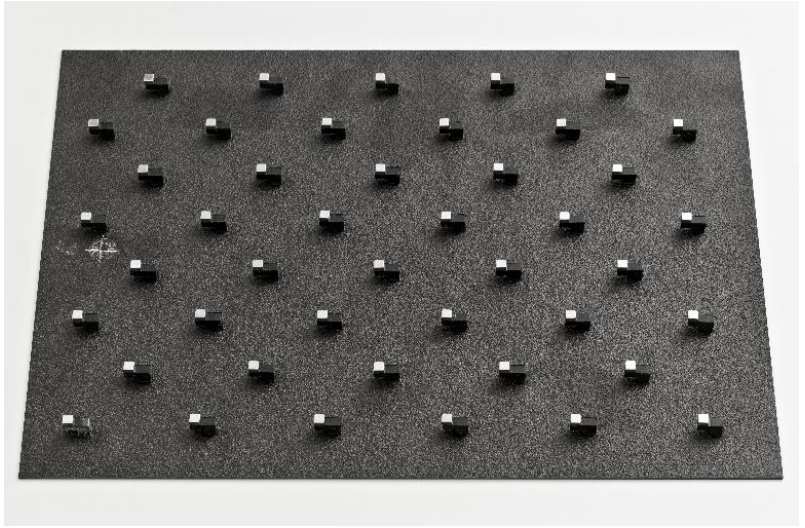


VAMM based on resonance effect

Conclusions

- Innovative technology for vibration and noise reduction
- Application in machine and plant construction as well as in the automotive industry

- Pros:
  - Broadband effect
  - Stronger attenuation compared to conventional measures
  - High lightweight potential
  - Flexible design and integration
  - Suitable for large and thin structures



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