ISD
INSTITUT FÜR STATIK UND DYNAMIK

MIREMAR 2010

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Bubble curtains as a protective measure for marine mammals in theory and practise

Overview
Research on bubble curtains

Research on bubble curtains at ISD

- Research objectives
- Theoretical aspects
- Practical aspects
- Application – comparison of concepts
- Comparison of two applications: FINO3, Alpha Ventus
- Further approach and next steps

Research objectives

- Bubble curtain with optimized physical efficiency
- Cost-efficient bubble curtain
- Applicable bubble curtain not disturbing the installation process
- Bubble Curtain with isotropic reduction effect

Theoretical aspects (1)

Backscattering length of a single gas bubble

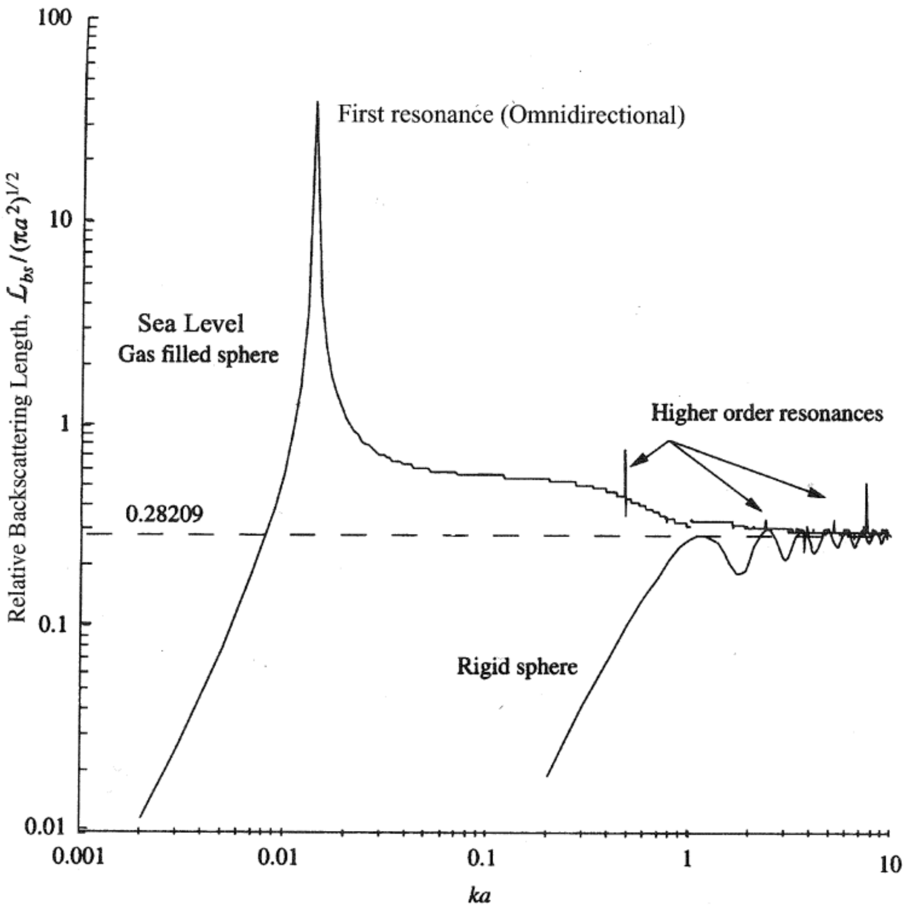
Assumptions:

- spherical gas bubble
- sea-level gas bubble
  → major resonance at

  $$ka = 0.0136$$

- if $ka << 1$

  → **omnidirectional scatter,**
  (radius a is small compared to acoustic wavelength λ)



Relative backscattering length of an air bubble at sea level compared with that of a rigid sphere as a function of *ka* (*Source: MEDWIN 2005: Sounds in the Sea*)

- with:

k:	*wave number*
a:	*bubble radius*

Theoretical aspects (2)

Acoustical cross-sections

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Scattering cross-section:

$$\sigma_s(f) = \frac{4\pi a^2}{\left(\frac{f_R^{\,2}}{f^2} - 1\right)^2 + \delta^2(f)}$$

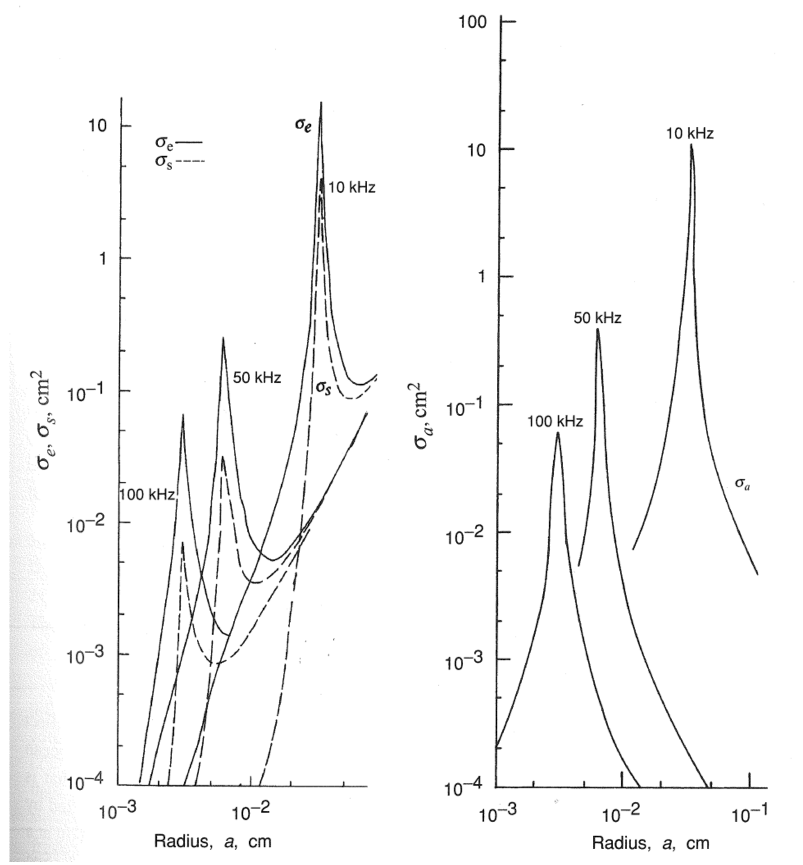
Extinction cross-section:

$$\sigma_e(f) = \frac{4\pi a^2 \left(\frac{\delta}{\delta_r}\right)}{\left(\frac{f_R^{\,2}}{f^2} - 1\right)^2 + \delta^2(f)}$$

Absorption cross-section:

$$\sigma_a(f) = \frac{4\pi a^2 \left(\frac{\delta_t + \delta_v}{\delta_r}\right)}{\left(\frac{f_R^{\,2}}{f^2} - 1\right)^2 + \delta^2(f)}$$

$$\frac{\sigma_a}{\sigma_s} = \frac{\delta_t + \delta_v}{\delta_r} \qquad \frac{\sigma_e}{\sigma_s} = \frac{\delta}{\delta_r}$$



Left: Extinction (solid line) and scattering (dashed line) cross-sections of small sea-level air bubbles insonified by 10, 50 or 100 kHz plane waves. *Right:* absorption cross-sections for the same parameters (*Source: MEDWIN 2005: Sounds in the Sea*)

Theoretical aspects (3)

Acoustical scattering cross-section, influence of damping

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Natural frequency of single bubble in water:

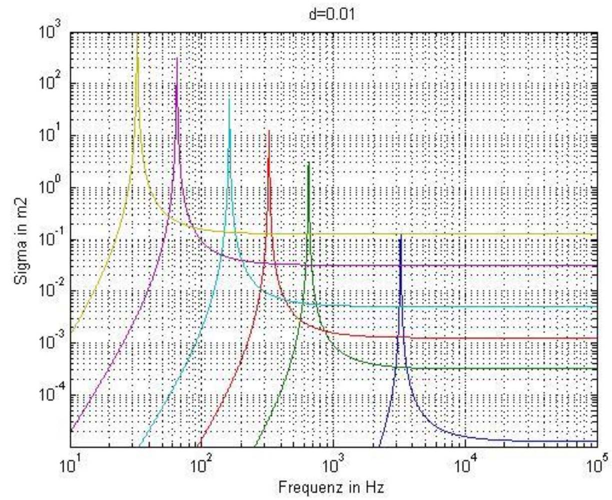
$$f_R = \frac{1}{2\pi a}\left(\frac{3\gamma P}{\rho}\right)^{\frac{1}{2}}$$

Ratio of acoustical scattering cross section to geometrical cross section :

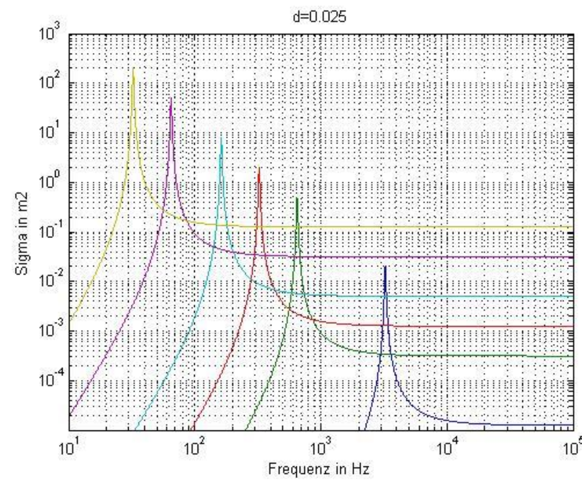
$$\frac{\sigma_s}{\sigma_{geo}} = \frac{1}{\left(\frac{f_R^{\ 2}}{f^2} - 1\right)^2 + \delta^2}$$

Ratio of acoustical scattering cross section to geometrical cross section at resonance:

$$\frac{\sigma_s}{\sigma_{geo}} = \frac{1}{\delta^2}$$



Acoustical scattering cross section at resonance (different bubble sizes, d = 0.01))



Acoustical scattering cross section at resonance (different bubble sizes, d = 0.025))

Theoretical aspects (4)

Definition of sound pressure levels

- SPL in dB:

$$L = 20 \log \left(p_{rms} / p_0 \right)$$

- *Sound exposure level (SEL) in dB:*

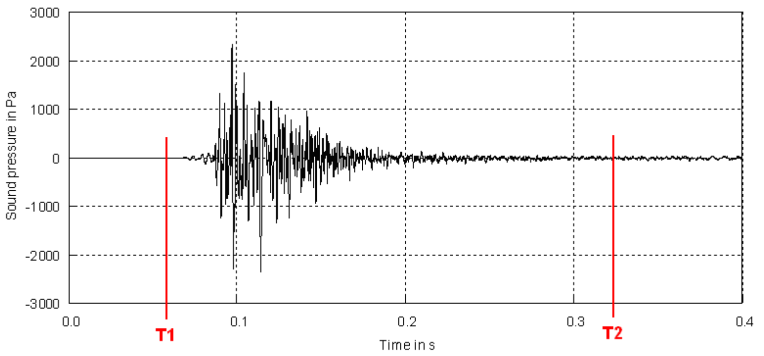
$$L_E = 10 \log \left(\frac{1}{T_0} \int_{T_1}^{T_2} \frac{p(t)^2}{p_0^2} dt \right)$$

- Maximum level L_{peak} *in dB:*

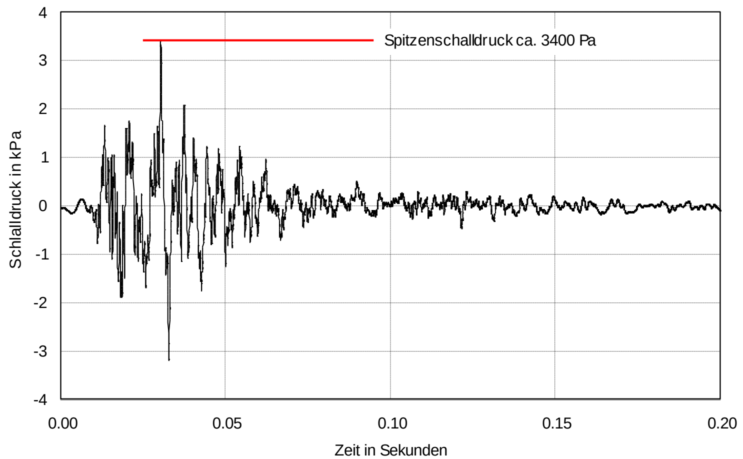
$$L_{peak} = 20 \log \left(\left| p_{peak} \right| / p_0 \right)$$

Reference pressure for water: $p_0 = 10^{-6}$ *Pa*

→ e.g. 180 dB re1µPa



Evaluation of L_E

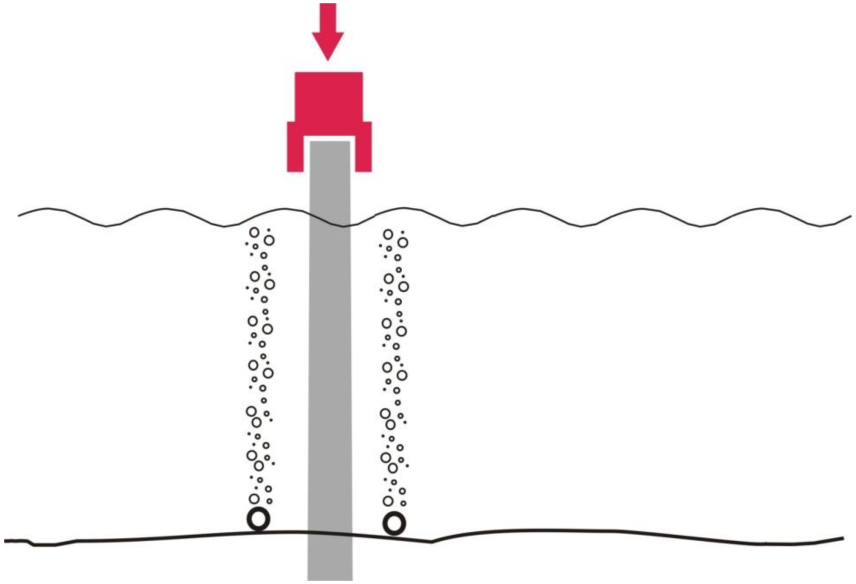


Evaluation of L_{Peak}

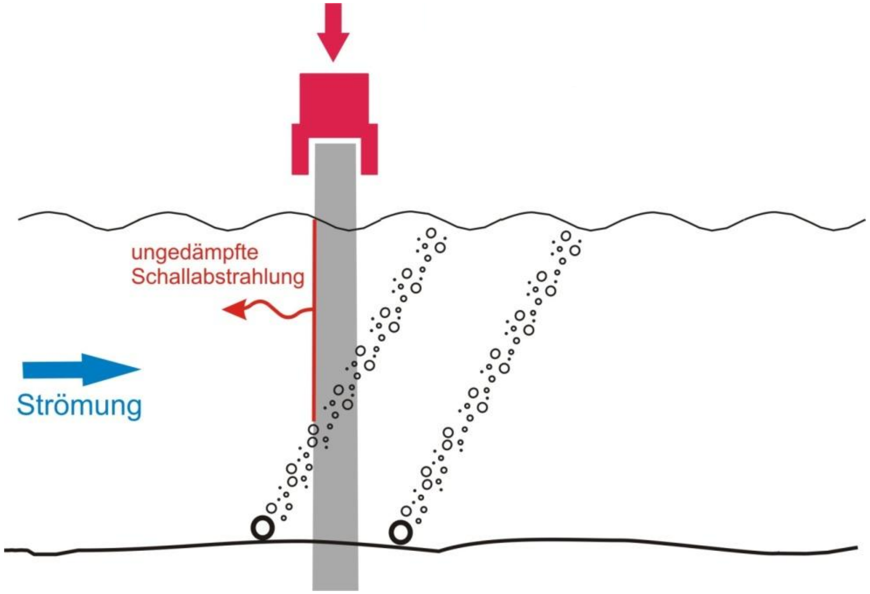
(Quelle: Elmer, K.-H. , Betke, K. , Neumann, T. : *Standardverfahren zur Ermittlung und Bewertung der Belastung der Meeresumwelt durch die Schallimmission von Offshore-Windenergieanlagen – „Schall II"*)

Practical aspects (1)

Bubble Curtain close to the pile



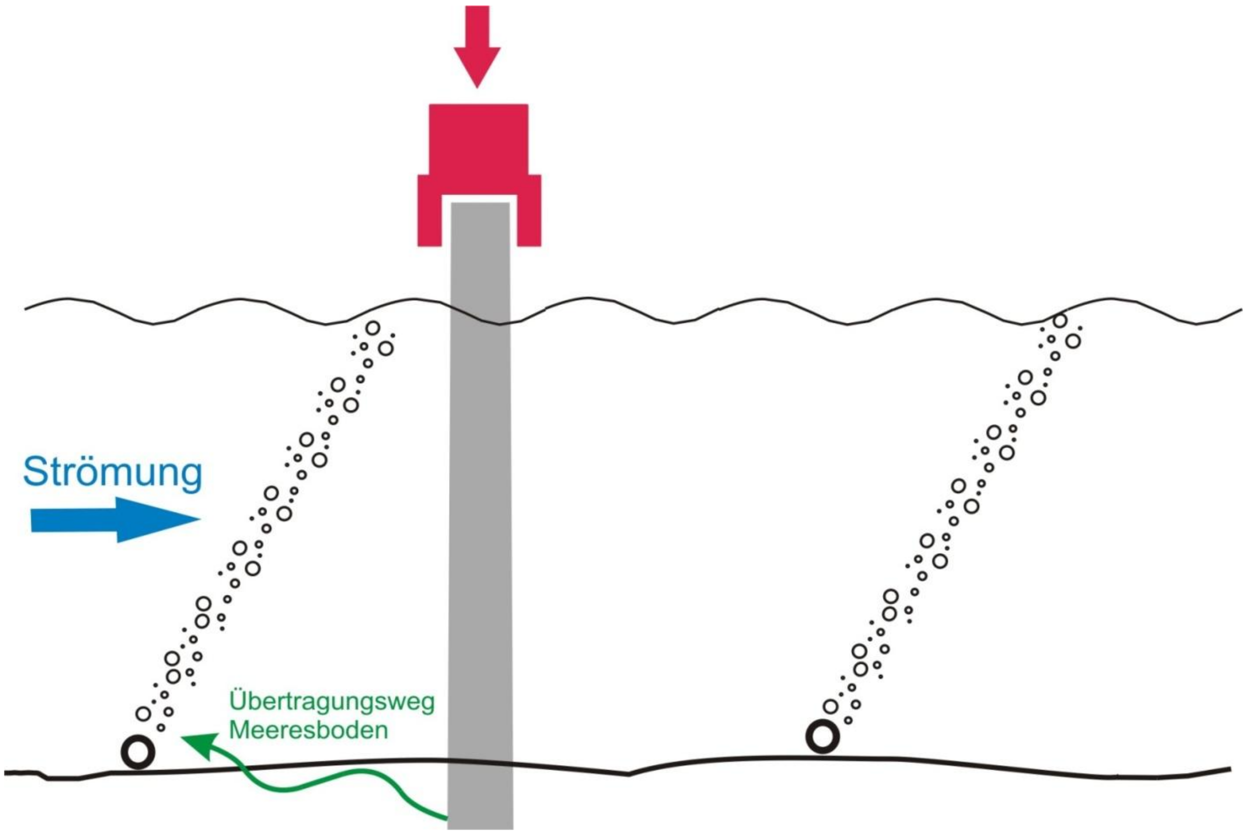
Bubble Curtain at turn of tide



Bubble Curtain subjected to sea current

Practical aspects (2)

Bubble Curtain at bigger distance from the pile (Example: FINO3)



Bubble Curtain subjected to sea current

Practical aspects (3)

Layered Bubble curtain (Example: Alpha Ventus)

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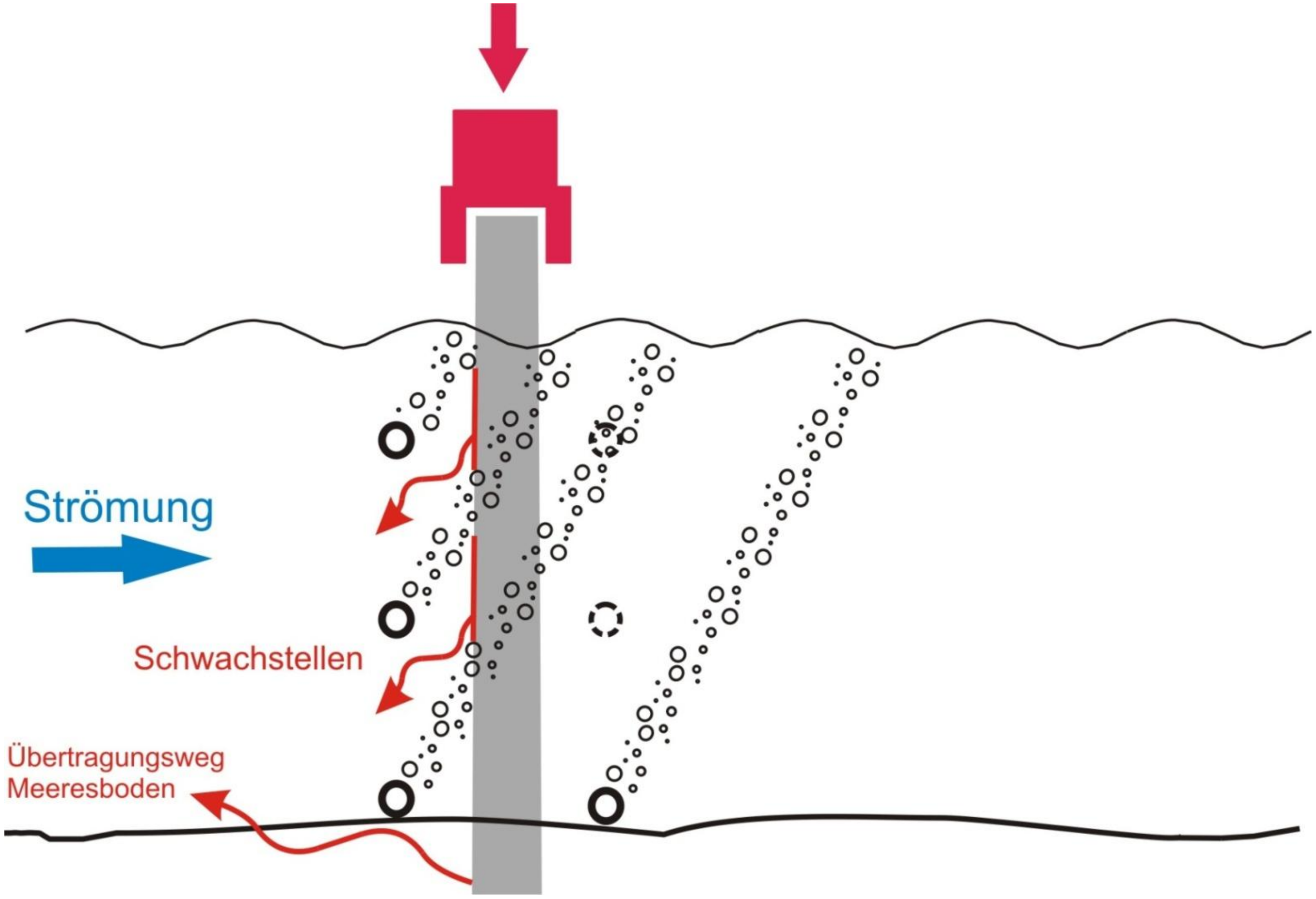

Bubble Curtain subjected to sea current

Research on and testing of a layered bubble curtain at alpha ventus

Project goals

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- Conceptional design and development of a layered bubble curtain close to the foundation of an offshore wind turbine of type Multibrid
- Testing and subsequent evaluation of the bubble curtain under offshore conditions and under the requirements of pile driving procedures
- Assessment of the tides‘s influence on the noise mitigation efficiency regarding the bubble curtain in progress
- Investigation of the influence of ram energy on the noise mitigation efficiency for the bubble curtain in progress

Gefördert durch:
Projektträger Jülich Forschungszentrum Jülich
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
aufgrund eines Beschlusses des Deutschen Bundestages

Research on and testing of a layered bubble curtain at alpha ventus

Project partners

Associated partners:

- Institute of Structural Analysis, Hannover (coordination)
- MENCK GmbH, Kaltenkirchen

Research partners:

- Deutsches Windenergie-Institut GmbH (DEWI), Wilhelmshaven
- Institut für technische und angewandte Physik GmbH (itap), Oldenburg

Industrial partners:

- Hydrotechnik Lübeck GmbH, Lübeck
- Prokon Nord Energiesysteme GmbH, Leer
- Prokon Nord Offshore Installations GmbH, Leer
- Karl Wrede Stahl- und Maschinenbau GmbH, Eddelak
- Bode und Wrede GmbH, Itzehoe

Research on and testing of a layered bubble curtain at alpha ventus

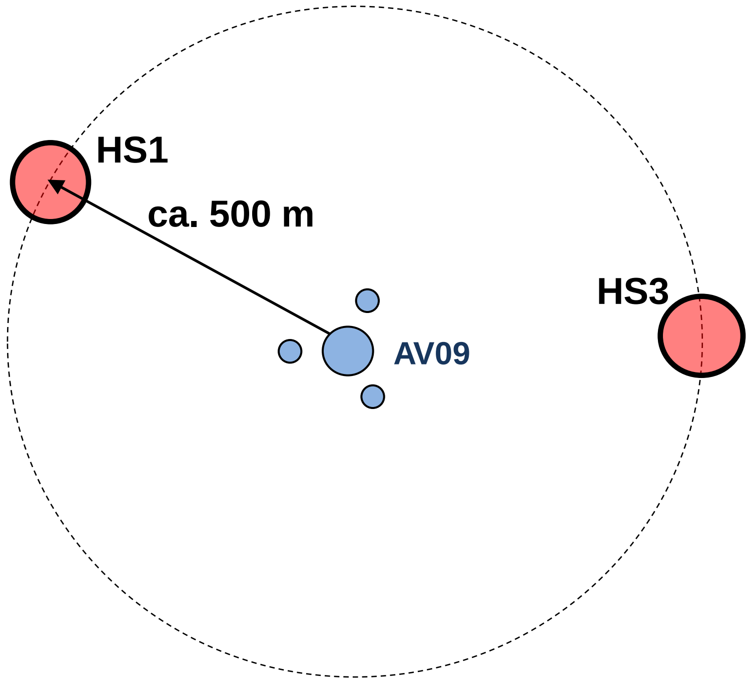
Systems of lower and upper part (Eemshaven)

AV09 in testfield alpha ventus with pre-installed lower part of tube system, designed by MENCK

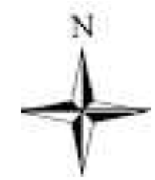
….and the upper tube system including uplift bodies, which couldn‘t be put into use, designed by Hydrotechnik Lübeck and MENCK

Source: Hydrotechnik Lübeck


ISD, itap – Arne Tiselius



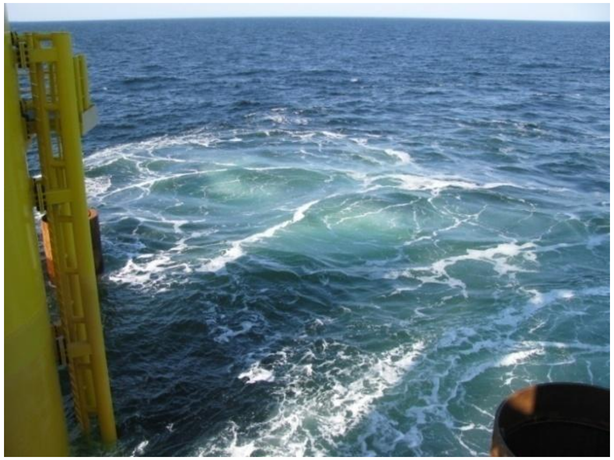

DEWI – Baltic Taucher 2



Research on and testing of a layered bubble curtain at alpha ventus

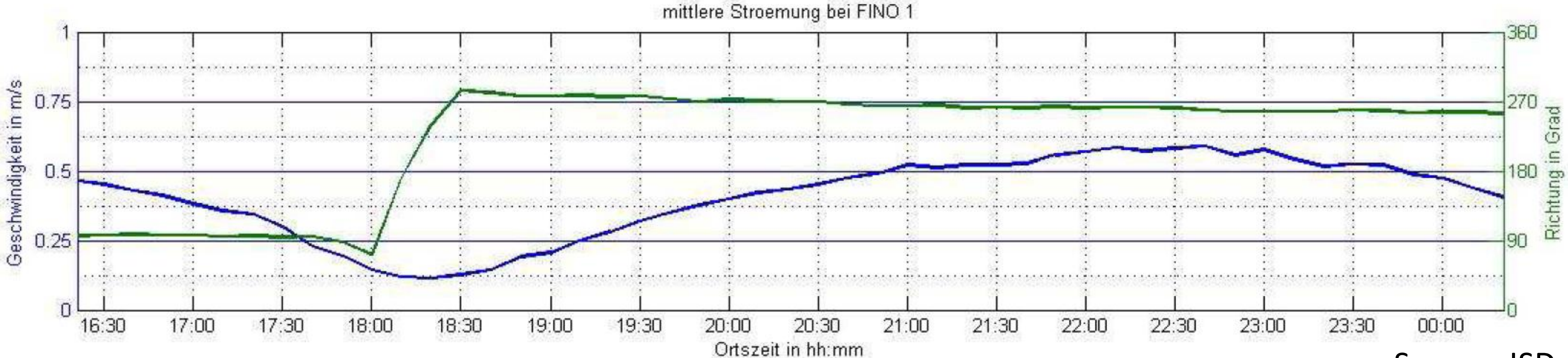
Influence of tide

16:43 p.m., flow direction: east

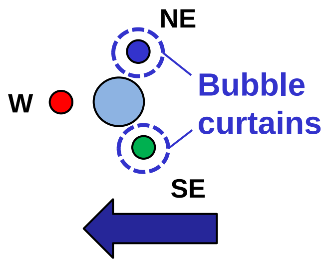


17:27 p.m., flow direction: east

18:18 p.m., turn of tide



Source: ISD



		Sound pressure level L_{peak} (SEL) in dB re1µPa		Reduction ΔL_{peak} (ΔL_E)
		21:20 p.m. (bubble curtain **off**)	21:25 p.m. (bubble curtain **on**)	
measurement - distance 500 m	west (LEE)	195 (172)	181 (160)	14 (12)
	east (LUV)	196 (173)	196 (172)	0 (1)
Calculation - distance 750 m	west (LEE)	192 (169)	**178 (157)**	**14 (12)**
	east (LUV)	193 (170)	**193 (169)**	**0 (1)**

Research on and testing of a layered bubble curtain at alpha ventus

Results of frequency domain

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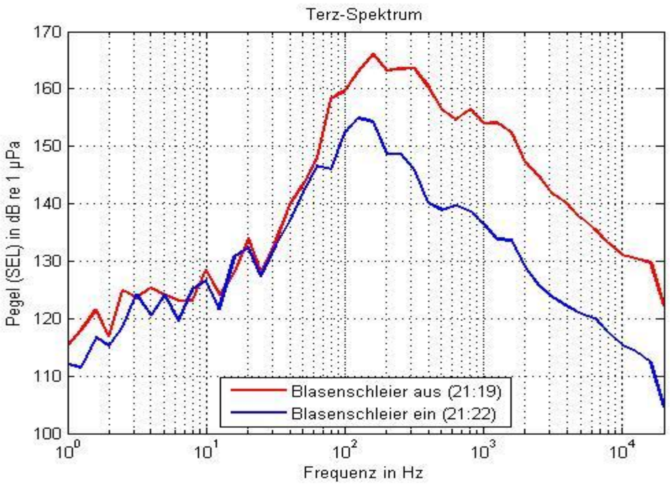
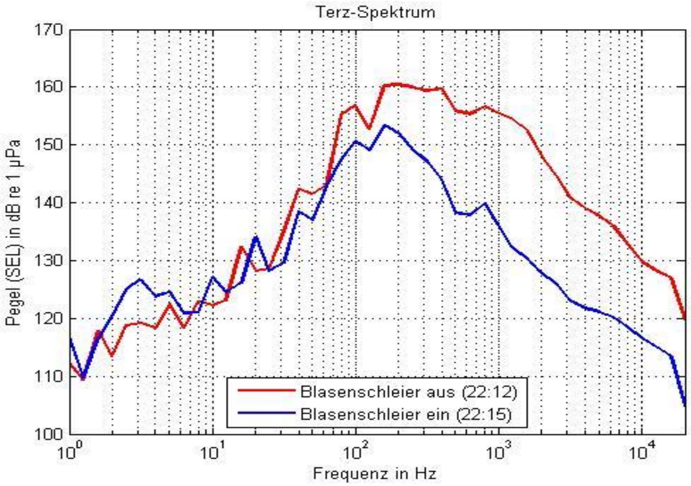
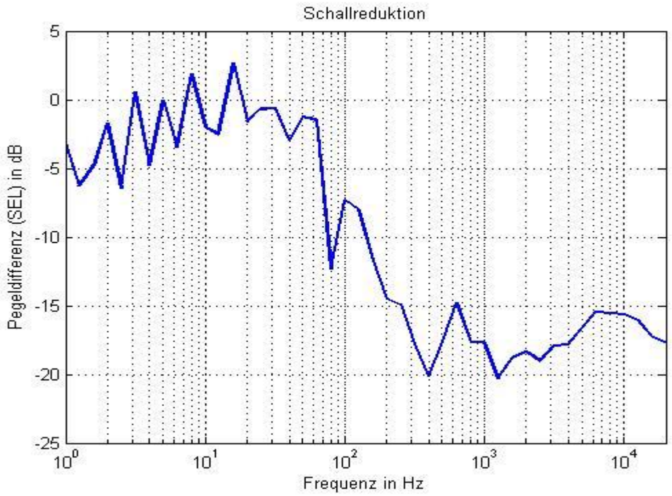
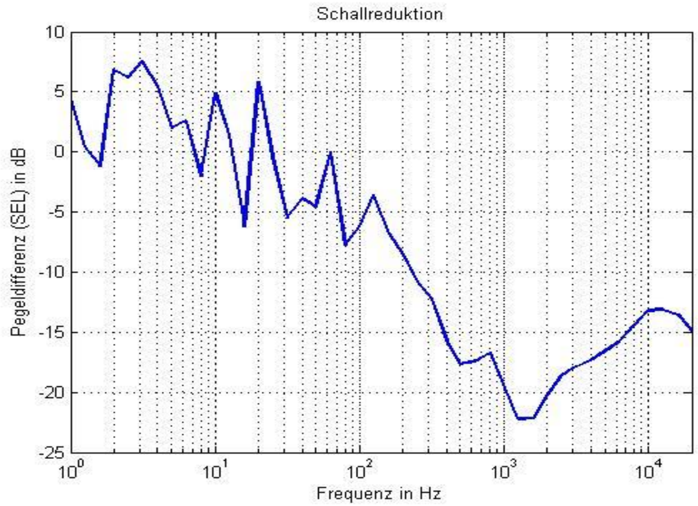


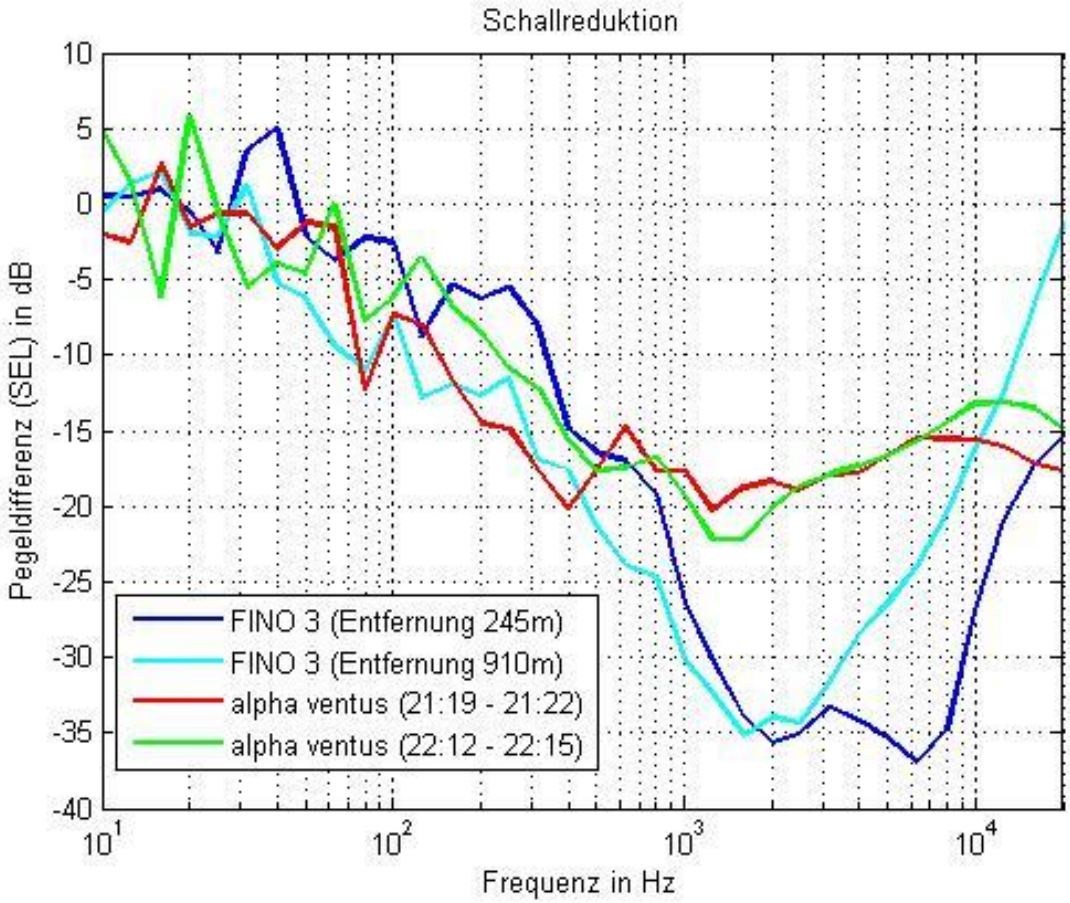


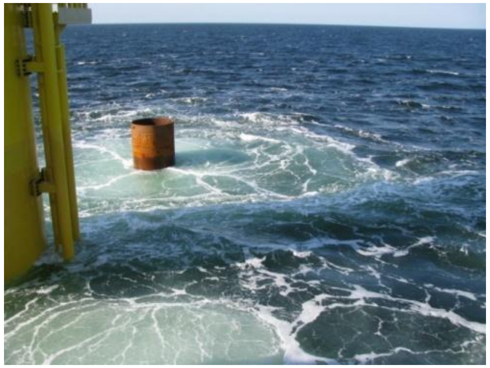




- Good results (12 dB for SEL, 14 dB for L_{Peak}) within a spatial sector changing due to tide
- Frequency range: best effect for f > 300 Hz
- But: at the same time in the opposite sector: no effect!
- Little bubble curtain: concept tested at alpha ventus needs to be improved and further developed for practical use

Comparison
LBC (Alpha Ventus) – BBC (FINO3)
Results: frequency range





LBC: best effect for

f > 300 Hz

BBC: best effect for

1 kHz < f < 3 kHz

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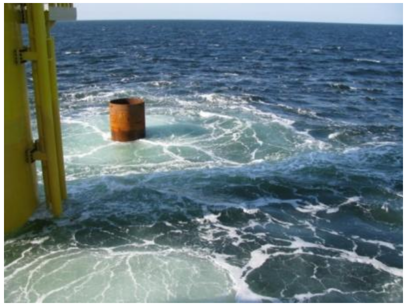
Little Bubble Curtain (Alpha Ventus) <u>and</u> Big Bubble Curtain (FINO3)

- Good reduction (12 dB for SEL, 14 dB for L_{peak}) possible

Little Bubble Curtain (Alpha Ventus):



- mitigation effect is limited to a spatial sector

Big Bubble Curtain (FINO3):

- mitigation effect availabe in all directions

Further approach and next steps at ISD

- Focus lies on the **Big Bubble Curtain - main reasons:**

  - isotropic mitigation effect in all directions
  - no disturbance of installation procedures
  - best developed concept so far

- **Until 7/2011: optimization of physical efficiency**
  - to reach this goal: tests in large tanks (l = 80, l = 300 m) are planned
  - identification of optimum compressed air flow, suitable material for the tubes, better understanding of physical effects in detail

- **From 7/2011 to 4/2012: optimization of cost-efficiency**
  (remember: the FINO3-application was too expensive)

- **Summer 2012**: application of optimized concept during the installation of an OWP


Thank you.