MARITIME TECHNOLOGY

A NEW APPROACH TO SPRING/DAMPER SYSTEMS IN SUSPENSION SEATS

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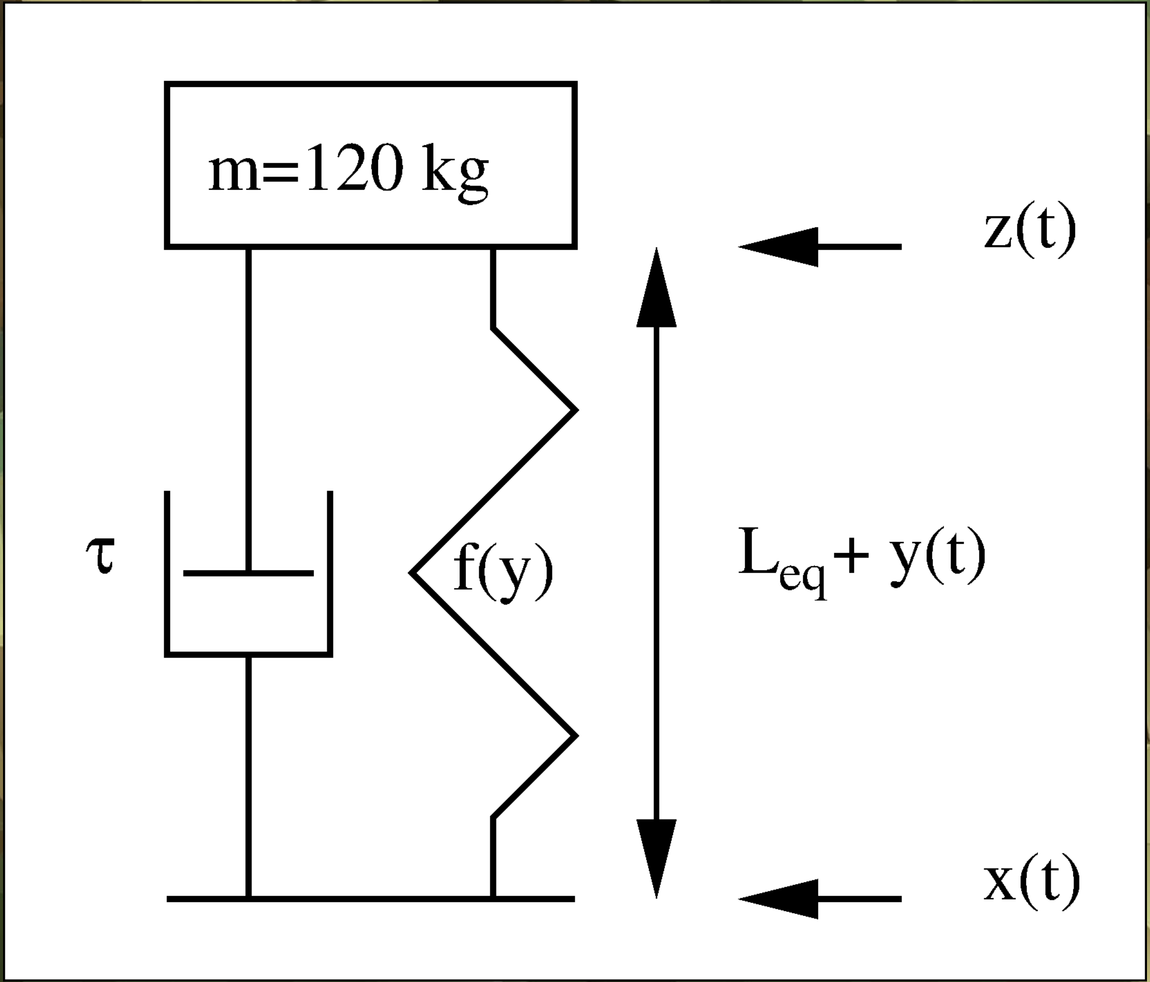
(unclassified)

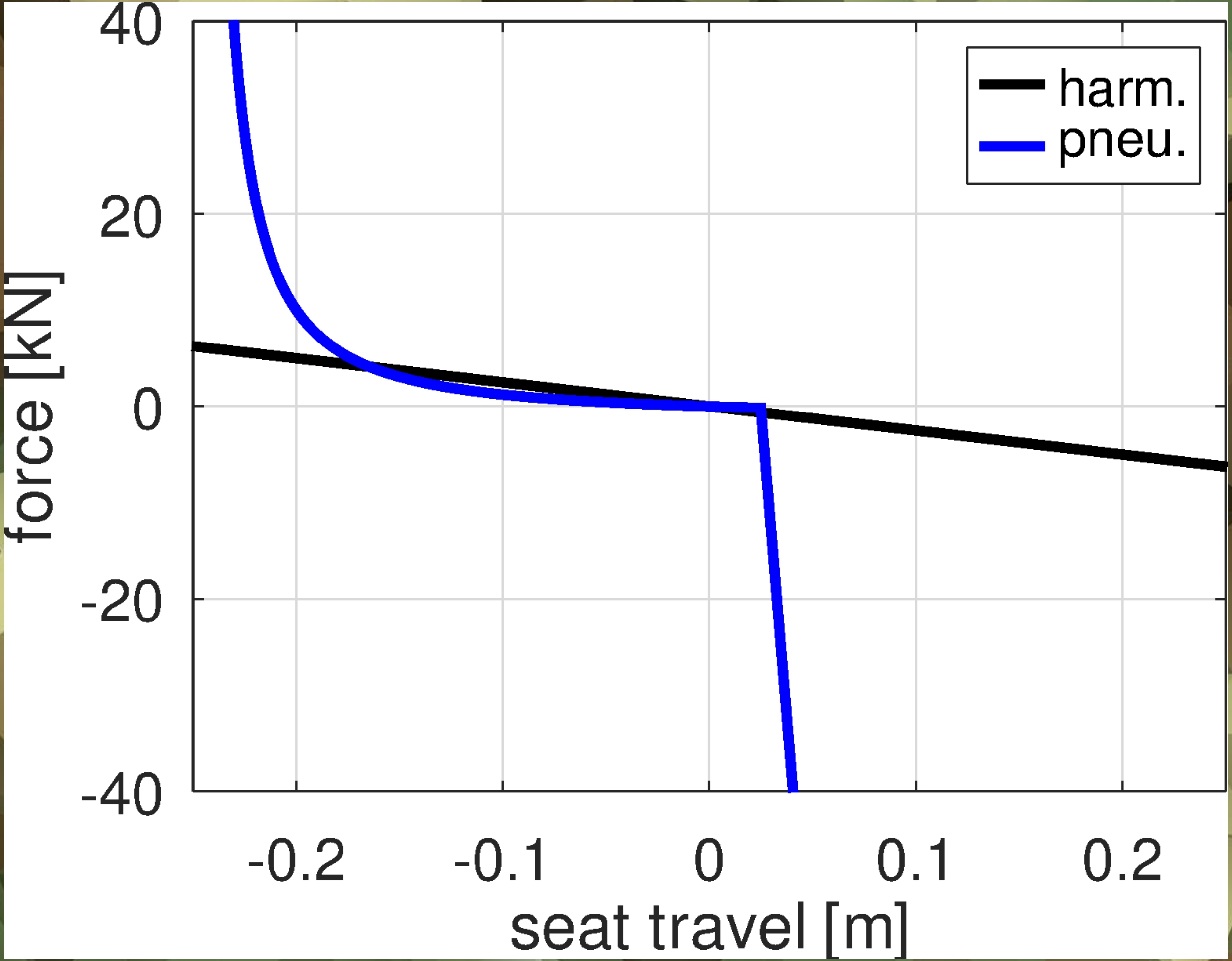
BUNDESWEHR

1. Introduction
2. Theory
3. Experimental Data
4. Limits and §§
5. New approach to get 3. closer to 4.

Introduction

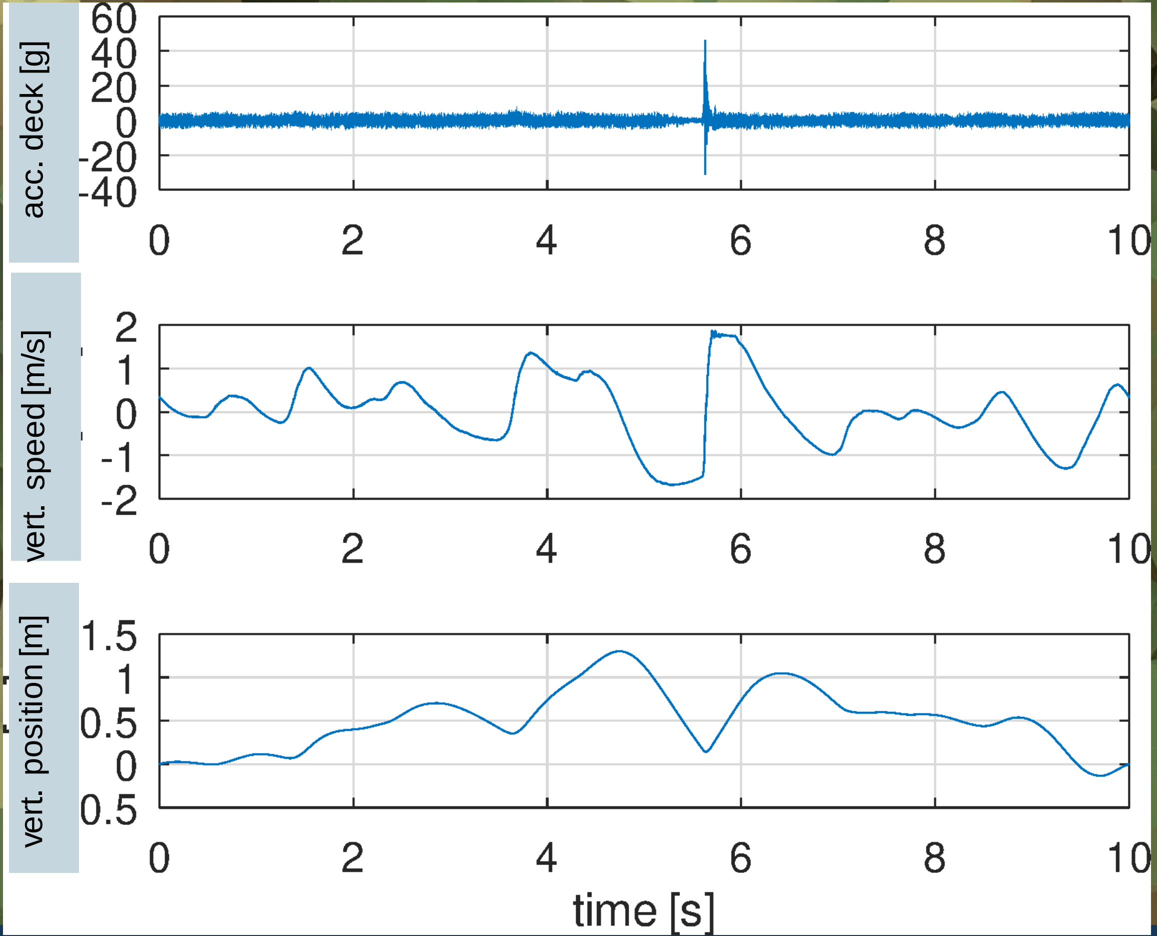
- WTD 71 = Bundeswehr Technical Center for Ships, Naval Weapons, Maritime Technology and Research
  - $\in$ Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw)
  - $\in$ DEU MoD
- Section 310 = Shipbuilding Technology, Equipment
- Section 340 = Shock and Vibration Center

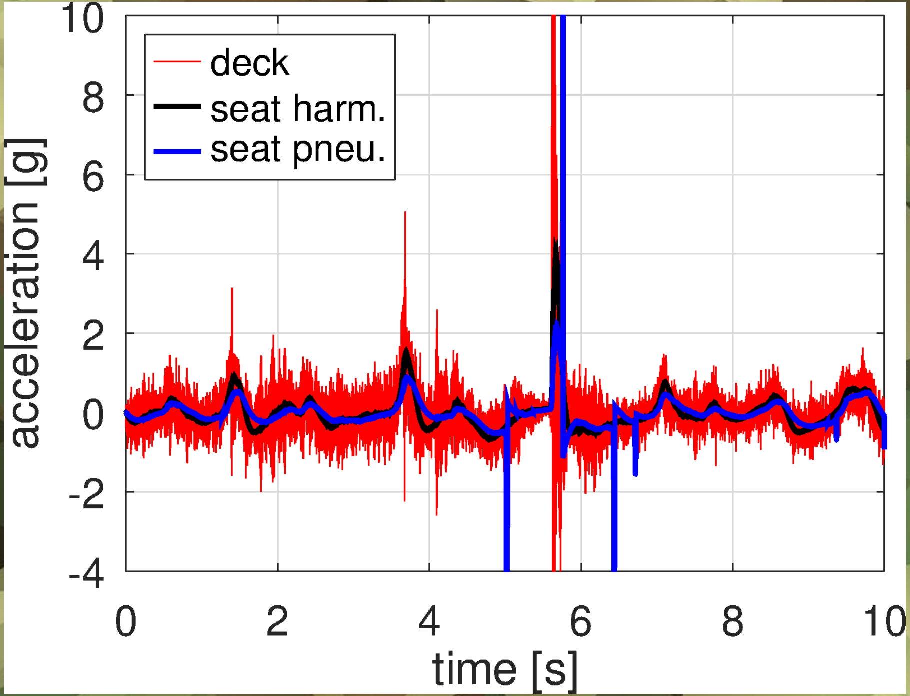

m=120 kg
z(t)
τ
f(y)
$L_{eq} + y(t)$
x(t)

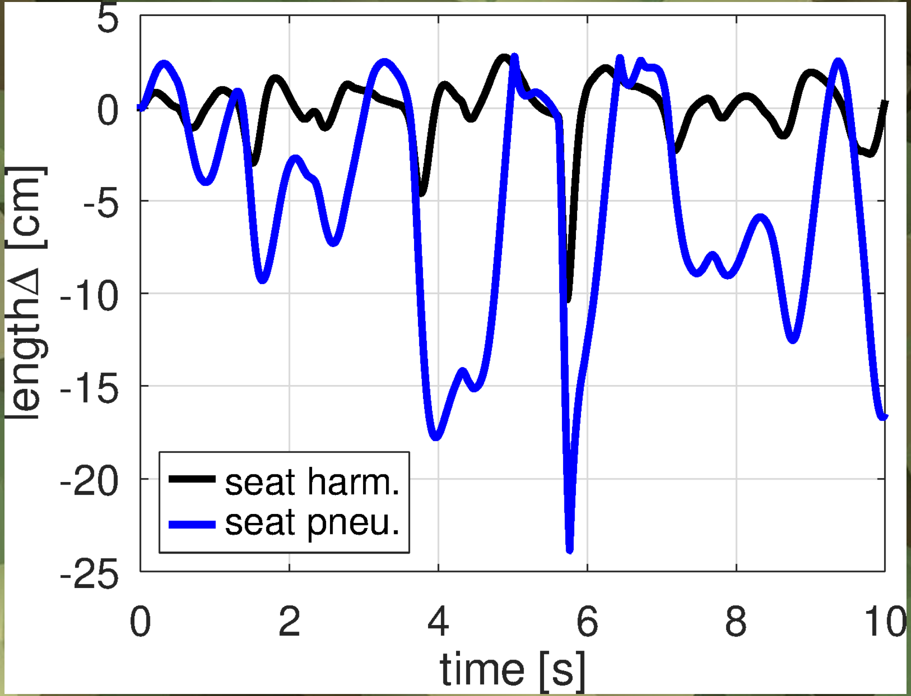


40
20
0
-20
-40
force [kN]
-0.2
-0.1
0
0.1
0.2
seat travel [m]
harm.
pneu.

- near Helgoland, North Sea
- 4 Bft
- SOG 24 kn
- Wave heigth 1,0 m – 1,5 m
- Sea state 3
- BUSTER boat, RHIB 10 m
- middle (of 3) seat
- deck acceleration
- raw data




deck
seat harm.
seat pneu.
acceleration [g]
10
8
6
4
2
0
-2
-4
0
2
4
6
8
10
time [s]


5
0
-5
-10
-15
-20
-25
lengthΔ [cm]
seat harm.
seat pneu.
0
2
4
6
8
10
time [s]

$$\text{DEU §§}: \; A(T) = \sqrt{\frac{1}{T} \cdot \int_0^T a_{wz}^2(t)\, dt} \quad ; \quad \boxed{A(8\text{h}) \leq 0.8\ \text{m/s}^2}$$

$$\Longrightarrow \boxed{T \leq 8\text{h} \cdot \left(\frac{0.8\ \text{m/s}^2}{A(T)} \right)^2}$$

$$\boxed{\text{DRI}:} \quad \ddot{z}(t) = \ddot{\delta}(t) + 2\varepsilon\omega \cdot \dot{\delta}(t) + \omega^2 \cdot \delta(t) \quad ; \quad \varepsilon = 0.224\ ,\ \omega = 52.9\ \text{rad/s}$$

$$\text{upwards, compression of spine}: \quad \boxed{\max\{\delta(t)\} \leq \begin{cases} 53.3\ \text{mm} \\ 63.3\ \text{mm} \end{cases}} \begin{matrix} \text{Training} \\ \text{Emergency} \end{matrix}$$

- DEU §§: Lärm– und Vibrationsarbeitsschutzverordnung (decree for the protection of personel against noise and vibration at work)
- DRI, Dynamic Response Index, see
  - Maritime Safety Commitee Resolution: „Testing of Life–Saving Appliances“
  - NATO Standard AEP-55: „Procedures For Evaluating The Protection Level of Armoured Vehicles - IED Threat“

deck: $A_{wz}(10\ s) = 3.45\ m/s^2$, $T \sim 26$ min
harm.: $A_{wz}(10\ s) = 2.91\ m/s^2$, $T \sim 36$ min
pneum.: $A_{wz}(10\ s) = 4.78\ m/s^2$, $T \sim 13$ min (hard stops!)

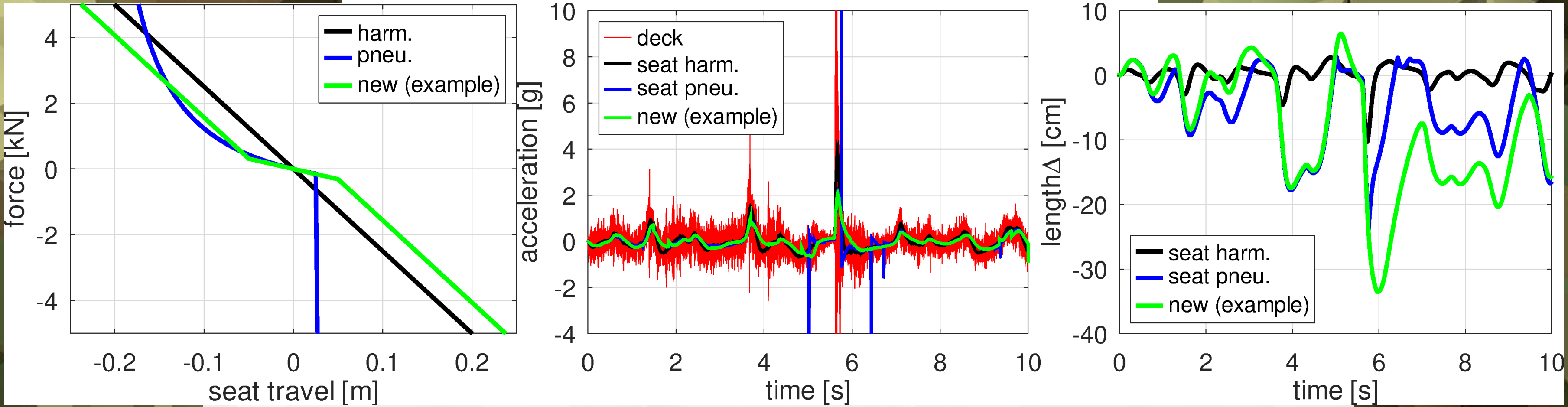
deck: $A_{wz}(2\ s) = 1.42\ m/s^2$, $T \sim 152$ min
harm.: $A_{wz}(2\ s) = 1.62\ m/s^2$, $T \sim 118$ min (excitation close to f_0)
pneum.: $A_{wz}(2\ s) = 0.98\ m/s^2$, $T \sim 320$ min

deck: $\delta_{max}(10\ s) = 25.8$ mm
harm.: $\delta_{max}(10\ s) = 18.4$ mm
pneum.: $\delta_{max}(10\ s) = 28.2$ mm

δ_{max} seems not to be critical.

1. Use soft/weak/long springs
2. Avoid hard stops

Define Spring characteristic

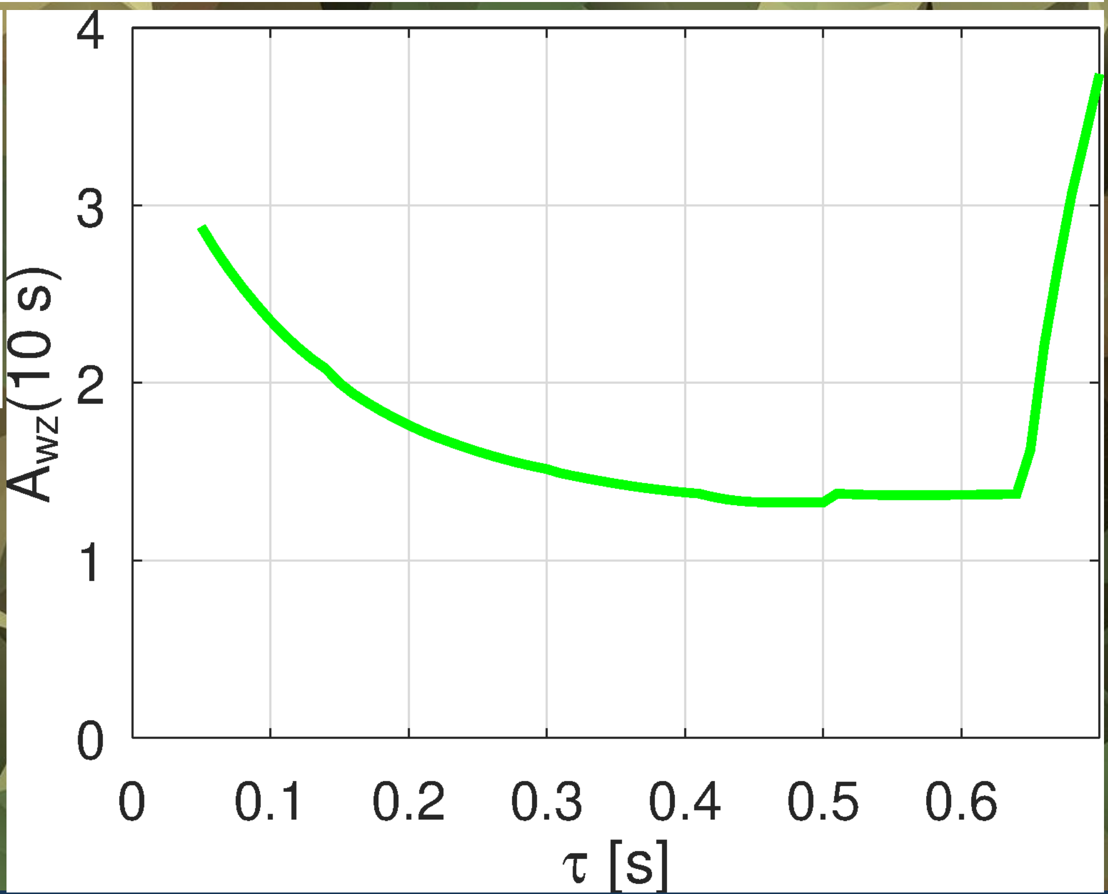


deck:	$A_{wz}(10\ s) = 3.45\ m/s^2$, T ~ 26 min	
harm.:	$A_{wz}(10\ s) = 2.91\ m/s^2$, T ~ 36 min	
pneum.:	$A_{wz}(10\ s) = 4.78\ m/s^2$, T ~ 13 min (hard stops!)	
new:	$A_{wz}(10\ s) = 1.73\ m/s^2$, T ~ 103 min	
deck:	$\delta_{max}(10\ s) = 25.8\ mm$	$\tau = 0.21\ s$
harm.:	$\delta_{max}(10\ s) = 18.4\ mm$	
pneum.:	$\delta_{max}(10\ s) = 28.2\ mm$	
new:	$\delta_{max}(10\ s) = 9.4\ mm$	

Optimize τ

new: $A_{wz}(10\ s) = 1.73\ m/s^2$
$T \sim 103\ min$, $\tau = 0.21\ s$
new_{opt}: $A_{wz}(10\ s) = 1.33\ m/s^2$
$T \sim 174\ min$, $\tau = 0.49\ s$

new: $\delta_{max}(10\ s) = 9.4\ mm$
new_{opt}: $\delta_{max}(10\ s) = 5.3\ mm$



Conclusion and way ahead

- Spring should work in + and – direction (avoid hard stops)
- Combine spring and damper in a single material.

  National study (2023) about rubber materials

  - select caoutchouc

  - design form

  - optimize τ (τ variable?, electro-rheologic?)
- Be aware of heating/cooling (P ~ some 10 W)
- Use „standard“ (t.b.d.) time signal.

Thank you for your attention

Spare 1

equation of motion : $-\ddot{x} = \ddot{y} + \frac{2}{\tau} \cdot \dot{y} + f(y)$; $\boxed{z = x + L_{eq} + y}$

harm. osc. : $f(y) = -\omega_0^2 \cdot y$

$\omega_0 = \sqrt{\kappa/m}\ , \quad \kappa = 25\ \mathrm{kN/m}$

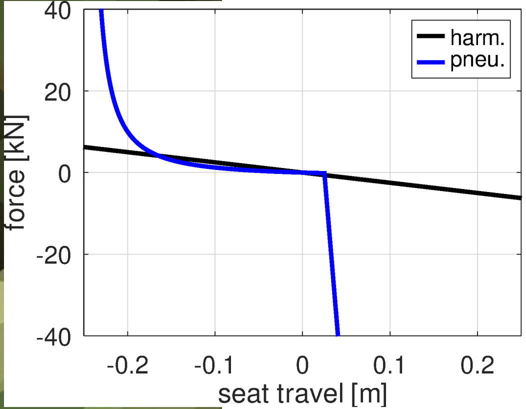
Eigenfrequency $\boxed{f_{0,harm.} \simeq 2.3\ \mathrm{Hz}}$

pneum. (one sided) : $f(y) = g \cdot \left(\frac{1}{\left(1 + \frac{y}{L_{eq}}\right)^{\gamma}} - 1 \right)$; $g = 9.81\ \mathrm{m/s^2}$

$L_{eq} = 25\ \mathrm{cm}\ ; \quad \gamma = c_p/c_v \simeq 1.4\ \mathrm{(air)}$

$y \ll L_{eq} \Rightarrow f(y) \simeq - \underbrace{\frac{g \cdot \gamma}{L_{eq}}}_{\omega^2_{0,pneum.}} \cdot y$

Eigenfrequency $\boxed{f_{0,pneum.} \simeq 1.2\ \mathrm{Hz}}$



both : $\tau := 1.5/\omega_0$

$\ddot{z}(t)$ must not be confused with measurements according to EN 30326-1

Spare 2

mean heating power <P>

$$\langle P \rangle = \frac{2 \cdot m}{\tau \cdot T} \int_{0}^{T} \left| \dot{y}(t) \right|^{2} \; dt$$

τ needed for calculation!

Spare 2

$$\begin{aligned}
\frac{y_0}{x_0} &= \frac{\varepsilon^2}{\sqrt{(1-\varepsilon^2)^2+(\varepsilon/\varepsilon_0)^2}} \\
\varepsilon &= \Omega/\omega_0 \\
\varepsilon_0 &= \omega_0\tau/2 \\
\Longrightarrow \tau &= \frac{2}{\omega_0\cdot\varepsilon}\cdot\frac{1}{\sqrt{(x_0/y_0)^2-(1-(1/\varepsilon)^2)^2}}
\end{aligned}$$

Helgoland data set: <P> ~ 65 W

Spare 3

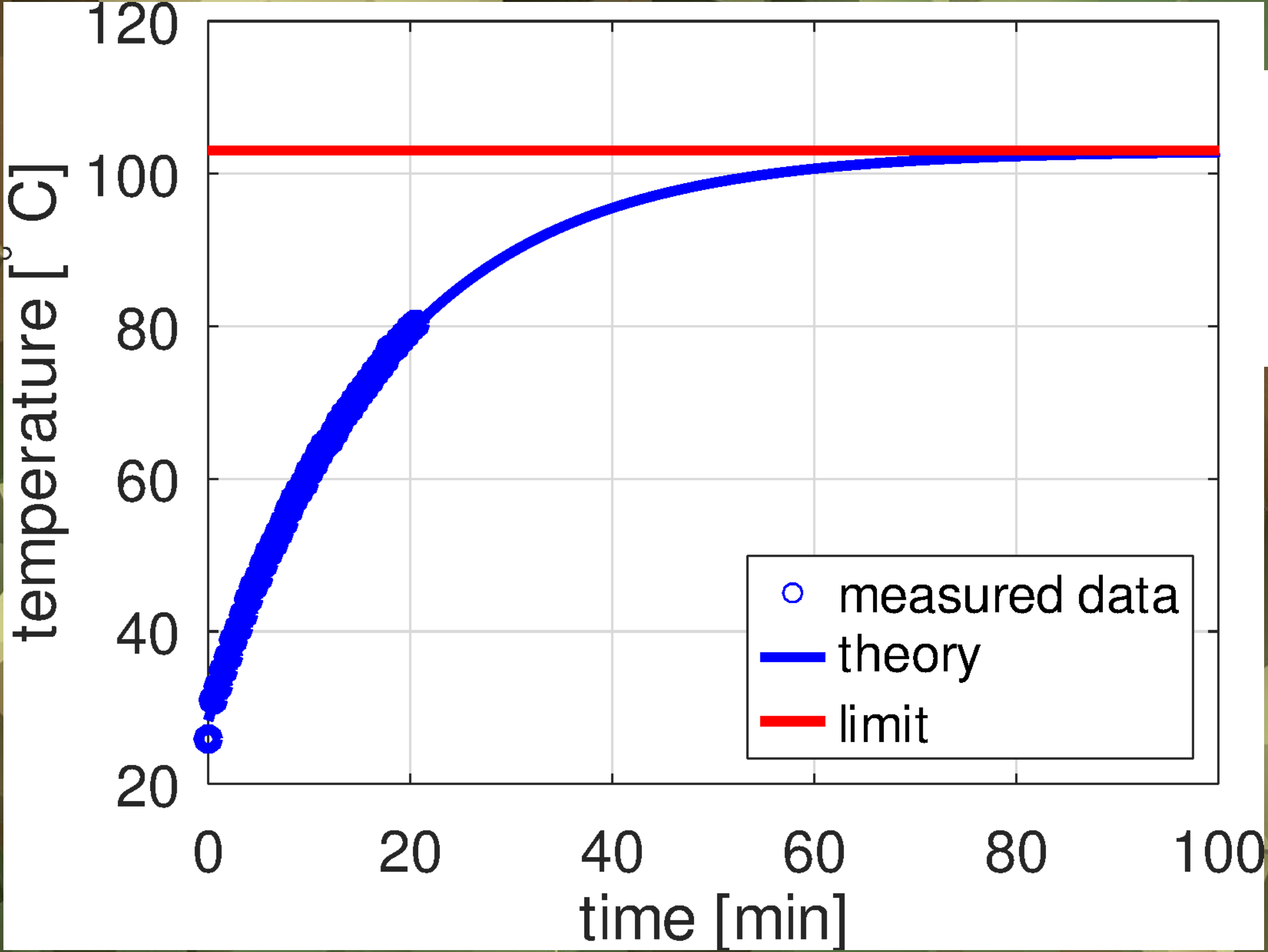
$$P = P_{em} + P_{conv.} + P_d$$

em: electro magnetic (radiation)
conv.: free convection
d: disspipation (heating the damper)

Ignoring higher orders of rescaled temperature $[(T-T_{air})/T_{air}]$in radiation terms: $[]^2$ $[])^3$ $[]^4$

$$T = T_{air} + \delta T \cdot \left(1 - e^{-t/\tau_T}\right)$$

Spare 4



6 Hz

x_0=15 mm
(peak2peak)

Spare 4

$$P_{eq.} = \frac{T - T_{air}}{T_{air}} \cdot 267\ \mathrm{W}$$

$$T_{air} = \text{(absolute) air Temperature [K]}$$

* Cooling mechanisms: Radiation and free convection, no forced convection (i.e. cooling air flow)

* P_{eq} = heating power, that leads to equilibrium temperature T_{eq}

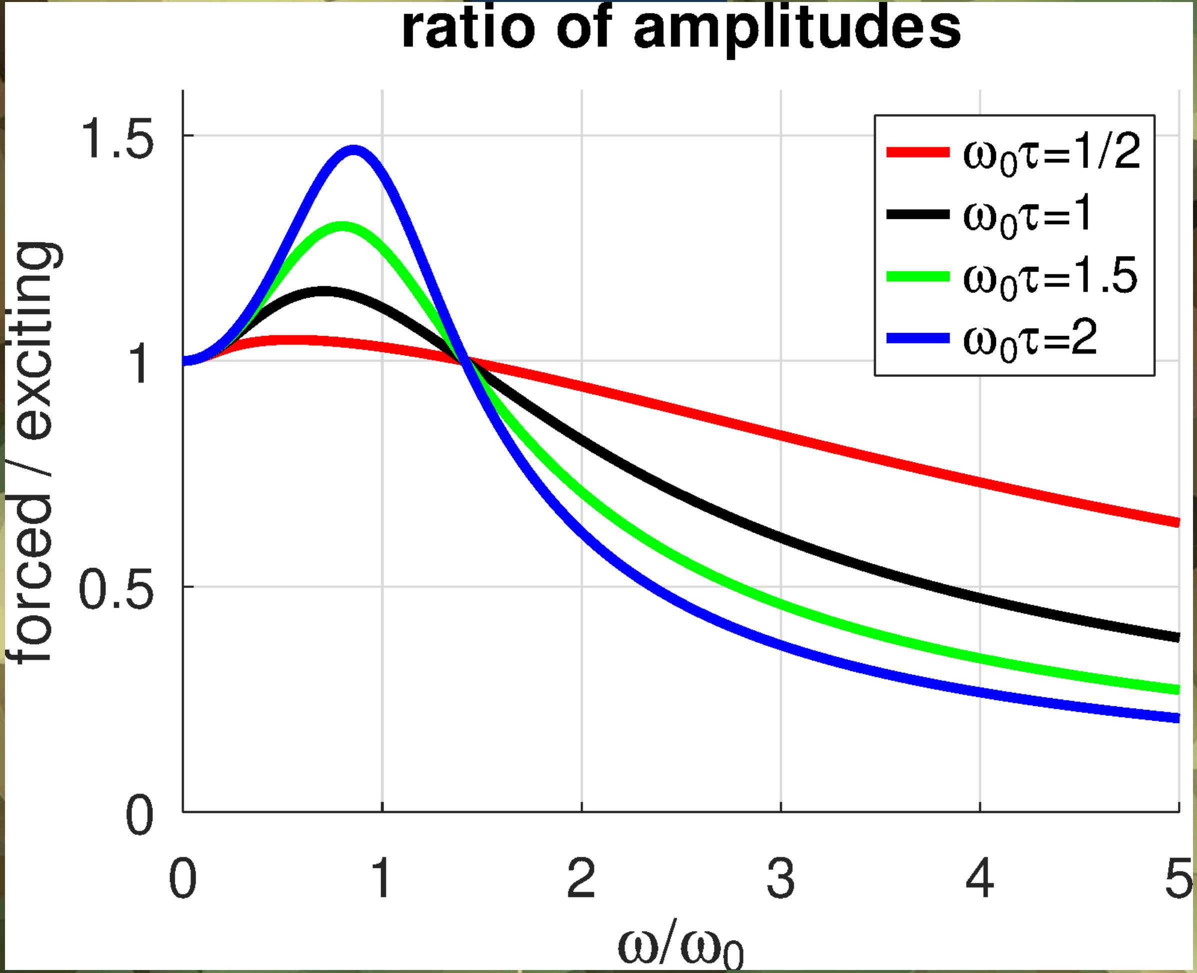
* Model damper is a cylinder

L_{eq} = 25 cm

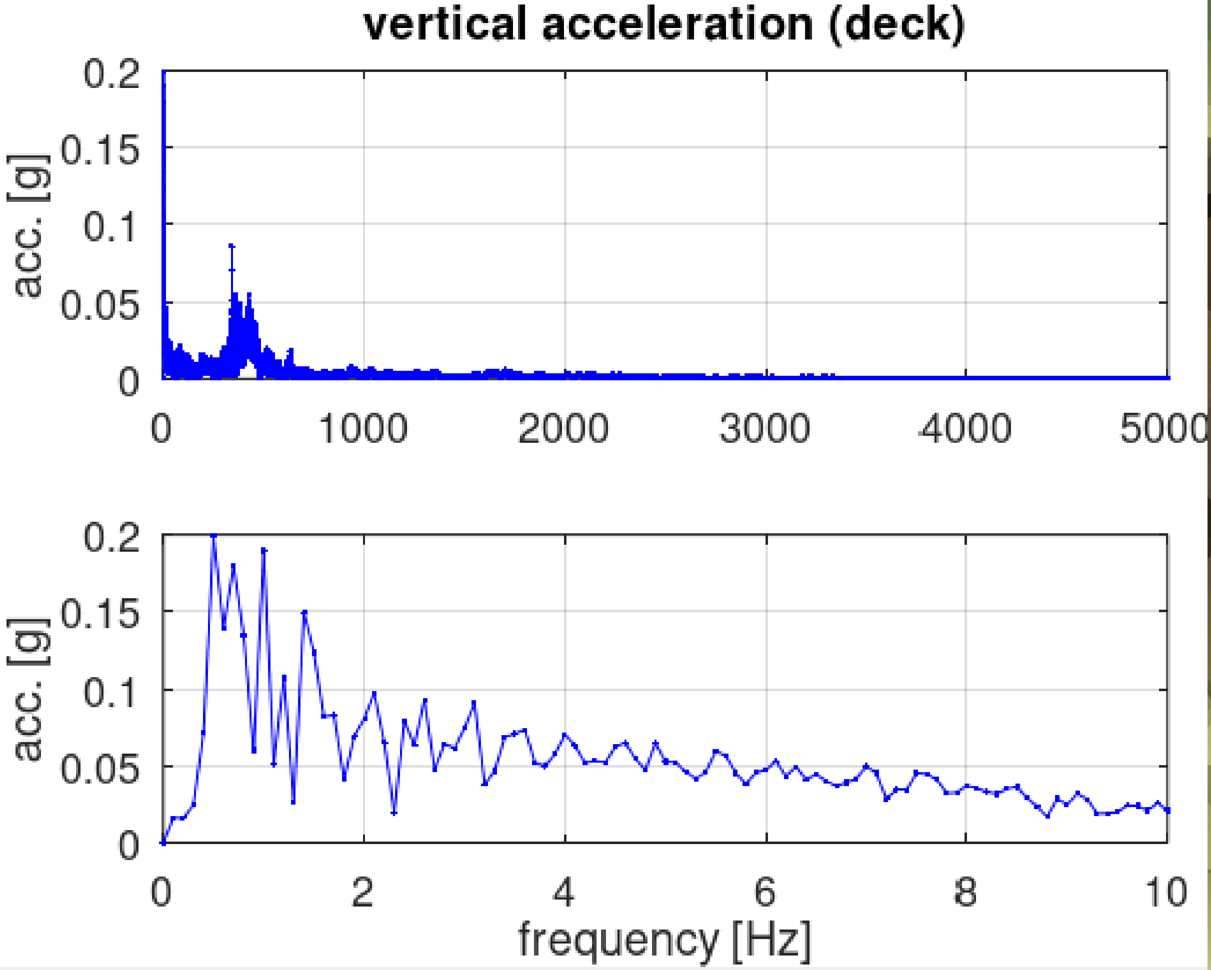
Diameter 5 cm

* T_{air} ~ 300 K

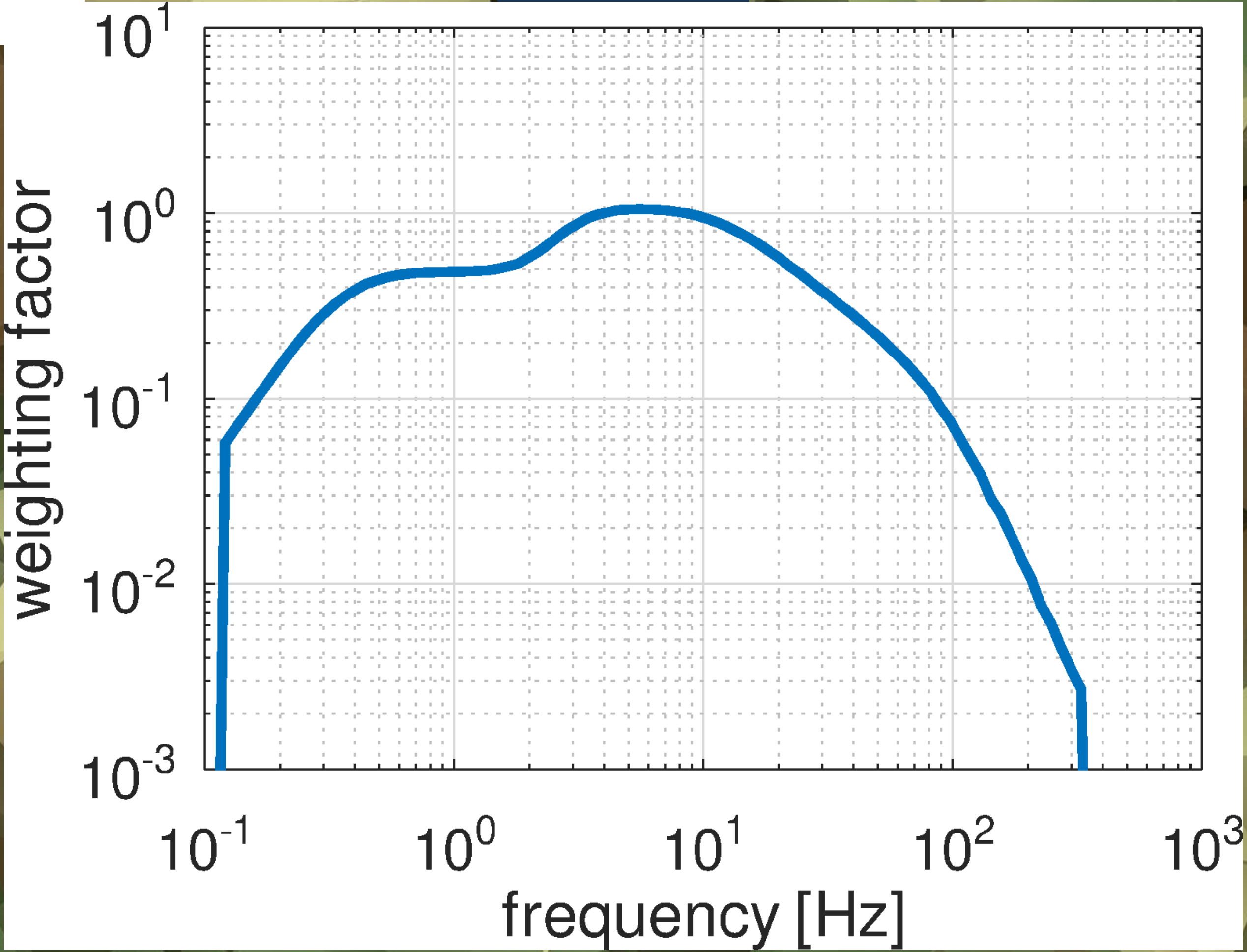
Spare 5


ratio of amplitudes
forced / exciting
ω/ω0
0
0.5
1
1.5
0
1
2
3
4
5
ω0τ=1/2
ω0τ=1
ω0τ=1.5
ω0τ=2

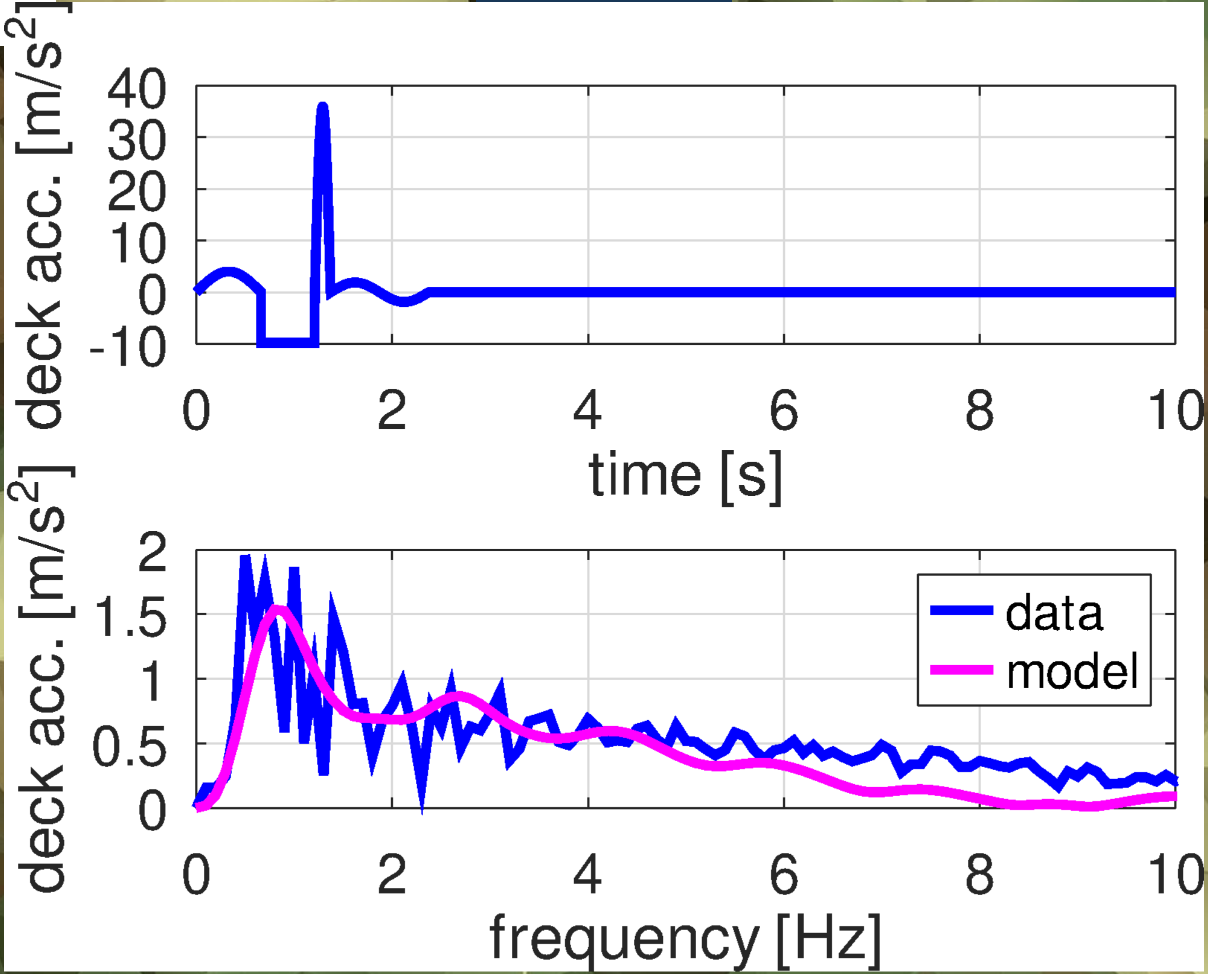
Spare 6


vertical acceleration (deck)
acc. [g]
0.2
0.15
0.1
0.05
0
0
1000
2000
3000
4000
5000
acc. [g]
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
frequency [Hz]

Spare 7


weighting factor
10^1
10^0
10^-1
10^-2
10^-3
10^-1
10^0
10^1
10^2
10^3
frequency [Hz]

Spare 8


deck acc. [m/s^2]
40
30
20
10
0
-10
0
2
4
6
8
10
time [s]
deck acc. [m/s^2]
2
1.5
1
0.5
0
0
2
4
6
8
10
frequency [Hz]
data
model