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Testing Methods for Verification of a Mounted Accelerometer Frequency Response

Dr. Th. Petzsche - Kistler Instrumente GmbH

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Introduction

Goal

- Mounted resonance frequency (MRF)
  - Part of specification in the data sheet of any accelerometer beside the damping coefficient (DmpCo), given for stiffest mounting
  - Expresses usually the frequency response of an accelerometer as key parameter, beside damping coefficient, mechanical quality of resonance, HP- & LP- filter frequency
  - Parameter function to combine sensitivity of the sensor over frequency

- MRF measurement represents (ISO16032-32:2016, ISO5347-14, ISA-RP37.2)
  - Quality of mounting (influenced by scratches, roughness, stiffness, …)
  - Provides hints on the mounting conditions
  - Ratio of masses between 'Structure under Test' and 'Sensor'
  - Sensor functionality at all

- Goal
  - Understanding of MRF in boundary conditions as depending:
    - (1) Sensor mounted to a large mass
    - (2) Sensor suspended in air, not mounted
  - Overview of different procedures to determine MRF, inverse and direct piezoelectric
  - **Does the results correlate with theory? What can we learn about mounting ?**

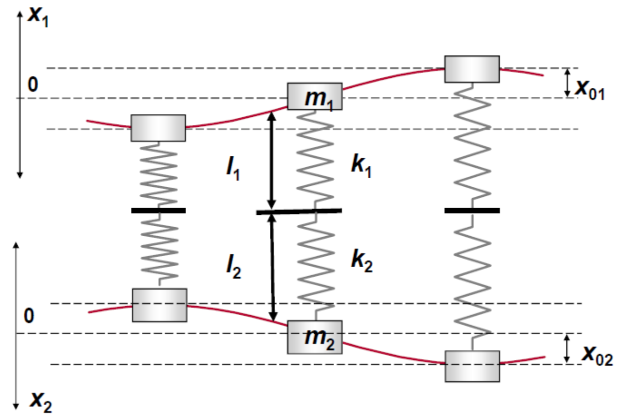
Conclusions to MRF

depending from the boundary conditions

(1) Non-fixed two mass spring system

$$\omega_0 = \sqrt{k \cdot \left(\frac{1}{m_1} + \frac{1}{m_2}\right)} \qquad \boldsymbol{k} = \frac{\boldsymbol{k}_1 \cdot \boldsymbol{k}_2}{\boldsymbol{k}_1 + \boldsymbol{k}_2}$$

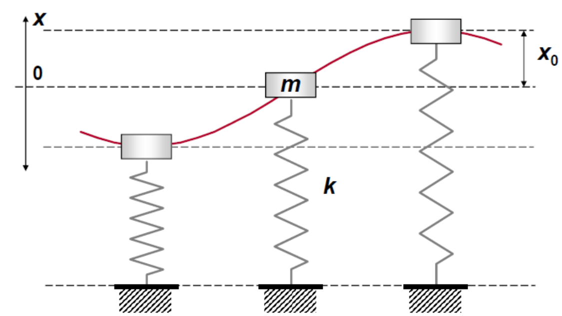
where spring constant $\boldsymbol{k}$ is formed by the two $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ in series



1. Non-fixed two mass spring system

(2) Fixed one mass spring system

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{E \cdot A}{l \cdot m}}$$



2. Fixed one mass spring system

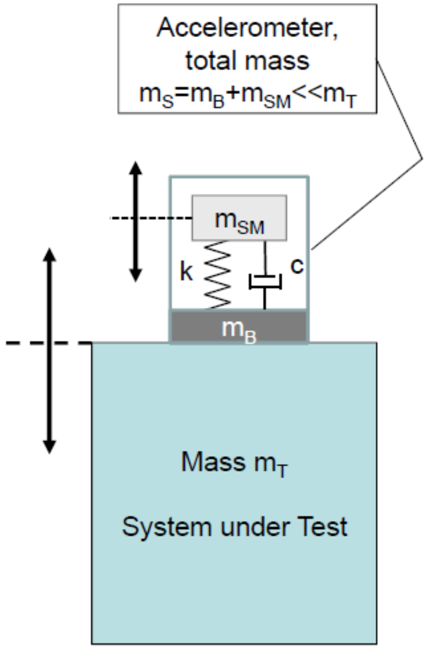
- For (1) $\boldsymbol{m}=\boldsymbol{m}_1=\boldsymbol{m}_2$: $\omega_0 = \sqrt{2}\,\omega$.

$$\omega_0 > \omega.$$

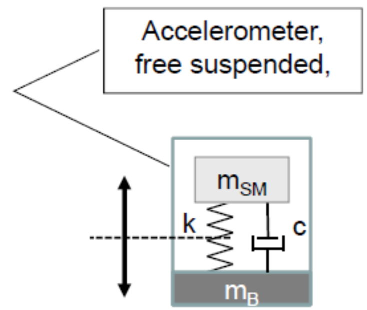
An Accelerometer under…

mounted and loose boundary conditions

- Left - Case 1: Typical Vibration Testing configuration, Accelerometer mass $\boldsymbol{m}_S = \boldsymbol{m}_B + \boldsymbol{m}_{SM}$
- Mass system under test $\boldsymbol{m}_T >> \boldsymbol{m}_S$



- Right - Case 2: Sensor free suspended in air, Accelerometer mass $\boldsymbol{m}_S = \boldsymbol{m}_B + \boldsymbol{m}_{SM}$



- The natural frequency in the mounted state f_m

Case 1 is given by:

$$f_m = \frac{1}{2\pi}\sqrt{\frac{k}{m_{SM}}}$$

Case 2 is given by:

$$fs = \frac{1}{2\pi}\sqrt{k\left(\frac{1}{m_B} + \frac{1}{m_{SM}}\right)}$$

- The mass of piezoelectric elements and its fixing tools has been neglected.

Accelerometer Resonance Test Methods

- For these two boundary conditions – test of MRF's
- Investigation using different excitation methods to excite the seismic mass using the **inverse piezoelectric effect** thanks to an alternating voltage applied to the capacitance of the sensor.
- Per standard definitions, the resonance frequency is achieved at the lowest frequency where the sensor reaches its maximum sensitivity while excited with an external vibration.
- Accelerometer under test:

KISTLER Type:	8203A50	8202A10
Minimal mounted resonance frequency belong to data sheet	>24 kHz	>45 kHz
Sensitivity at 100 Hz	50 pC/g	10 pC/g
Principle	Ceramic shear	
Capacitance	1400 pF	500 pF
Total sensor mass	44,5 g	14,5 g
Total Mass of seismic element	13,06 g	2,335
Total mass of sensor without pe element and seismic mass	30,62 g	11,813 g

Methods to Determine MRF‘s

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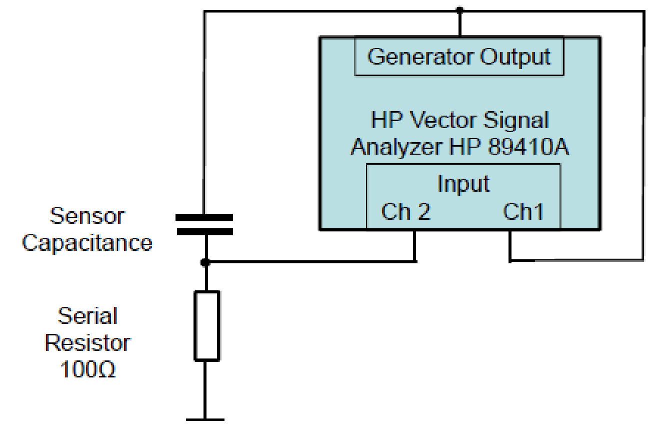
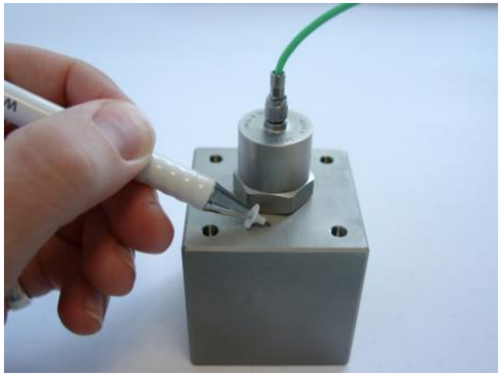
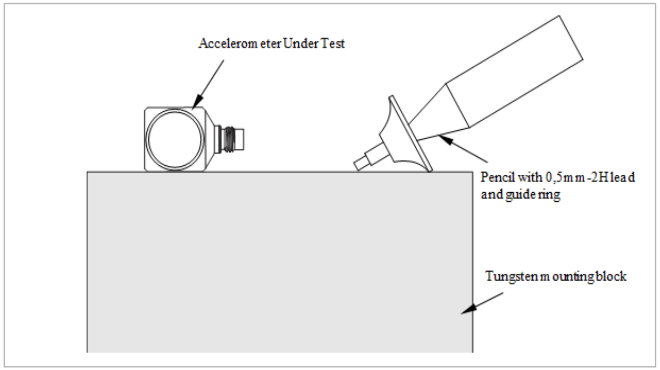
- Different methods to determine the accelerometer resonance frequency
- **Inverse piezoelectric** resonance excitation of an accelerometer with the
  - (1) Vector Analyzer Technology (HP 89410 (DC to 10 MHz), transfer fct.
  - (2) with a single electric pulse, FFT transfer fct.
  - (3) Random noise test, FFT transfer fct.
- **Direct piezoelectric** excitation with a
  - (4) short mechanical pulse (HSU-Nielson pencil test)
  - (5) Swept sine shaker test, sinusoidal excitation



(1): Method Vector Analyzer. Sensor in series with resistor

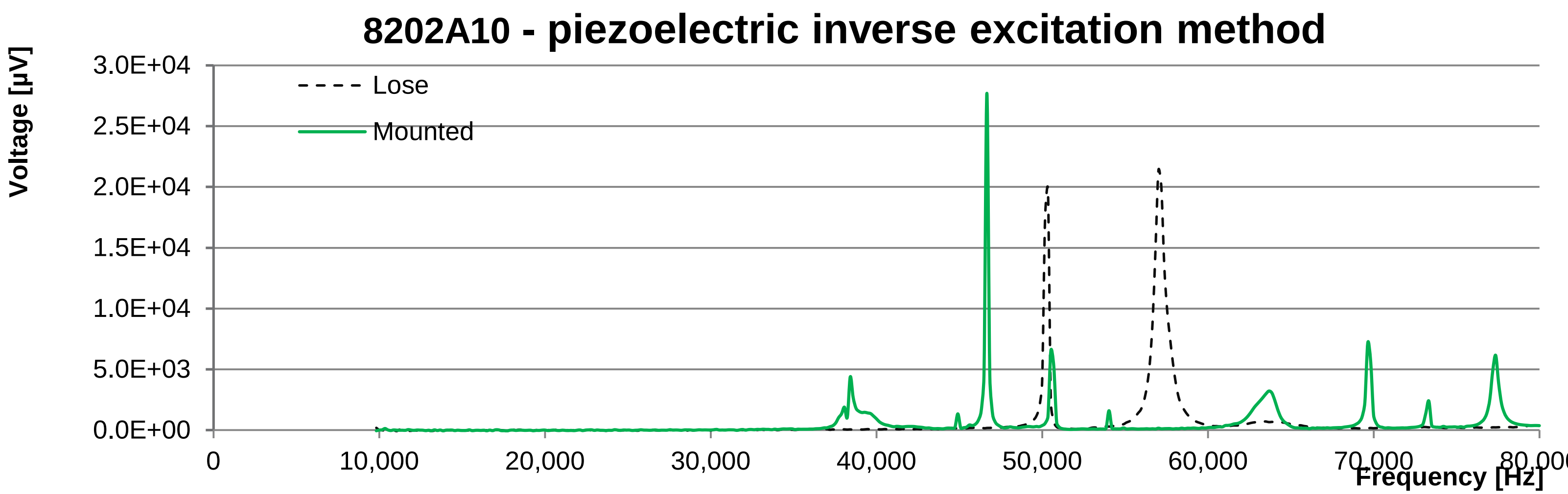


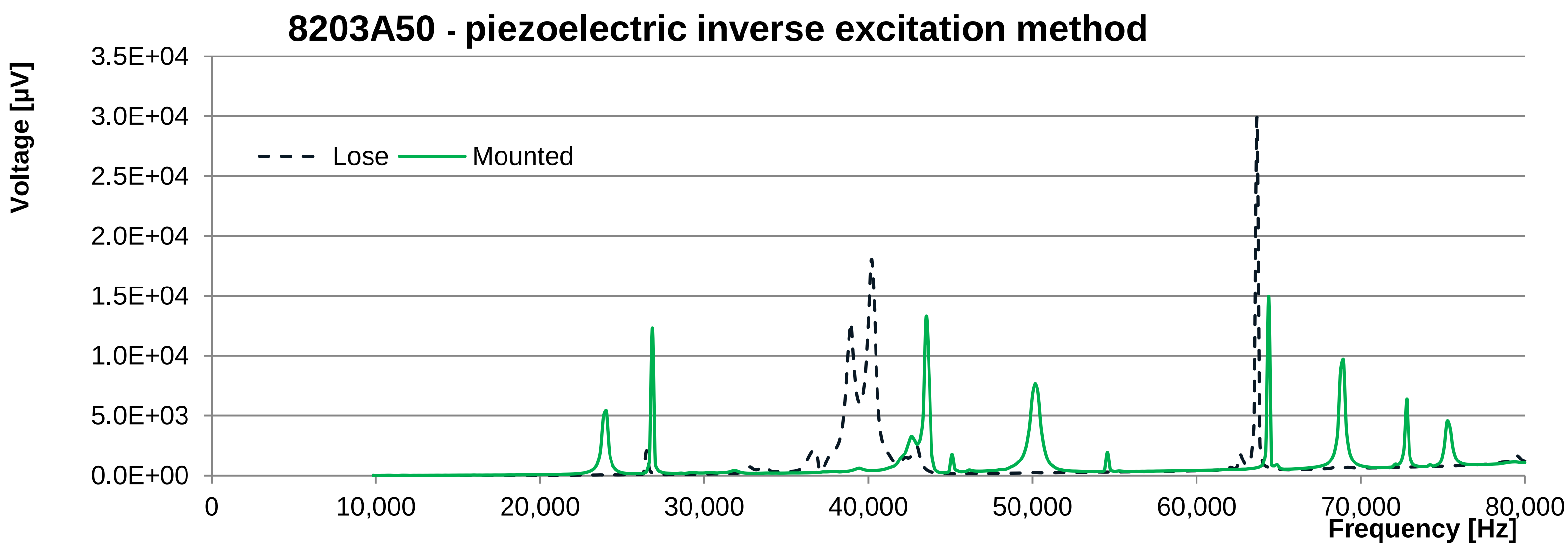


(4) Pencil lead break on a steel cube of 25,4 mm^3 (similar to the HSU-Nielson source for acoustic emission testing)

Results with Method (1) , Resonance Search

Vector Anayzer Method





Res. with Method (1), Spring-Mass System Calc.

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Vector Anayzer Method

- Hanging and mounted resonances for sensors type 8203A50 and 8202A10.
  (It means: $1/\boldsymbol{m} = 1/\boldsymbol{m_1} + 1/\boldsymbol{m_2}$; $\boldsymbol{m_1} = \boldsymbol{m_S} - (\boldsymbol{m_{PE}} + \boldsymbol{m_2})$;
  mass of the piezoelectric element and its fixing $\boldsymbol{m_{PE}}$).

Sensor Type	Mass of seismic mass m_2	Total Mass of sensor m_S	Mass of Sensor - seis. Mass & PE element) m_1	Redu-ced mass m	Measured res. freq., hanging $f_{res,\ loose}$	Calculated spring const. k	Calcu-lated mounted res. freq. $f_{res,\ mount}$	Measured mounted res. freq., $f_{res,\ mount}$	
	g	g	g	g	Hz	N/m	Hz	Hz	Hz
								1st mode	2nd mode
8203A50	13,06	44,5	30,62	9,155	26316	250287758	**22033**	**23850**	26842
8202A10	2,335	14,5	11,81	1,949	50350	195112505	**46007**	38421	**46666**

- Comparison of calculated MRF with spring constant calculated from the ‘Not mounted loose’ data and measured MRF
- Good correlation of results, uncertainties by not individually known masses (like pe element, …)

Method (4), HSU-Nielson Test

Direct Piezoelectric Generated Signal

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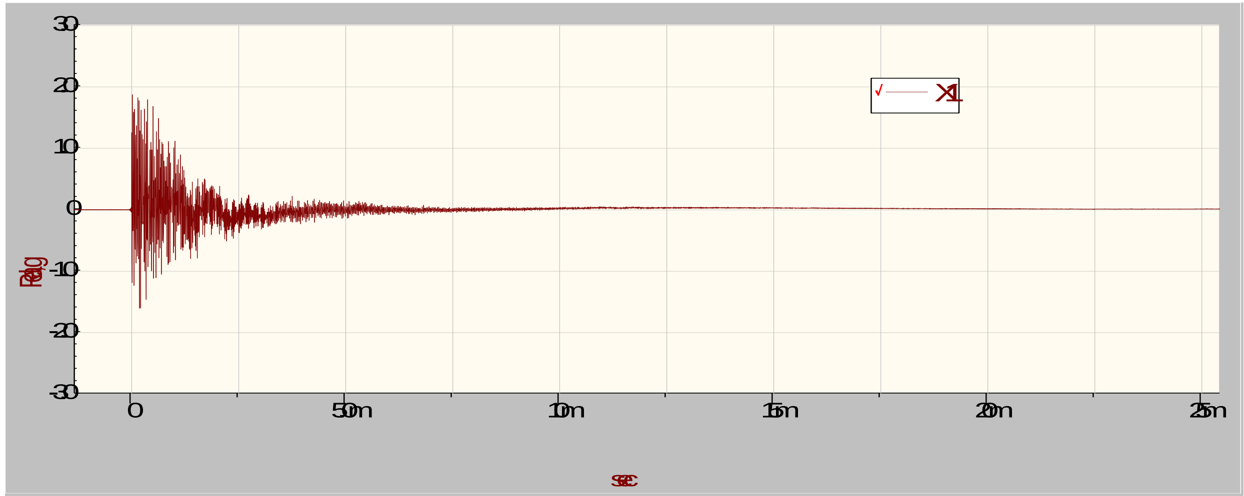
- FFT Auto Power Spectrum from the time signal for the sensor 8202A10
- Sensor resonances at:

1	2	3	4
39,13 kHz	46,70 kHz	50,62 kHz	54,16 kHz

5	6	7	8
61,62 kHz	64,23 kHz	70,11 kHz	73,37 kHz

9
78,21 kHz

X1

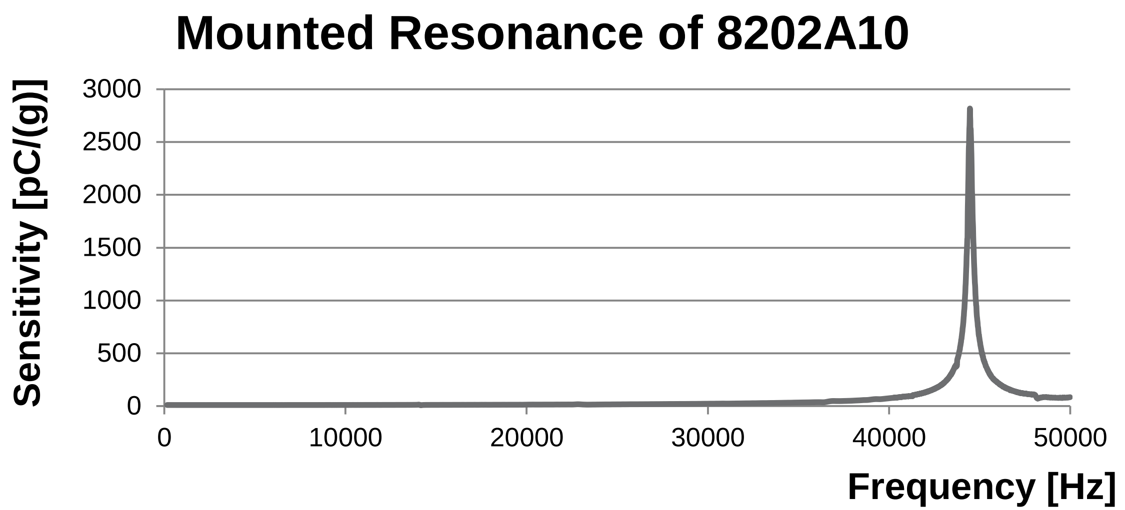


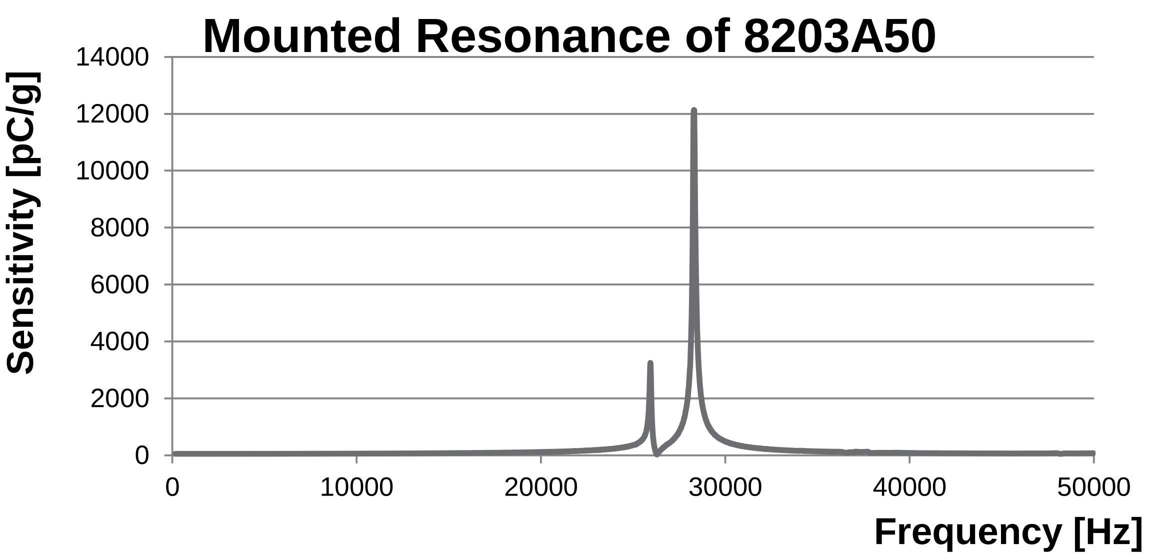
S1

Swept Sine Shaker Test, Method (5)

- Shaker: Spektra SE-09, 1 kHz up to 50 kHz
- Resonance search with tight frequency steps, min. 1600 points
- Results:
  8202A10
  f_{res} = 44,47 kHz; 48 dB

  8203A50
  f_{res1} = 25,93 kHz; 35 dB
  f_{res2} = 28,32 kHz; 48 dB





Summary of Results - 1

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Excitation	Inverse Piezoelectric					Piezoelectric			
	Vector Signal Analyzer (1)				Impuls (2) White Noise (3)	HSU-Nielson (4)		Swept Sine Test (5)	
Sensor Type	Measured res. freq., loose $f_{res, loose}$,	Calculated MRF $f_{res, mount.}$	Measured MRF $f_{res, mount.}$		Measured MRF $f_{res, mount.}$	Measured MRF $f_{res, mount.}$		Measured MRF $f_{res, mount.}$	
	Hz	Hz	Hz	Hz	Hz	Hz	Hz	Hz	Hz
			1^{st} mode	2^{nd} mode	2^{nd} mode			1^{st}	2^{nd}
8203A50	26316	**22033**	**23850**	26842	27730 27040	**24930**	27090	25120 25930	28180 28321
8202A10	50350	**46007**	38421	**46666**	46670 46680	39130	**46700**	**36226 (weak)**	**44670 44465**

INTERPRETATION

- Impressive consistancy within loose and mounted results
- Inverse PE: Excitation of all possible resonances (length, shear, thickness and more)
- Less excited modes for direct piezoelectric excitation
- Slighly different mounting conditions influences results

Summary of Results-2, Method (1)-(5)

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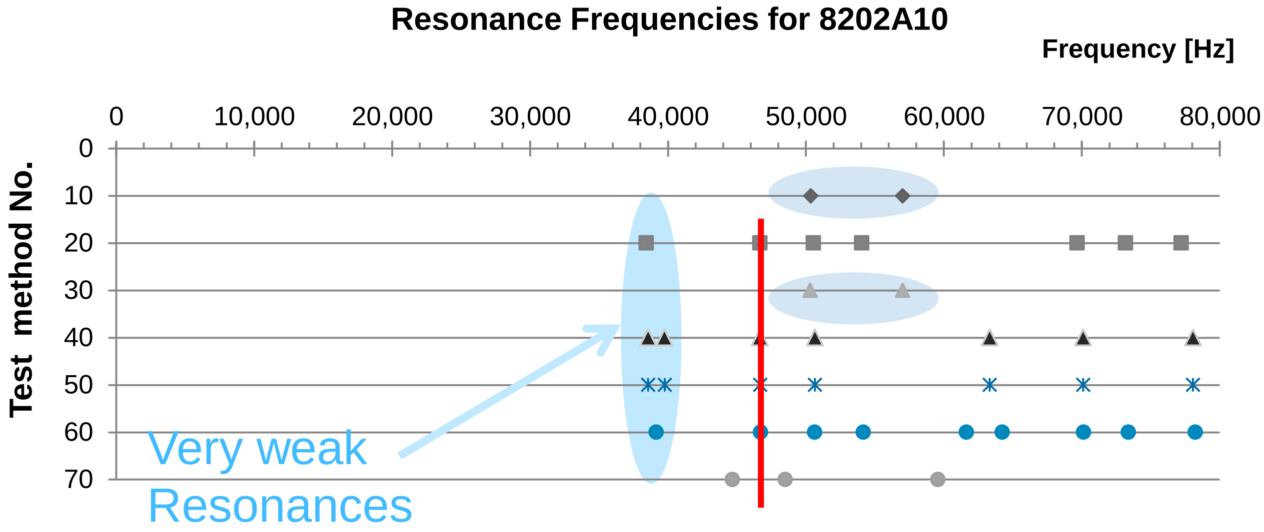
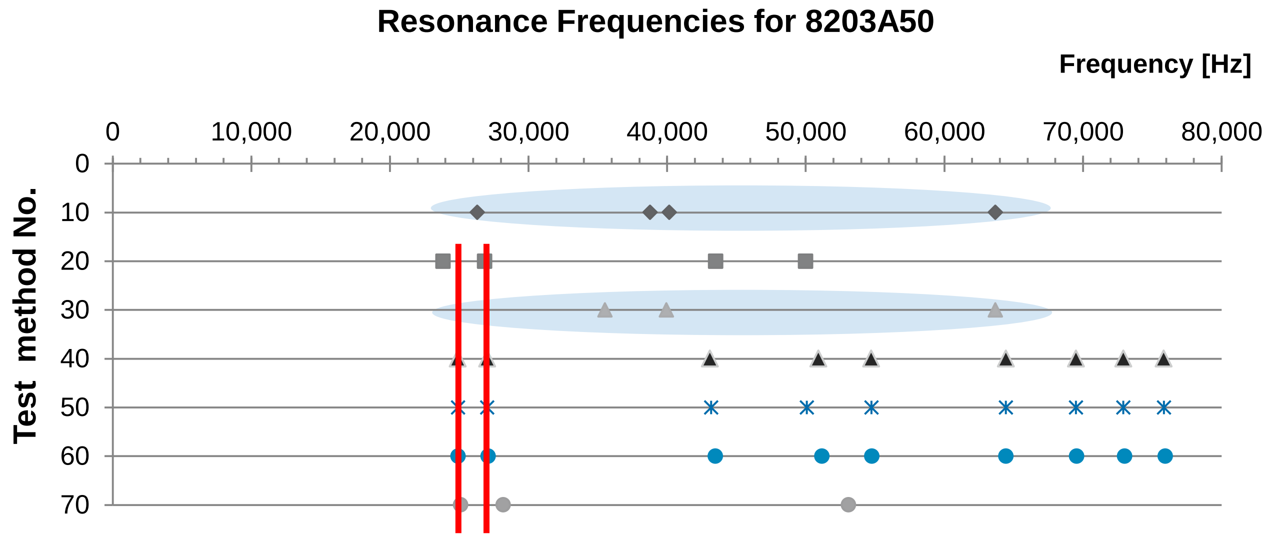
Test method No.	Sensor	Test description
10	**loose**	Vector Signal Analyzer
20	mount.	Vector Signal Analyzer
30	**loose**	Single electrical pulse, transfer fct.
40	mount.	Single electrical pulse, transfer fct.
50	mount.	Random noise test, transfer fct.
60	mount.	HSU-Nielson test (pencil lead), transfer fct.
70	mount.	Shaker test, sinusoidal excitation

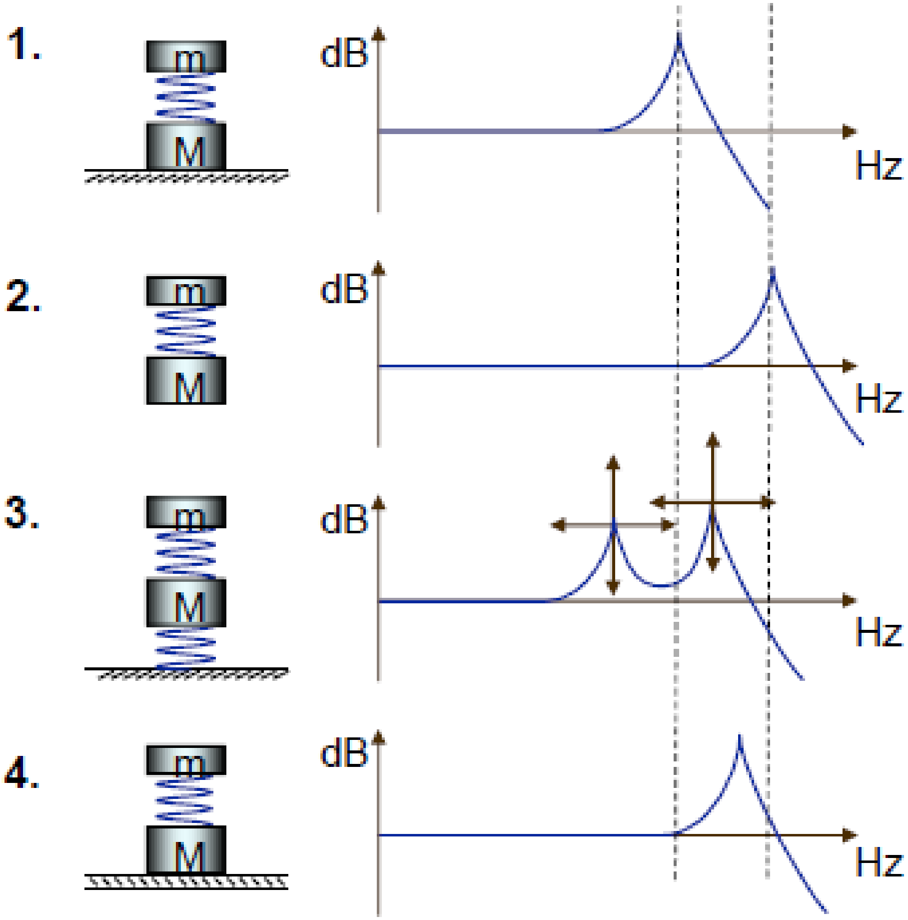




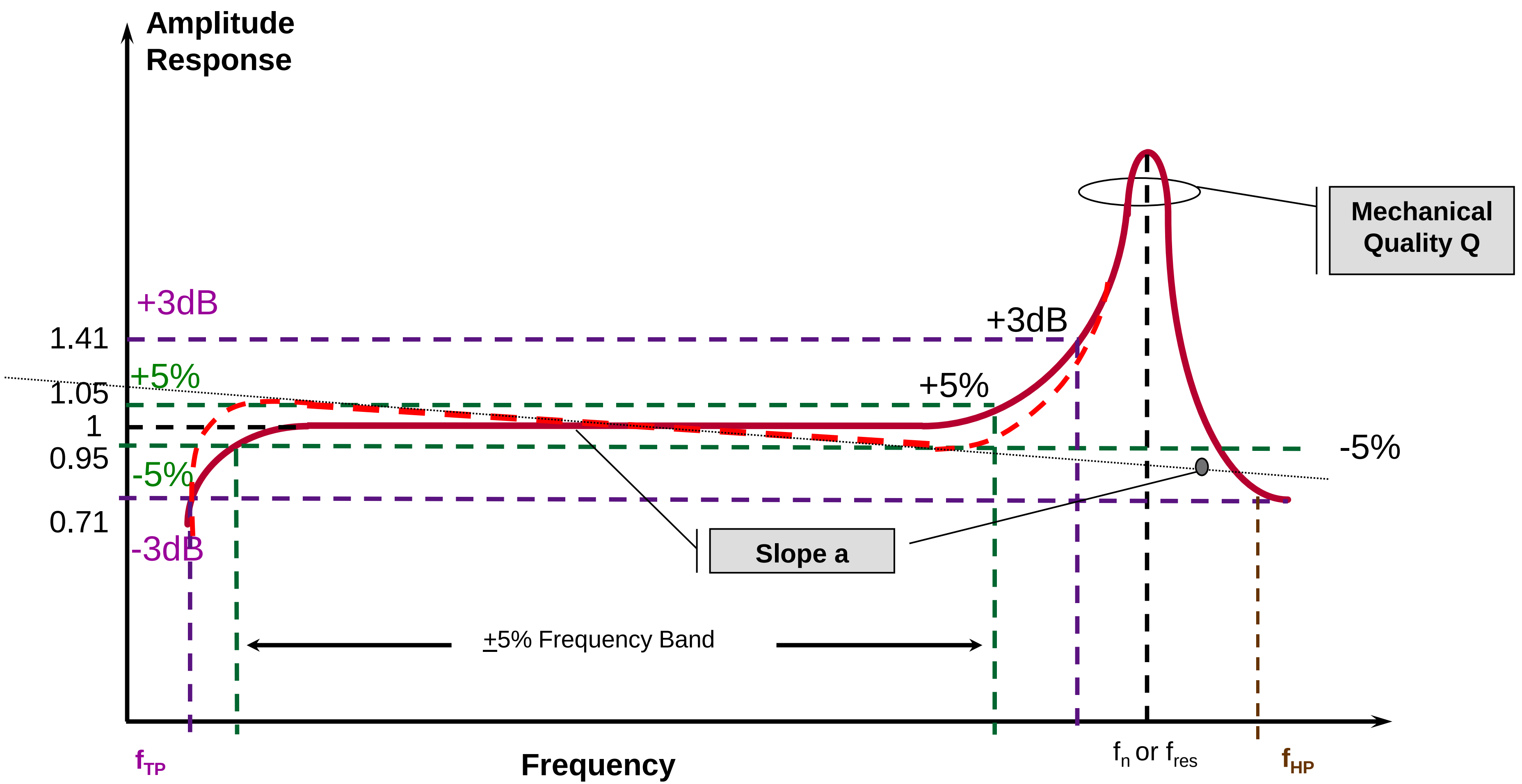
Conclusions:

What do we see in our daily routine? What can we learn ?

- **Configuration 1**
  Fixed to UUT with large mass
- **Configuration 2**
  Not mounted, suspended in air
- **Configuration 3**
  Soft mounted, loose mounted, scratches, lower mounting torque o high roughness of the mounting area, ….
- **Configuration 4**
  Mounted to a lightweight structure
  →inclusive possible mass loading effects
- **→ Influences directly MRF !**
  20% of MRF sensitivity change
  ±5% (weak damping)



FFT Frequency Response Correction with Accelerometer Frequency Response



Accelerometer Transfer Function, used in TEDS Template 25

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$$S(f) := \hat{I}_c \, (\mathrm{Sign}) \cdot S_{ref} \cdot \left[1 + b \cdot \left(T - T_{ref}\right)\right] \cdot \frac{\frac{j \cdot f}{f_{hp}} \cdot \left(\frac{j \cdot f}{f_{ref}}\right)^{\frac{a}{\ln(10)}}}{\left(1 + \frac{j \cdot f}{f_{hp}}\right) \cdot \left(1 + \frac{j \cdot f}{f_{lp}}\right) \cdot \left[1 + \left(\frac{j \cdot f}{f_{res}}\right)^2 + \frac{j \cdot f}{Q \cdot f_{res}}\right]}$$

Summary of Parameter

Sign, References

$\hat{I}_c$ - sensitivity direction

Sign – polarity

S_{ref} - reference sensitivity

Temperature Response

b - temperature coefficient

T - temperature

T_{ref} - reference temperature

Frequency Response

f - frequency

f_{hp} - high-pass cut off frequency

f_{lp} - low-pass cut off frequency

f_{res} - resonance frequency

f_{ref} - reference frequency

Q - Quality factor

a - amplitude slope / decade