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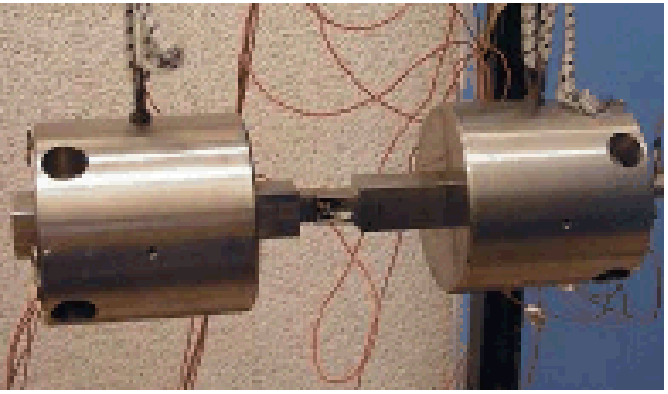
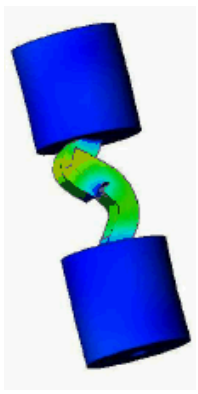
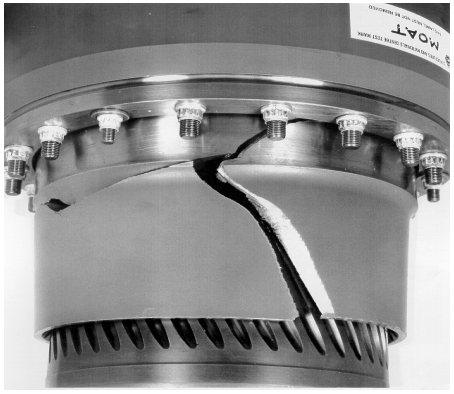
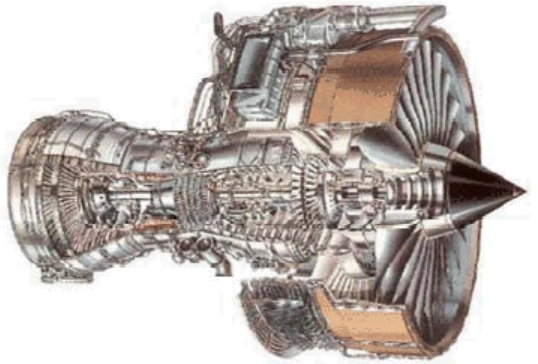
SAND2014-16833PE









Project 1: Nonlinear Testing – Variability & Repeatability…

Scott Smith, Simone Catalfamo, Juan Carlos Bilbao Ludena, Pascal Reuss, Matt Brake

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Agenda

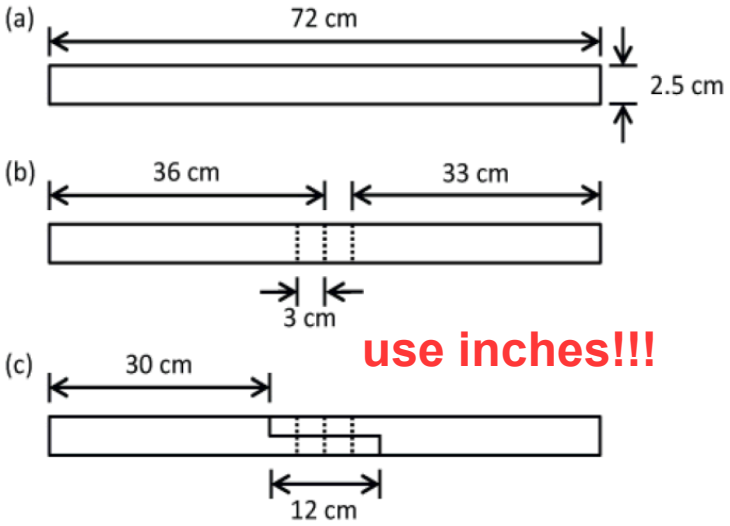
Project 1: Participants

- Scott Smith
  - …
- Juan Carlos Bilboa Ludena
  - …
- Simone Catalfamo
  - Institute of Applied and Experimental Mechanics (IAM),
  - University of Stuttgart,
  - Advisor: Pascal Reuß

Project overview and goals

Scopes:

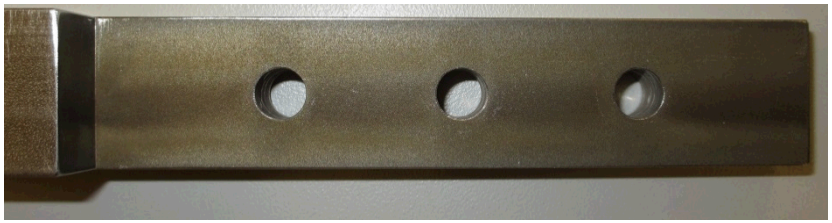
- Formulate Measurement ~~Guidelines~~:
  - boundary conditions
  - measurement techniques
  - excitation techniques



use inches!!!

- Nonlinear effects of bolted joints in BRB
  - interface conditions (rough-rough, mirror-mirror, mixed)
    - Interferometer tests (?)
  - residual stresses
  - geometric alignment

Pics of all beam pairs!



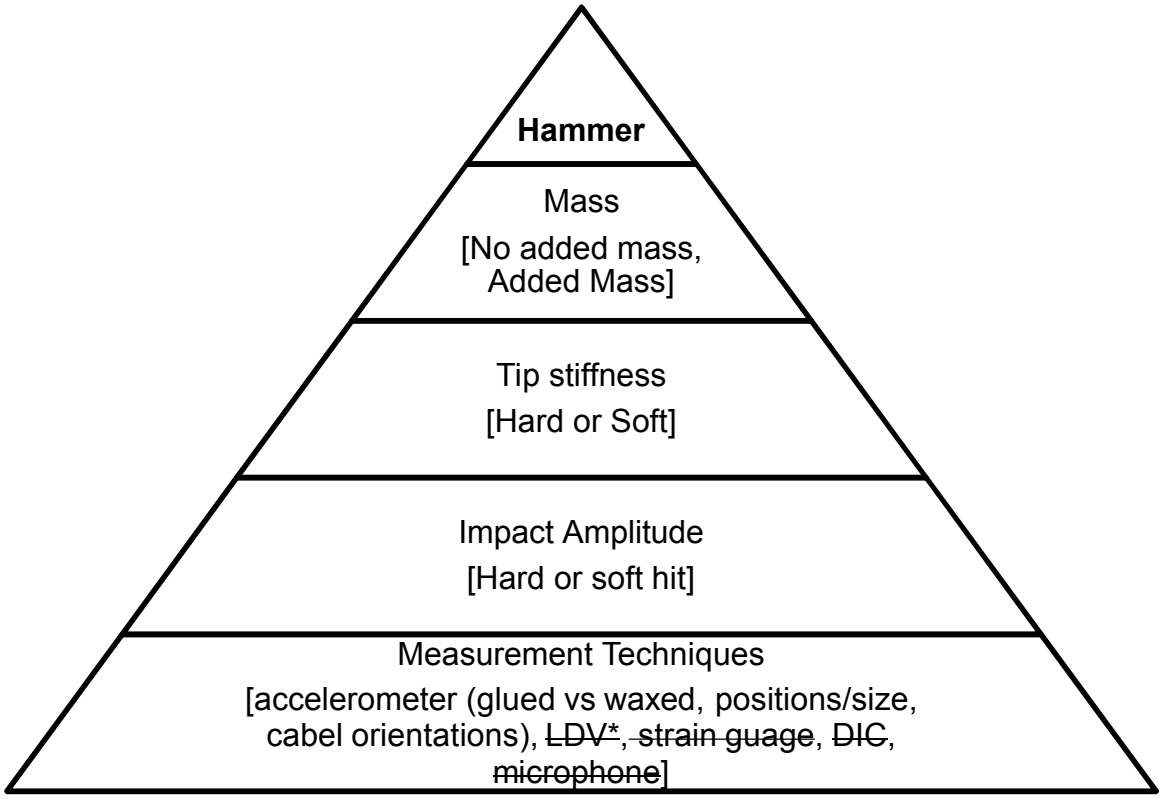
How manufactured?
LASER-cutting?
How polished?

Test strategy/ test plan

Investigation of the effects of…

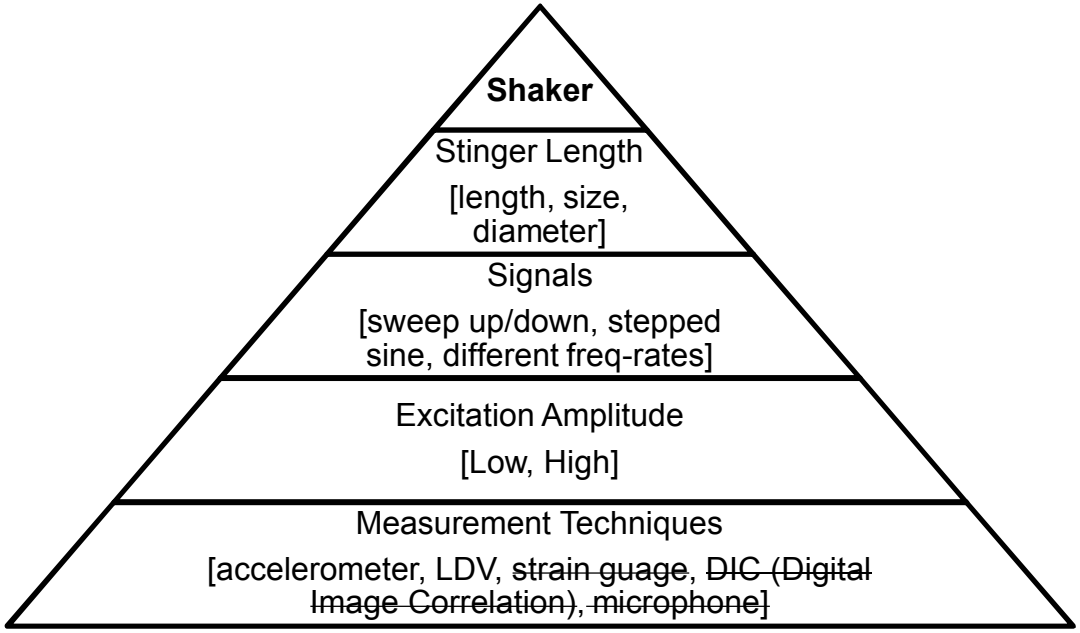
- hammer tips (+ mass)
- metal vs. white tip
- hit amplitude (metal tip)
- bungee length
- bungee position (in vs. out)
- number of sensors at diff locations (2, 4, 6)
- effect of hitting test rig at diff. positions: none
- cable orientation
- waxed vs. glued sensors
- black vs. white bungees

Test plan: impact hammer

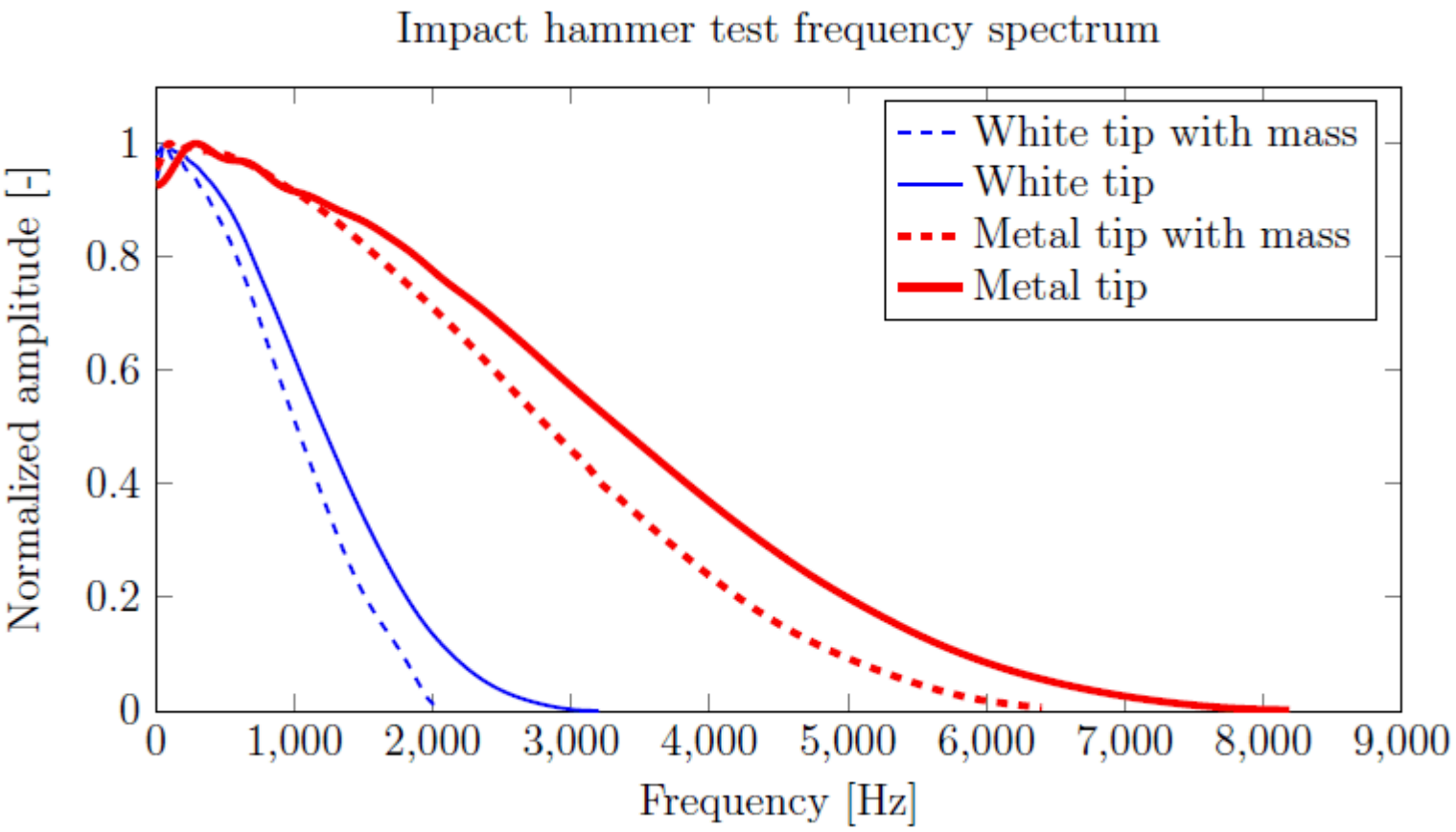


Reasons why some trechniques aren‘t investigated…

Test plan: shaker

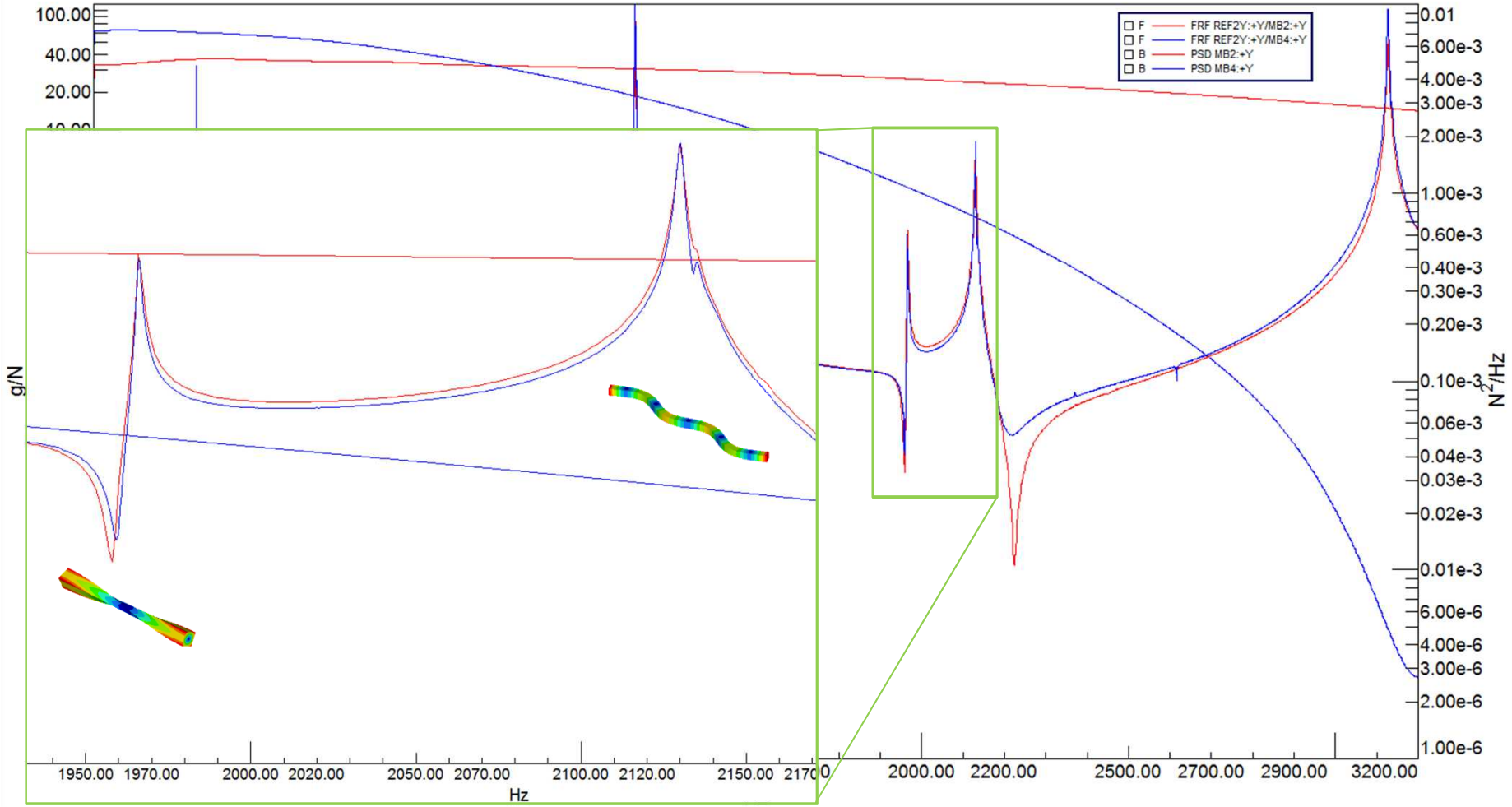


Step 1: getting familiar with the equipment: Tip PSD



- harder tip → wider freq range
- added mass (+75g) → lower freq range

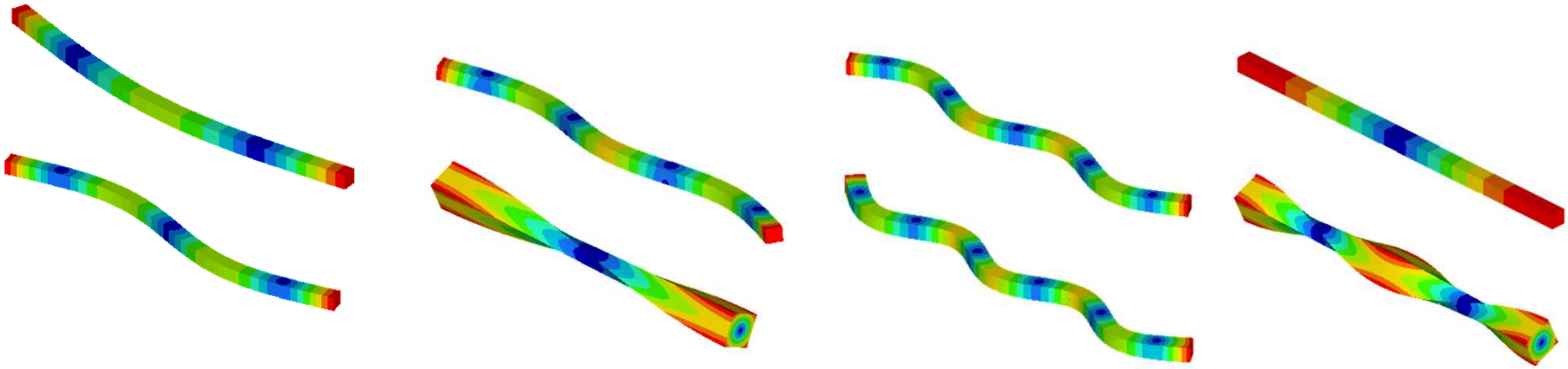
metal vs. white tip



Step 1: Modal Analysis

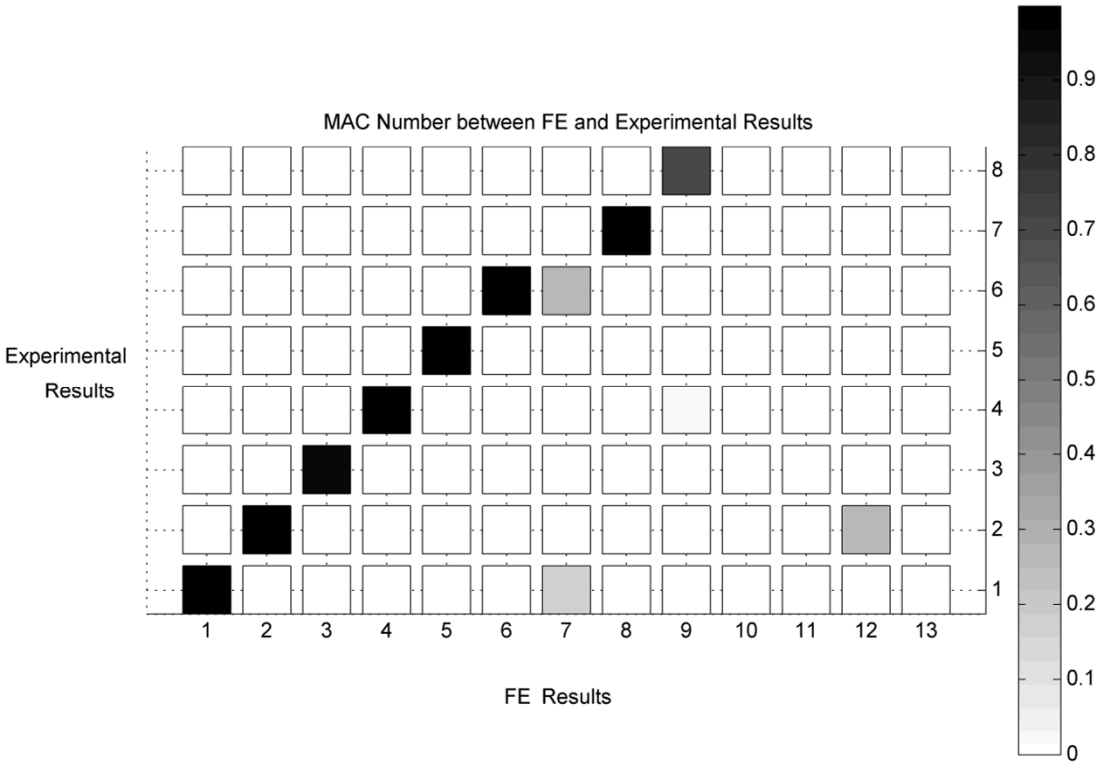
Run HW with same mesh!
Check order in FRF!

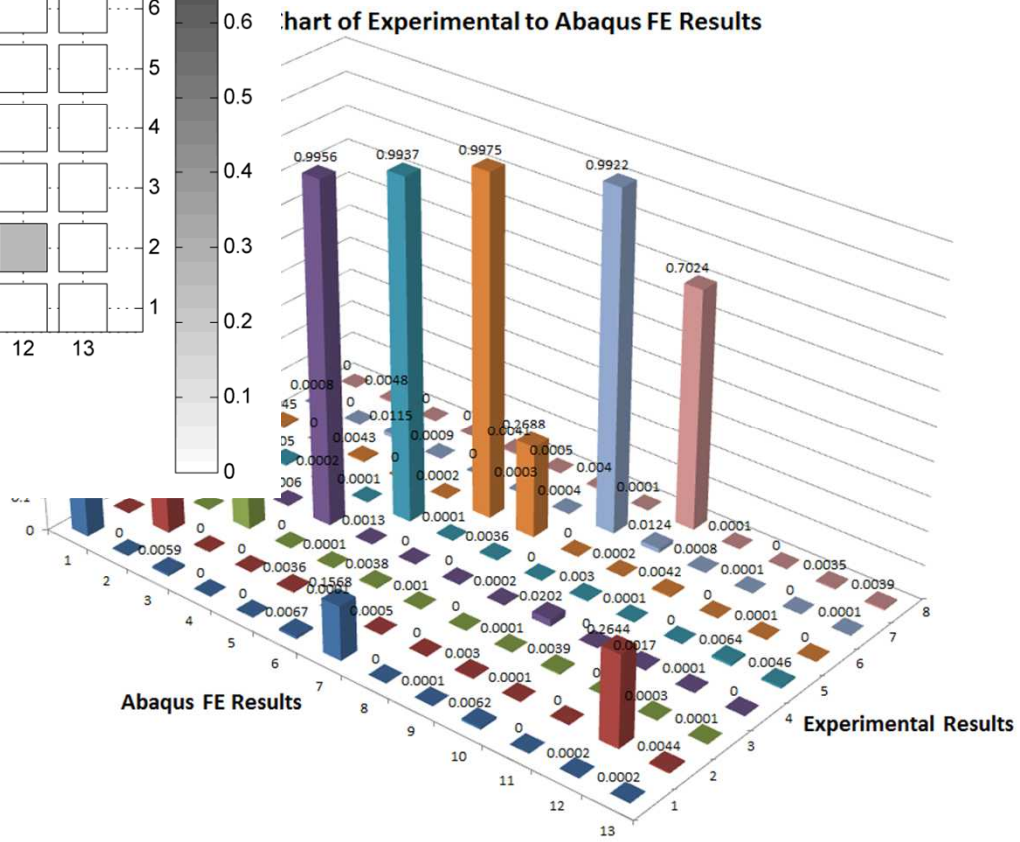
Modal Frequencies								
Mode	**FE (ABAQUS)**		**FE (HW)**		**FE (Calculix)**		**EXP**	
	freq	% Diff	freq	% Diff	freq	% Diff	freq	damp [%]
1st Bending	242,3	-1,61%	247,9	0,65%	242,35	-1,60%	246,3	0.10
2nd Bending	662,5	-1,78%	677,6	0,47%	662,59	-1,76%	674,5	0.04
3rd Bending	1.284,4	-1,84%	1.313,0	0,34%	1285,40	-1,77%	1.308,5	0.03
1st Torsional	1.932,1	-1,68%	1.982,7	0,90%	1946,64	-0,94%	1.965,0	0.03
4th Bending	2.091,7	-1,83%	2.138,0	0,34%	2092,81	-1,78%	2.130,7	0.04
5th Bending	3.068,3	-1,87%	3.136,0	0,30%	3070,17	-1,81%	3.126,8	0.04
1st Longitudinal	3.331,1	-	3.330,8	-	3331,18	-	not picked up	-
2nd Torsional	3.864,4	-1,72%	3.967,1	0,90%	3893,45	-0,98%	3.931,8	0.05



Modal Analysis

2D-plot of MAC-nr??!!
Formula for MAC?

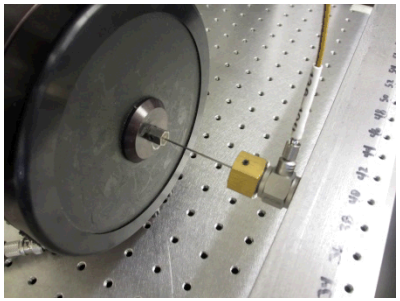


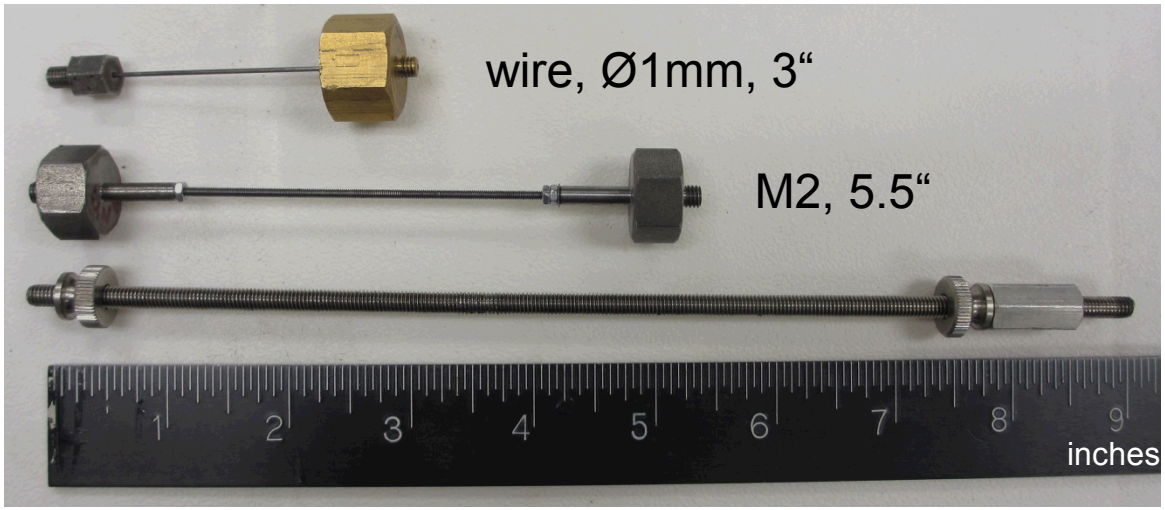


More modes!

Stinger investigation

- thickness
- length
- material?





10/32 UNF, 9“ & 18“

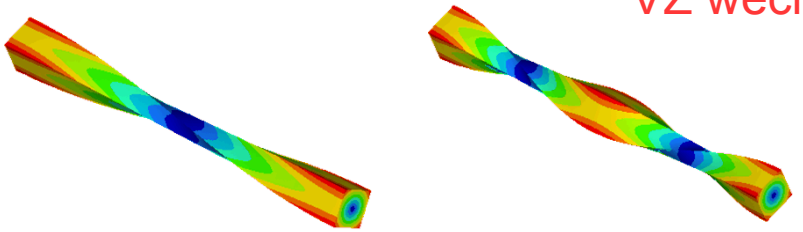
Multiple sensors

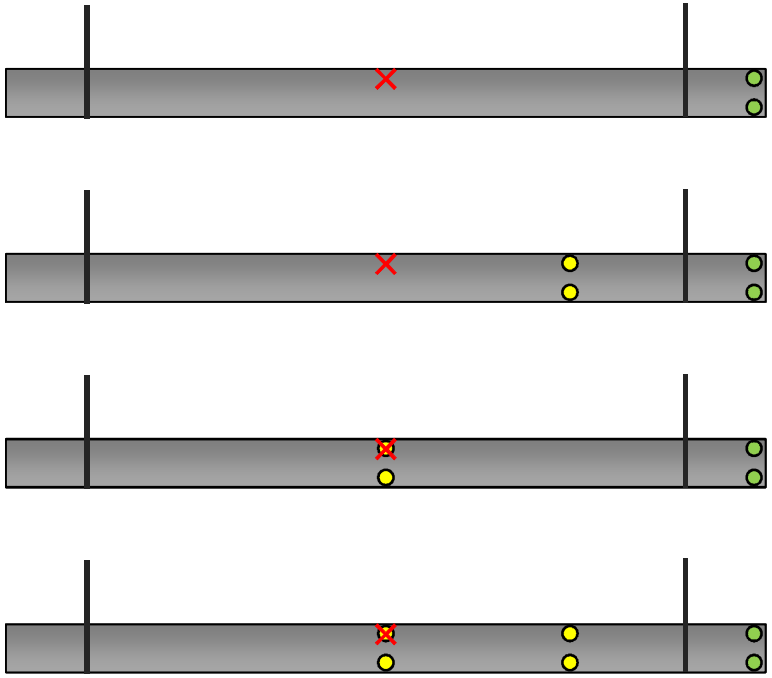
Explanation of damping changes??

- Dummies placed in the nodes of the torsional modes (red)

	no dummies		all 4 dummies		delta_f	delta_d
Mode Nr	freq	damp (%)	freq	damp (%)		
1	246,328	0,04	245,883	0,04	0,18%	0,00%
2	673,898	0,04	672,564	0,05	0,20%	-25,00%
3	1307,751	0,03	1301,512	0,03	0,48%	0,00%
4	1963,698	0,05	1953,256	0,05	0,53%	0,00%
5	2129,388	0,04	2127,019	0,04	0,11%	0,00%
6	3125,132	0,06	3114,592	0,07	0,34%	-16,67%
7	3930,293	0,07	3886,863	0,04	1,11%	42,86%
8	4280,148	0,04	4266,559	0,05	0,32%	-25,00%
9	5573,527	0,07	5545,578	0,06	0,50%	14,29%
10	5901,333	0,05	5865,952	0,05	0,60%	0,00%
11	6895,007	0,06	6969,186	0,07	-1,08%	-16,67%
12	6990,658	0,06	7659,553	0,05	-9,57%	16,67%
13	7861,133	0,04	7906,089	0,06	-0,57%	-50,00%

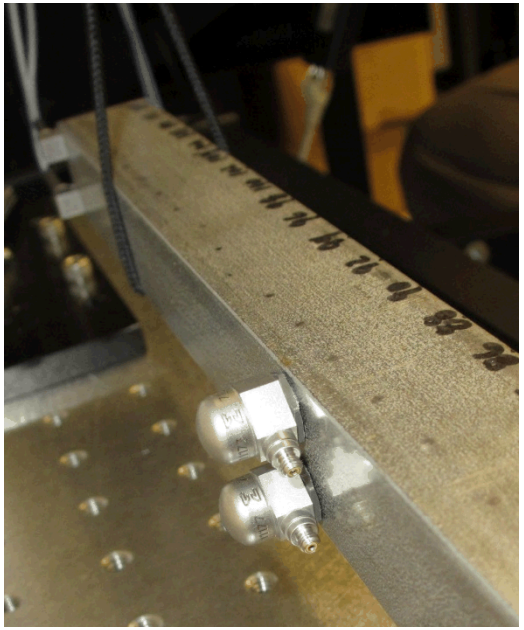
VZ wechseln!





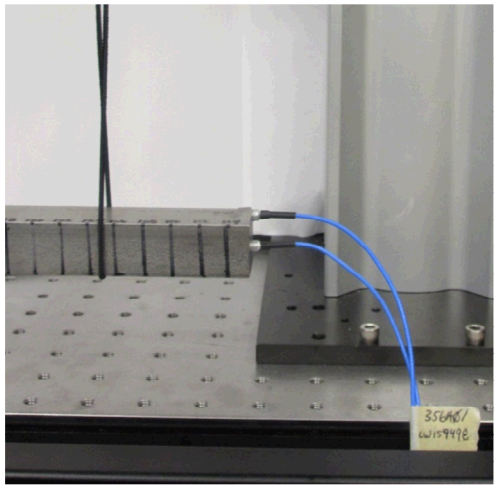
accel-dummy (5g each)
meas. accel.
impact point

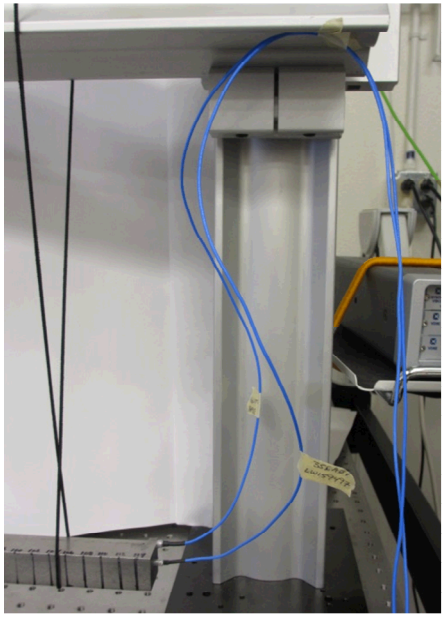
FRF multiple sensors

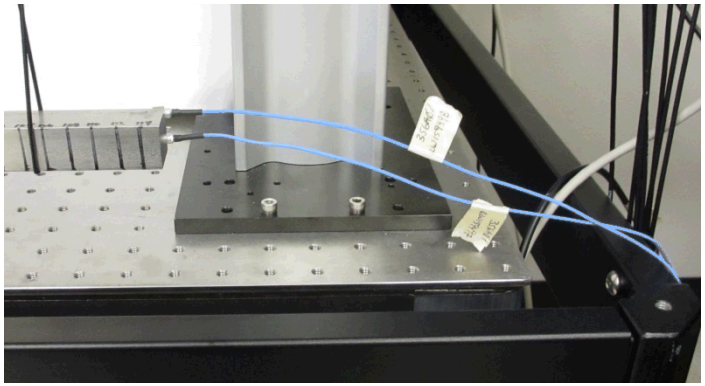


Sensor cable orientation

- up
- down
- middle



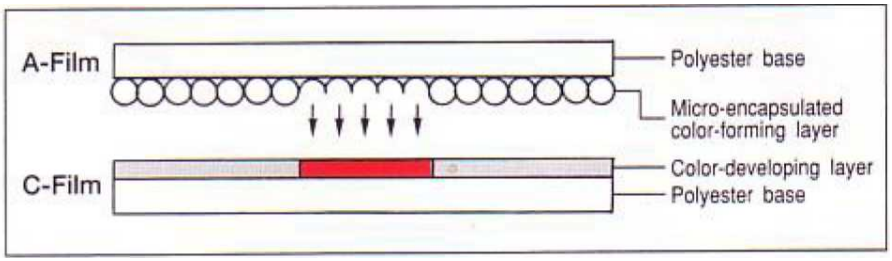




- Influence of… = high/ med/ low/none… effect
- Table/matrix

Investigation of different effects on pressure distribution in beam interface

- Used beam pairs:
  - Rough-rough (2x)
  - Mirror-mirror/ high polish (1x)
  - Mixed (rough-mirror)
- Tightening torque
- Tightening order
- Misalignment
- Tightening with clamps (no bolts)
- Used films: Fuji Prescale … LW & MS !
- General procedure: …



taken from Fujifilm prescale manual

Pairing rough-rough (A3/B3)

- rough-rough (A3/B3):
  - diff. tightening torques
  - diff. tightening orders
  - diff. pressure sensitive films (Low, Mid)

Plots tightened with c-clamps on the edges! -> bending effect vs. Middle bolt effect!

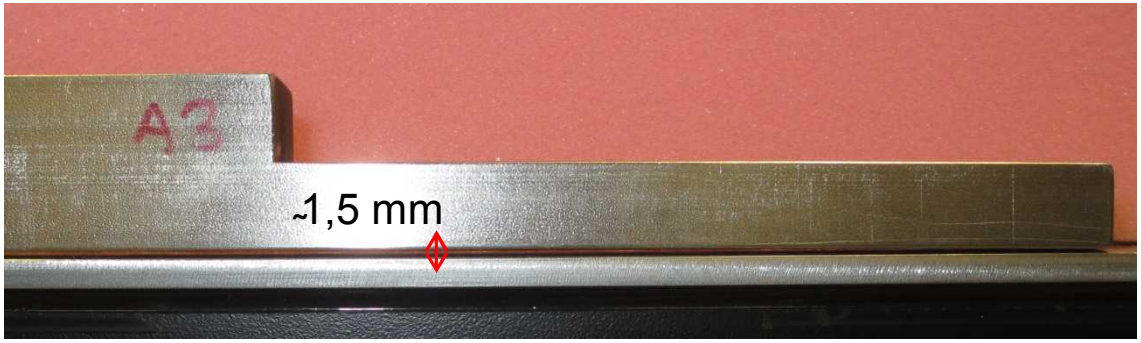
→ Results show…

…a strong dependency on tightening order,

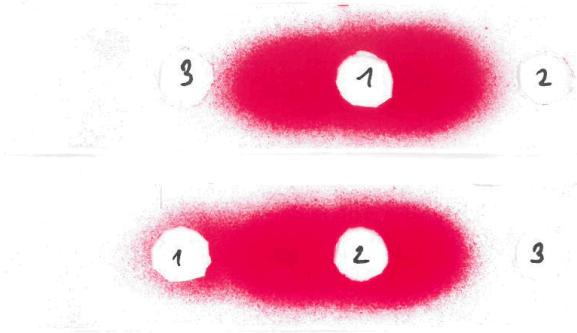
…pressure concentrated around the bolts,

…no contact radius outside the outside bolts

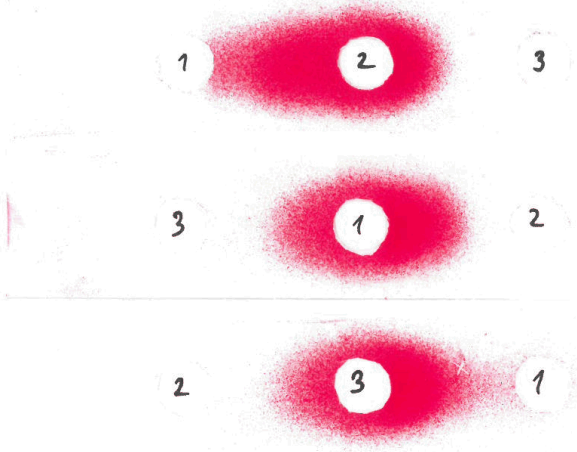
- Problem: opposite curvatures in rough beams at interface



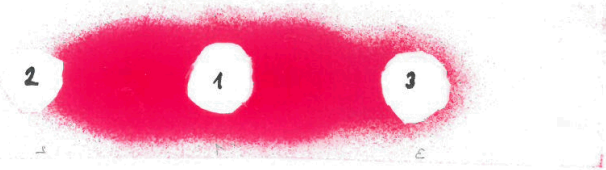
A3/B3 ; 10 Nm (h→f) ; CW ; 0



A3/B3 ; 5 Nm (h→f) ; CW ; on beam ;

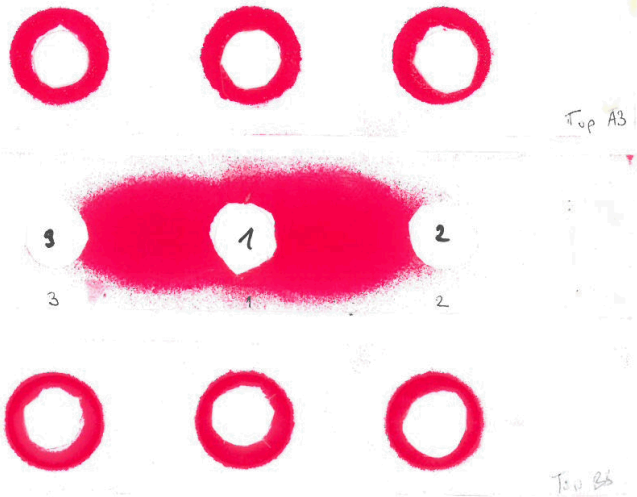


tightening torque: ~8.4 Nm (middle bolt ~8,2 Nm) ; double checked ; ~2 min
used films: Fuji Prescale CW ; T ≈ 68°F ; full torque



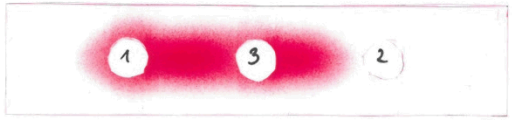
same test ; all 8.4 Nm ; on beam (=aligned) ; 05.08.14 ; full torque

A3/B3 ; 7,4 Nm ; CW ; 16.02.14 ; 2min ; on foam



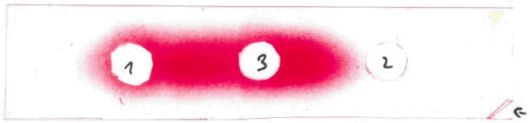
A3/B3 ; 20 Nm (half → full t.) ; MS ; 72°F ; 29.07.14 ; foam

A3/B3 ; 8 Nm (h→f) ; ; foam



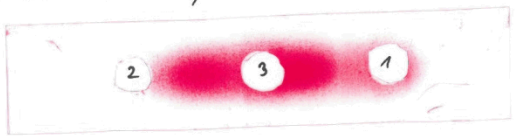
A3/B3; 15 Nm (h→f) ; foam

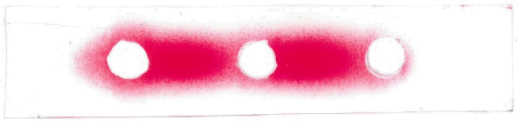
1 3 2



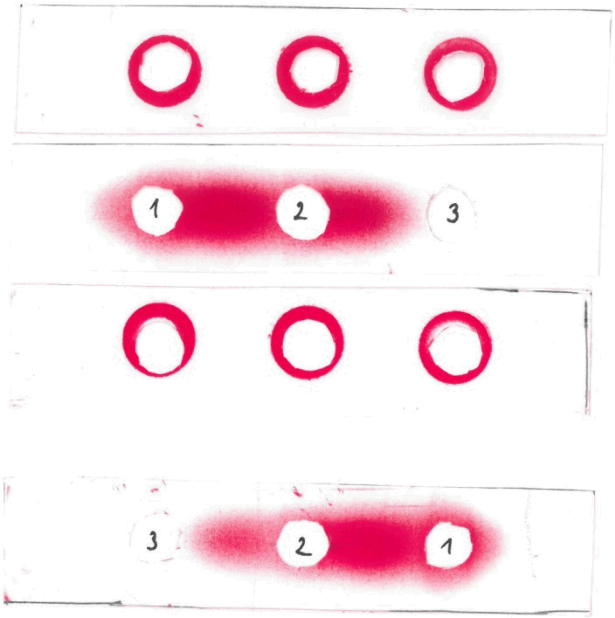
← not part of measurement!

A3/B3; 8 Nm (h→f) ; foam

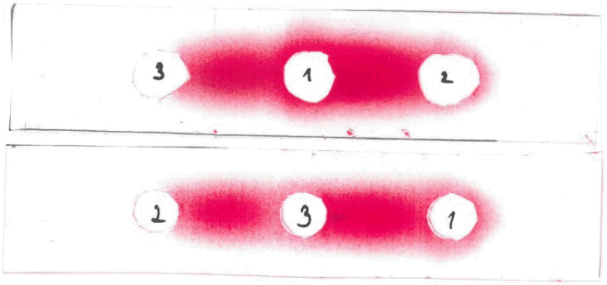




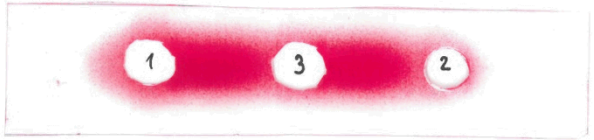
A3/B3 ; 8 Nm ; new silver wrench ; 22.02.14 ; 2min ; MS ; 69°F ; foam full torque



" ; 15 Nm ; — " — ; full



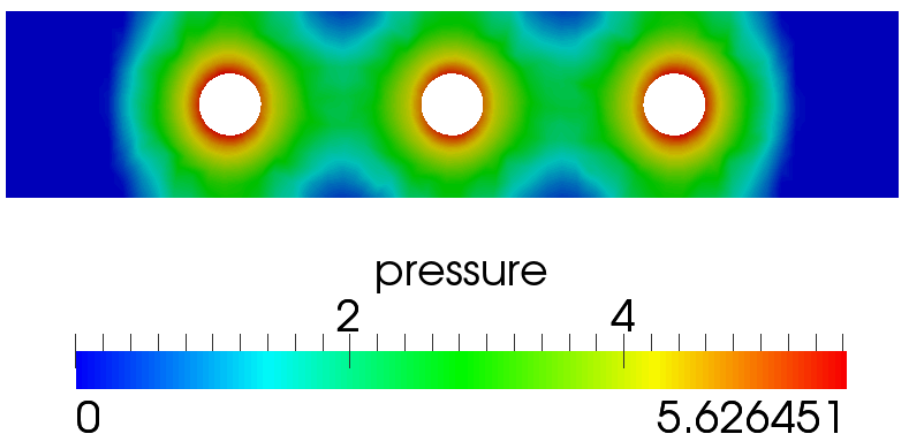
— ; 20 Nm ; — " — ; full

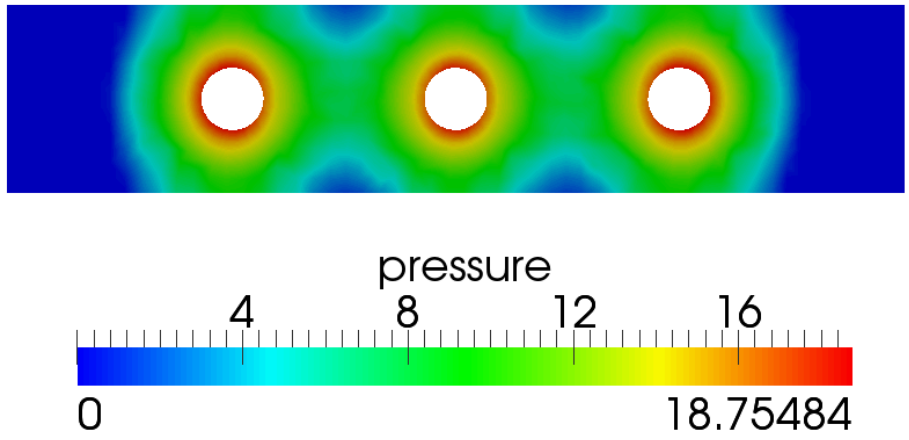


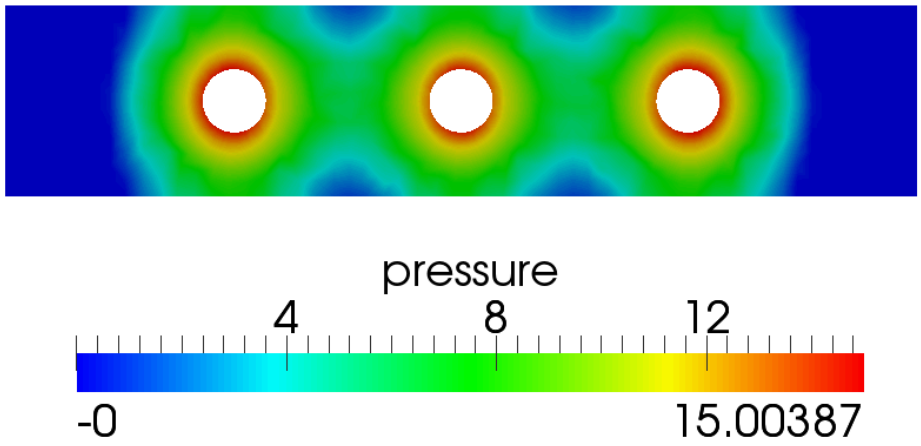
Pressure plot: FE vs. test

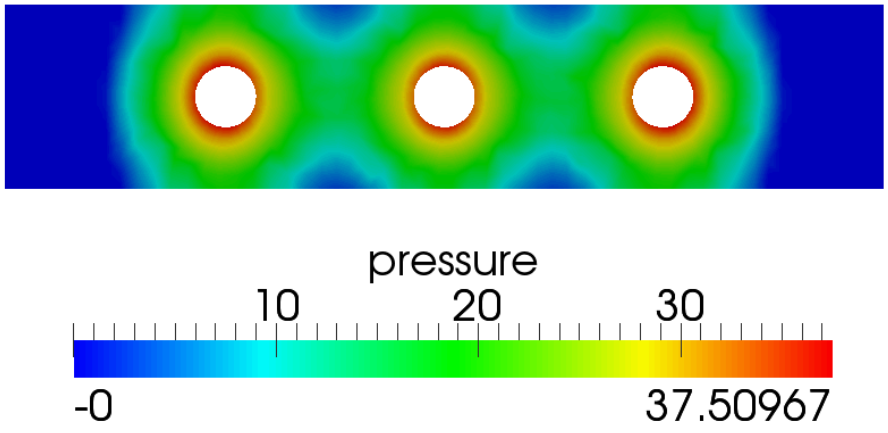
FE plots from Loic

- Simulation in Code-Aster:
  Augmented Lagrangian method
  Coefficient of friction : 0.3



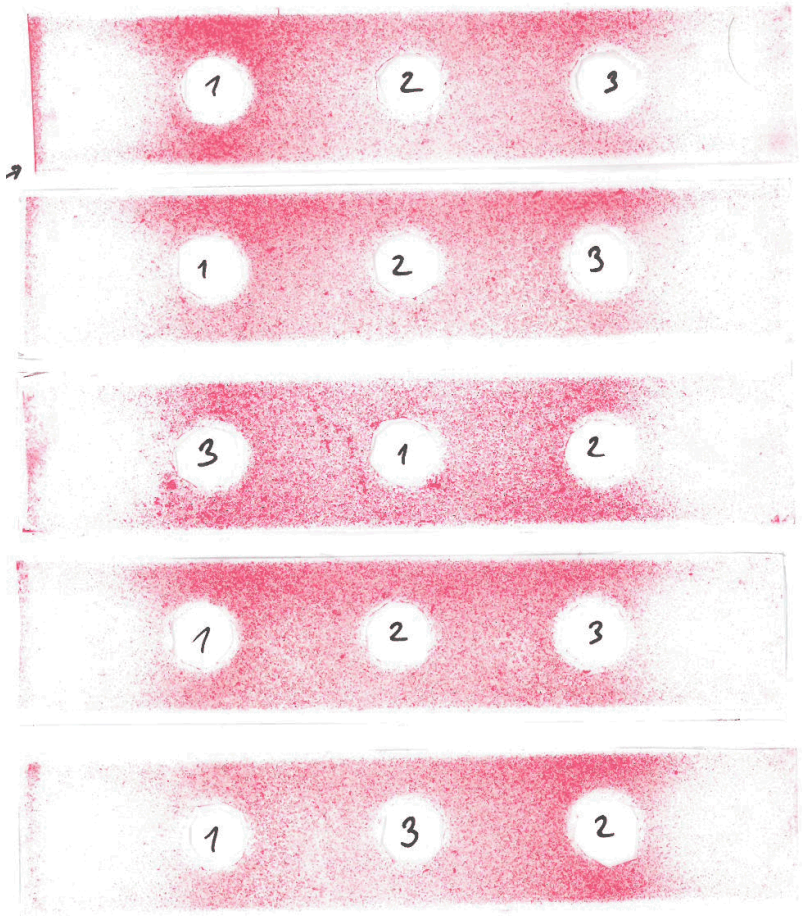




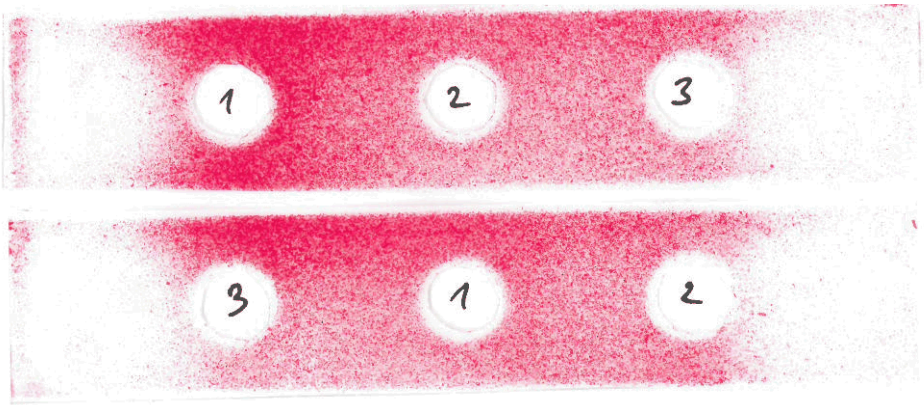


Pressure plots: mirror-mirror (A4/B4)

- 5 Nm (h → f), LW, aligned



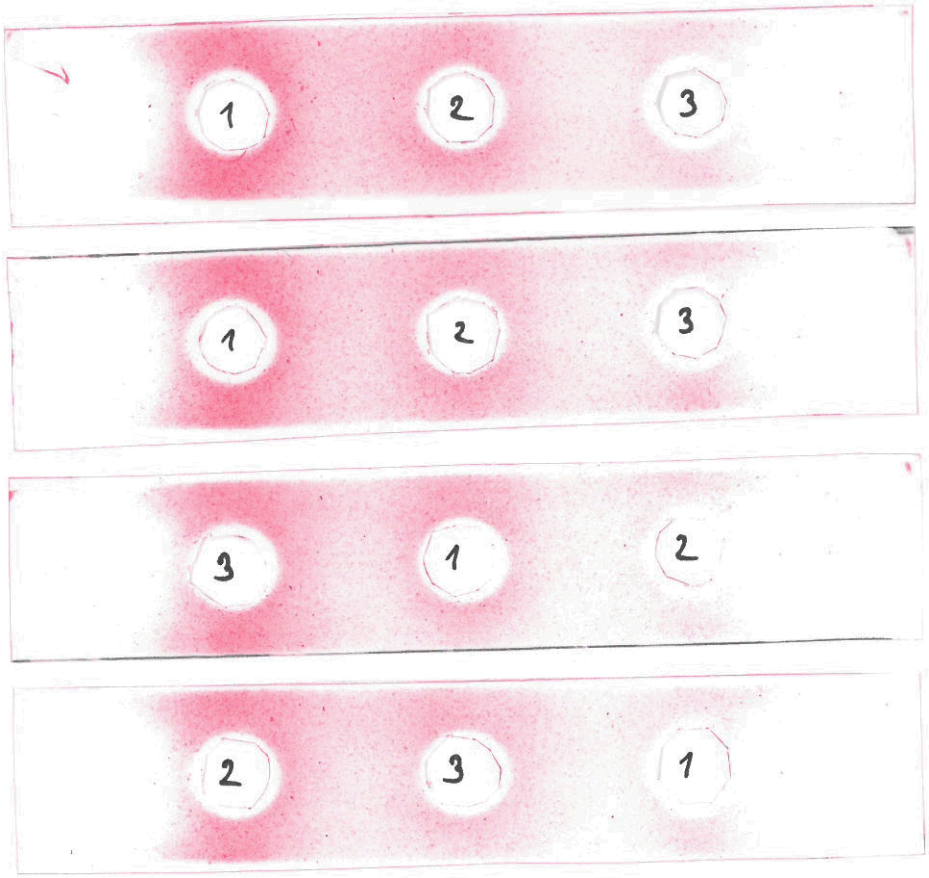
- 10 Nm (h → f), LW, aligned



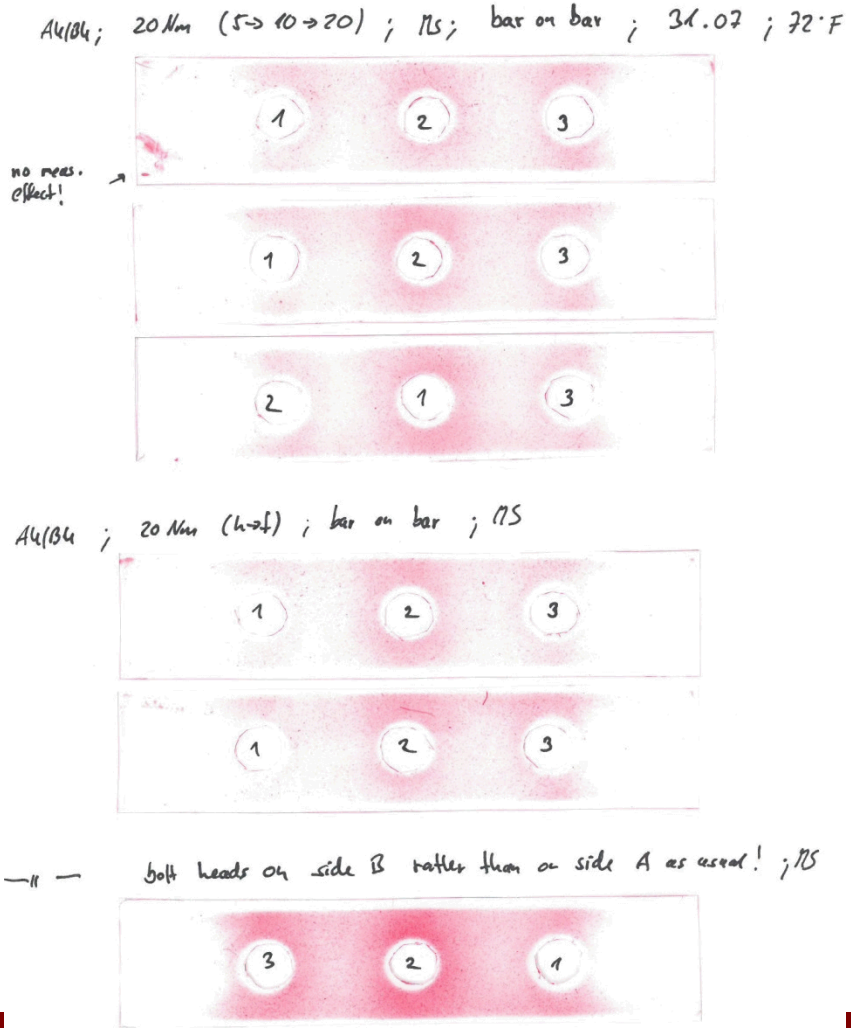
- 20 Nm (h → f), LW, aligned

Pressure plots: mirror-mirror (A4/B4)

- 20 Nm (h → f), MS, aligned

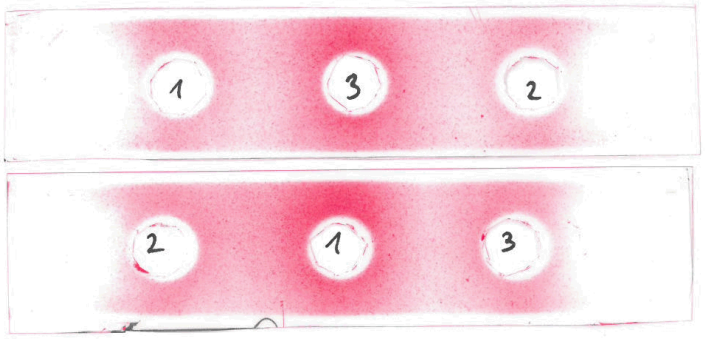


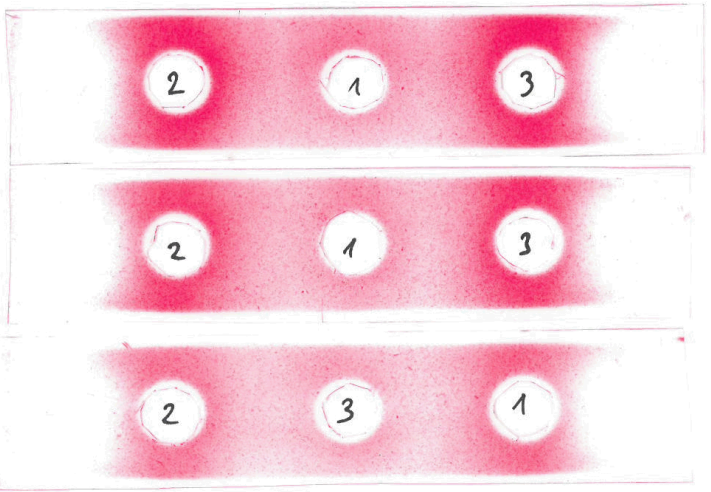
- 10 Nm (h → f), LW, aligned



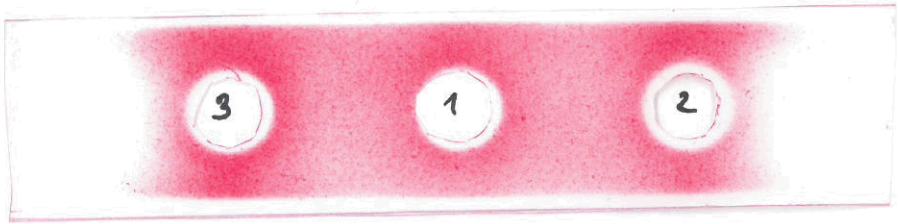
- Misalignment appr. 1-2°

; 20 Nm (h→f) ; foam ; MS ; 29.07

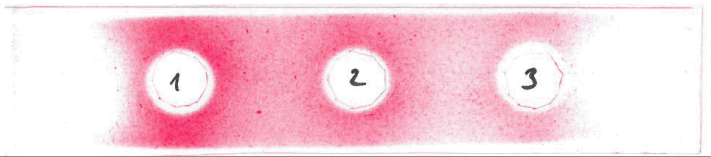




A4/B4 ; 25 Nm (h→f) ; foam ; 29.03 ; MS ; max. torque!



on foam (= misalignment $\alpha \approx 1°$)

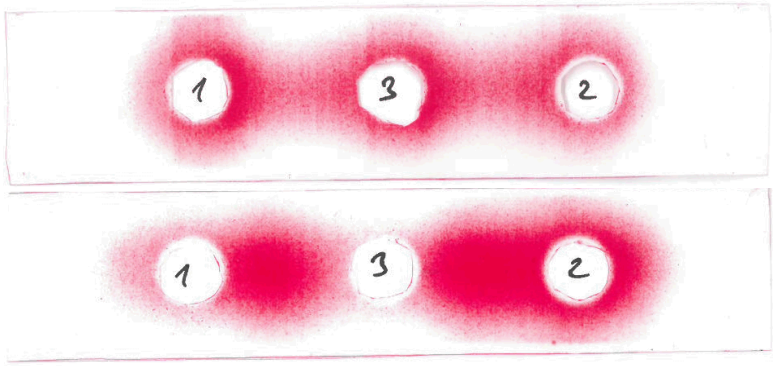


Pressure Plots XY

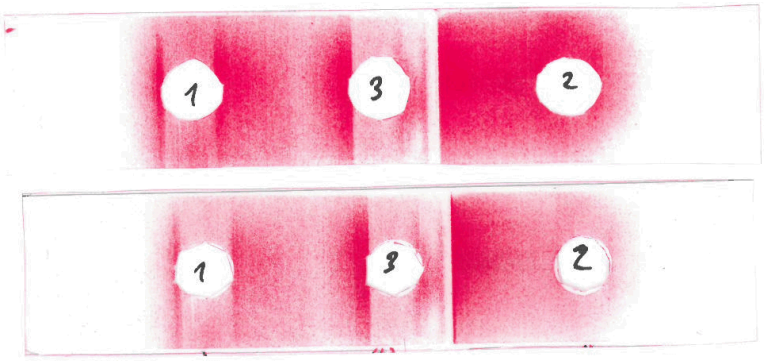
include beam int pics!

- Mixed, **20Nm** (h → f), MS, aligned
  - A4/B3
  - A3/B4

→ huge variability



- A1/B1, **20Nm** (h → f), MS
- Beam interfaces not well machined
- Machining pattern easily visible in pressure plot
- Consistent for constant tightening order



- Effect at largest f-shifts in BRB force control, those cannot be separated!, diff. Torques:
  - Curvature in interface (contact, no contact)
  - Contact stiffness shanging with diff. Toques (high torque –> higher contact stiffnes expected, rough surf -> higher contact stiff….)
  - Delta f in FRF plots!
  - Repeatability tests! (3Nm, 5Nm, 10Nm), all of them again!

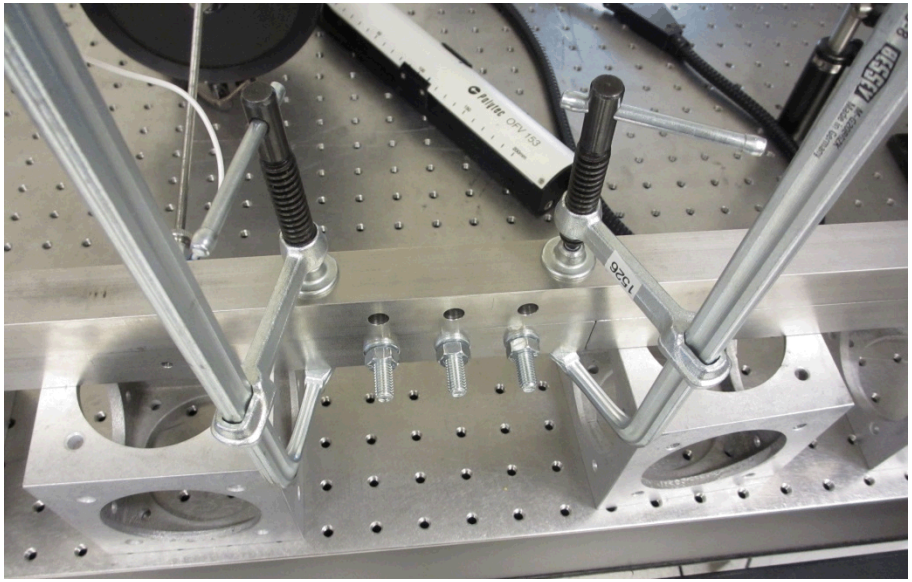
Pairing rough-rough (A1/B1)

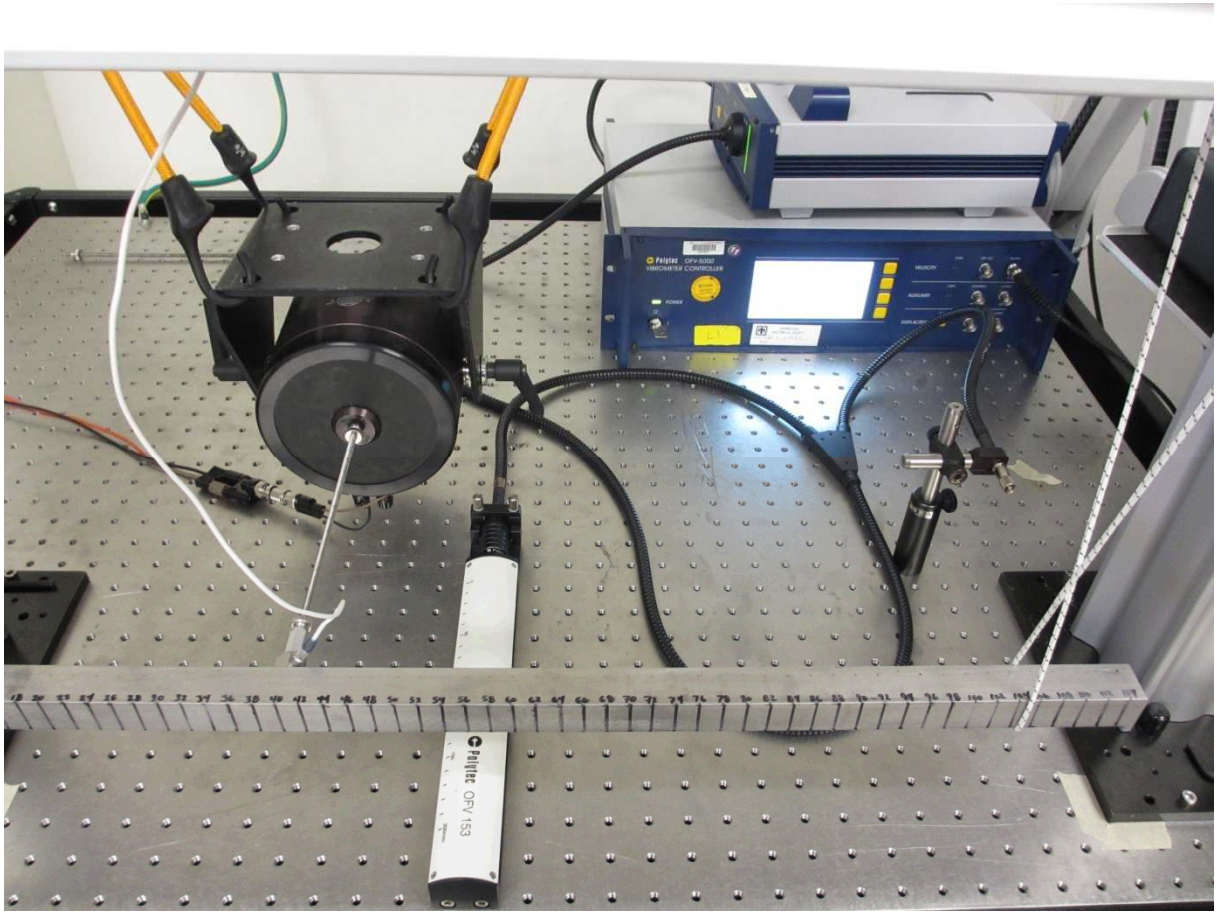
- A1/B1, 20Nm (h → f), MS
- Beam interfaces not well machined
- Machining pattern easily visible in pressure plot

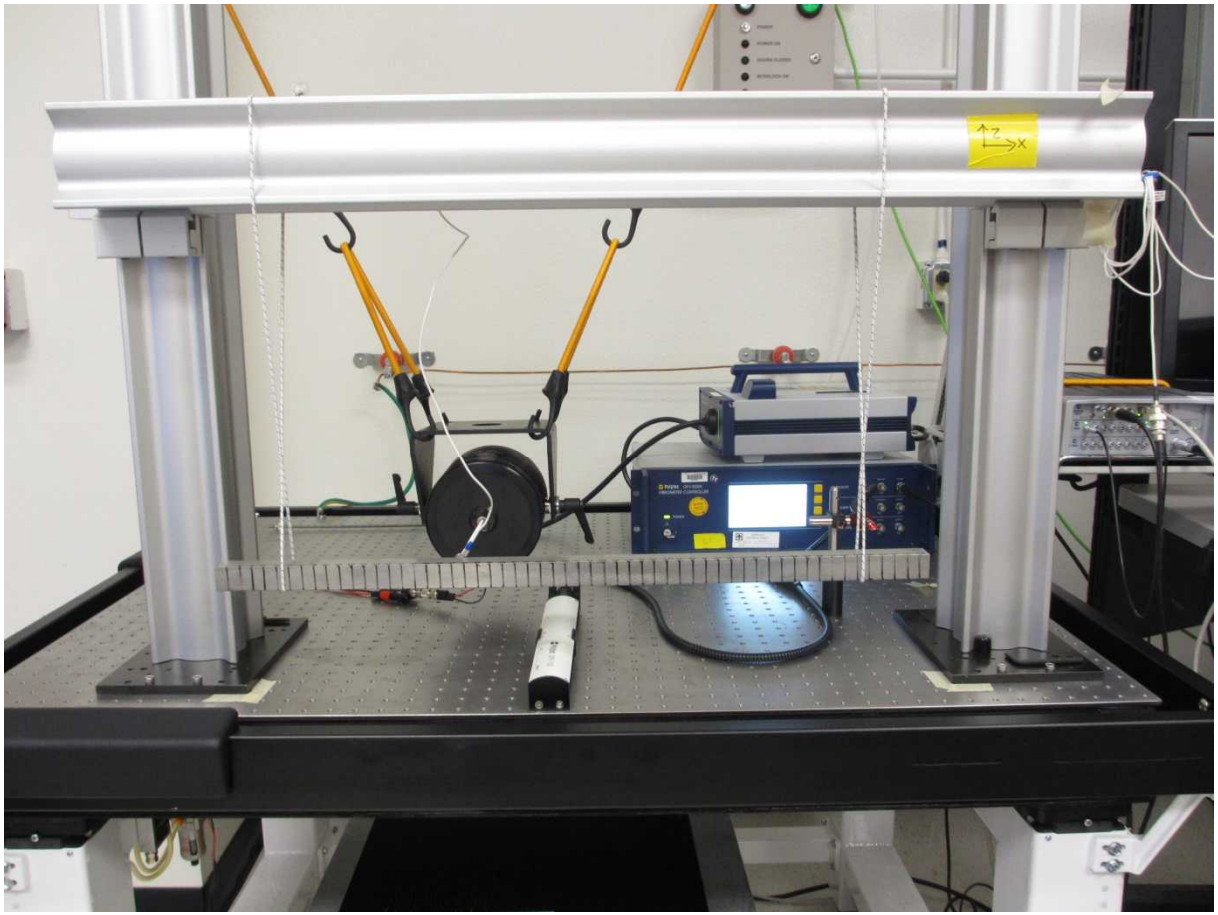
Overall findings

- No contact in area near the interface edges
- Area around middle bolt always in contact
- Bending/ curvature has a huge impact on pressure distribution
  - Beam doesn‘t straighten after all bolts are tightened
- Medium pressure value…
  - Rough: 5Nm, 10, ….
  - Mirror:
  - Mixed: range…

Comparison plots vs. FE-sim


OPV153
1326


Polytec
OFV-5000
VIBROMETER CONTROLLER
Polytec OFV 153


z
x

Pressure distribution plots

→ influence on FRF-measurement?

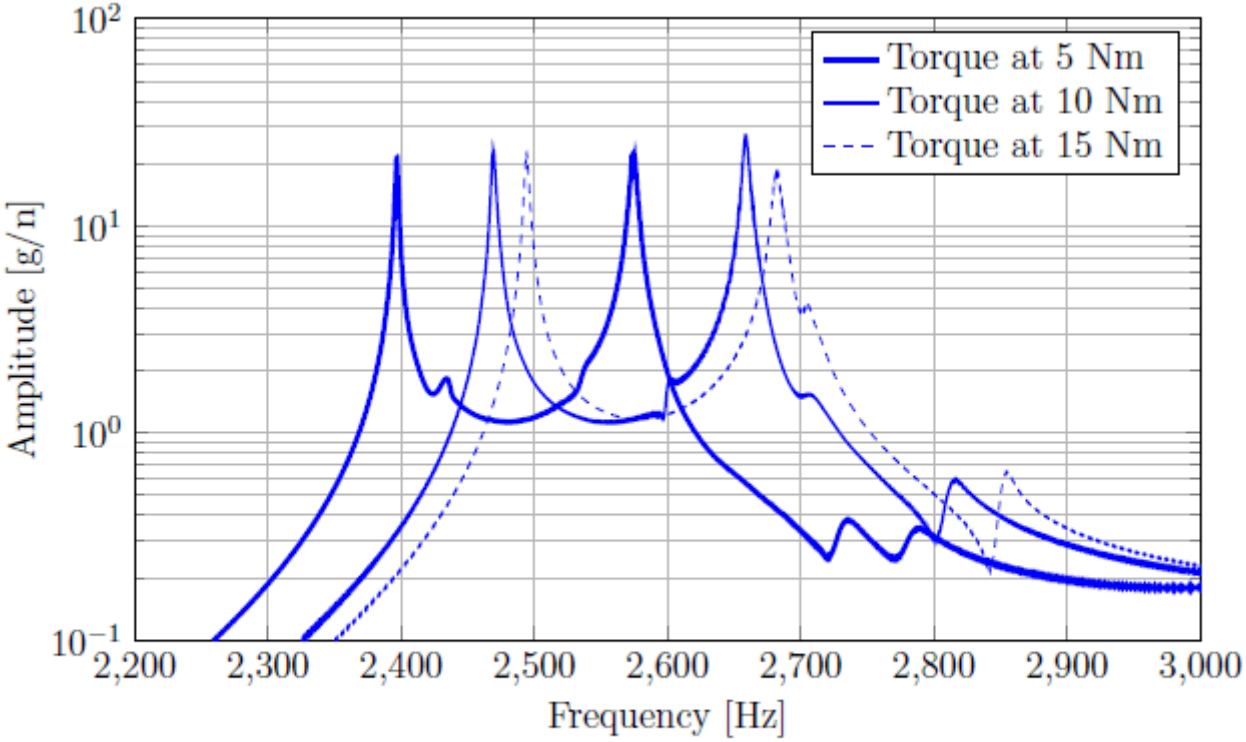
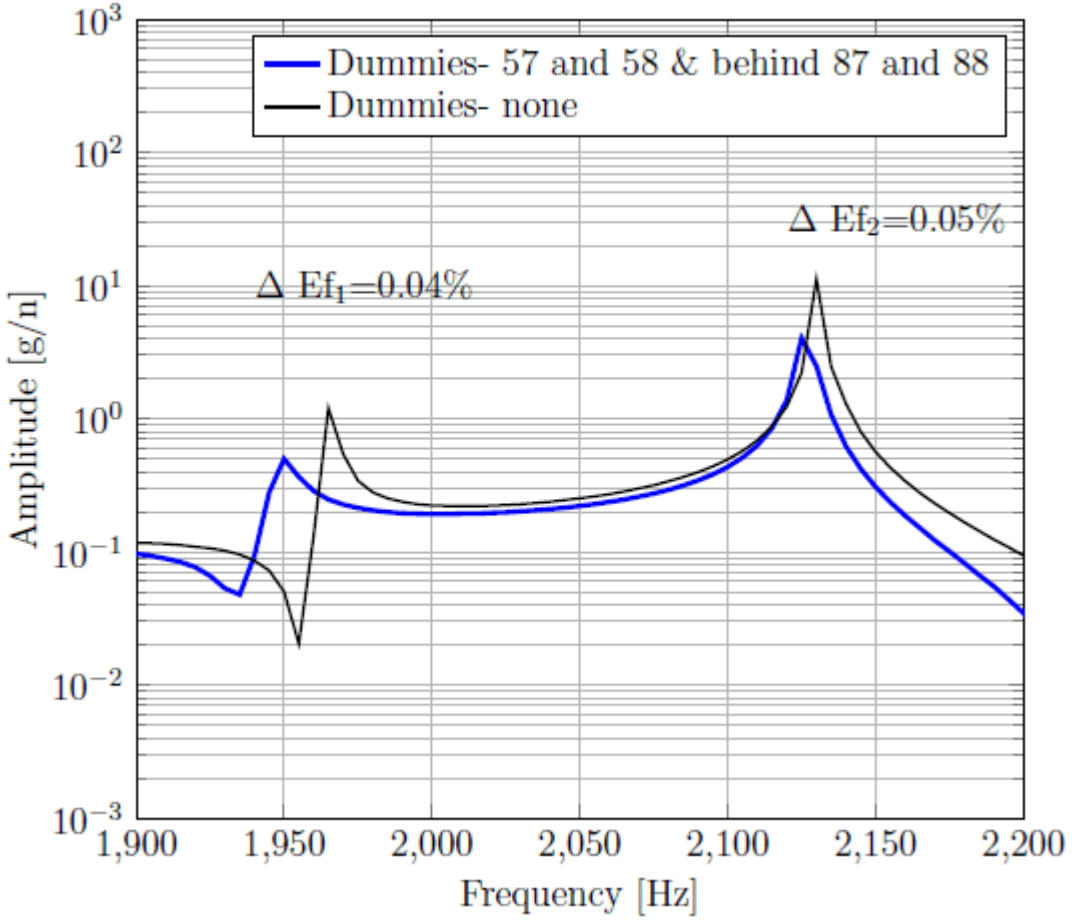
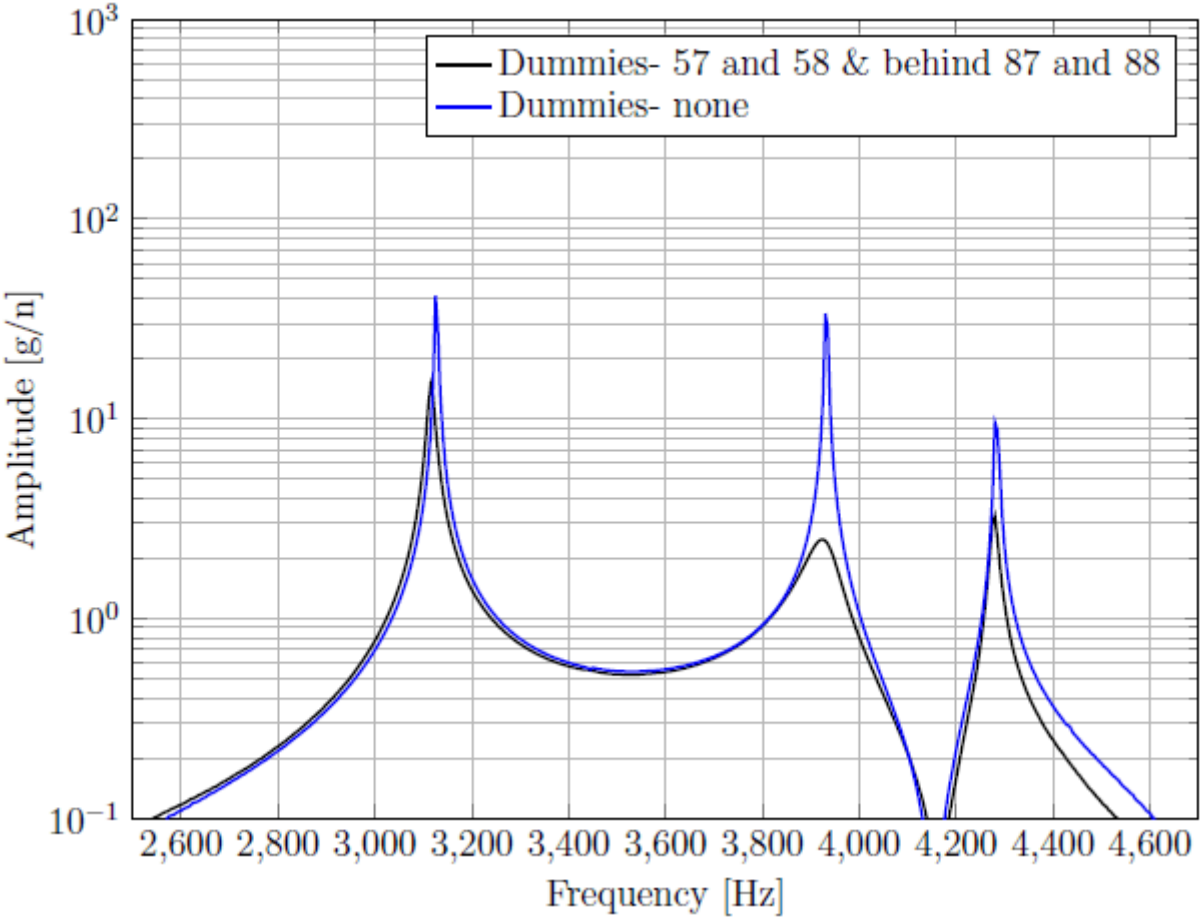
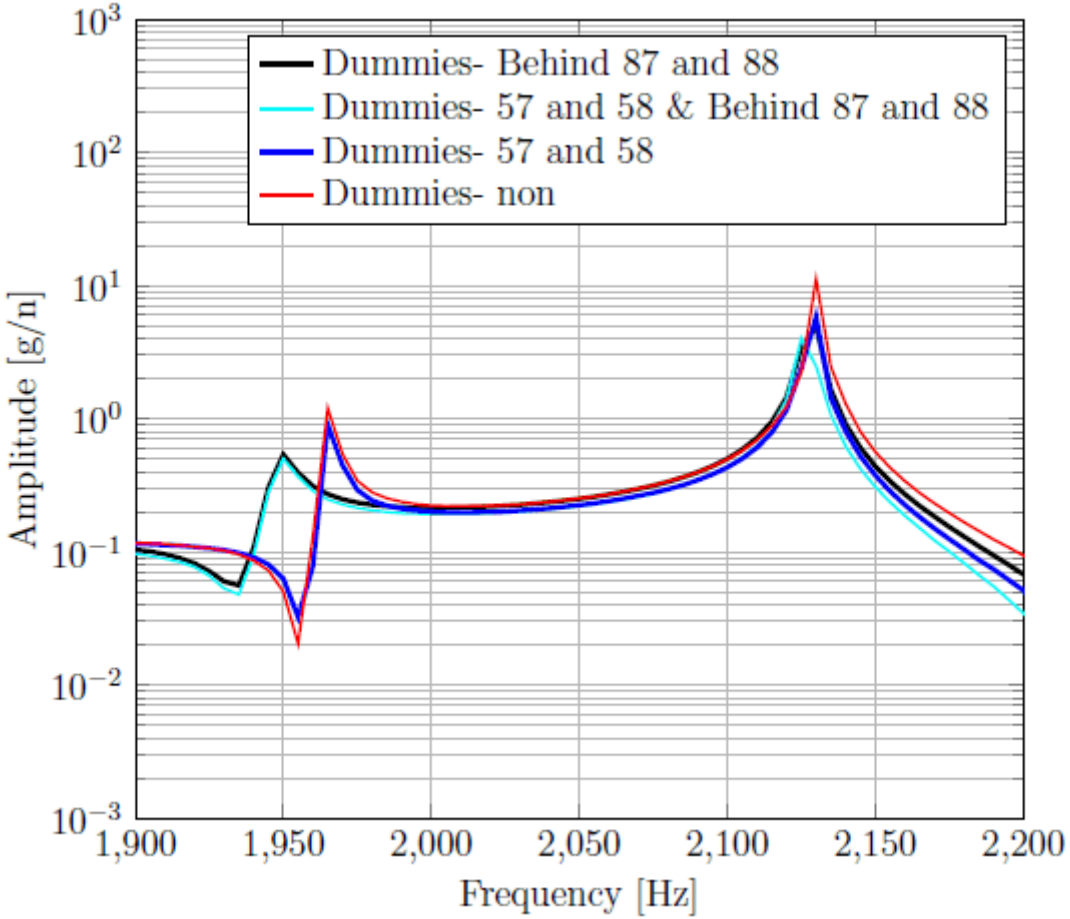


Figure 2: Brake-Reuß Beam forced response using diferent torques


Dummies- 57 and 58 & behind 87 and 88
Dummies- none
Δ Ef2=0.05%
Δ Ef1=0.04%
Amplitude [g/n]
Frequency [Hz]
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
1,900
1,950
2,000
2,050
2,100
2,150
2,200


Dummies- 57 and 58 & behind 87 and 88
Dummies- none
10^3
10^2
10^1
10^0
10^{-1}
Amplitude [g/n]
2,600 2,800 3,000 3,200 3,400 3,600 3,800 4,000 4,200 4,400 4,600
Frequency [Hz]


Dummies- Behind 87 and 88
Dummies- 57 and 58 & Behind 87 and 88
Dummies- 57 and 58
Dummies- non
Amplitude [g/n]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
1,900
1,950
2,000
2,050
2,100
2,150
2,200
Frequency [Hz]

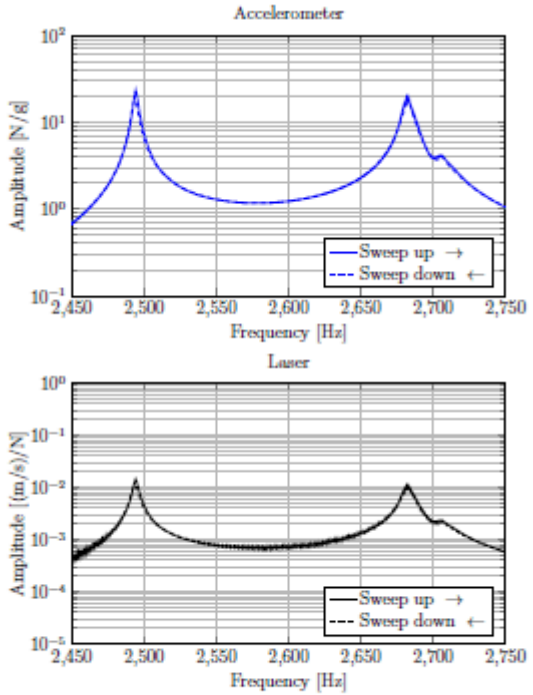
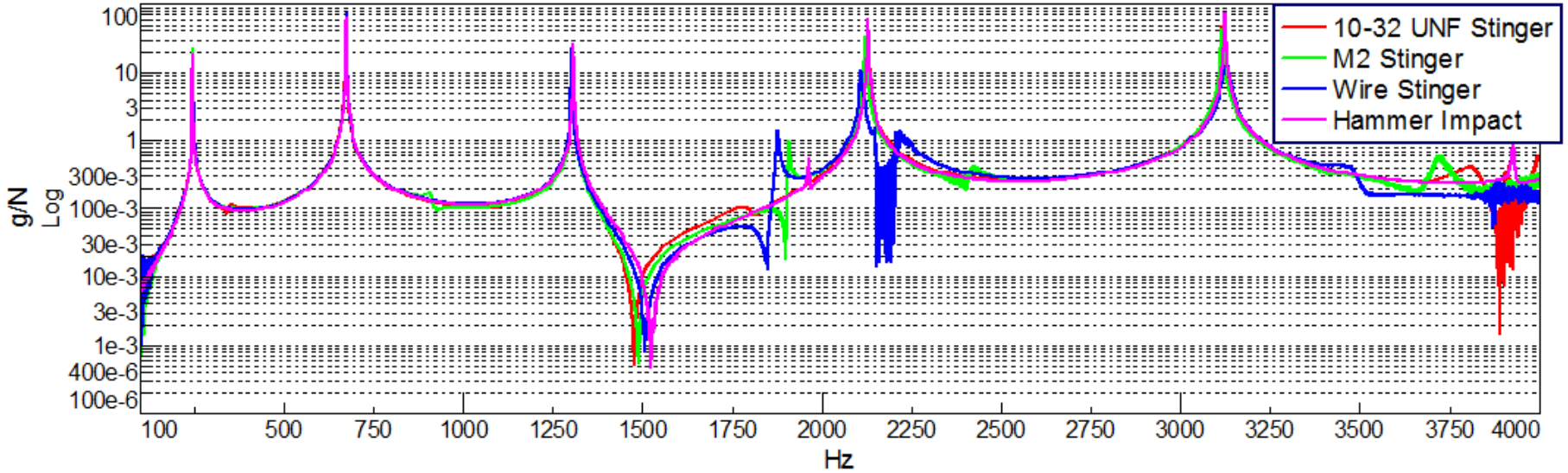
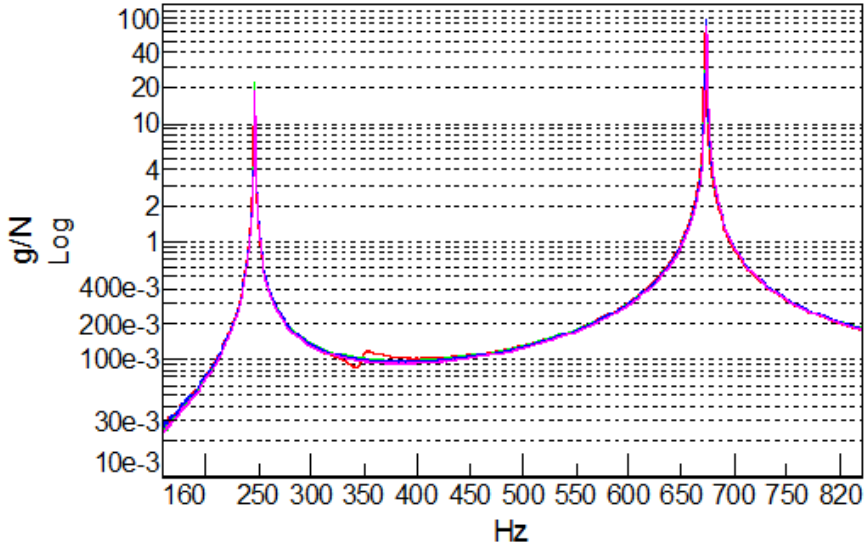
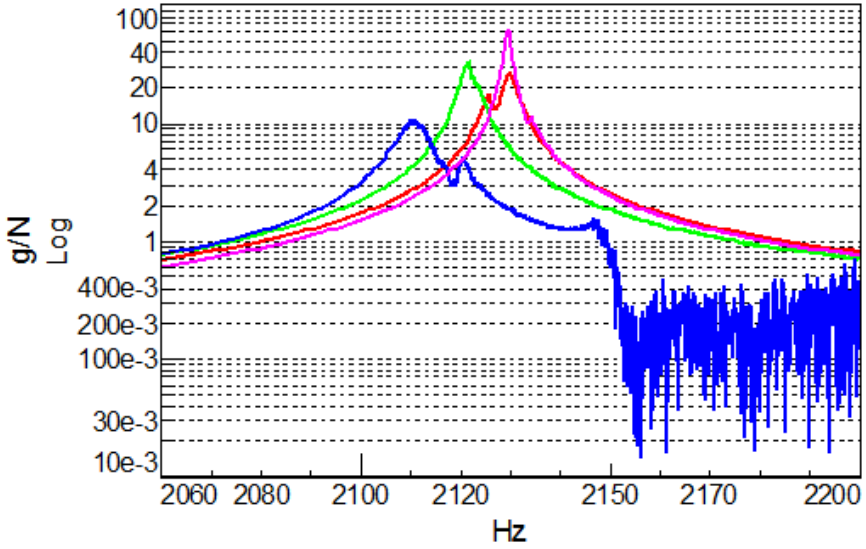


Figure 2: Brake-Reuß Beam forced response(sweep up and down) using accelerometers and laser

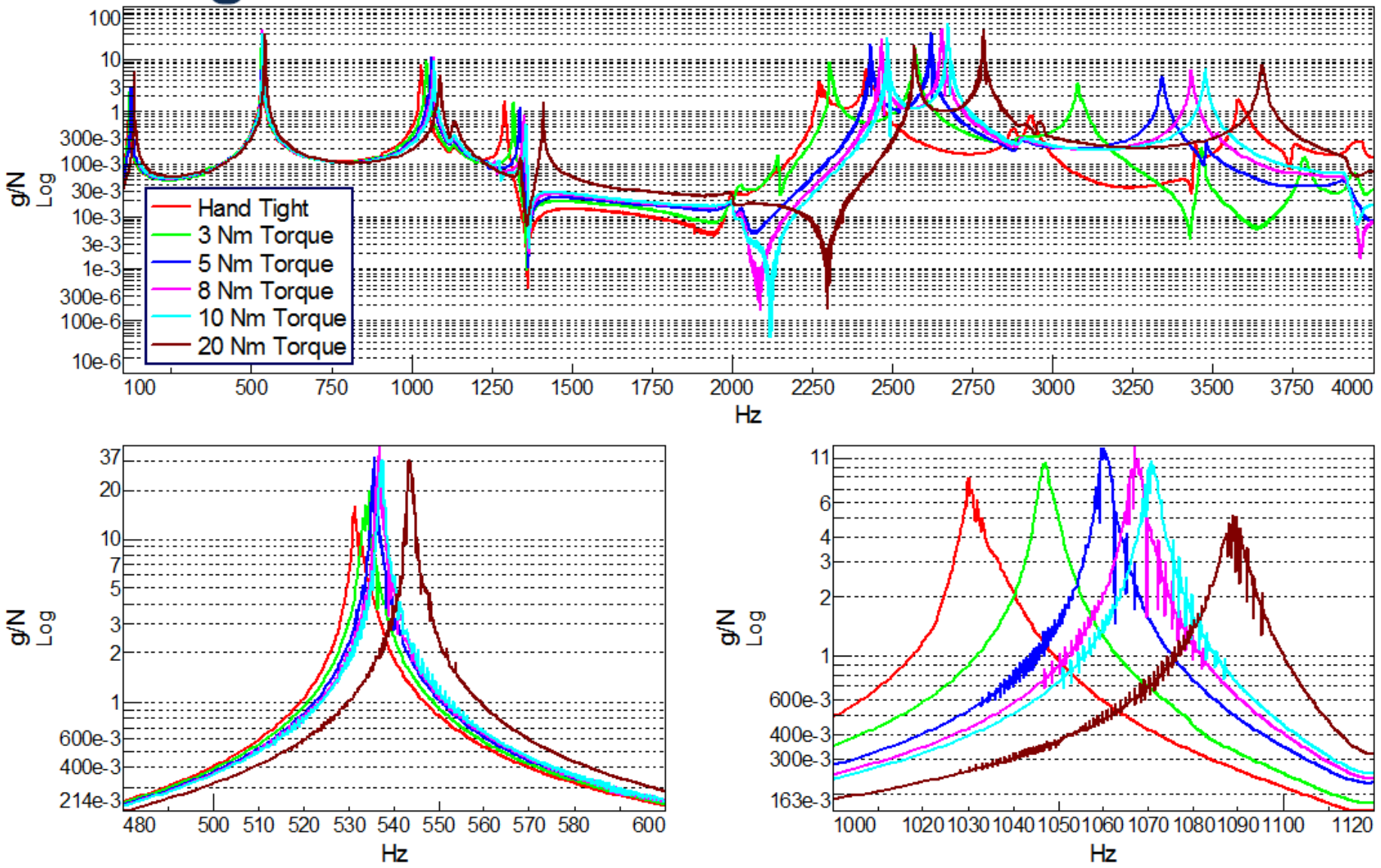
Stinger Test BRB Rough Force Control



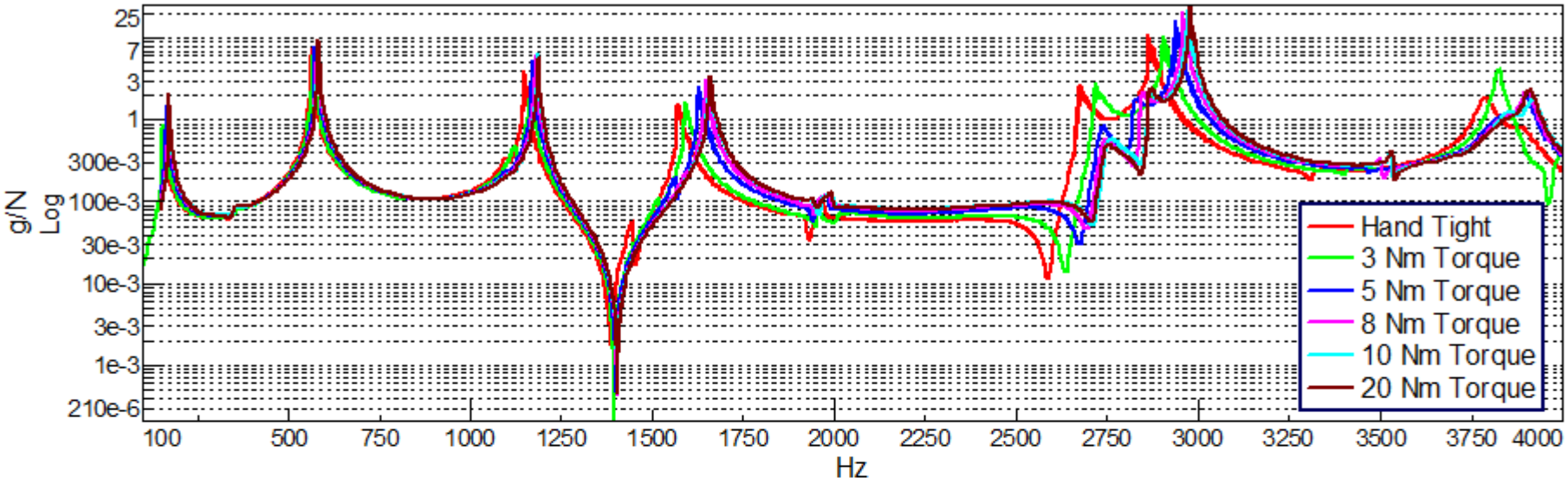


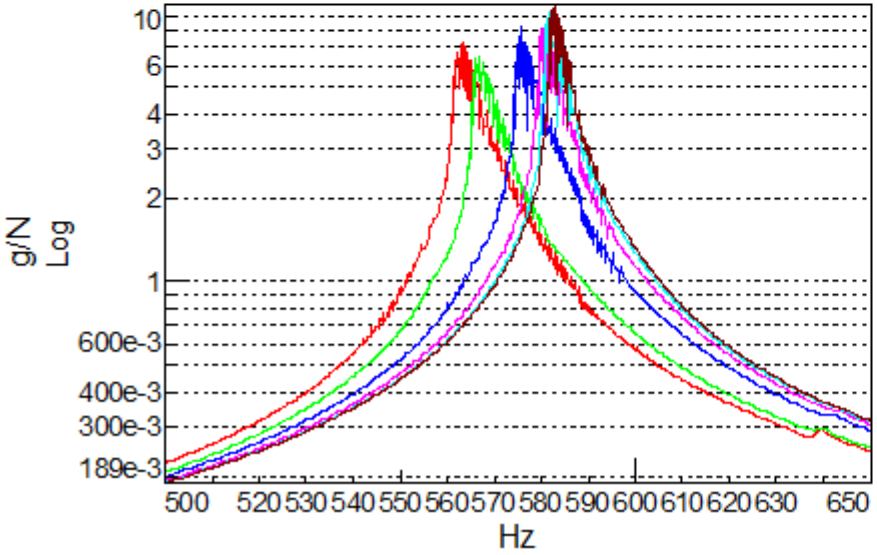


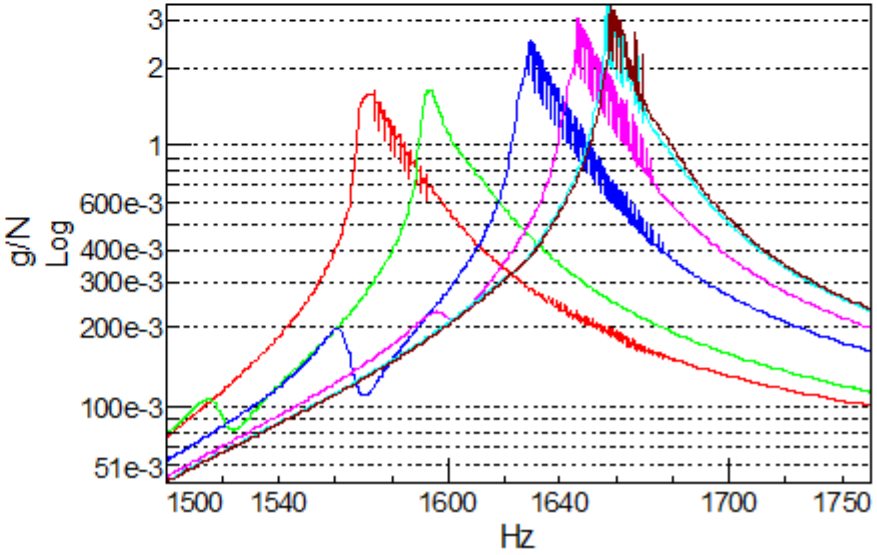
Rough Force Control



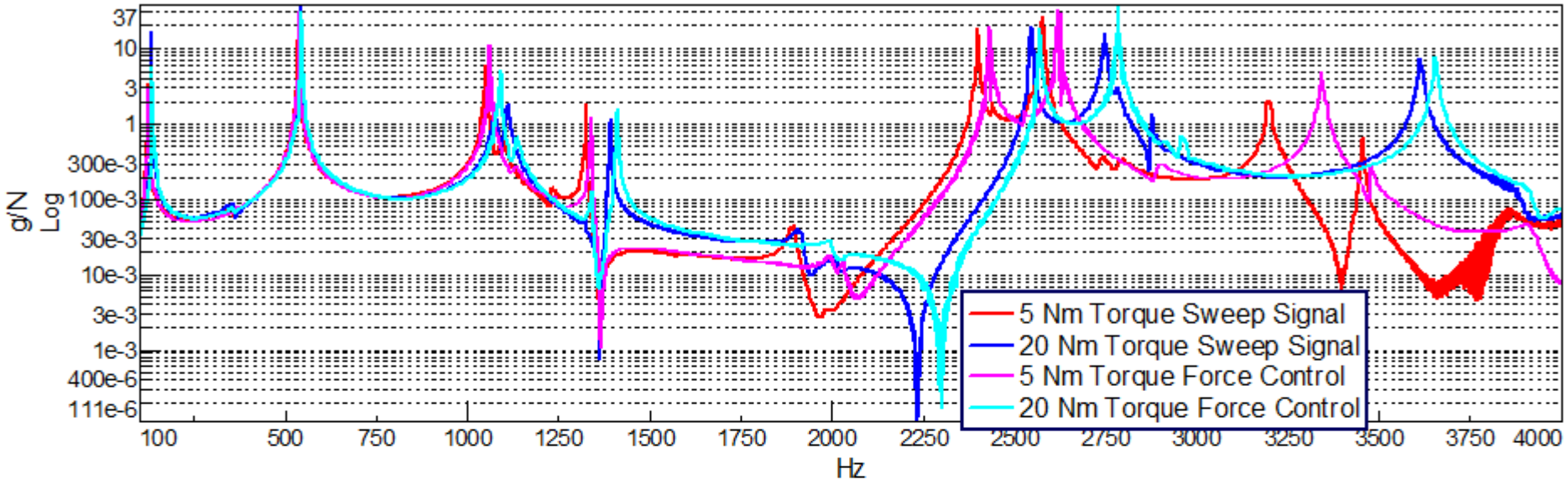
Mirror Force Control

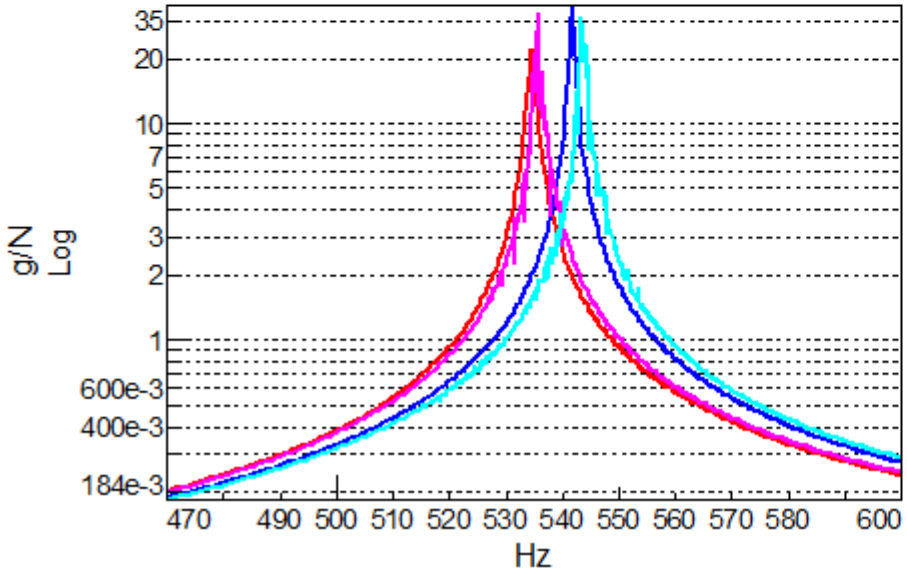


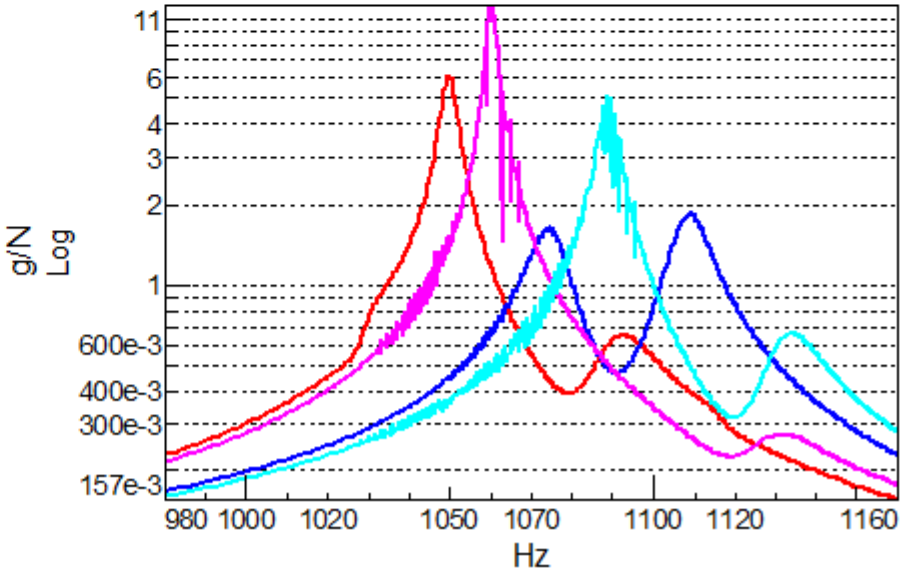




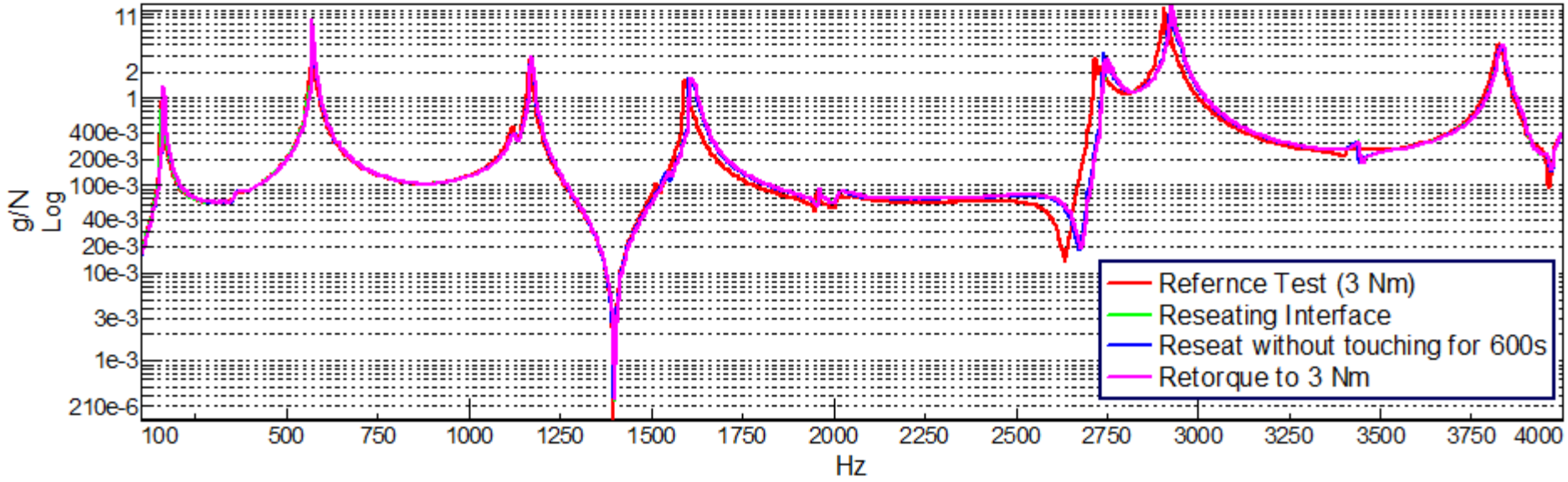
Sweep Torque difference

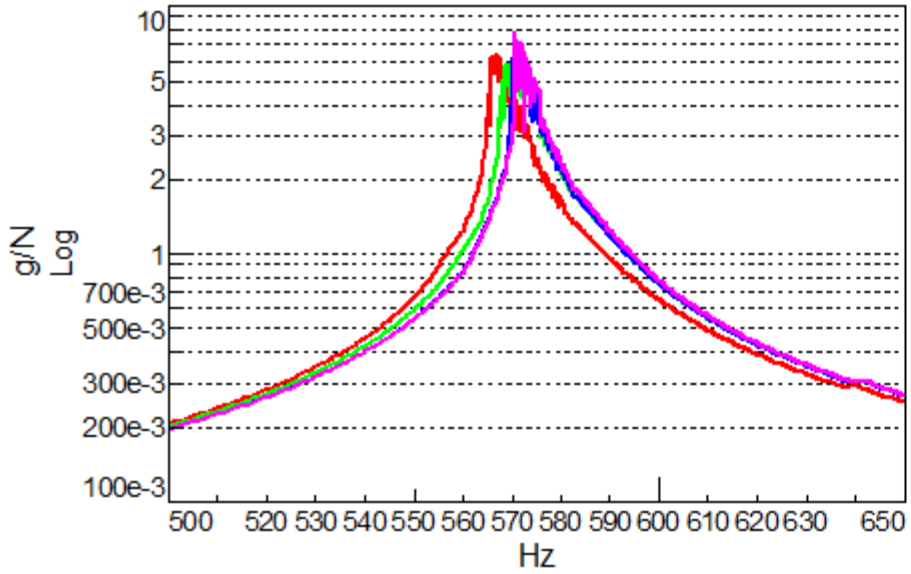


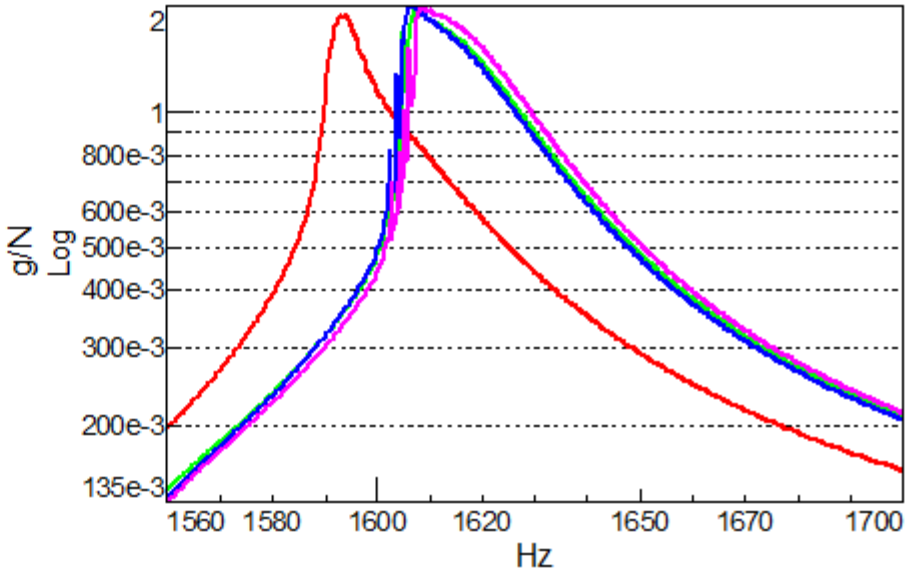




Mirror Repeatability 3 Nm

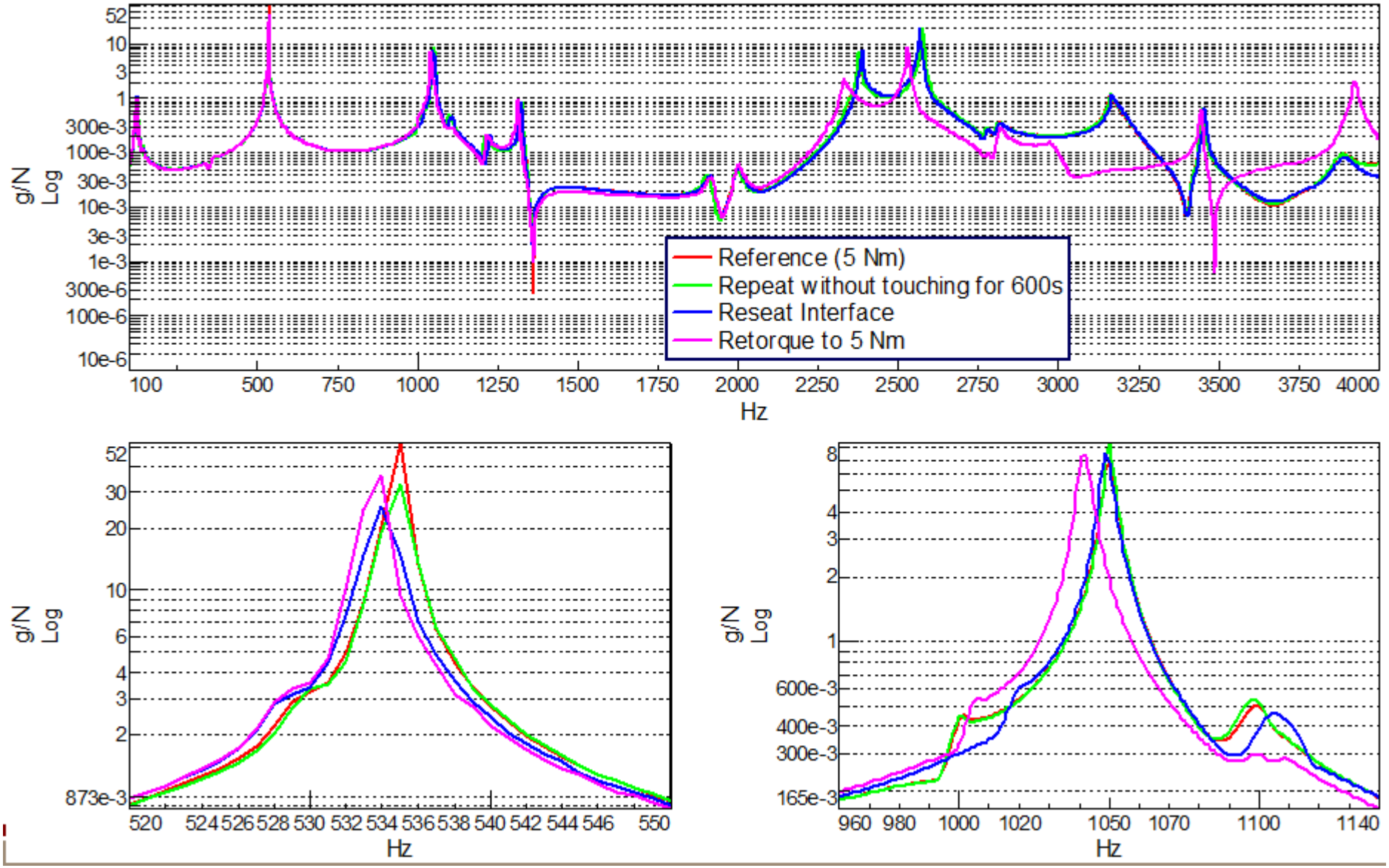






Mirror Repeatability 10 Nm

Rough Repeatability 10 Nm



Damping