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Evolution of AC loss, inter-strand resistance and mechanical properties in prototype EU DEMO TF conductors during 30,000 load cycles

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Outline of this presentation:

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1. INTRODUCTION, SAMPLE PREPARATION AND INSTRUMENTATION
2. AC LOSS OF VIRGIN SAMPLES
3. AC LOSS ALONG LOAD CYCLING
4. CONTACT RESISTANSES ALONG LOAD CYCLING
5. MECHANICAL PROPERTIES ALONG LOAD CYCLING
6. SUMMARY

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1. DEMO TF prototype conductors

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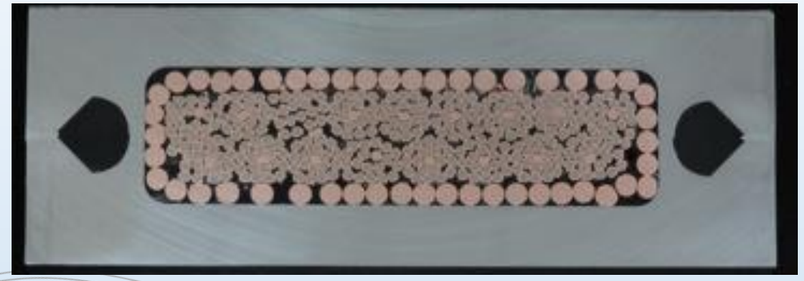
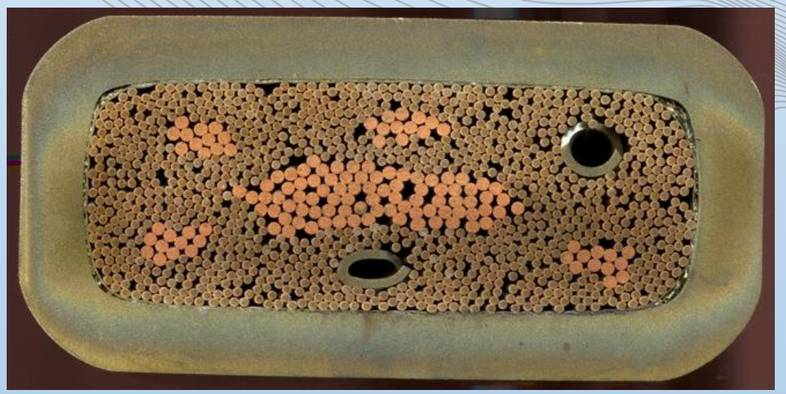


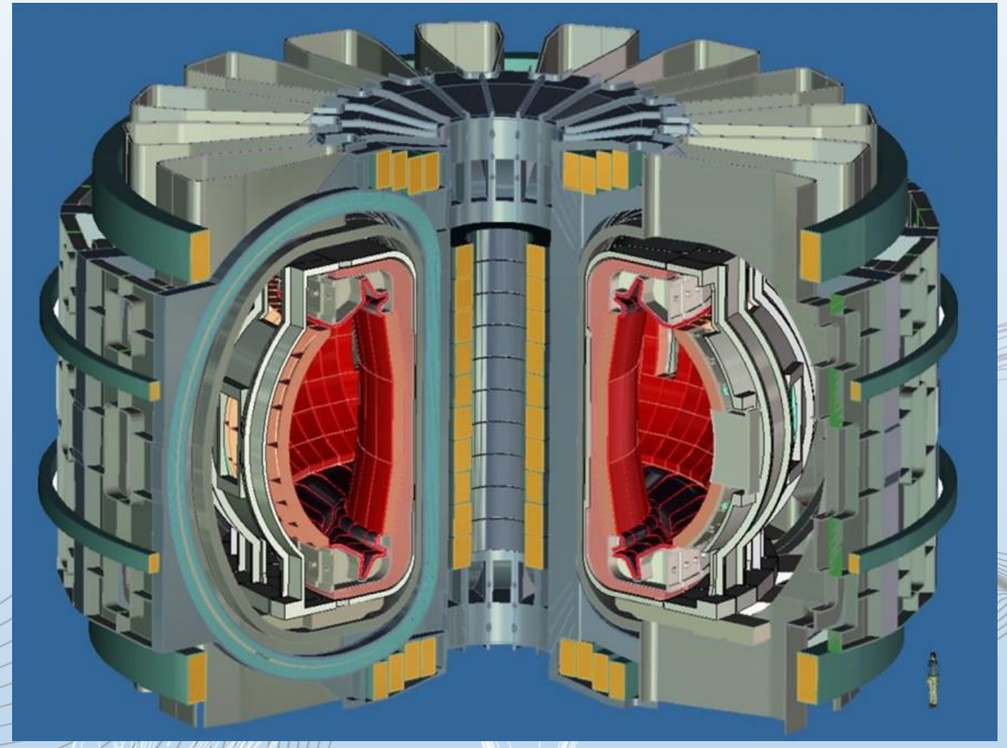
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE SWISS PLASMA CENTER

- Strand type - Nb_3Sn; 1.5 mm diameter
- Number of strands - 306
- React & Wind route (**RW WP1** sample)



ENEA

- Strand type - Nb_3Sn; 1.0 mm diameter
- Number of strands – 1080
- Wind & React route (**WR WP2** sample)



Toroidal field conductor requirements:

- Current 80 - 100 kA
- Background field 13 - 13.5 T
- Current and field result in accumulating load up to 1350 kN

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1. Instrumentation

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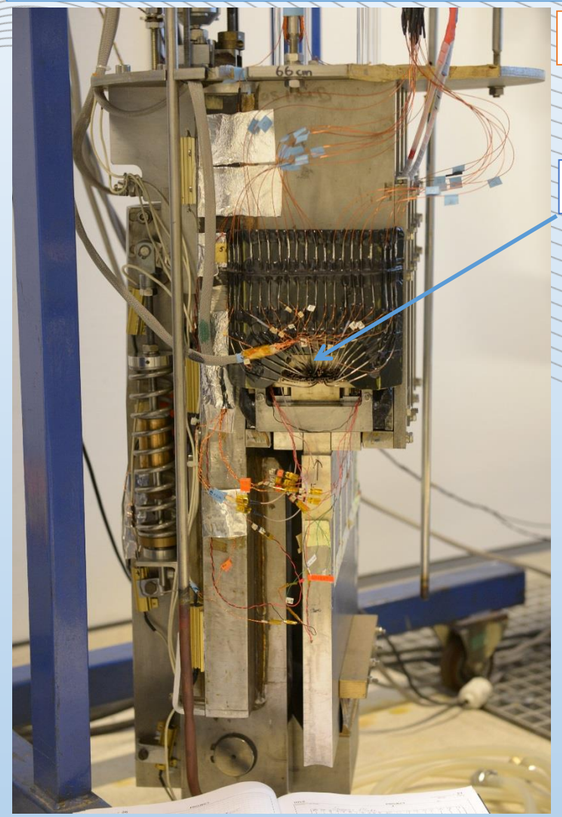
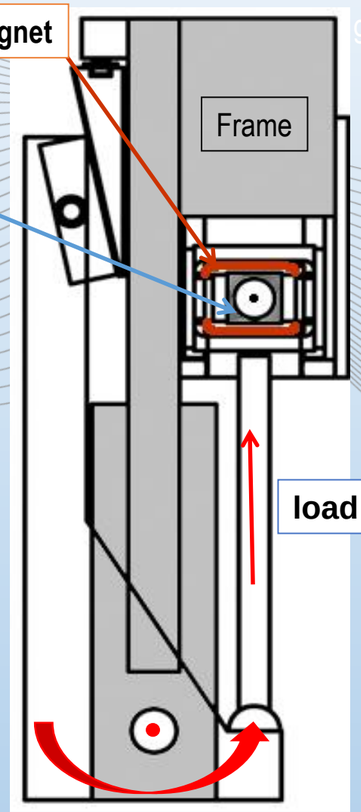
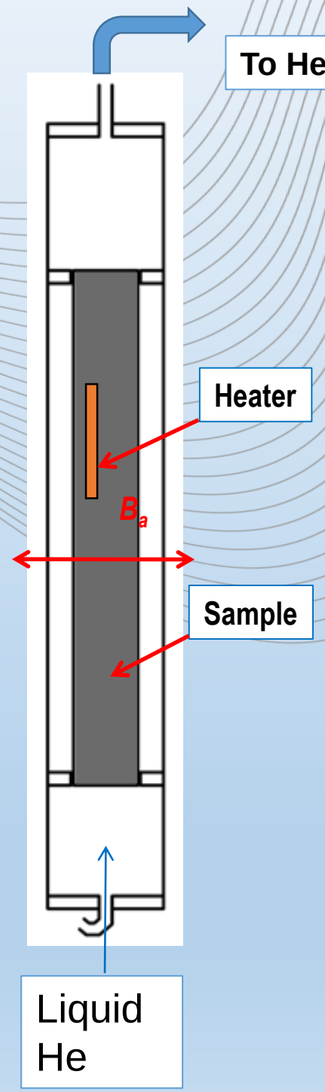
Twente cable press for transverse load

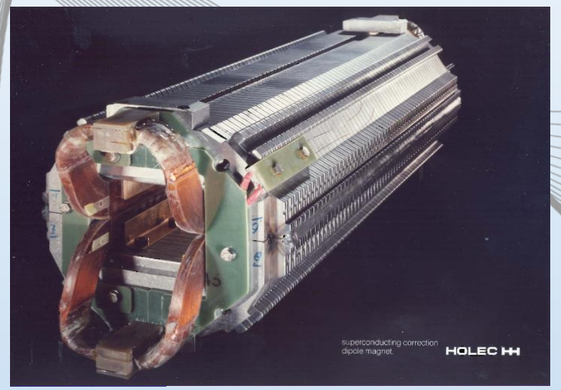




- Force up to 800 kN/m
- Operated at 4.2 K
- Up to 600 load cycles per hour
- Dipole magnet to study AC loss

Dipole magnet





Gas flow calorimetry

- AC loss causes heat generation and helium boil off
- Heater used to calibrate gas flow
- Dipole magnet up to ± 1.5 T field.
- AC loss measured by calorimetry and magnetisation.

Dipole samples in “virgin condition”, i.e. with minimum handling.

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1. RW WP1 sample preparation

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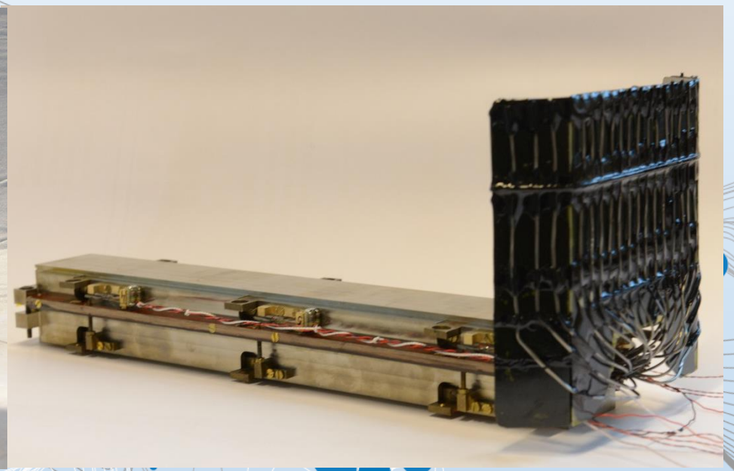
Two conductor specimens are prepared
Each sample is 40 cm long
Jacket: 316LN steel

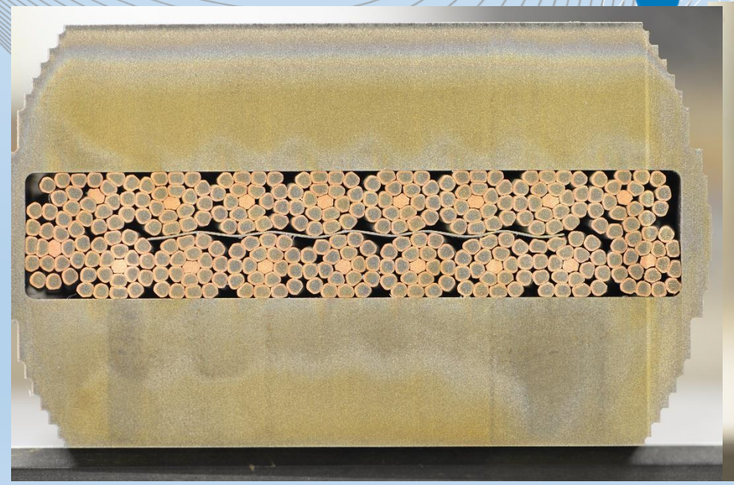
Virgin sample
- Minimum handling

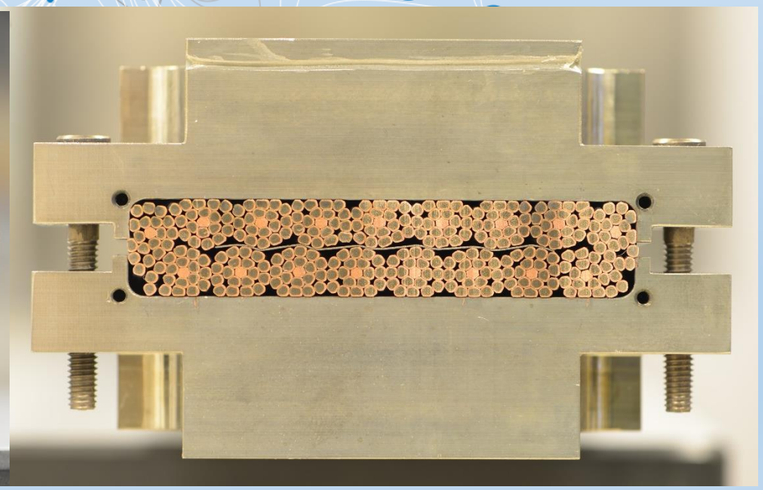
Press sample
- Locked void fraction
- Displacement meters
- Contact resistance measurement.

"Virgin" sample for dipole

Press sample







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1. WR WP2 sample preparation

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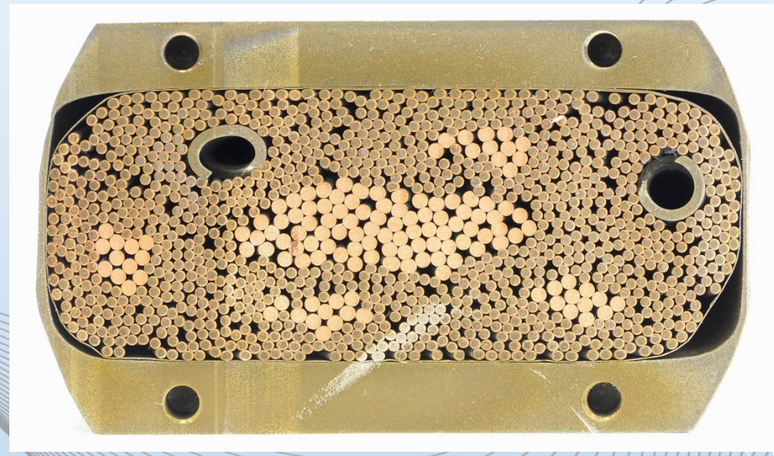
Sample lengths 40 cm

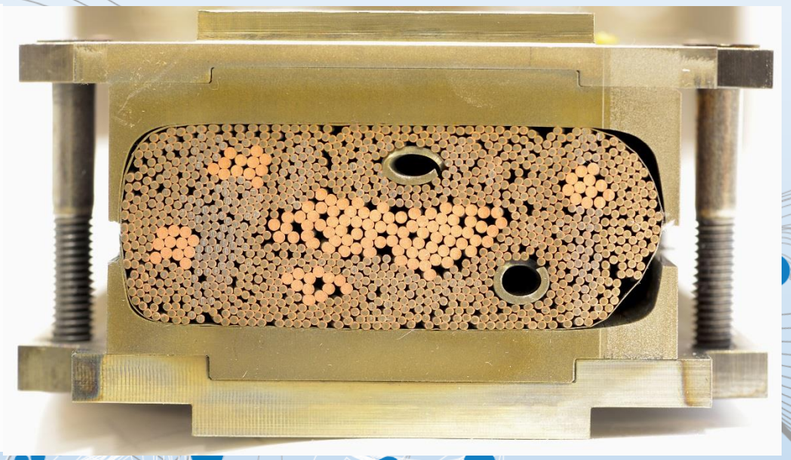
Virgin sample
- Minimum handling

Press sample
- Locked void fraction
- Displacement meters
- Contact resistance measurement.

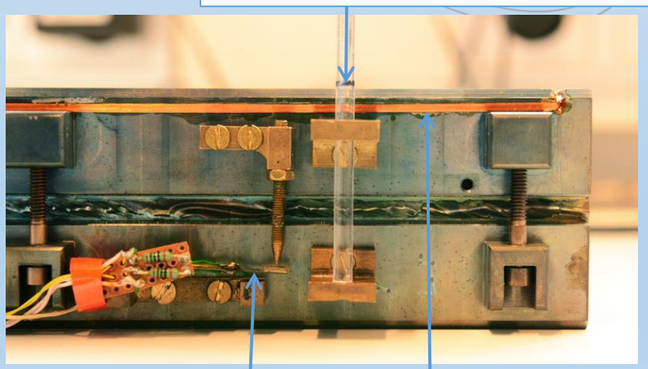
Virgin sample for dipole



Press sample

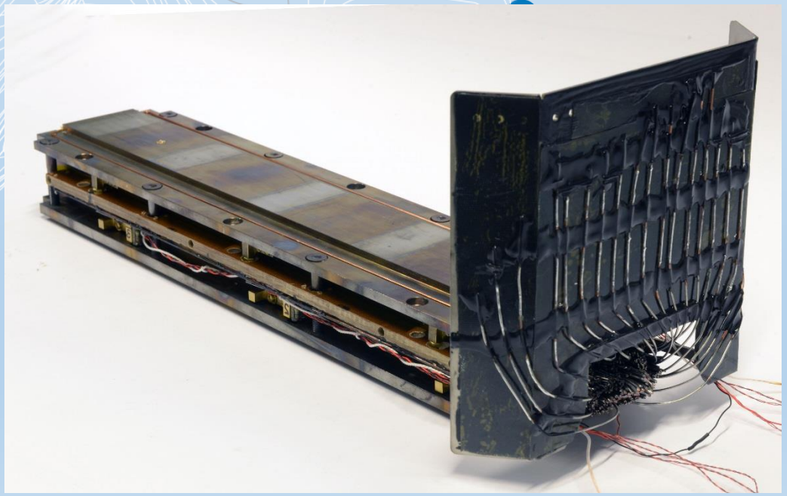


Quartz rod + micrometer



Strain gauge

Pick-up coil



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2. AC loss of virgin samples

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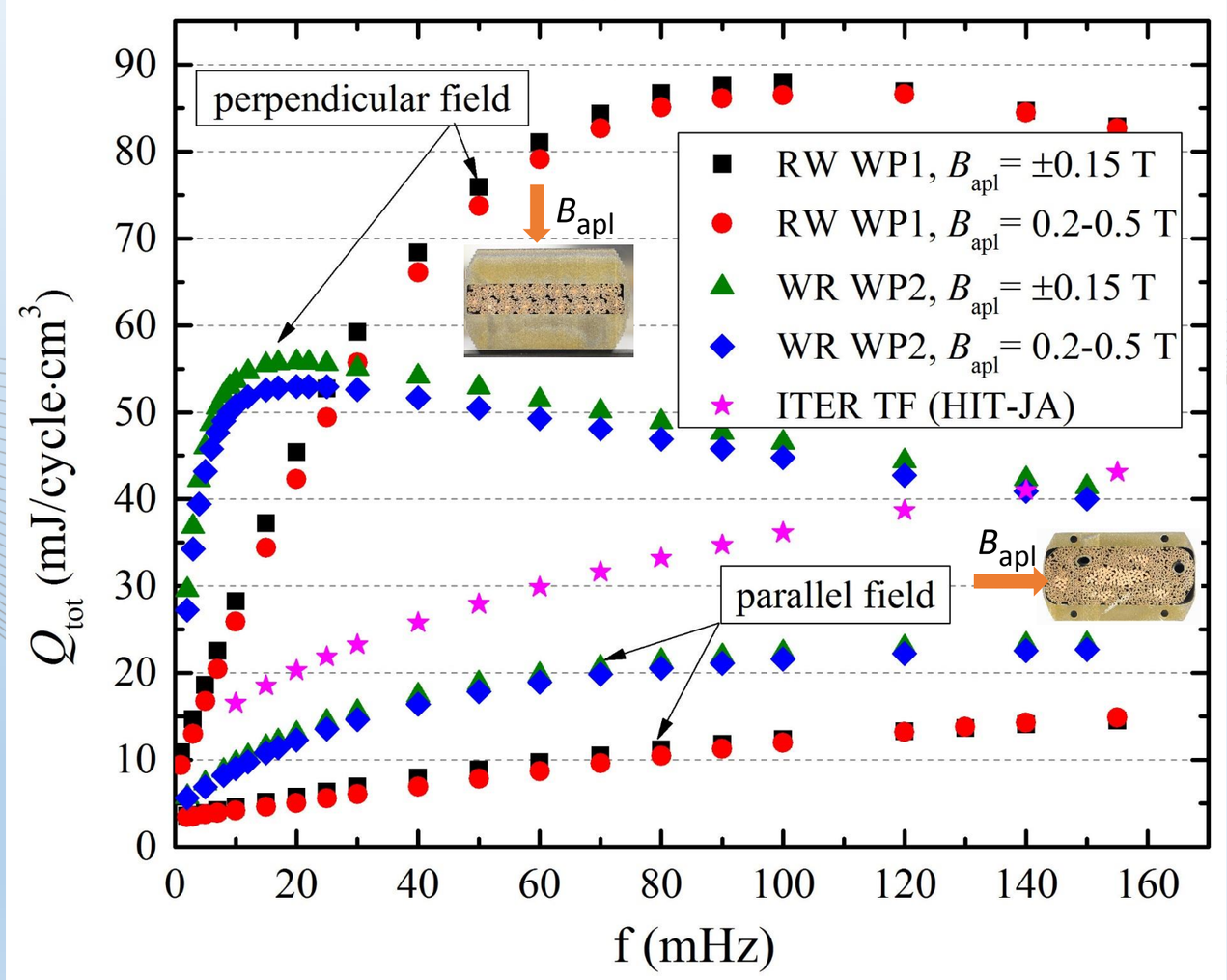
Coupling loss time constant $n\tau$ of the sample:

$$n\tau = \alpha \frac{\mu_0}{2\pi^2 B_a^{\,2}}$$

Where α is loss-frequency dependence slope

	perpendicular field orientation		parallel field orientation	
	nτ (s)			
B_{apl} = ± 0.15 T	6.1±0.1	37.9±0.2	0.4 ± 0.1	1.4 ± 0.1
B_{apl} = 0.2 - 0.5 T	5.8±0.1	34.5±0.5	0.3 ± 0.1	1.3 ± 0.1
	AC loss peak position (mHz)			
B_{apl} = ± 0.15 T	100± 5	21.4±0.4	-	-
B_{apl} = 0.2 - 0.5 T	100± 5	22.7±0.5	-	-

Loss-frequency dependencies



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3. Evolution of AC loss during load cycling

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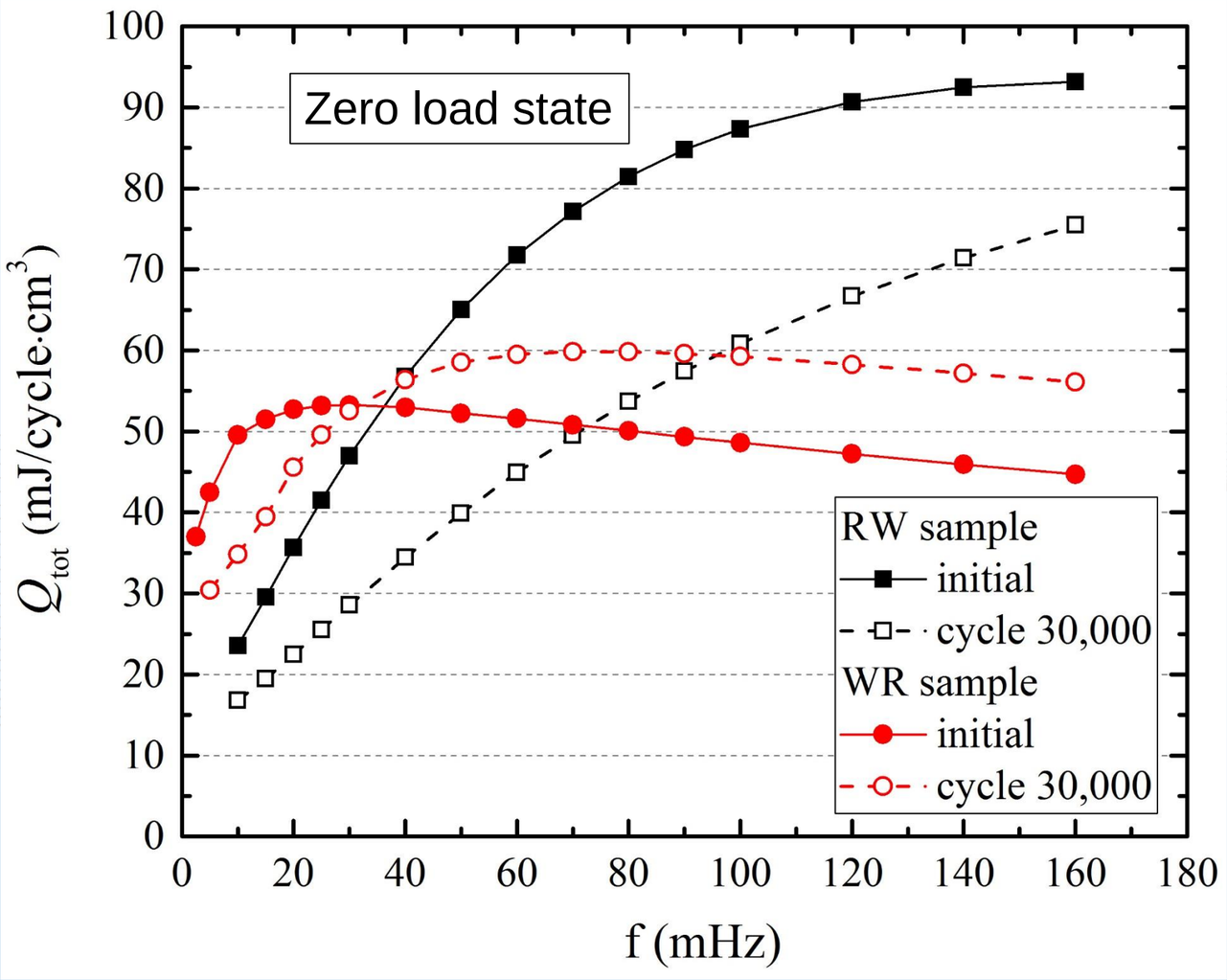
- Load is cycled between 0 and 538 kN/m (corresponds to 1076 kN/m of accumulated load)
- AC coupling loss of both DEMO conductors decreases after load cycling
- Total loss of WR WP1 sample rises at frequencies above AC loss peak position after load cycling
- No significant change of hysteresis loss could be observed for both samples



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3. AC coupling loss versus cycle number

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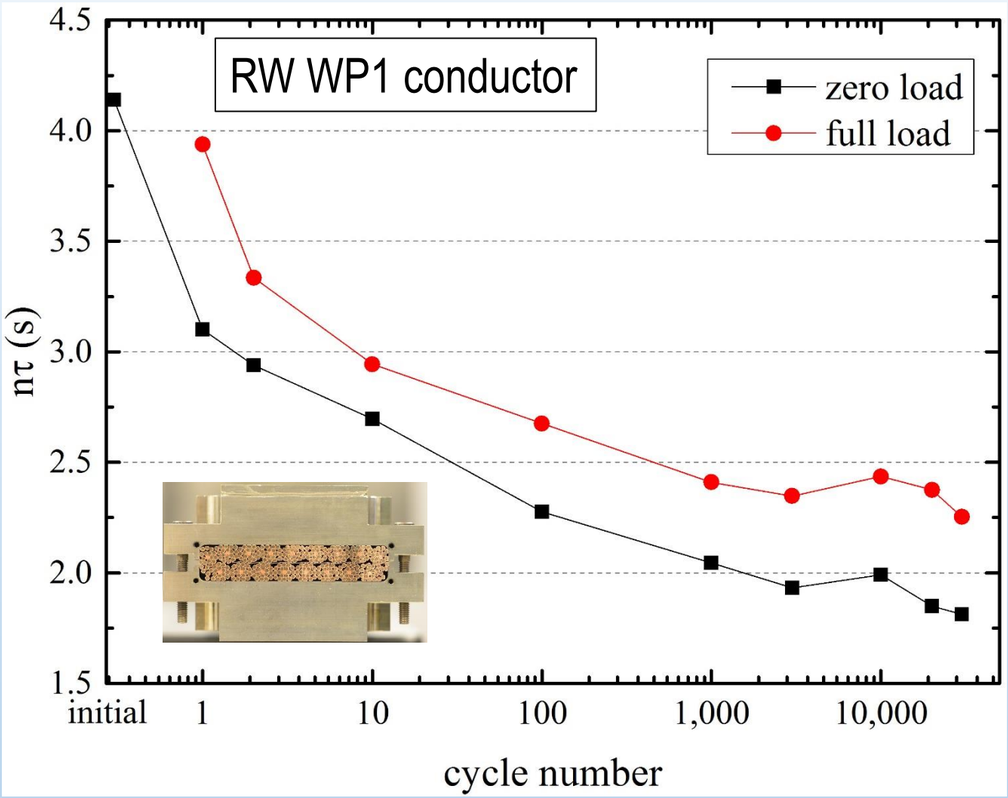

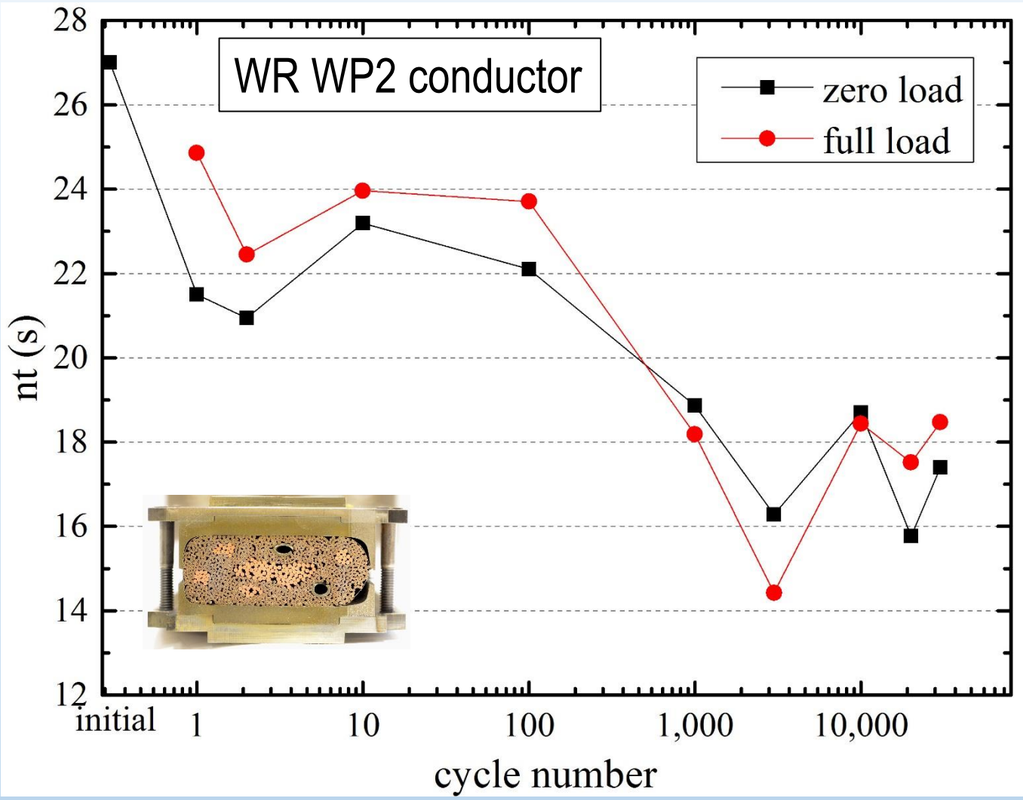

- AC coupling loss of both DEMO conductors stays at high level after load cycling.
- The scattered behavior of WR WP1 sample is due to limited number of data points below AC loss peak.

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4. Strands selection for R_c measurement

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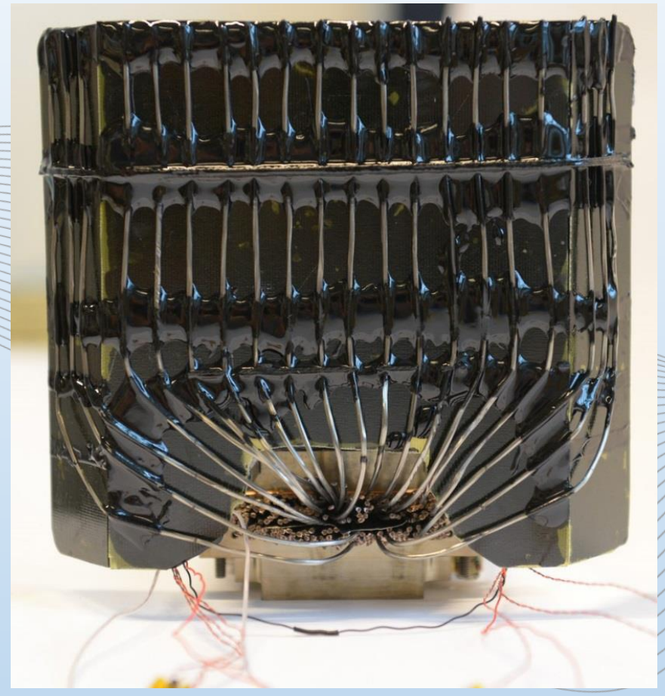
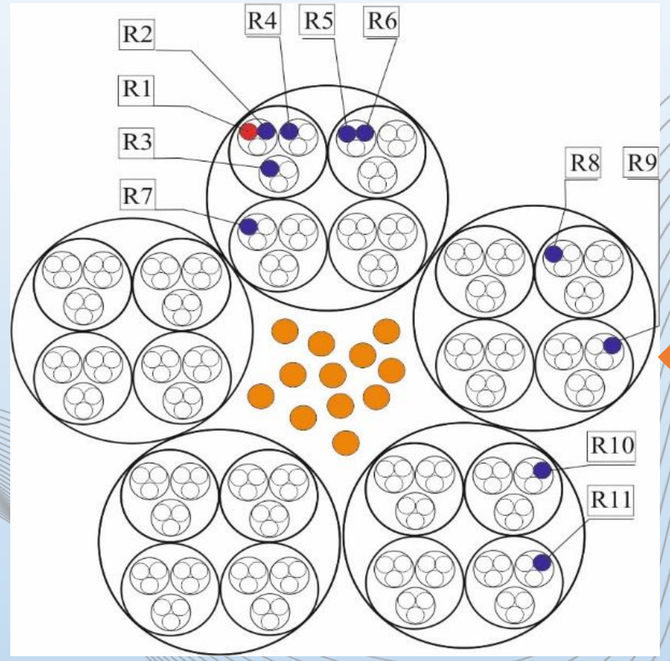
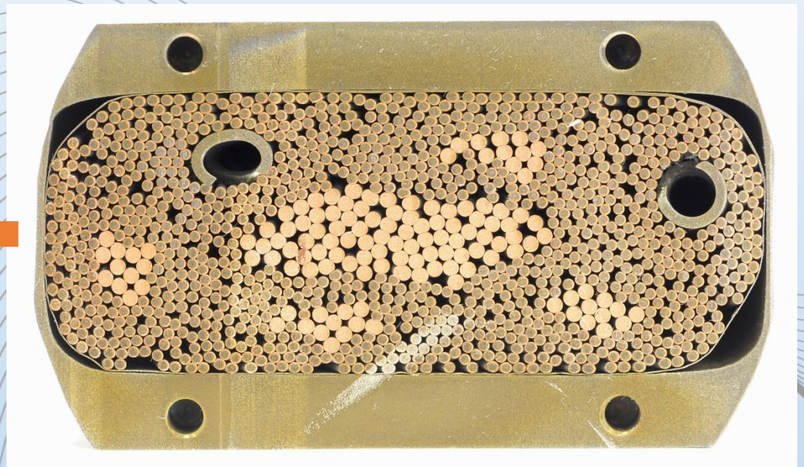
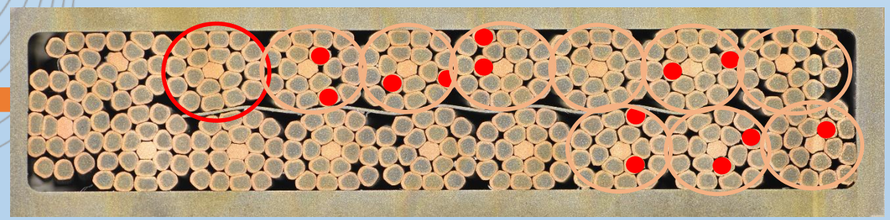


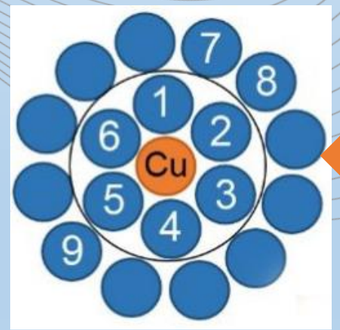


WR WP2 sample.



RW WP1 sample.





- Resistance is measured between strand #1 and corresponding strand.
- Four-point probe method using current of 50 A.

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4. Evolution of R_c with load cycling

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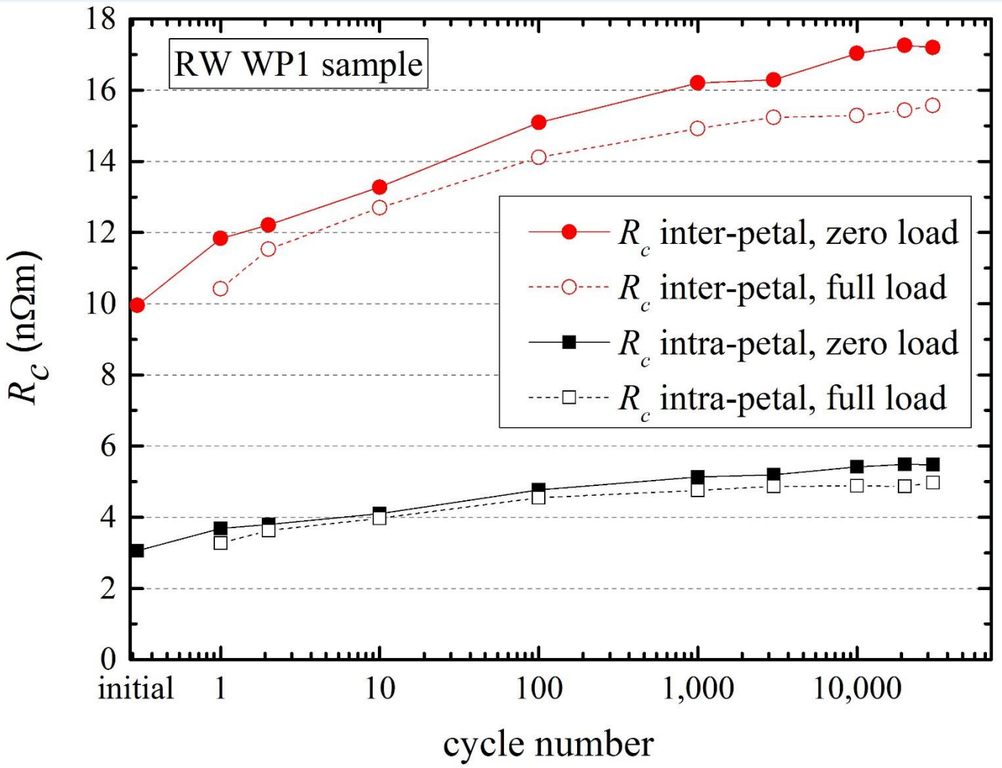

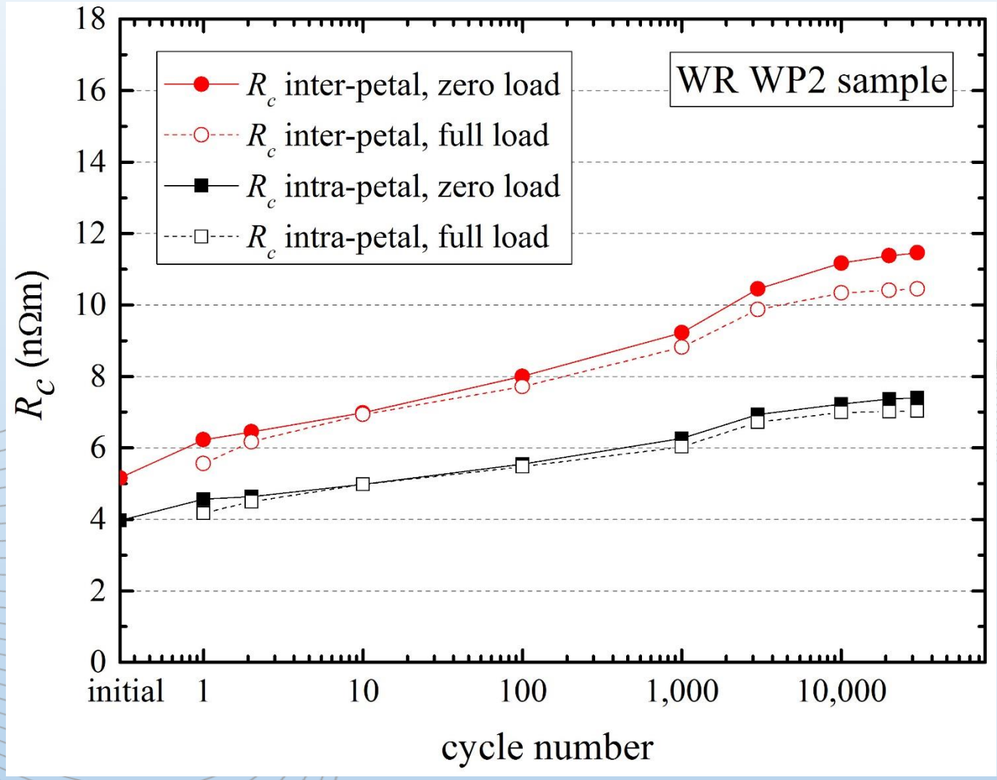

- Contact resistance rises with number of load cycles
- Intra-petal resistance values and evolution with load cycle hardy depends on load level.
- RW WP1 sample has higher inter-petal resistance.

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5. Evolution of mechanical properties

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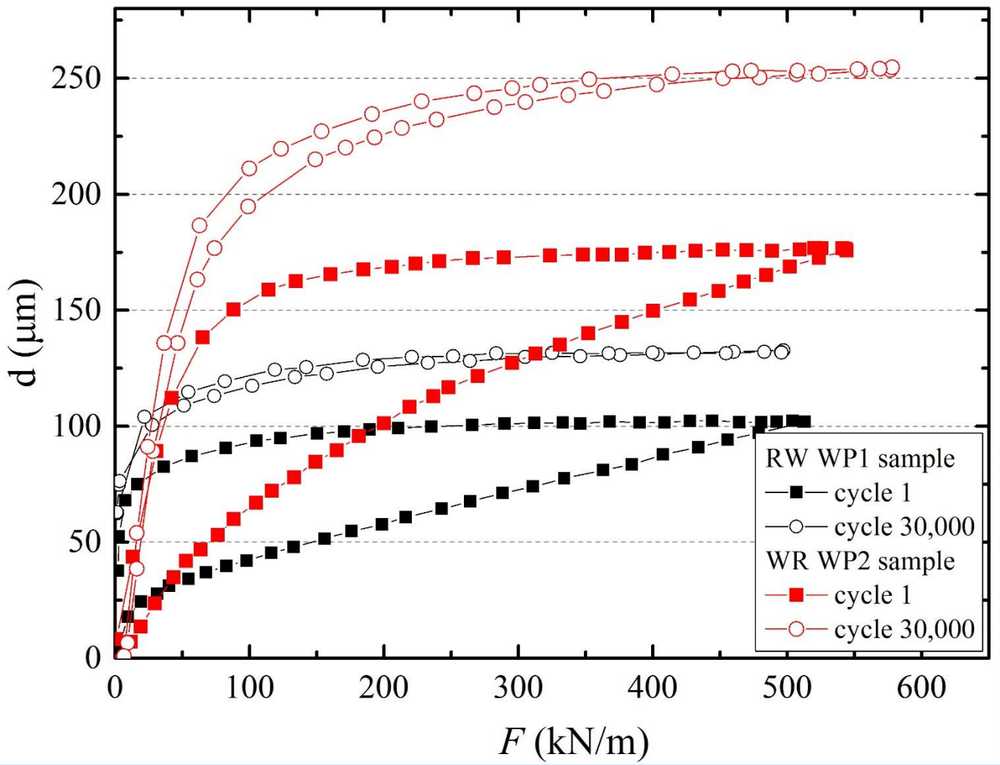
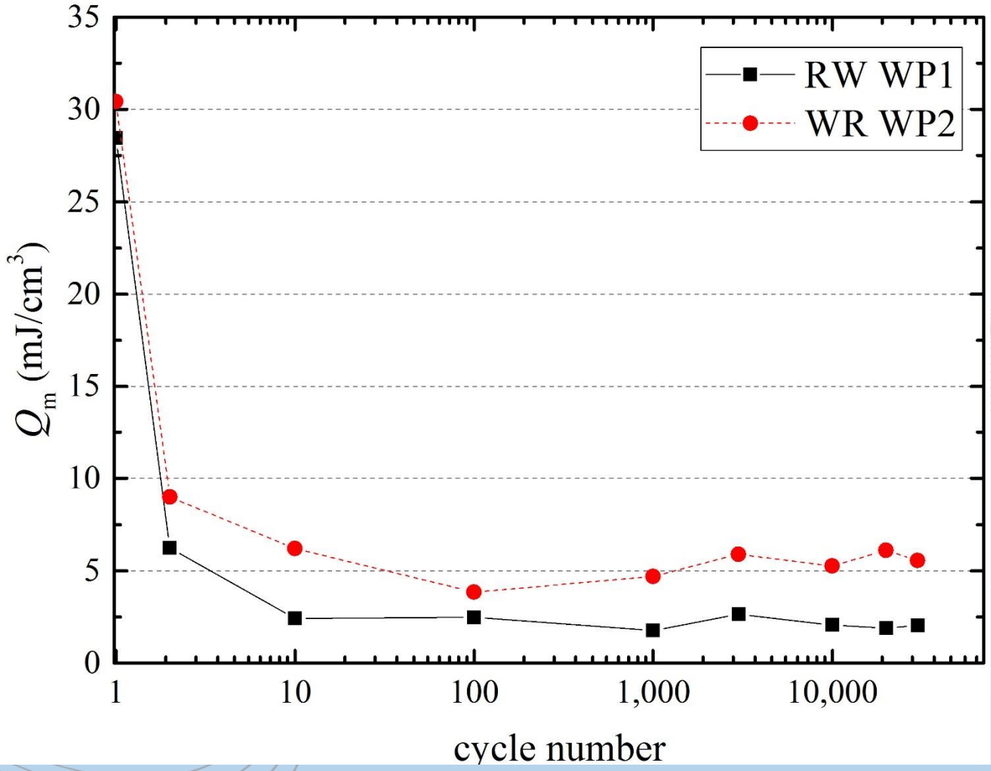
Force-displacement curves for RW & WR conductors



Mechanical loss versus cycle number



- Displacement-force curves show visco-elasto-plastic deformations as observed previously for Nb_3Sn conductors.
- Mechanical losses Q_m are small and negligible compared with AC loss for both conductors.

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5. Evolution of mechanical properties

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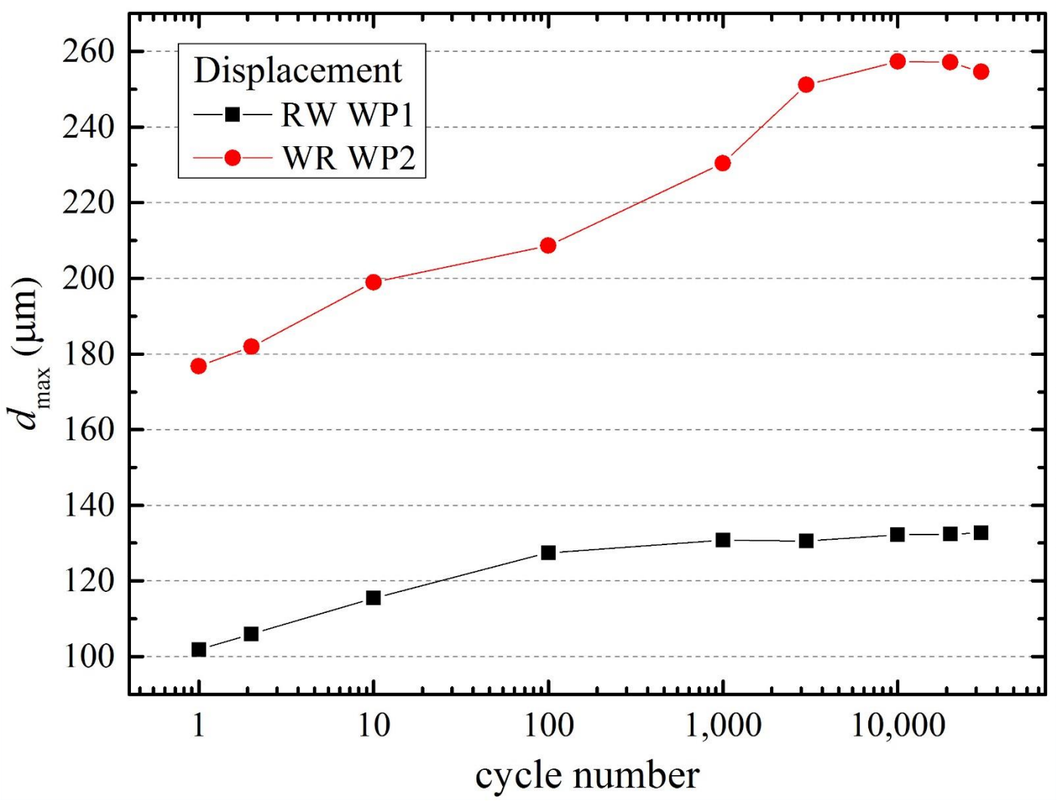
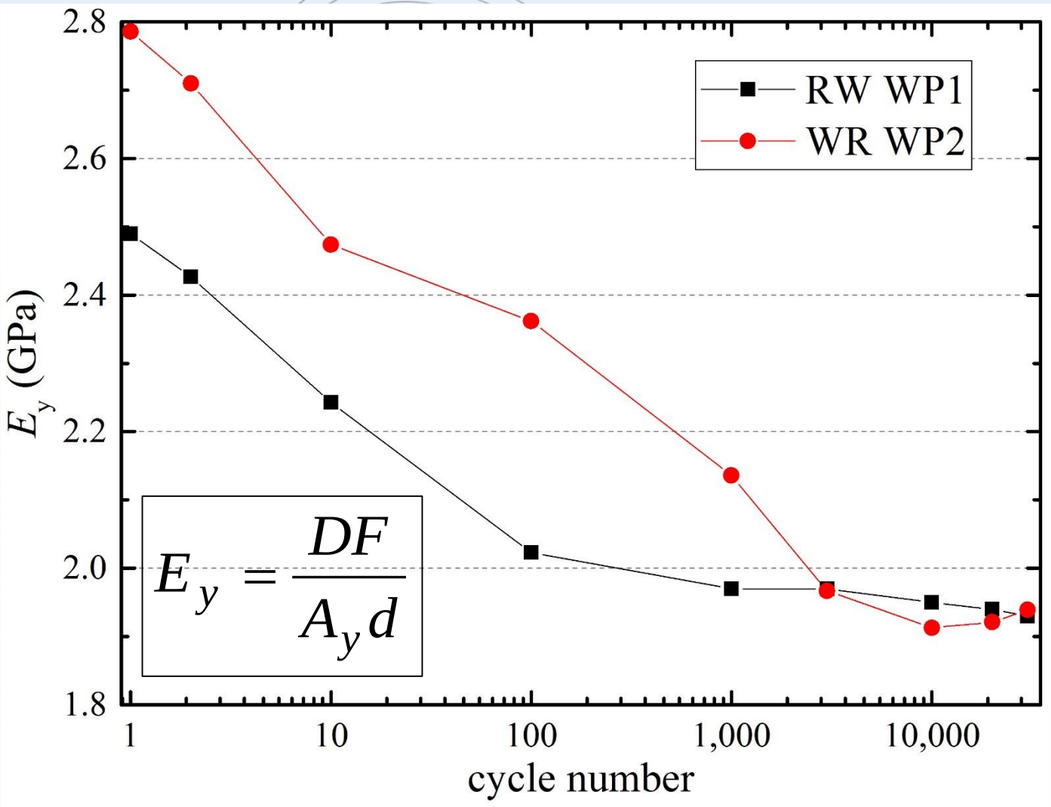
Maximum displacement vs cycle number



Conductors elastic moduli versus cycle number



- Displacement is saturated after 3,000 cycles.
- Displacement limited due to low void fractions, smallest for WR WP2.
- Effective elastic modules are similar for both conductors after 3,000 load cycles.

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6. Summary

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- Both EU DEMO conductors showed high AC coupling loss while hysteresis loss is on the same level as ITER TF conductors.
- The RW WP1 conductor has lower AC coupling loss compared to WR WP2.
- After cycling of the load, AC coupling loss time constant stays at the high level.
- Main changes in coupling loss, contact resistance and mechanical properties take place at first 3,000 cycles.
- Both conductors have small mechanical deformation under load (likely limited degradation to expect) and hence small mechanical heat production during cycling of the load.
- Both conductors have contact resistance of ~3 nΩm between neighbouring strands in initial state increasing to ~6 nΩ after 30,000 cycles.
- RW WP1 and WR WP2 samples have inter-petal resistances of ~10 nΩm and ~5 nΩm respectively, in the initial state. After 30,000 cycles inter-petal resistance rises to ~ 17 nΩm and ~ 11 nΩm for RW WP1 and WR WP2 respectively.