EUROfusion

AC Loss in the DEMO TF React&Wind Conductor Prototype no. 2

Kamil Sedlák, Pierluigi Bruzzone, Boris Stepanov, Valentina Corato

EPFL
SWISS PLASMA CENTER

MT 26
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Vancouver, Canada | 2019

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Outlook

- React & wind conductor for DEMO TF/CS
- AC loss measurement using sinusoidal AC field
- AC loss measurement using trapezoidal AC pulsed field

TF coil options of EU DEMO

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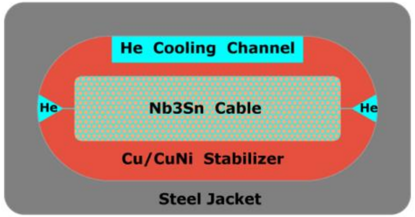
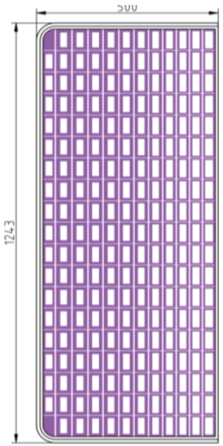
WP#1

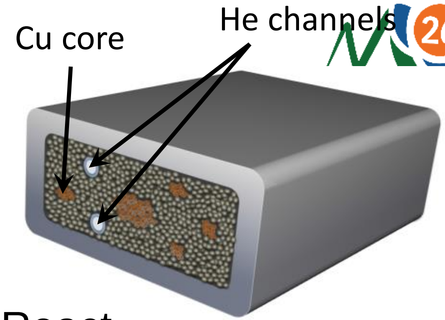


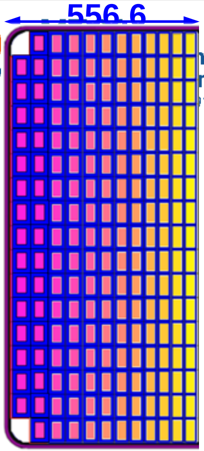


- React & Wind (low strain)
- Layer winding (grading)
- No radial plates

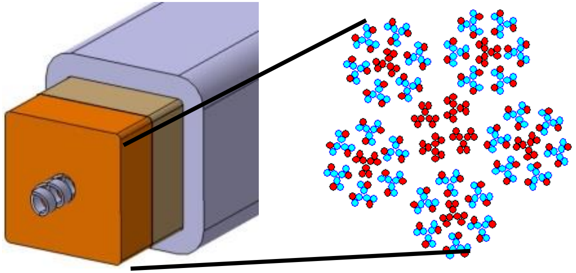
WP#2

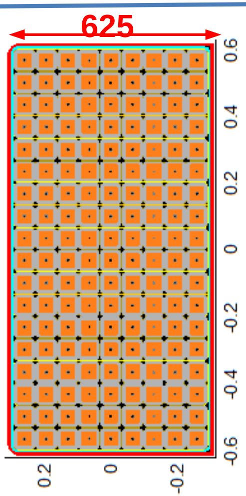
ENEA





- Wind & React
- Double-Layer winding (grading)
- No radial plates

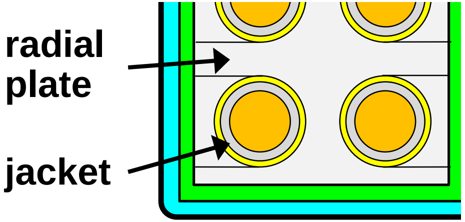


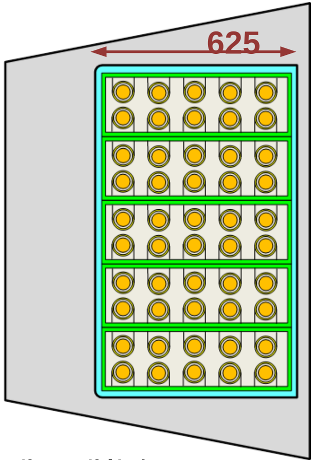


WP#3

cea

- Wind & React
- Pancake winding
- No radial plates





WP#4

cea

- Wind & React
- Pancake winding
- Radial plates

React & Wind (RW) Conductor

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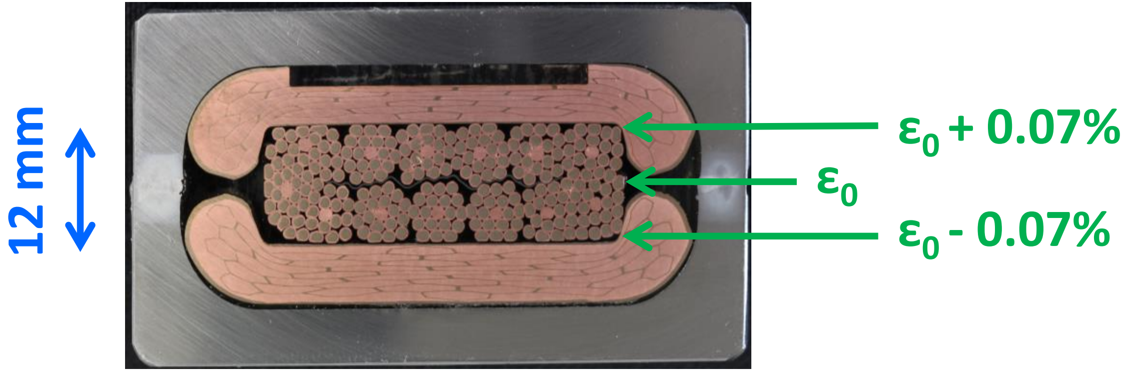
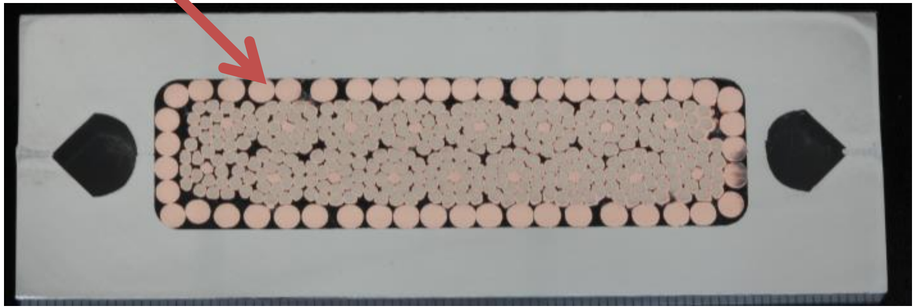


- Much lower thermal strain in Nb_3Sn ($\varepsilon_{eff}^{RW} \approx -0.3\%$ vs. $\varepsilon_{eff}^{ITER\ TF} \approx -0.7\%$).
- Layer winding with grading
  - Grading in superconductor ➔ saves expensive Nb_3Sn
  - Grading in steel ➔ saves radial build (overall DEMO size)
- Longitudinally welded steel jacket
  - Large flexibility in the jacket shape and wall thickness
  - Jacketing done after heat treatment ➔ welds not exposed to high temperatures

RW1 and RW2 Prototypes

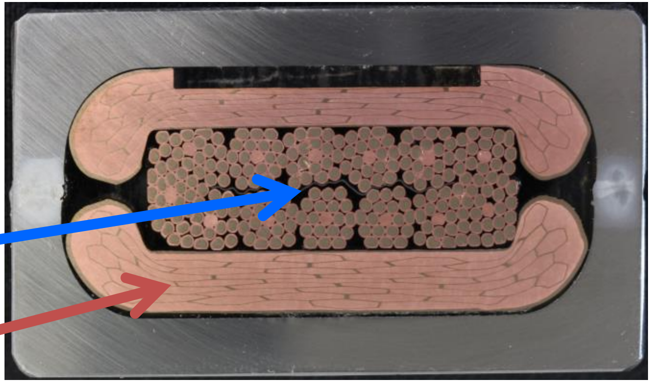


RW 1 prototype (2015-2016):

- Based on 2013 DEMO reference
- 13.5 T, 82.4 kA.

RW 2 prototype (2017-2019):

- Based on 2015 DEMO reference
- 12.23 T, 63.3 kA.



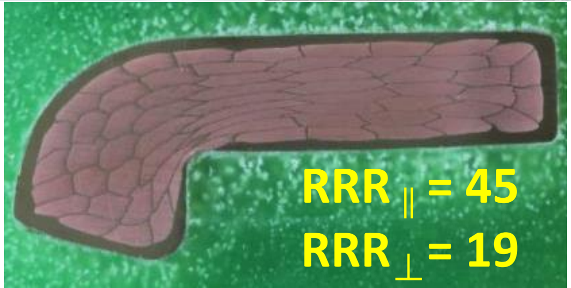
RW2 Samples Tested in SULTAN

Brass profile

"loose" cable in the conduit (0.3 mm)

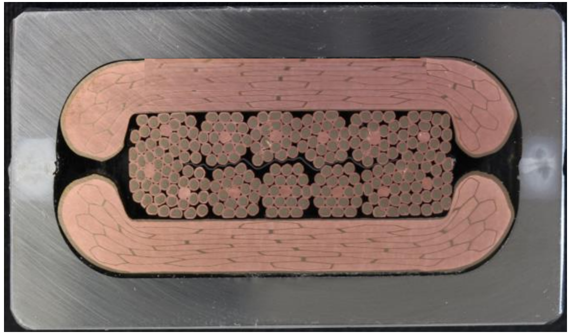
Half-size mixed matrix

ENEA, Tratos; "tight fit"



Full-size mixed matrix

WST, China; cable "preloaded" (-0.4 mm)

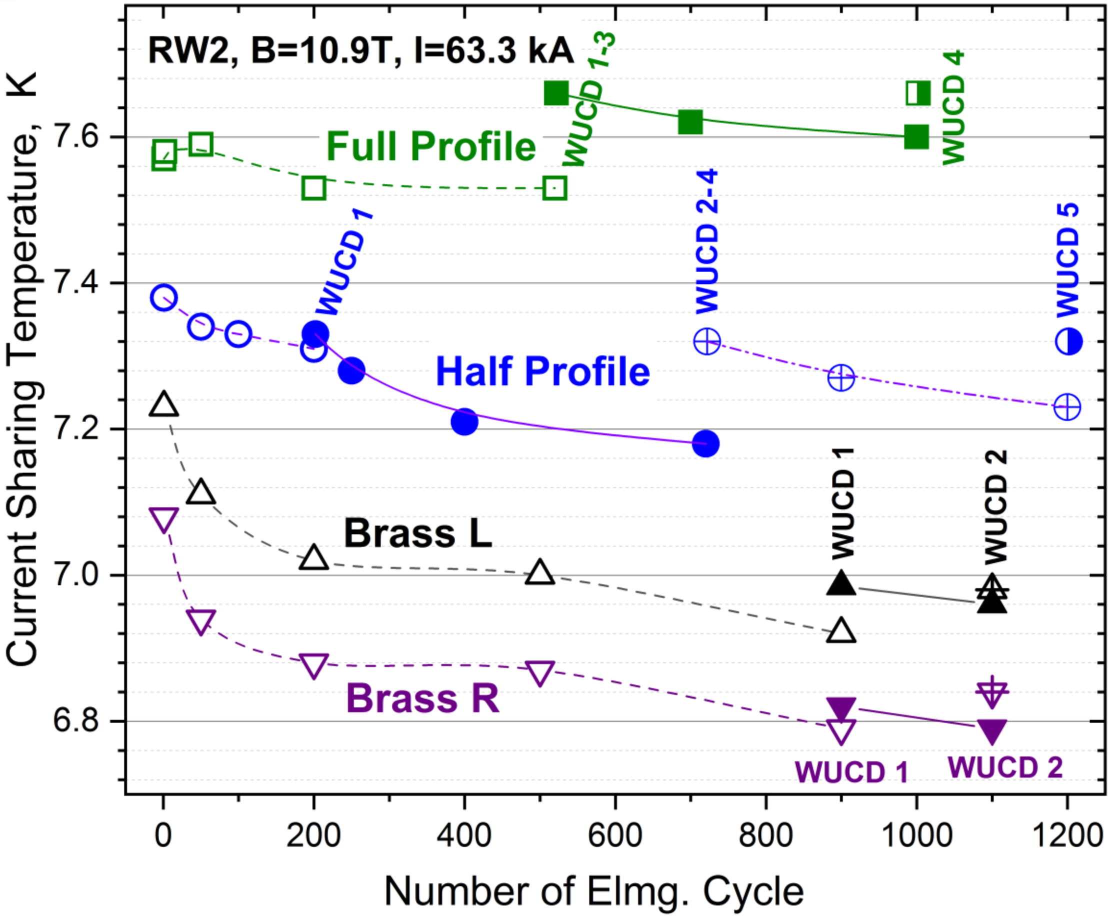


RRR $_{\parallel}$ = 400

RRR $_{\perp}$ = 140

- Jacketing – welding after the heat treatment.
- Cable space 0.4 mm thinner compared to the cable thickness.

T_{cs} Evolution along Cyclic Loading



"Full Profile" sample:

- Highest T_{cs}
- Stable DC performance

AC Loss – Sinusoidal, Perpend. Field

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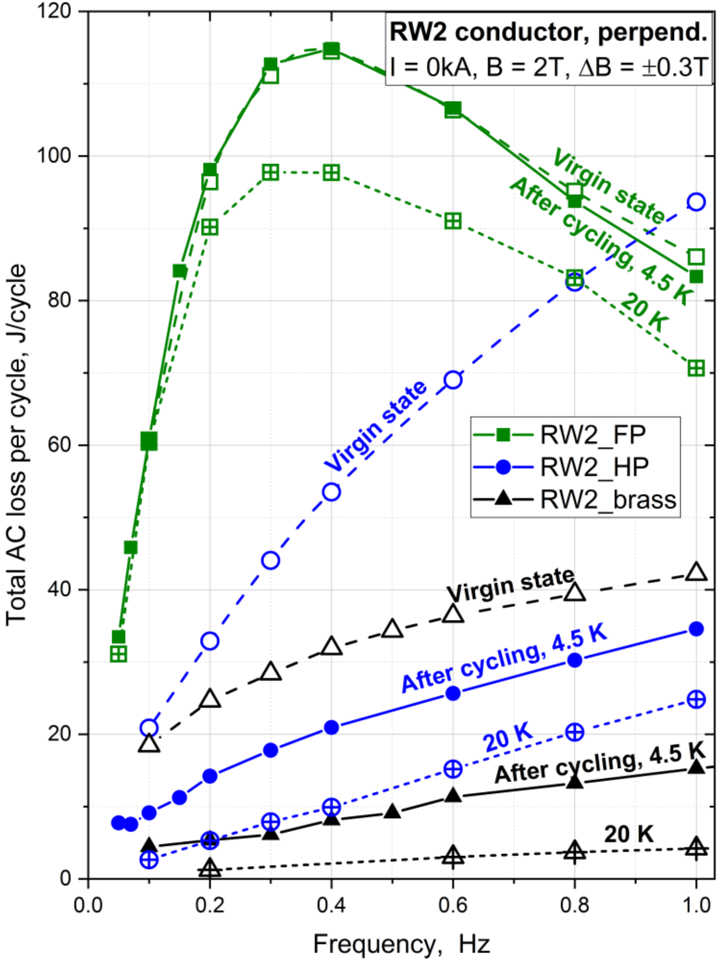
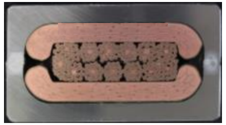


"Full Profile" sample:

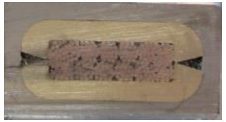


- Highest AC loss (due to low $R_\perp$ of MM)
- No drop of AC after cyclic loading

"Half Profile" sample:

- Medium AC loss (moderate $R_\perp$ of MM; cut of MM profile in two halves)

"Brass" sample:



- Lowest AC loss dominated by coupling loss in the cable.

AC Loss – Sinusoidal, Parallel Field

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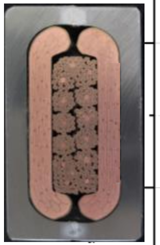
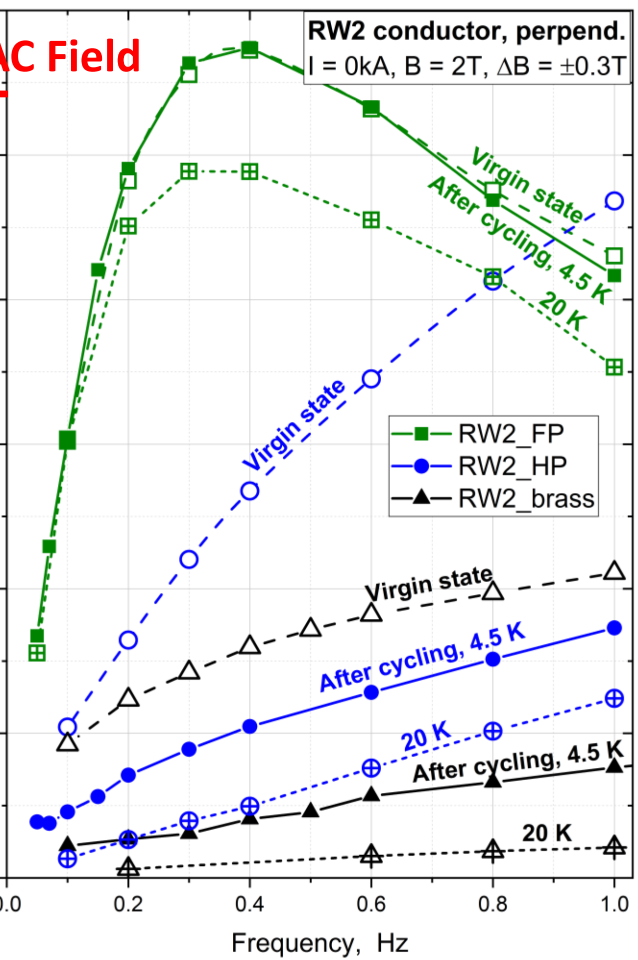
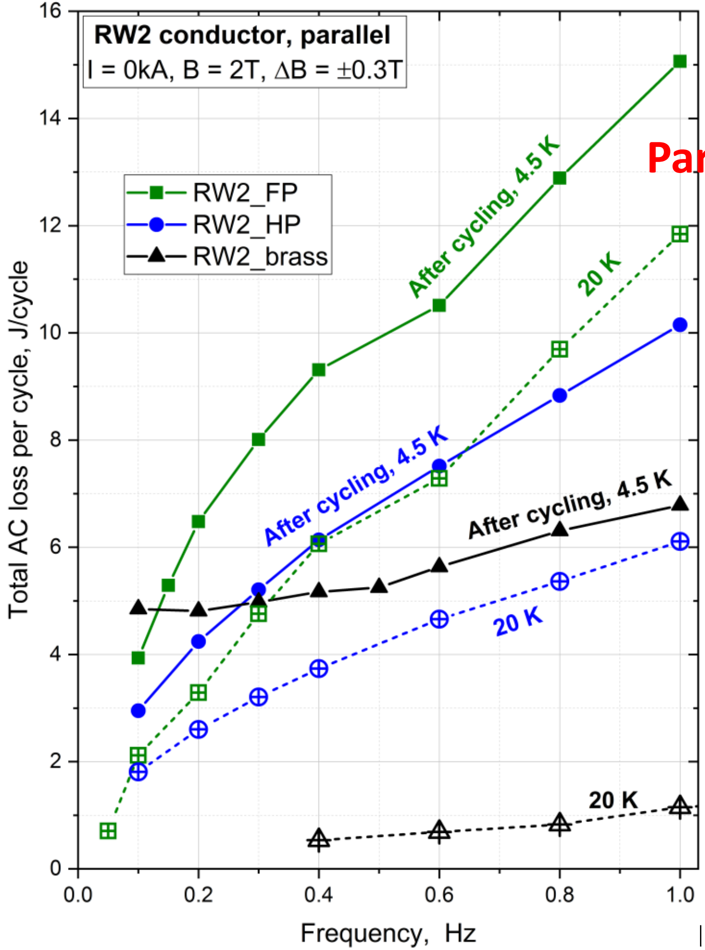
Perpend. AC Field



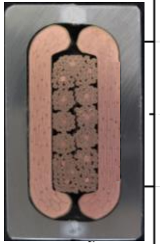


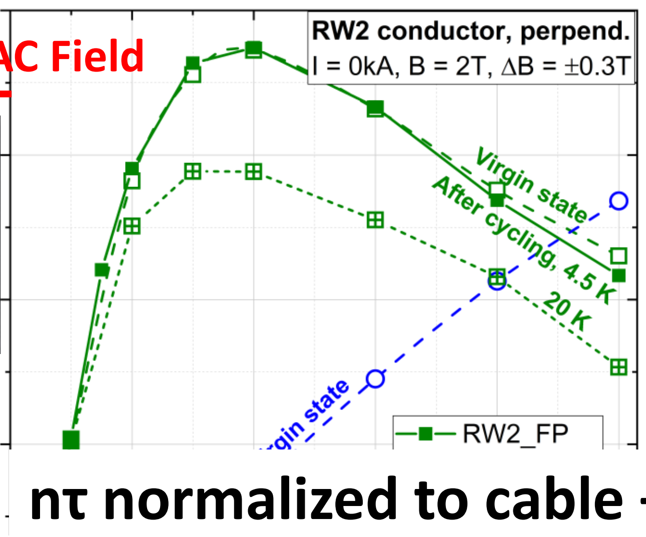
Parallel AC Field

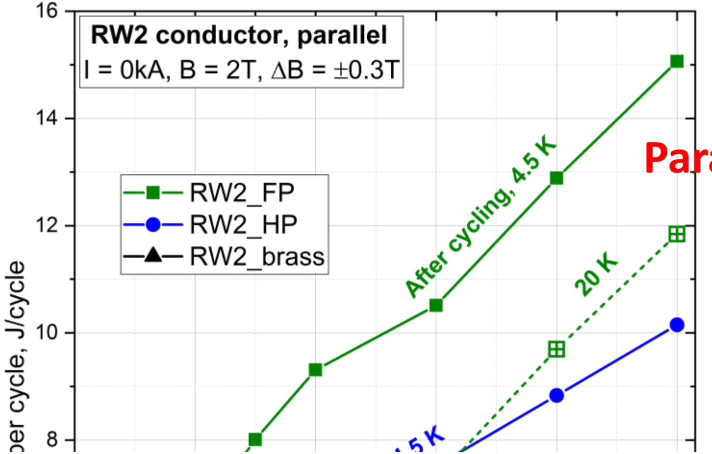


Fitted nτ

Perpend. AC Field







Parallel AC Field

nτ normalized to cable + mixed matrix stabilizer area:

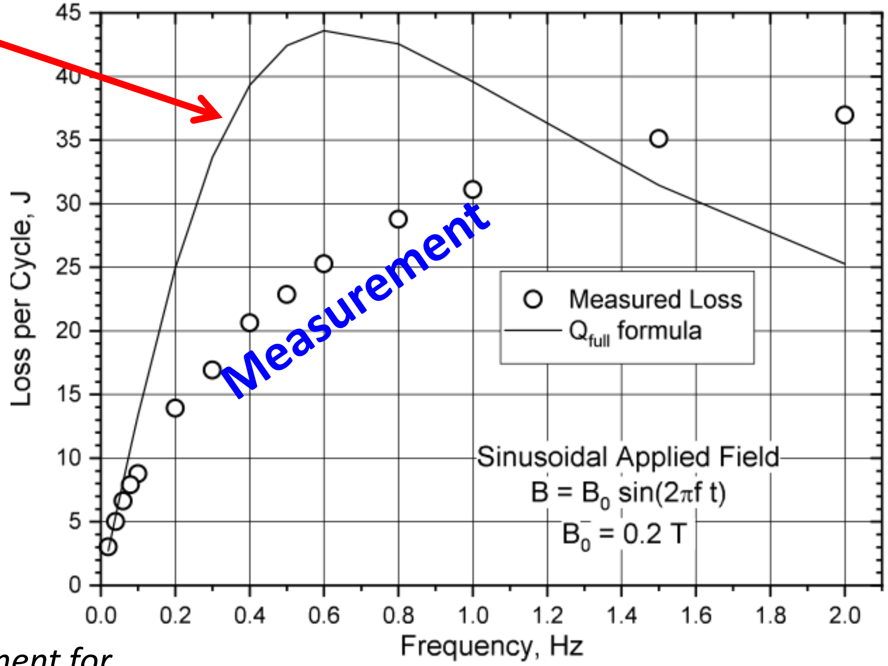
	RW2_brass	RW2_HP	RW2_FP
$n\tau_{perpend}$	17 ms	98 ms	1060 ms
$n\tau_{parallel}$	3 ms	22 ms	50 ms

AC Loss – Problem with Multistage CICC

$$Q = \frac{B_0^2 \pi \omega n\tau}{\mu_0}$$

Fit based on nτ extracted at low frequencies

ITER CSIO2, sinusoidal AC field



The coupling currents loss for the multistage CS and PF conductors of ITER and DEMO are largely overestimated when the nτ coupling loss constant derived from the initial slope of the loss curve is applied.

P. Bruzzone et al. “*A new test method of AC loss assessment for fusion conductors*”, Fusion Eng. Des. 146, 2019, pp. 928-931.

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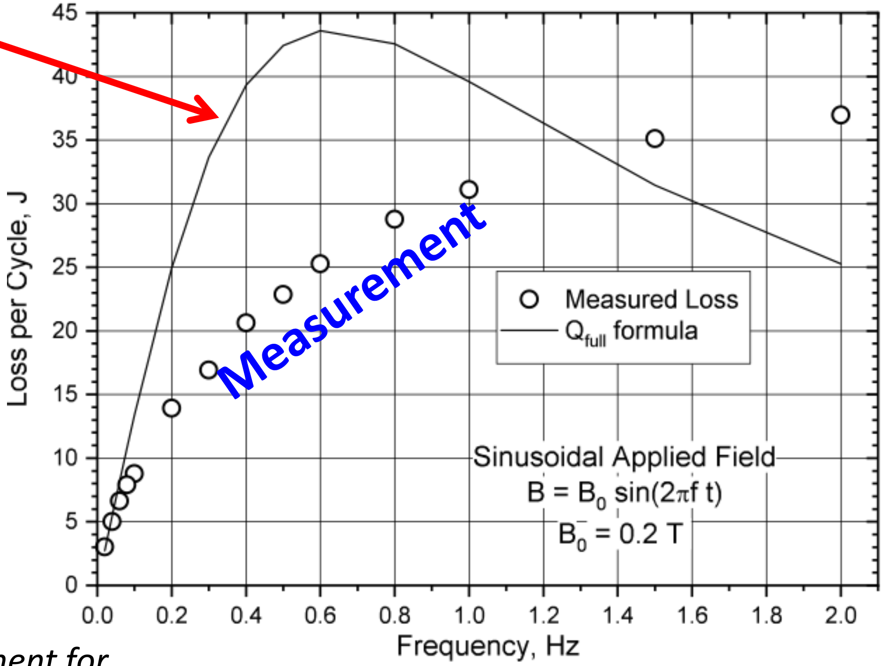


Proposed solution:

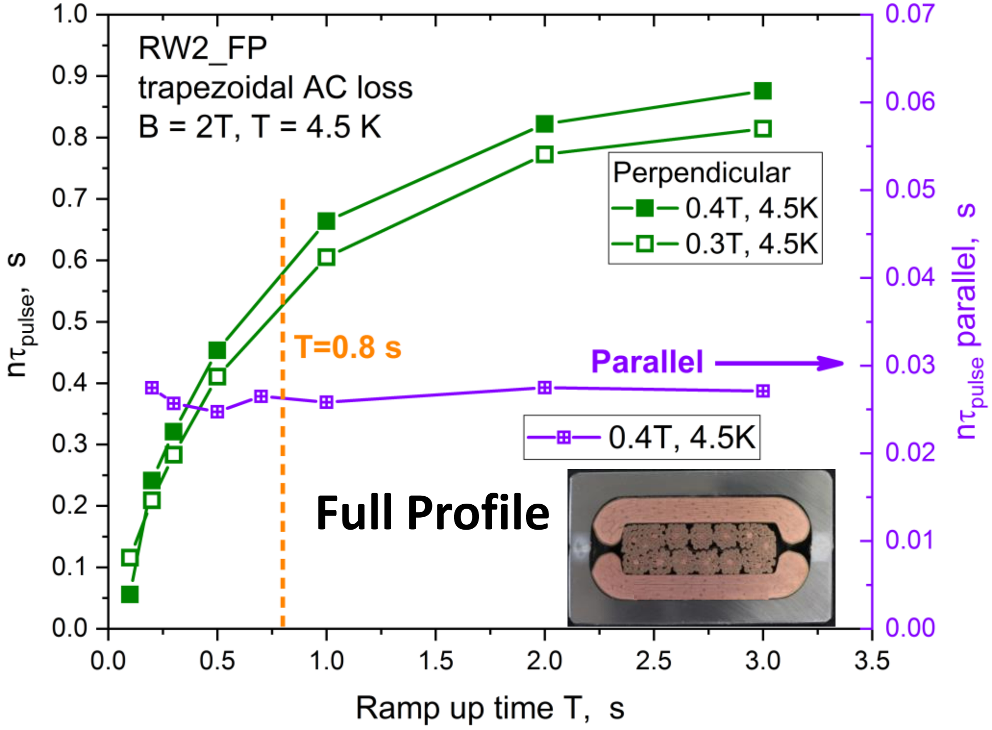
Measure AC loss for linear dB/dt ramp (trapezoidal AC field pulse)

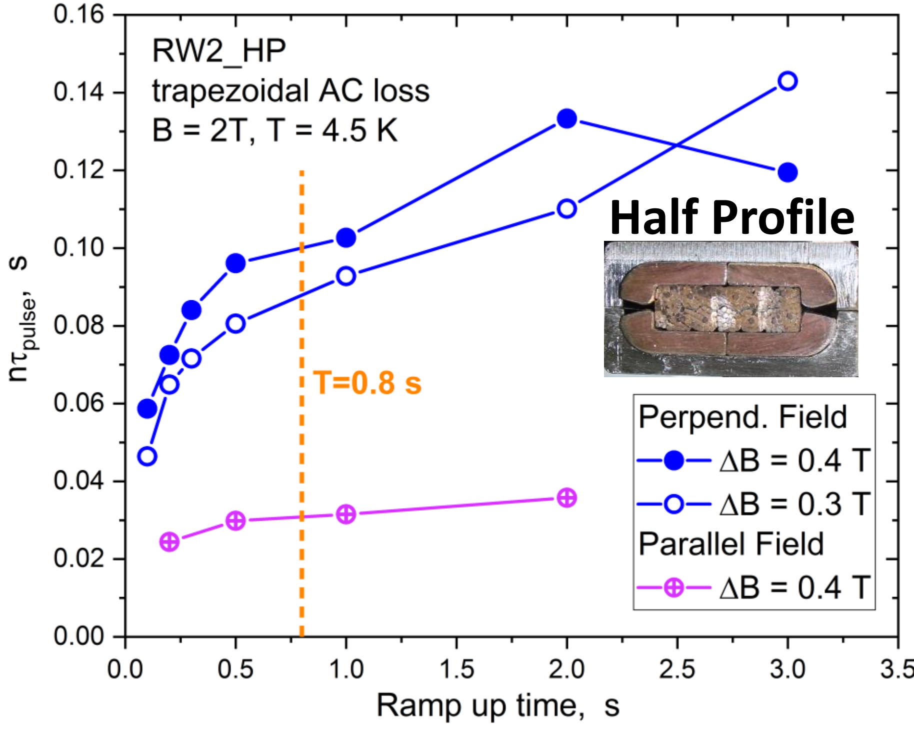
$$Q = \frac{\dot{B} \Delta B n \tau_{pulse}}{\mu_0}$$

and extract effective $n\tau_{pulse}$, which a function of the ramp-up time T.

P. Bruzzone et al. "*A new test method of AC loss assessment for fusion conductors*", Fusion Eng. Des. 146, 2019, pp. 928-931.

AC Loss – Trapezoidal





Conclusions

- AC loss of the RW2 conductor:
  - For mixed matrix stabilizer dominated by eddy current loss.

    ➔ MM will be replaced by a highly compacted Rutherford cable of cladded Cu wires.
  - The coupling current loss in the cable alone is very small due to:
    - Flat cable geometry.
    - Stainless steel strip inserted between the 2 rows of the sub-bundle layers.
- Once eddy currents in the segregated stabilizer will be reduced, the cable will be suitable also for the CS conductors.
- Usage of effective $n\tau_{pulse}$, experimentally determined from the trapezoidal field pulse, is expected to lead to more realistic and precise predictive calculation of the AC loss.

Thanks for your attention!

- Steady state: a sinus sweep with variable frequency is applied as long as stable temperature gradient is established downstream of the AC field. The AC power loss is proportional to ΔT·dm/dt -> "Loss curve" -> initial slope -> **$n\tau_{sinus}$**

Transient: a trapezoidal pulse with variable ramp time, T, is applied with a long flat top. The temperature increase is integrated. The AC energy loss is proportional to -> **$n\tau_{pulse}(T)$**