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AC loss, contact resistance, and cabling degradation analysis of various Nb3Sn sub-size CICC cable designs

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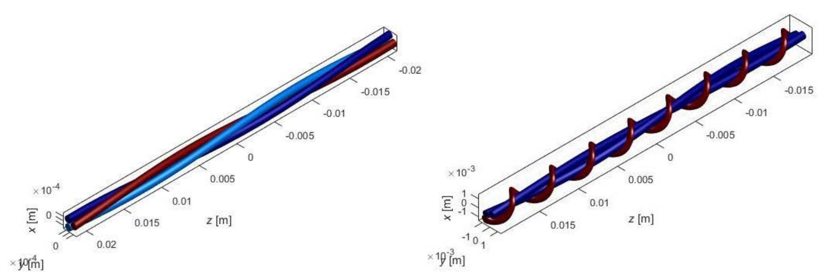
Abstract

- The superconducting cables for magnet systems in nuclear fusion reactors usually adopt the Cable-in-Conduit conductor (CICC) concept.
- Six sub-size CICC cables made of Nb3Sn strands are manufactured and tested experimentally on AC coupling loss, interstrand contact resistance, and cabling degradation.
- The inter-strand coupling loss is analyzed with the numerical code JackPot ACDC, developed at the University of Twente, to find an optimal cable pattern.
- Transport current degradation is measured on a few selected strands in the cables and strand indentation from cabling and compaction are analyzed as well

Six Sub-size CICC cable patterns

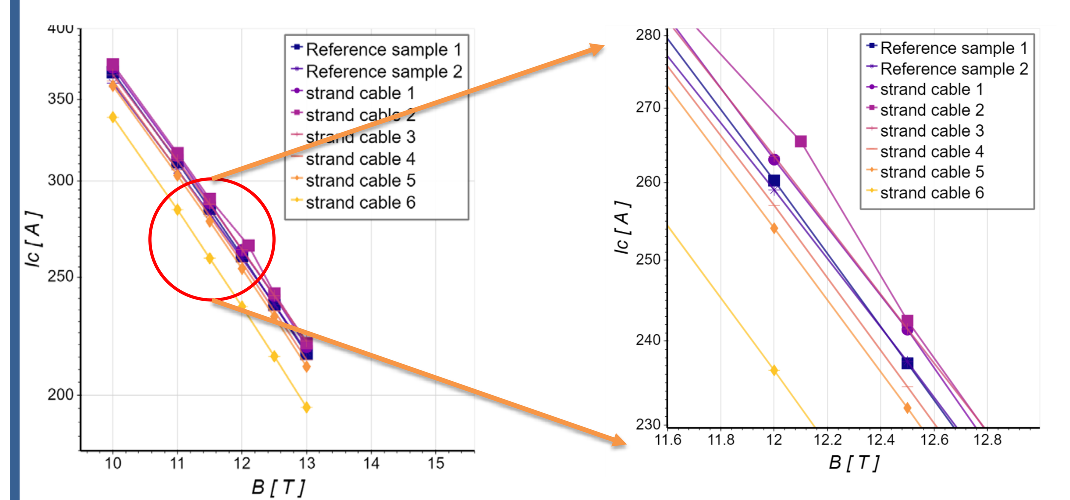
	Design	Void fraction [%]	Twist pitch lengths [mm]	Cabling angle Cosθ	Jacket inner diameter [mm]
Cable 1	Twente	27.9 ± 1	50×58×66×76	0.941	11.95
Cable 2	Twente	28.0 ± 1	110×118×126×140	0.983	11.70
Cable 3	Twente	23.2 ± 1	50×58×66×76	0.945	11.55
Cable 4	Twente	32.3 ± 1	50×58×66×76	0.938	12.35
Cable 5	CSMC	32.6 ± 1	25×50×90×160	0.966	12.20
Cable 6	CWS-I	32.5 ± 1	(40+10)×60×90×160	0.925	12.45



- Soft copper strand around Nb3Sn strands in short twist pitch
- Twente design with twist pitch ratio close to one
- ITER Baseline for comparison

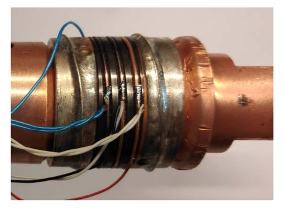
Critical current degradation

- Strands are extracted from each cable
- Wound on short size ITER Barrels and heat treated

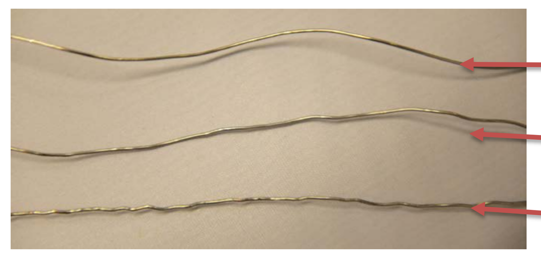


Ic(B) results show that all strands are have close performance, except from cable 6 (CWS), 10% at 13 T.

All Twente cables showed similar and lowest Ic degradation



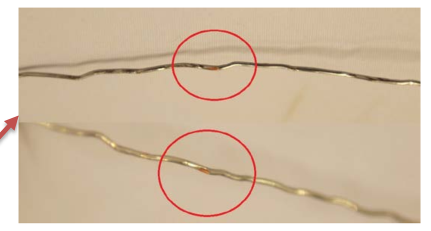
Visible indentations



Strands of cable 4

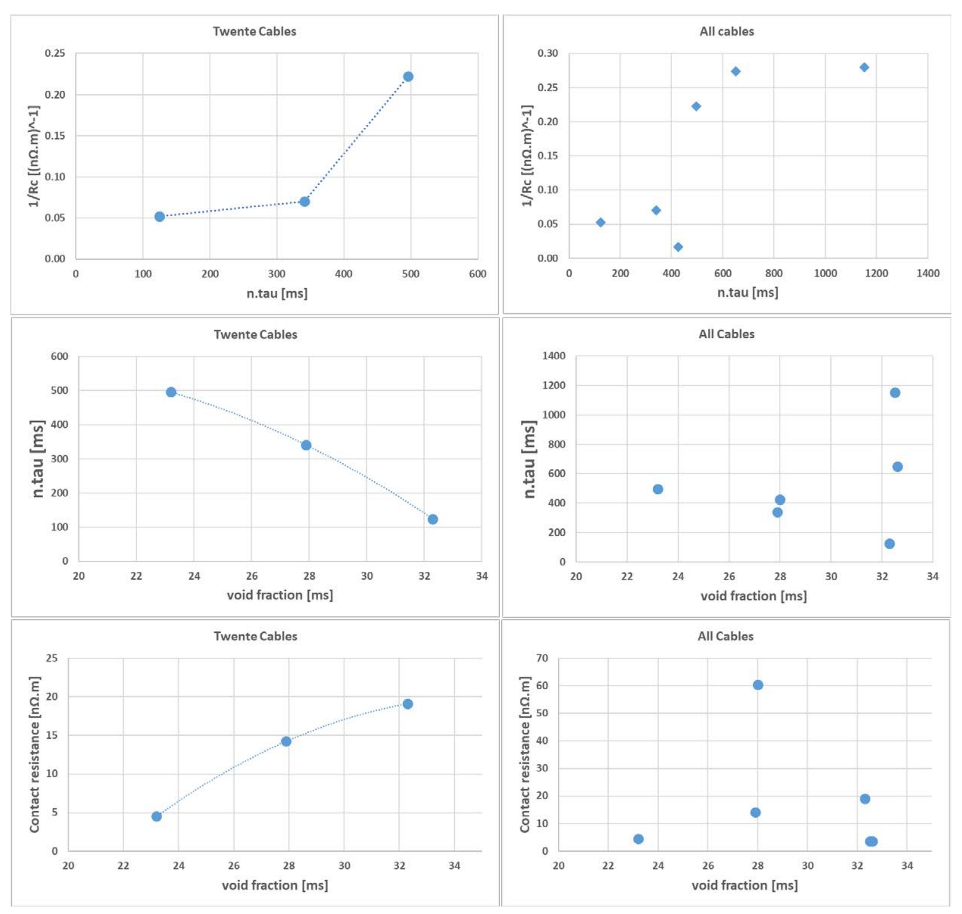
Strands of cable 5

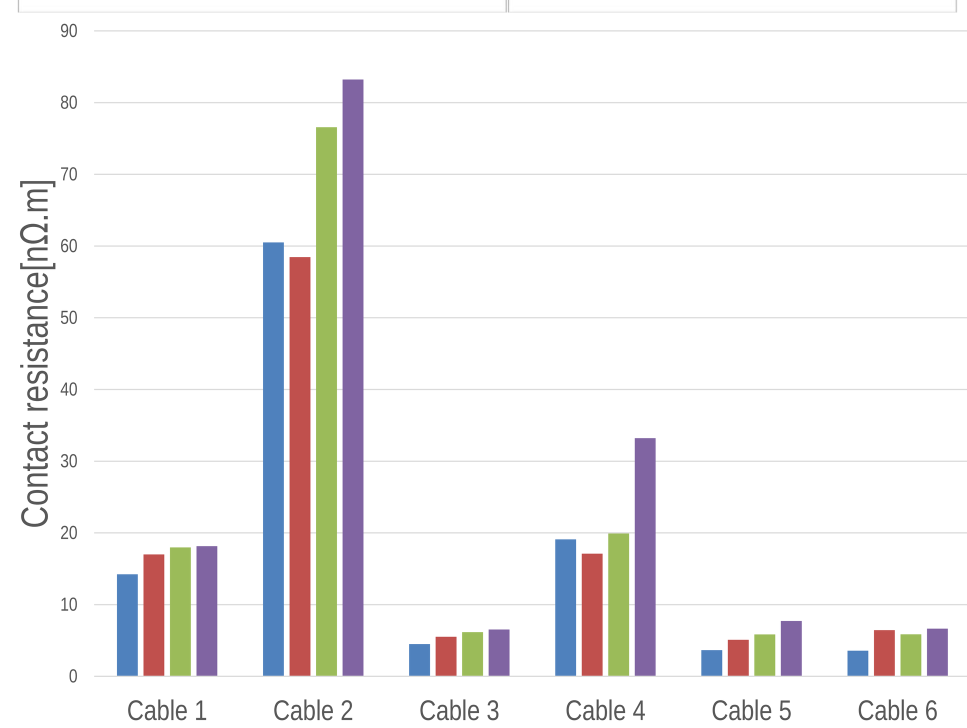
Strands of cable 6

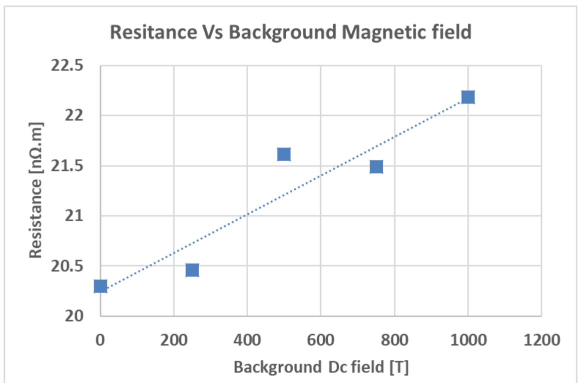


Contact resistance measurement (R_c)

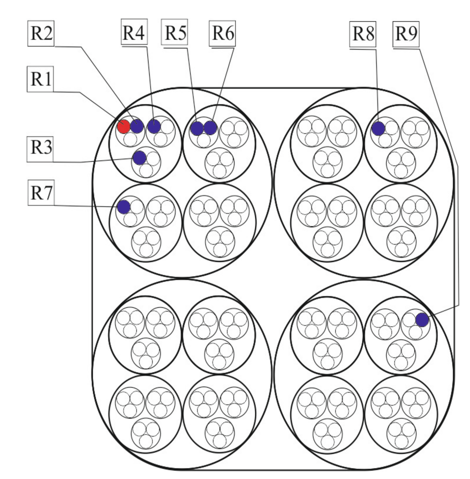
- 10 Nb3Sn strands are selected from all four stages
- Sample prepared before heat treatment (brittle Nb_3Sn Strands)
- Four-point measurement using current of 50 A.
- Measured in LHe @ 4.2 K



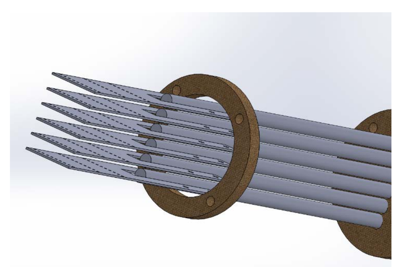




Contact resistance increases with Bdc

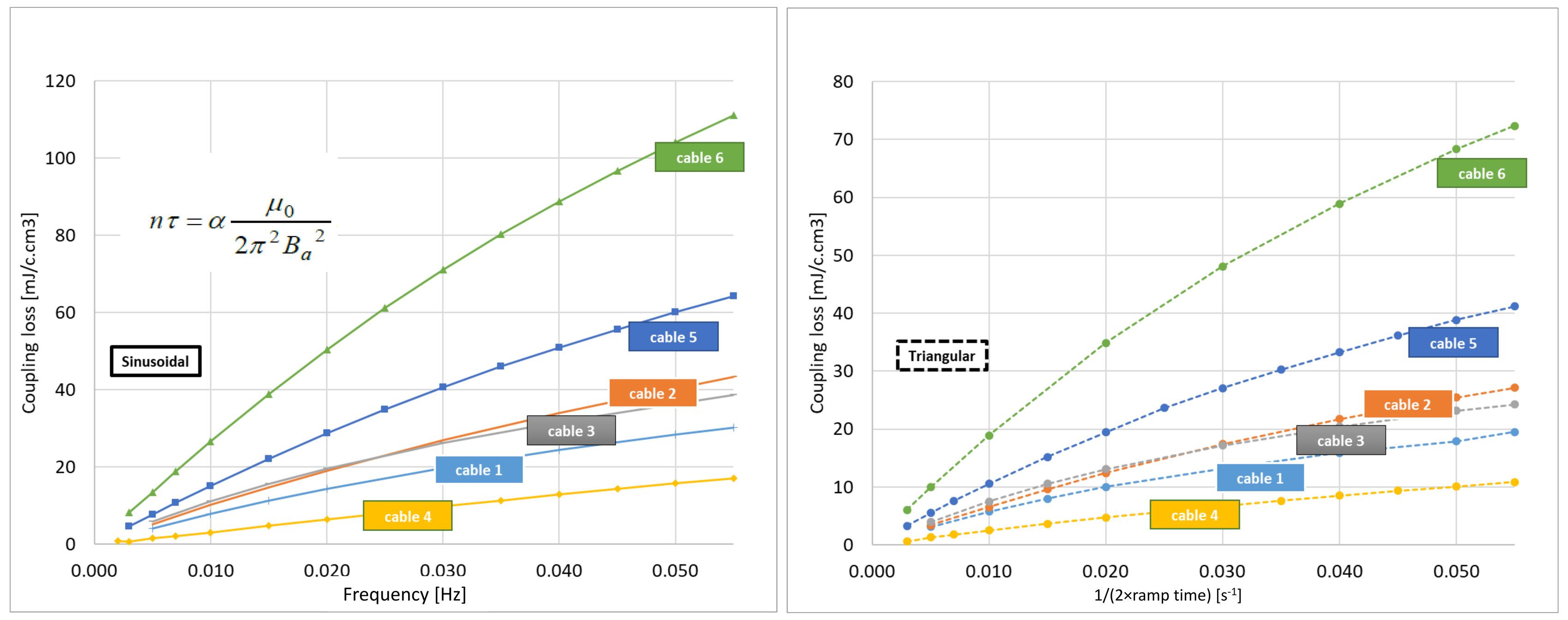


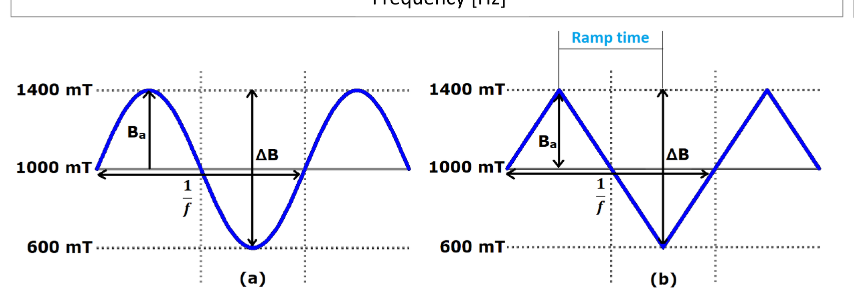
Selected strand set from each cable



All six cable measured together in LHe

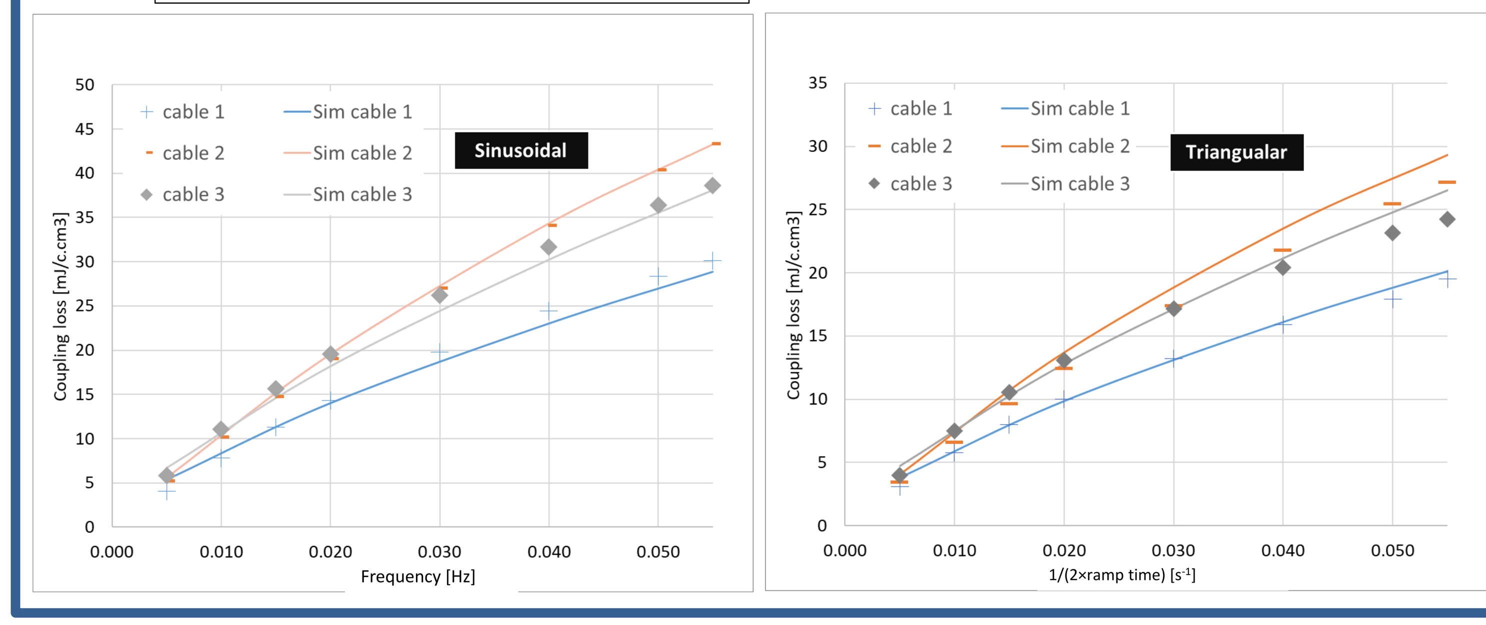
AC loss measurement and simulation





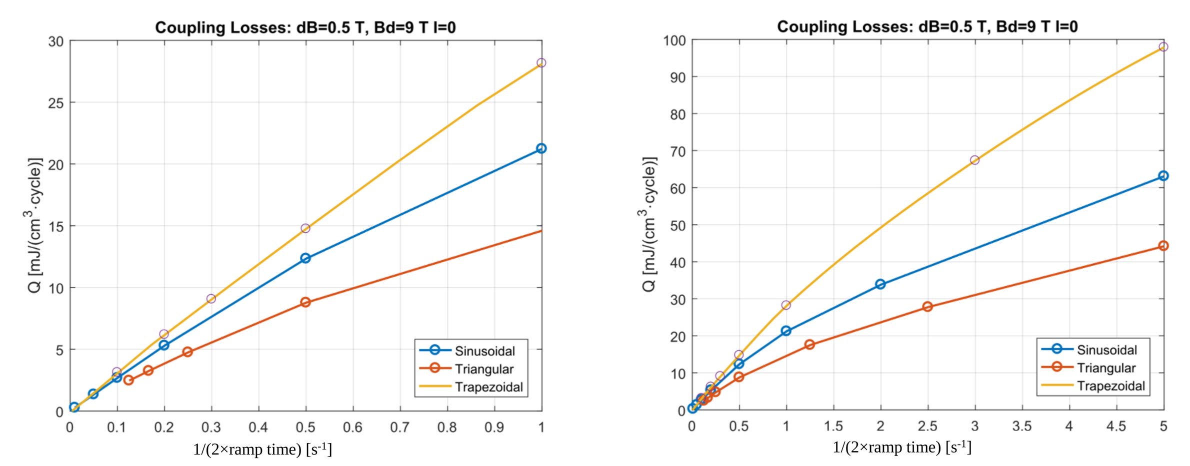
Sinusoidal and triangular field profiles

	n.tau	Intra-triplet Rc	Void fraction
	[ms]	[nΩ.m]	[%]
Cable 1	341	14.2	27.9
Cable 2	426	60.5	28
Cable 3	496	4.5	23.2
Cable 4	124	19.1	32.3
Cable 5	650	3.7	32.6
Cable 6	1153	3.6	32.5

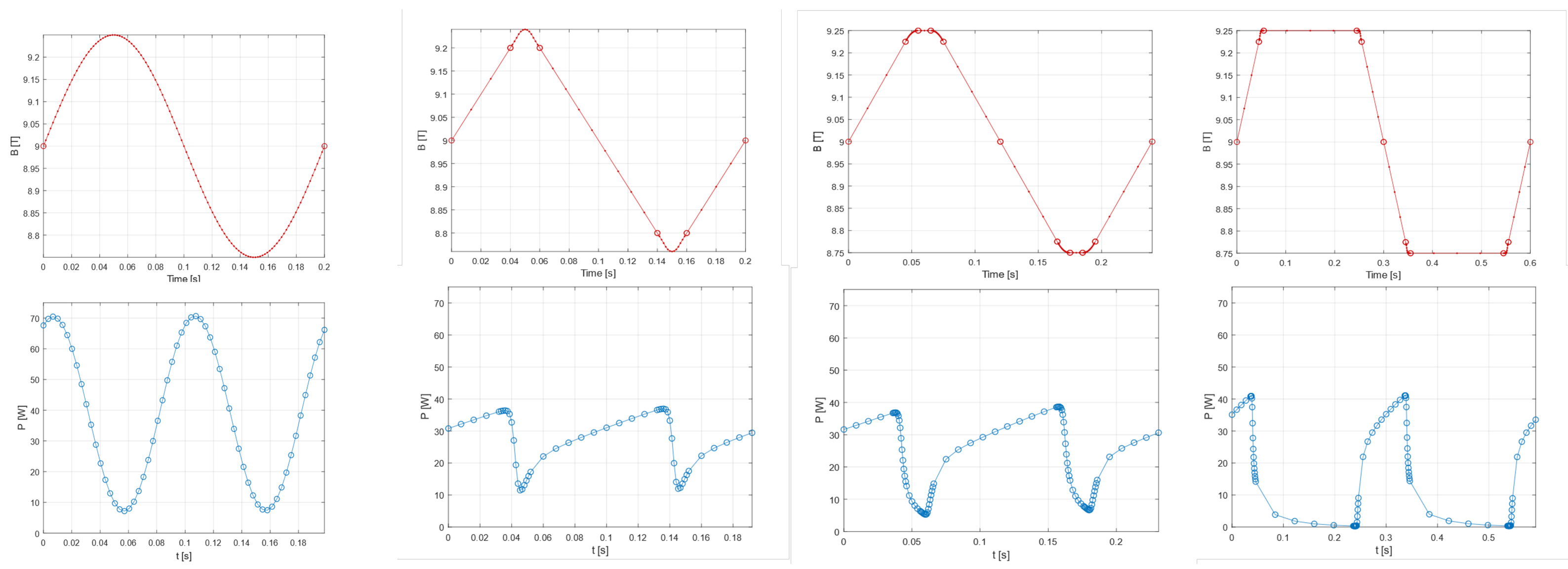


Simulation is in agreement with experimental data for first 3 cables

AC loss for different magnetic field profiles



- Coupling loss simulation done on ITER CS full size cable – CSJA8
- ΔB = 0.5 T and Background DC field of 9T



Conclusions

- All the Twente cable designs showed lowest coupling loss with no visible strand indentation and critical current degradation
- Inspection of strand indentation shows no relevant deformation of strands for the Twente design but strong deformation in CWS, intermediate in CSMC.
- Extracted strands show degraded performance for CWS design (10%), while samples from other SS CICC designs perform close to reference (more extracted strand tests foreseen).
- Twente cable design is a suitable candidate for high J_c Nb3Sn CFETR conductors