UNIVERSITY OF TWENTE.

Coupling loss in prototype CFETR CS conductors with different cable patterns, measurement and modeling

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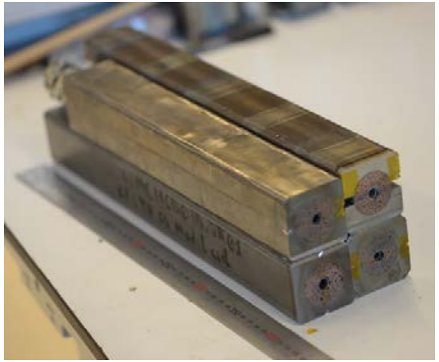
EMS

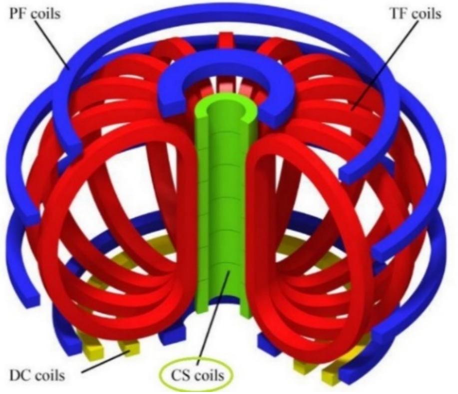
Outline

- Introduction
- Experiments
- JackPot – Modeling
- Results
- Conclusion

Introduction

- CFETR stands for “China Fusion Engineering Test Reactor”
- CS – Central solenoid
  - 6 Coils made of Nb_3Sn strands, 0.82 mm diam.
  - Design requirement CFETR CS model coil: 12 T peak field

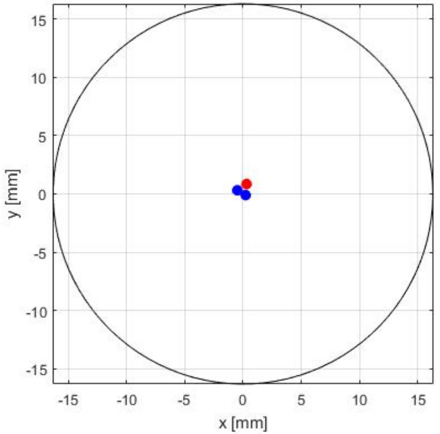




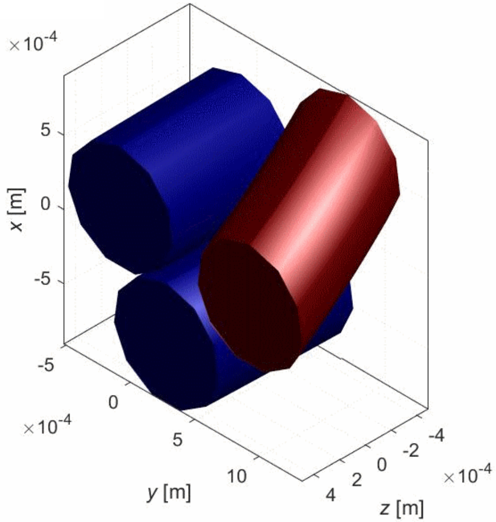
	New ASIPP cable design - Triplet modification	New Twente Cable Design	ASIPP CSMC cable
Sample state	Virgin (2) Press – Initial state (1)	Virgin	Virgin (2)
Cable pattern	(2Sc + 1Cu) x 3 x 4 x 4 x 6		
Twist length (mm)	(40/10)x49x89x160x450	50x58x66x76x450	20x50x80x150x450
Void fraction	32	28	33.4
Outer diam. (mm)	32.6	31.6	32.6

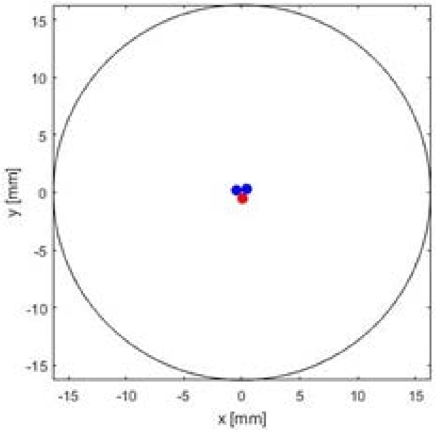
Introduction

Cable patterns

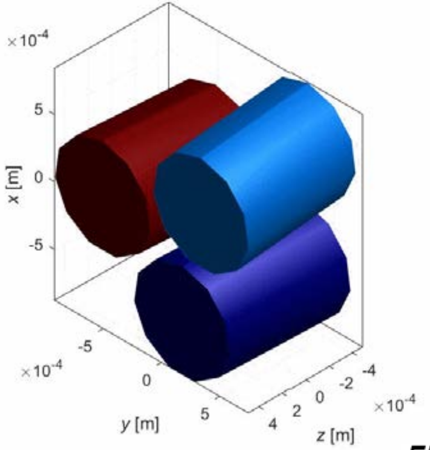


New triplet ASIPP cable design - triplet modification only in first stage by shorter twist pitch for copper strand



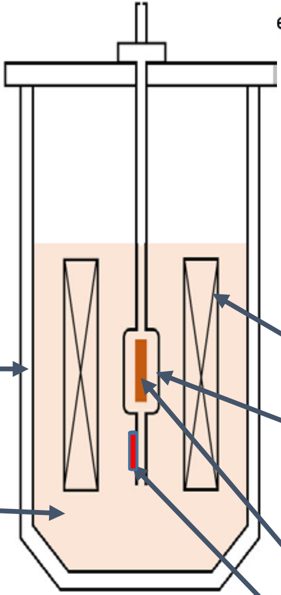


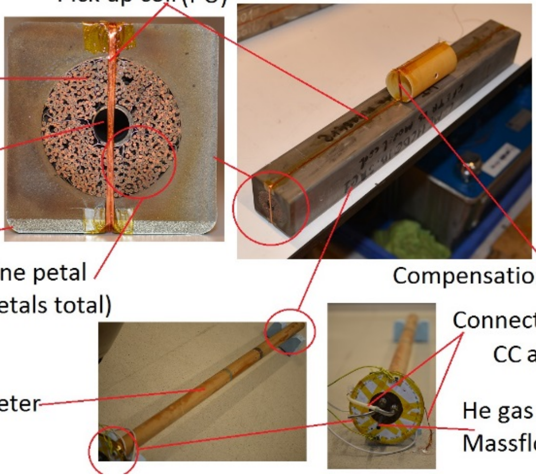
Regular ITER CS cable design for CICC cables with same twist pitch for all strands in same stage



Experiment - Ac loss Measurement

Sample preparation

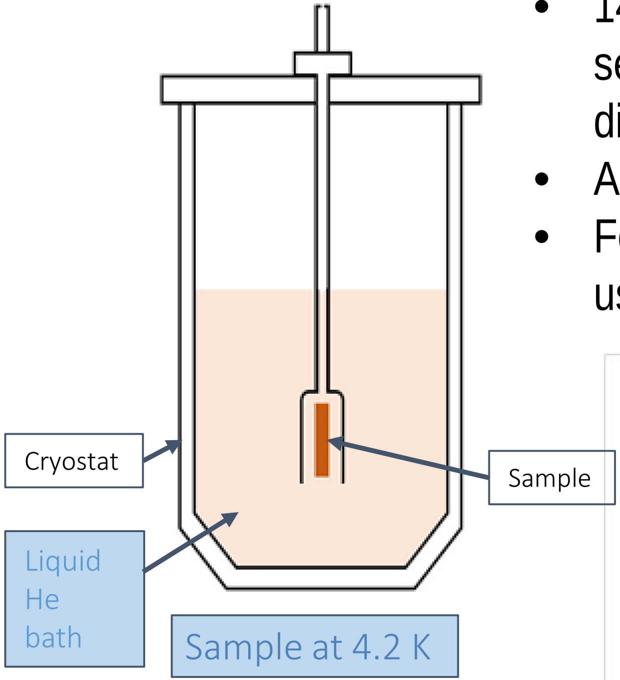




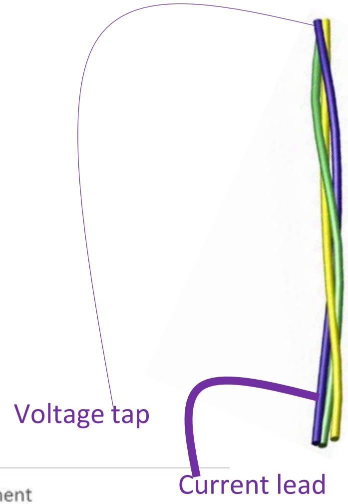
Sample at 4.2 K

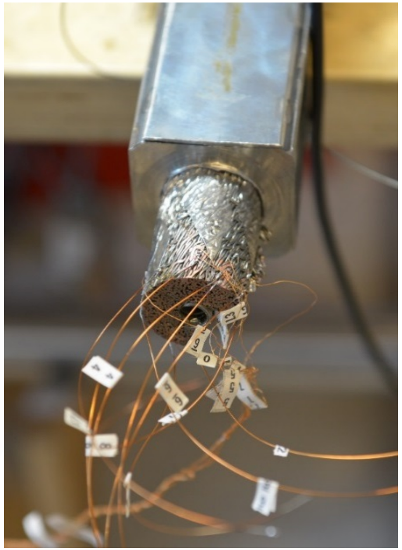
Experiment – Resistance Measurement

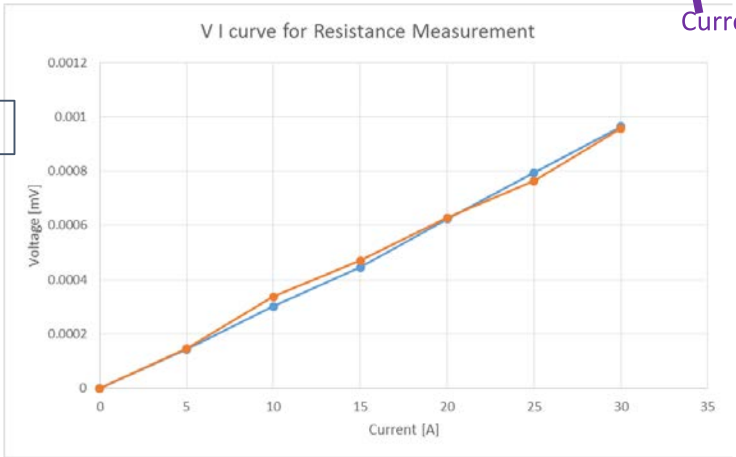
Sample Preparation – Inter-strand Resistance measurement

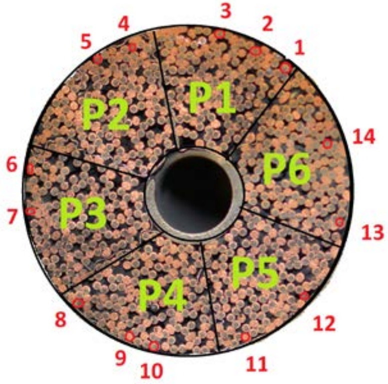


- 14 Nb_3Sn strands are selected at random from different petals
- After heat treatment (brittle)
- Four-point measurement using current of 20 – 30 A.



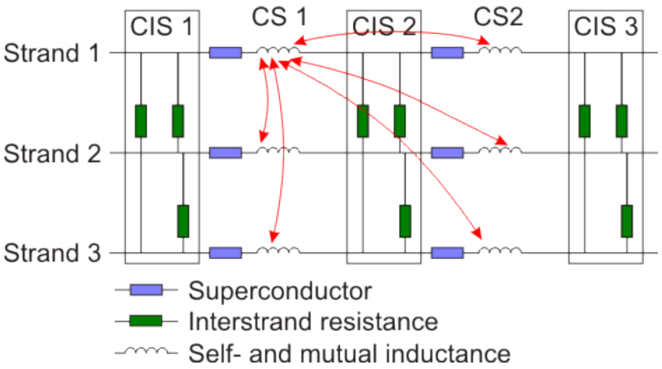


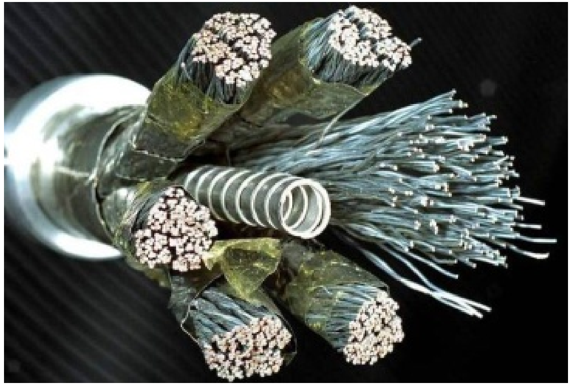


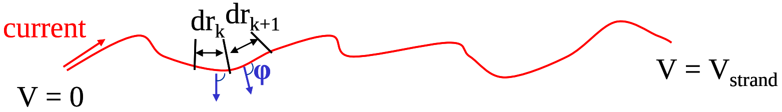


JackPot - ACDC CICC cable model

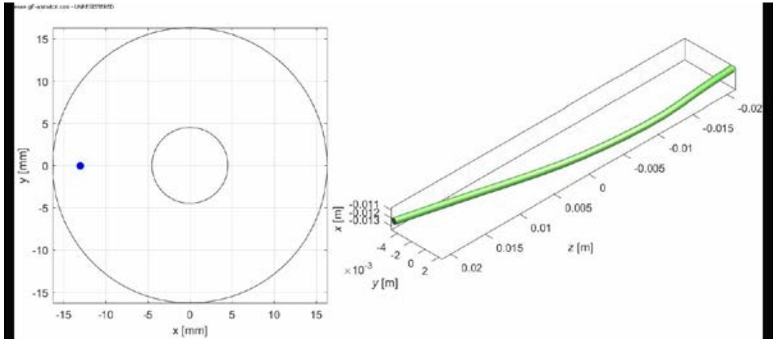
- Inter-strand contact resistance distribution from contact area
- Strand's mutual inductances
- Coupling with self & background field
- Strand properties scaling law $I_c(B,T,e)$ & n-value

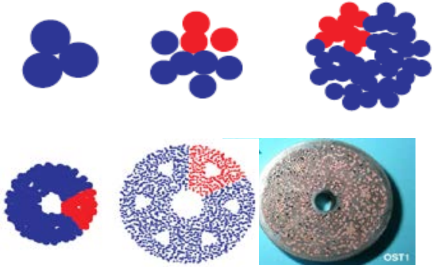






Cable / joint model describing *all* (>1000) strand trajectories in CICC; including cable compaction steps.

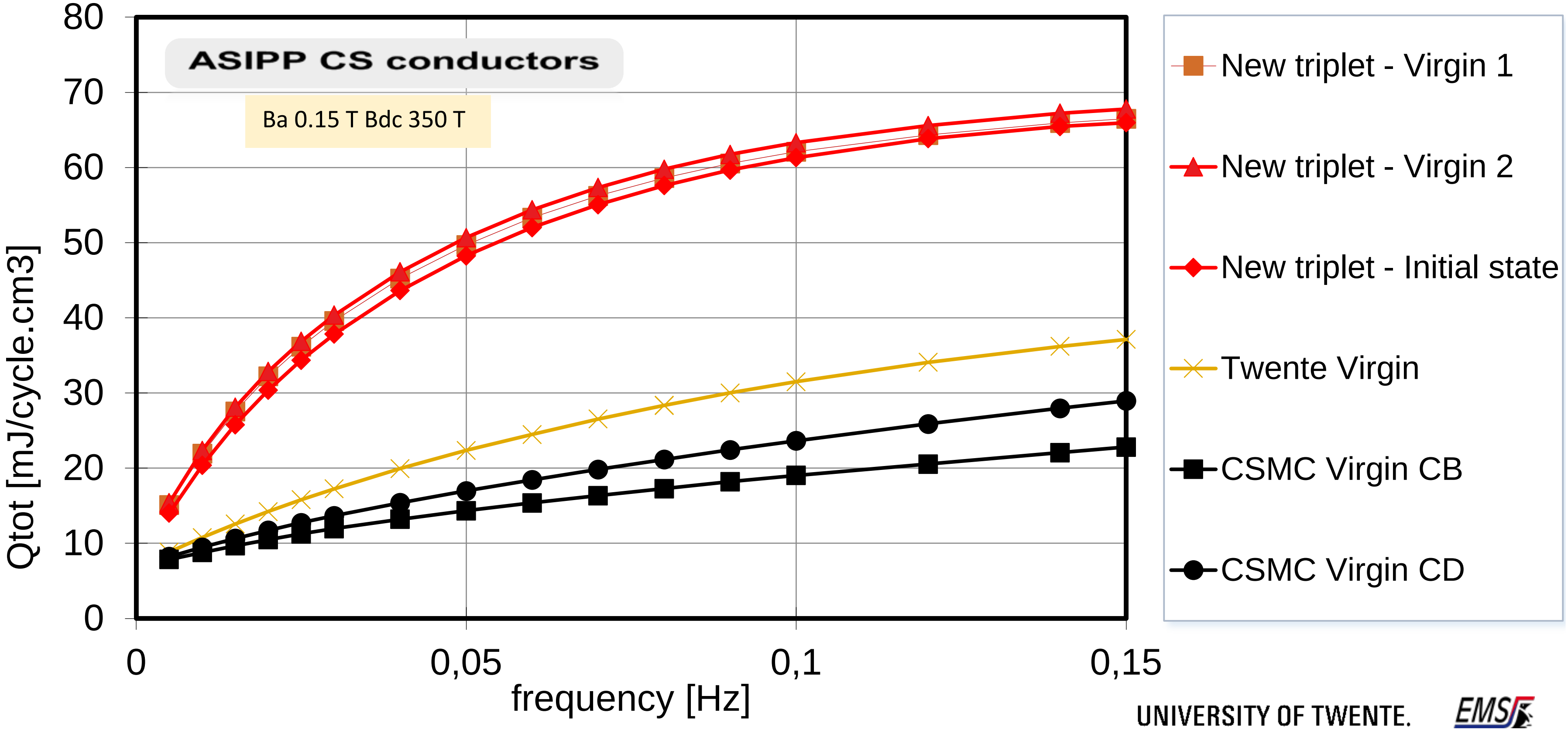




Cable cross section from JackPot simulation

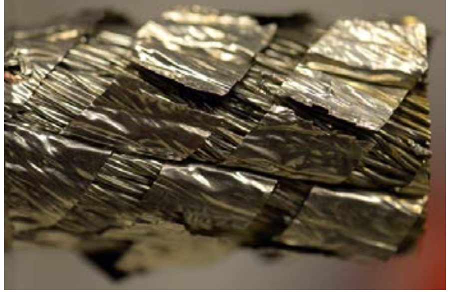
Results

AC loss - Experiment

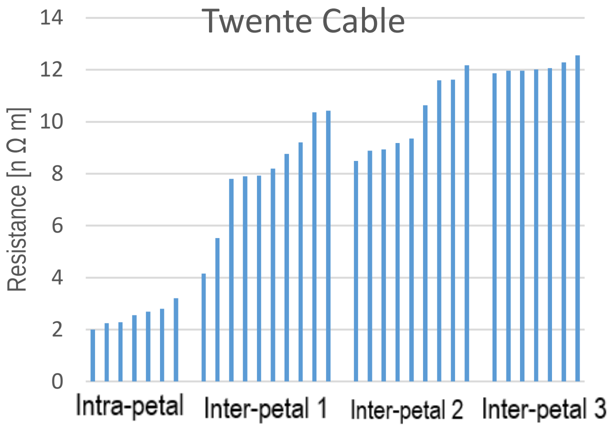


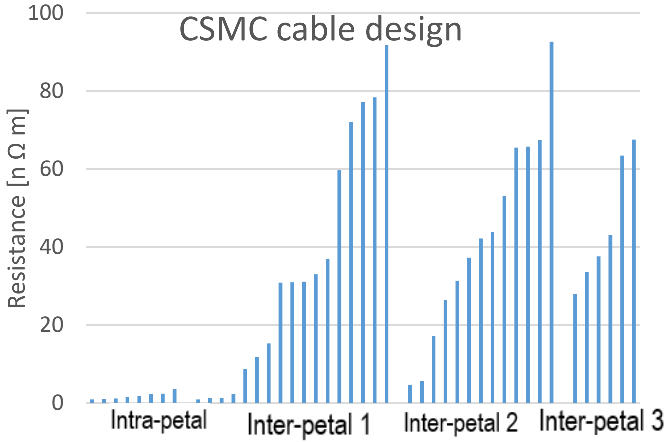
R_c Results

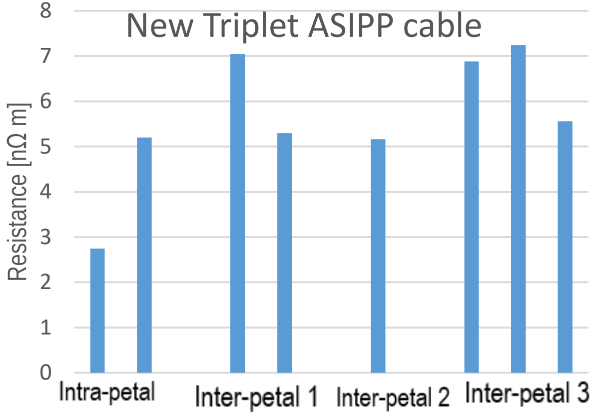
Resistance measurement - Experiment



Intra-petal → within a petal
Inter-petal → between petals







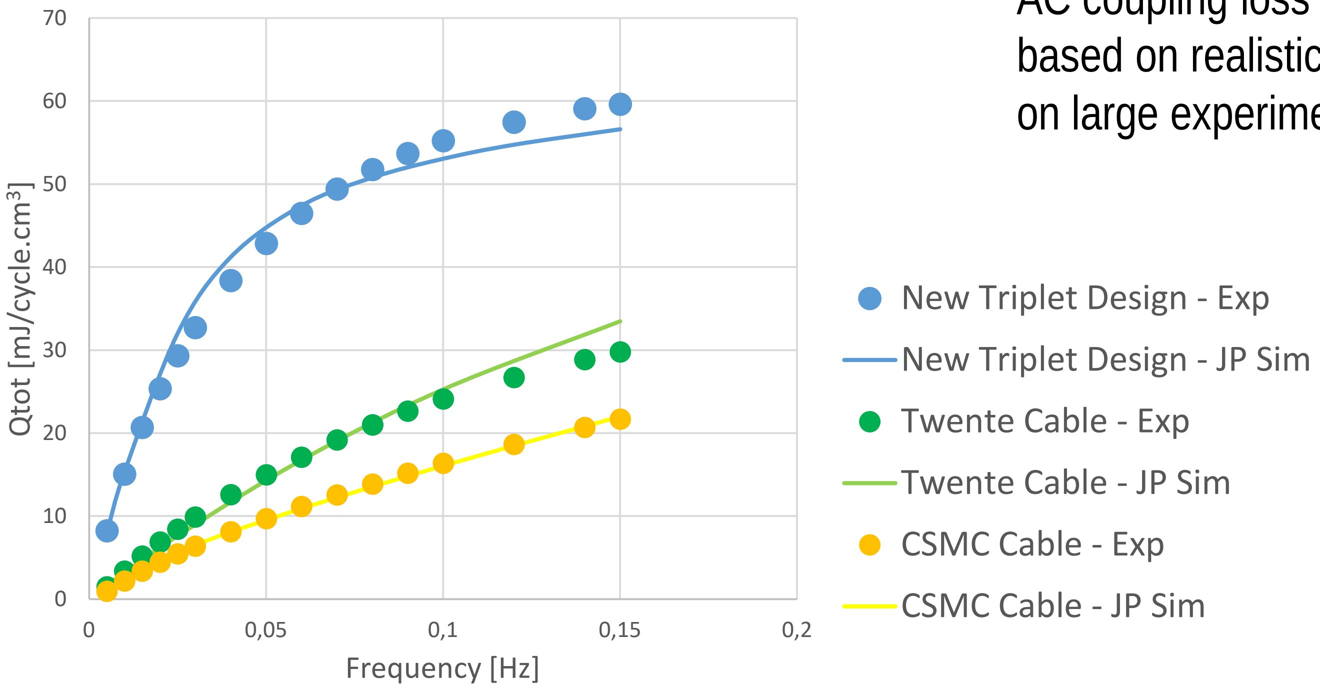
Intra-petal R_c expected range.
Inter-petal R_c very low (unintended low petal wrap coverage, 40%)

Large spread in Rc of direct neighboring petals due to direct interstrand contacts (locally no petal wrap coverage)

R_c distribution measured for New Triplet design somewhat unexpected, confirmation needed.

Results JackPot

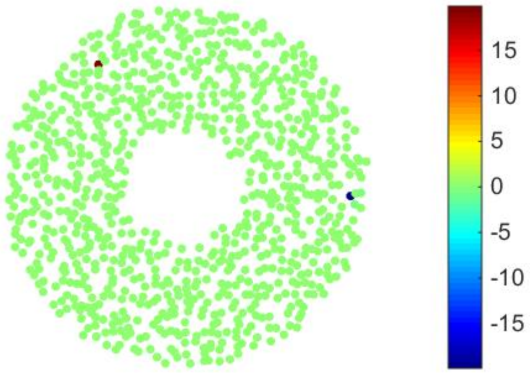
Coupling loss Experiment and Modelling

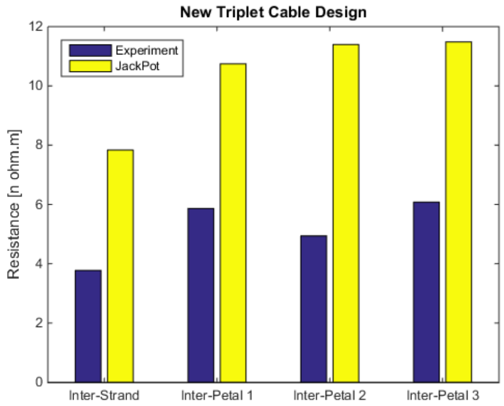


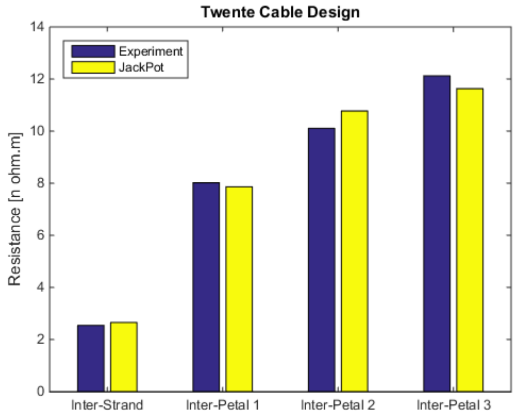
AC coupling loss calculated by JackPot based on realistic R_c distributions founded on large experimental data base.

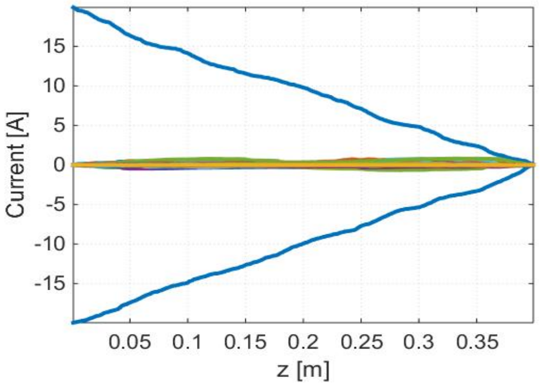
Results JackPot

Interstrand Resistances: Experiment and Coupling loss Modelling



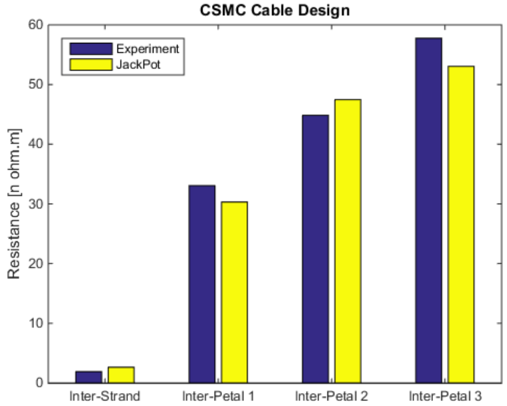






R_c measurements and JackPot model in good agreement for Twente & CSMC

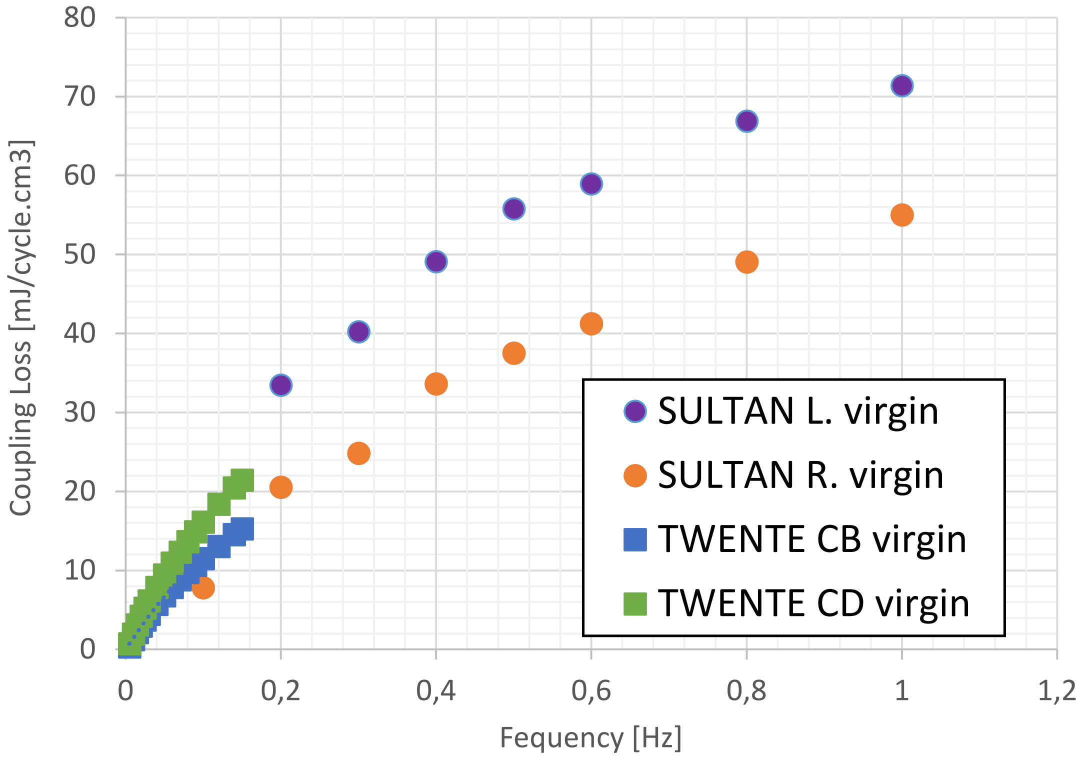
R_c measurements - New Triplet design: data confirmation needed on values and distribution (petal wrap coverage petals 40 instead of 70%).



Results Comparison

	New triplet ASIPP Cable Design	Twente cable Design	CSMC ASIPP cable Design
Coupling loss time constant nτ [ms]	3900	1110	770
Inter-strand Resistance [nΩ m]	10	7	6
Inter-petal Resistance [nΩ m]	13 – 16	20 – 30	80 – 150
Petal wrap Coverage (%)	70 (40)	70 (40)	70
Void fraction (%)	32	28 (22)	33.4

Comparison of experiments - SULTAN and TWENTE



Good agreement Sultan - Twente

Time constant (nτ) represents the coupling loss

CICC is multiple time constant system

For single nτ concept, as mostly used, determined nτ value depends strongly on considered frequency range

Approach used here: initial slope $Q_{cpl}(f)$ curve (higher nτ).

Conclusion

- New triplet ASIPP design, but also Twente design shows higher coupling loss than CSMC layouts.
- Void fraction doesn't play much role in inter-strand resistances.
- Petal wrap coverage is one of the dominant factors determining intra-petal resistances, hence coupling loss
- No definitive conclusion about better geometry for CS cable at this stage. Multiple parameters varied unintended for different cable pattern variations; void fraction and petal wrap coverage.
- More work needed.

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Thank you!

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