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:

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

- Strand type - Nb$_3$Sn; 1.5 mm diameter
- Number of strands - 306
- React & Wind route (RW WP1 sample)

- Strand type - Nb$_3$Sn; 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
• Force up to 800 kN/m
• Operated at 4.2 K
• Up to 600 load cycles per hour
• Dipole magnet to study AC loss

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.
One. RW WP1 sample preparation

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.
1. WR WP2 sample preparation

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
2. AC loss of virgin samples

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

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

Where $\alpha$ is loss-frequency dependence slope.

### Loss-frequency dependencies

<table>
<thead>
<tr>
<th>Perpendicular field orientation</th>
<th>Parallel field orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{apl} = \pm 0.15$ T</td>
<td>$6.1 \pm 0.1$ 37.9$\pm 0.2$</td>
</tr>
<tr>
<td>$B_{apl} = 0.2$ - 0.5 T</td>
<td>$5.8 \pm 0.1$ 34.5$\pm 0.5$</td>
</tr>
<tr>
<td>AC loss peak position (mHz)</td>
<td></td>
</tr>
<tr>
<td>$B_{apl} = \pm 0.15$ T</td>
<td>$100 \pm 5$ 21.4$\pm 0.4$</td>
</tr>
<tr>
<td>$B_{apl} = 0.2$ - 0.5 T</td>
<td>$100 \pm 5$ 22.7$\pm 0.5$</td>
</tr>
</tbody>
</table>
3. Evolution of AC loss during load cycling

- 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
• 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.
4. Strands selection for $R_c$ measurement

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

WR WP2 sample.

RW WP1 sample.
4. Evolution of $R_c$ with load cycling

- 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.
5. Evolution of mechanical properties

- Displacement-force curves show visco-elasto-plastic deformations as observed previously for Nb$_3$Sn conductors.
- Mechanical losses $Q_m$ are small and negligible compared with AC loss for both conductors.
5. Evolution of mechanical properties

Maximum displacement vs 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.
6. Summary

• 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.