2) FRESCA-compatible specimen

- Two insulated 1.73 m long Rutherford cables
- Cables are impregnated and keystoned-compensated arranged to reach a planar surface for transversal stress application
- Top ends connected to Nb-Ti current leads
- Bottom ends soldered together, i.e. the current flows anti-parallel.
- Area of pressing was chosen in the centre of the specimen between the inner voltage-taps to ensure a homogenous field condition over the measured area.

Type: Cable properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu No Co-Ni volume ratio</td>
<td>1.10</td>
</tr>
<tr>
<td>Strand diameter</td>
<td>0.7 mm</td>
</tr>
<tr>
<td>Sub-conductor diameter</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Sub-conductor pitch</td>
<td>5.0 mm</td>
</tr>
<tr>
<td>Virgin (30 x 50)</td>
<td>358 A</td>
</tr>
<tr>
<td>Virgin (42 x 32, T)</td>
<td>438 A</td>
</tr>
<tr>
<td>Heat Treatment</td>
<td>710 °C</td>
</tr>
<tr>
<td>Transversal Stress</td>
<td>50 MPa</td>
</tr>
<tr>
<td>100 MPa</td>
<td></td>
</tr>
<tr>
<td>150 MPa</td>
<td></td>
</tr>
</tbody>
</table>

Specimen cross section (15.6 x 3.8) mm²

Area of pressing 50 mm

3) Application of transversal compressive stress

- Iterative compression at room temperature before every Ic measurement
- Applying stress by using a hydraulic press and evaluation of force with LoadCells
- Evaluation of pressure distribution and optimization of the alignment parameters by using FULLJIM Prescale©
- Self-written image processing software for evaluation of the results
- Multilayer of Prescale films of different sensitivity was used to cover a higher range.

Stress application results

<table>
<thead>
<tr>
<th>Nominal</th>
<th>68.64</th>
<th>75.00</th>
<th>85.80</th>
<th>102.96</th>
<th>120.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>σnom 50 MPa</td>
<td>100.00</td>
<td>106.20</td>
<td>125.00</td>
<td>150.00</td>
<td>175.00</td>
</tr>
<tr>
<td>Iapp</td>
<td>7.91</td>
<td>8.36</td>
<td>9.63</td>
<td>10.80</td>
<td>11.00</td>
</tr>
<tr>
<td>Ic</td>
<td>7.92</td>
<td>8.36</td>
<td>9.63</td>
<td>10.80</td>
<td>11.00</td>
</tr>
<tr>
<td>Ic/nom</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

4) Ic measurement with FRESCA

Subsequent to each stress application, the sample was transferred to the FRESCA test station for Ic measurement.

- **FRESCA test station properties** [9]
  - Operation current Ic = 32 kA (70 kA)
  - Applied dipole field Bapp = 9 T with self-field up to 12 T
  - Homogeneity Bapp(max(Bapp)) > 99% over a length of 475 mm
- **Measurement condition of specimen**
  - Applied field Bapp = 9 T
  - Temperature T = 4.2 K
  - Bapp parallel to large surface of specimen and perpendicular to the current
  - Both cables were measured and showed the same degradation behaviour.

Ic measurement results at maxi(Bapp) = 9.6 T and T = 4.2 K

<table>
<thead>
<tr>
<th>σnom</th>
<th>Ic</th>
<th>Ic/nom</th>
<th>Ic/nom Ic</th>
<th>n**</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 MPa</td>
<td>22.1</td>
<td>1.00</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>100 MPa</td>
<td>22.1</td>
<td>1.00</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>150 MPa</td>
<td>22.1</td>
<td>1.00</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

5) Post analysis

Investigation carried out after the measurement campaign

- Visual inspection of the pressing area shows on both sides several cracks of the epoxy resin matrix. An average displacement is height of 0.62 mm due to transversal stress was measured.
- Non-destructive 3D X-ray tomography by the Federal Institute for Materials Research and Testing (BAM) was carried out to identify damages caused by compressive stress.

- Plastic cable deformations caused by the applied stress are not revealed by the results. The spatial resolution is insufficient to visualise cracks in the expected Nb5Sn filaments.
- Deformations on the edges of the cables and displacements of the core due to specimen manufacturing could be detected independent of the pressure. This leads to a degradation less than 5% compared to the strand performance [11].

6) Conclusion

In order to determine the limits of pre-stress on the coil assembly for future high field accelerator magnets, a FRESCA-compatible Rutherford cable specimen was exposed to transversal compressive stress at room temperature and subsequently the critical current at 4.2 K was quantified in several iterations up to 200 MPa.

A hydraulic press was used to perform transversal compressive stress and the pressure distribution on the specimen was optimized. The critical current was measured in the FRESCA test station.

The results show a small degradation after an applied stress of 175 MPa and the specimen was heavily damaged after the 200 MPa cycle. The critical current Ic and the resistive transition index n of the cable are reduced, which is caused by higher current sharing. This measurement campaign also confirms that the common pre-stress of 150 MPa does not cause any degradation of the coil based on this study.

First visual inspection has shown cracks and deformation on the surface of the epoxy resin. Plastic deformation on the strand level and cracks in the impregnation layer or superconductive sub-elements could not be identified by the X-ray tomography.

7) Outlook

Additional to the non-destructive tomography a microscopy of the specimen is ongoing to understand the impact of transversal stress during room temperature on the superconductive Rutherford cable, especially the Nb5Sn sub-elements of the strands.

Further campaigns with cables from the 11 T- and the MOXRF programme have been organised to confirm the obtained results.

8) Acknowledgements

The main author would like to thank his working group for the great support as well as the colleagues from the SC section, especially the FRESCA team for providing the specimen and performing the Ic measurements.

References