Pressure-induced critical current reduction in impregnated Nb₃Sn Rutherford cables for use in future accelerator magnets

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Objective:
Study of the deviatoric strain in the strands of a Nb₃Sn Rutherford cable using 2D FE mechanical models, to:
• Understand the influence of the epoxy and glass properties;
• Understand the influence of the confinement geometry.

Strand and Cables:
• Strand Sample:
  Bruker OST RRP-132/169, diameter 1.0 mm, filament size 58 μm, Cu / non-Cu ratio 1.22;
• Cable Sample:
  18 strands of Ø 1.0 mm, rectangular size 9.97 mm x 1.81 mm, twist pitch 63 mm;
  Cables developed for the 16 T Nb₃Sn Short Model Coil (SMC) demonstrator magnets at CERN.

Result 1:
The average deviatoric strain in strands in Nb₃Sn Rutherford cables decreases with increasing $E_{epoxy}$ as the epoxy resin increasingly carries part of the transverse load;
• An increasing Poisson's ratio $\nu_{epoxy}$ and therefore an increasing bulk modulus $K_{epoxy} = E_{epoxy}/(3(1-2\nu_{epoxy}))$ renders the stress in the strand more hydrostatic and thus also reduces the deviatoric strain component.
• Cable impregnation with CTD-101/glass-fiber mixture, causes a 5% lower average deviatoric strain than with pure CTD-101K!

Result 2:
• $\epsilon_{dev}$ of strand 9 ($\theta=0.2^\circ$) is 3 to 3.5 times higher than in the ‘perfect’ experiment ($\theta=0^\circ$) when no ‘alignment’ impregnation is applied.
• A small misalignment angle of 0.15° already causes a 13% lower critical current at a transverse pressure of 200 MPa compared to the ‘perfect’ aligned case.
• With the ‘alignment’ impregnation, the effect of the misalignment angle is eliminated and the variation of the deviatoric strain in strands is reduced to less than 1%, which $\epsilon_{dev}$ value is nearly identical to the one found for $\theta = 0^\circ$.

Conclusion:
• Since the deviatoric strain in Nb₃Sn filaments has a direct impact on the critical current density, the use of a stiff and relatively incompressible epoxy resin significantly improves the pressure tolerance of cables.
• The mechanical effect of an insulating glass sleeve around the cable is relatively small.
• A misalignment angle as small as 0.2° between pressure block and cable surface causes a strain concentration by some factor 3 in the strands at the side of the cable that comes into contact with the anvil first.
• It should be noted that similar imperfections leading to stress- and strain concentrations may well occur also in the winding pack of real magnets, which our experiment is designed to mimic.
• The corrective alignment impregnation significantly improves the strain homogeneity in the transverse press experiments, rendering it essentially equal to the strain modelled for the perfectly aligned situation.