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Viscoelastic explanation of the loss of pre-stress in impregnated superconducting magnets

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The SMC (Short Model Coil) program was started at CERN around 2008 to develop the Nb3Sn technology. The small magnet structure allowed relatively cheap and fast test of various superconducting coils. One of the key questions was the relation between the pre-stress and the magnet's performance, to measure which dozens of strain gauges were installed on the coil, axial tie-rods and the external shell. The experimental campaign of strain measurements during all stages of load: room temperature (RT) pre-stress, cool-down, powering, warm-up was analyzed in an extensive report [1]. A repeatable pattern of decreasing strain after the warm-up was observed on the external cylinder for all the tested coils with considerable values from 19 % to 51 %. Such decreased strain was not predicted by any state-of-the art FEM models used by magnet designers.
The SMC program has several successor programs: RMC (Racetrack Model Coil), ERMC (Enhanced Racetrack Model Coil) and RMM (Racetrack Model Magnet) relying on similar design principles and pre-stress with bladders and keys. In the recent tests of the ERMC magnet the decreased strain by 30 % was reported [2]. Similar effect was observed for another Nb3Sn magnet MQXF [3] where strain decrease of 10-19 % measured by strain gauges and 18-25 % by optical fibers were reported for 4 coils.
To understand the effect of decreasing strain on the external shell of impregnated superconducting magnets the visco-elastic material model was applied to the resin used for the impregnation. A conceptual magnet model was developed with the Prony model and solved in Ansys, including the elastic shell and visco-elastic coil. With the two visco-elastic paramters controlling the Prony model: relative relaxation modulus and relaxation time the level of strain decrease was possible to control. The visco-elastic model can describe the effect of loss of pre-stress in a phenomenological way, predicting softening of the elastic constants, an effect analogous to damage and fracture but achieved with much smaller computational cost.

References

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