Fine Tuning of the Inner Dipole Design of MCBXF Magnets

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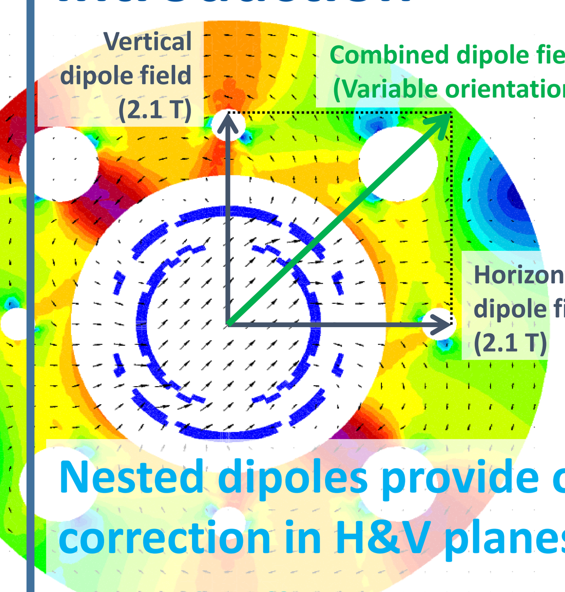
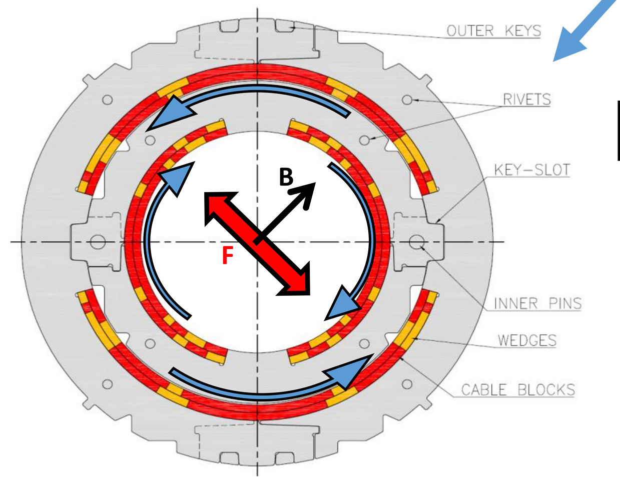
Abstract: Two types of nested orbit correctors are necessary for LHC upgrade, the so-called MCBXFA and MCBXFB. They share the same cross section, but feature different lengths, 2.5 and 1.5 m, respectively. The power tests performed on two MCBXFB prototypes showed excellent performance when individually powered, but the training to reach nominal torque in combined operation was very long. Moreover, memory was lost after torque direction reversal.
A detailed analysis of the power test results concluded that the origin of the problem was insufficient support for the torque at the inner dipole coil ends. A fine tuning of the inner dipole design is proposed to improve the performance of both types of magnets. This poster describes the analytical and numerical models developed to analyse the problem and their results.

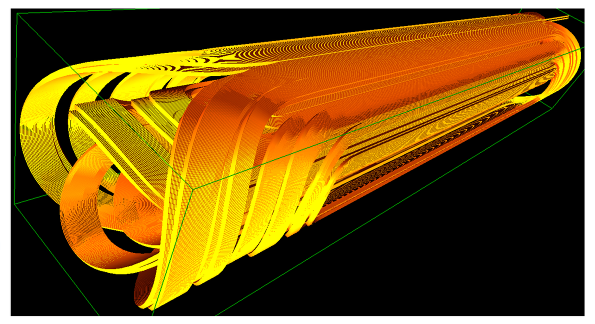
Introduction

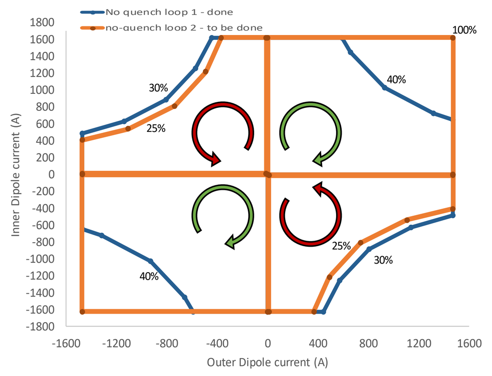




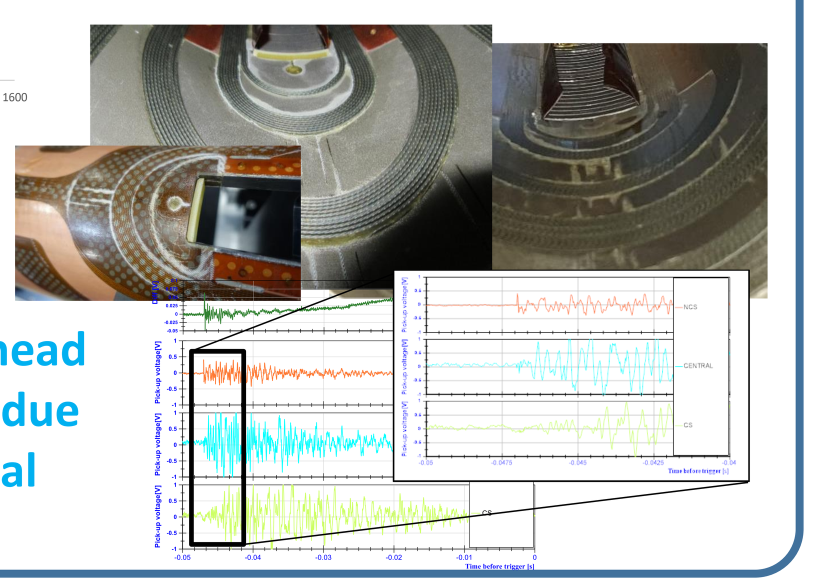
Nested dipoles provide orbit correction in H&V planes.

Nested collaring structure to hold large torque (132 kNm/m) and precompress the coils.





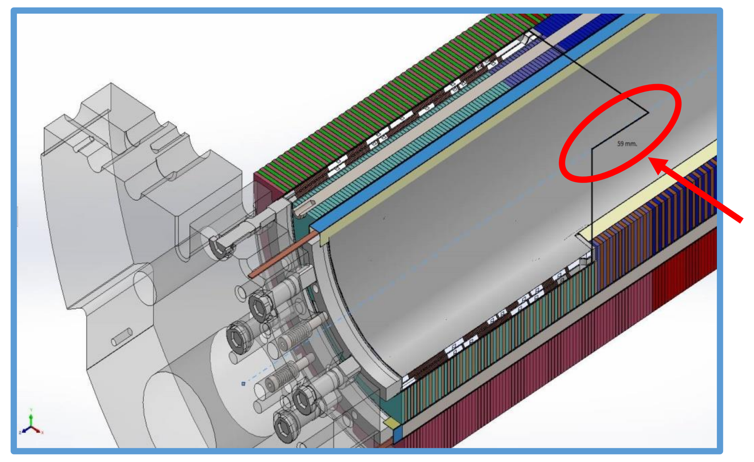
P1 & P2: Changing the torque direction required additional training beyond 30% torque to reach nominal operation.



Main origin of the quenches was inner dipole heads.

Cause: Inner dipole head plastic deformation, due to excessive azimuthal displacement [8].

Inner Dipole Design Tunning Proposal



There is no torque support along 59 mm at each end of the inner dipole pole window due to its shorter heads.

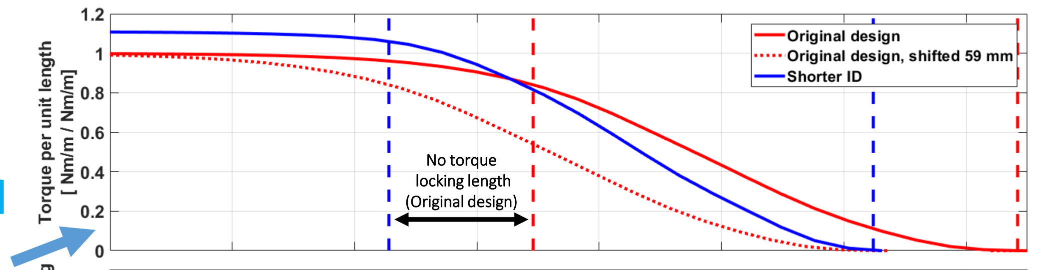
Torque locking is only possible at the outer dipole pole window with the collaring structure used.

Torque redistribution: Equal length of inner and outer pole windows

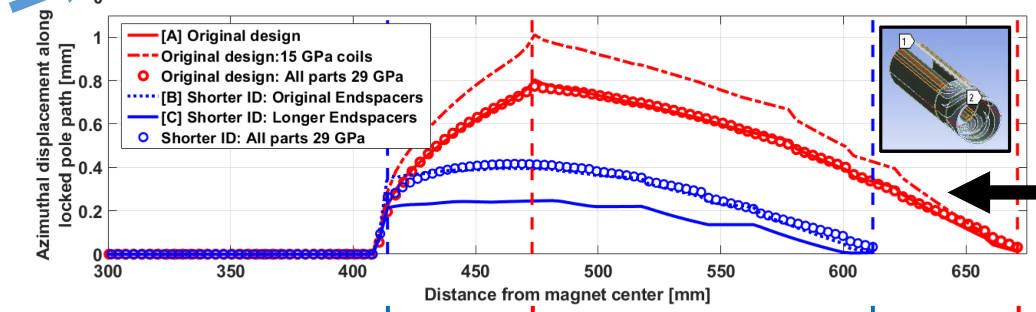
Parameter	ID	OD	Units
Nominal individual field	2.11 / 2.36	2.22 / 2.24	T
Nominal combined field	3.07 / 3.25	3.07 / 3.25	T
Field integral	2.5	2.5	Tm
Nominal current	1580 / 1755	1430 / 1435	A
Pole length	946 / 828	828	mm
Coil length	1342 / 1224	1342	mm
Torque at the straight section	132 / 147	132 / 147	kNm/m

Original design / Fine tuning with a shorter inner dipole

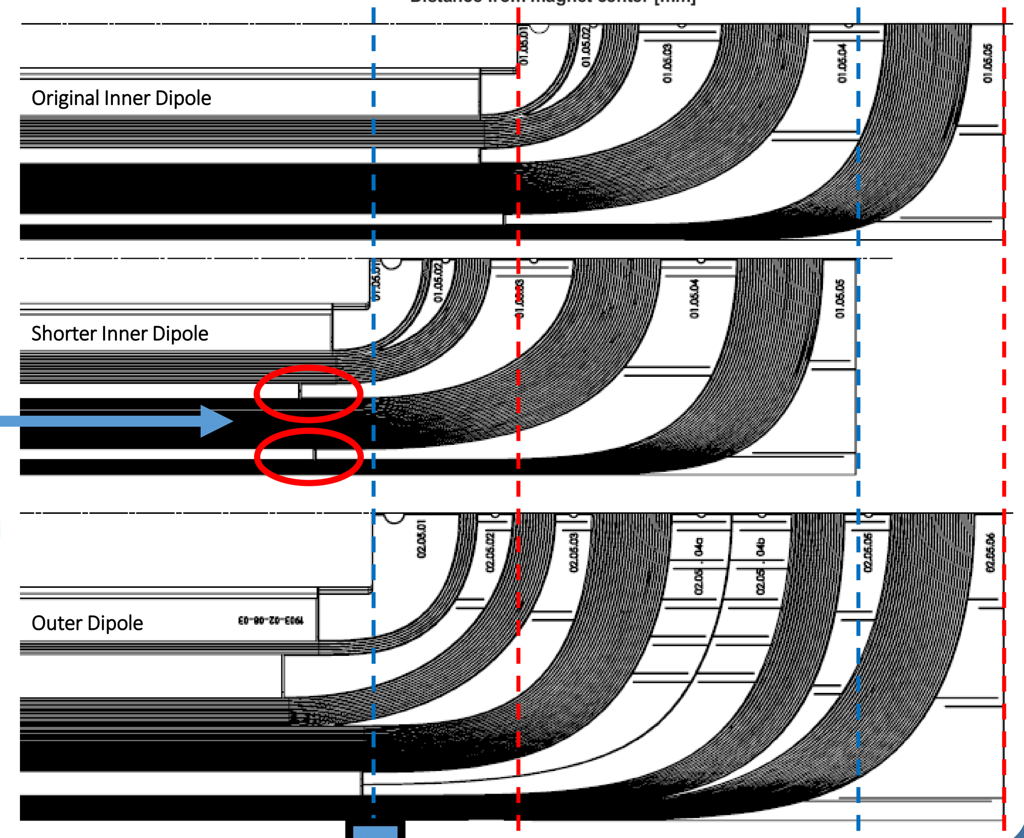
Torque is higher at straight section and coil heads for a shorter inner dipole



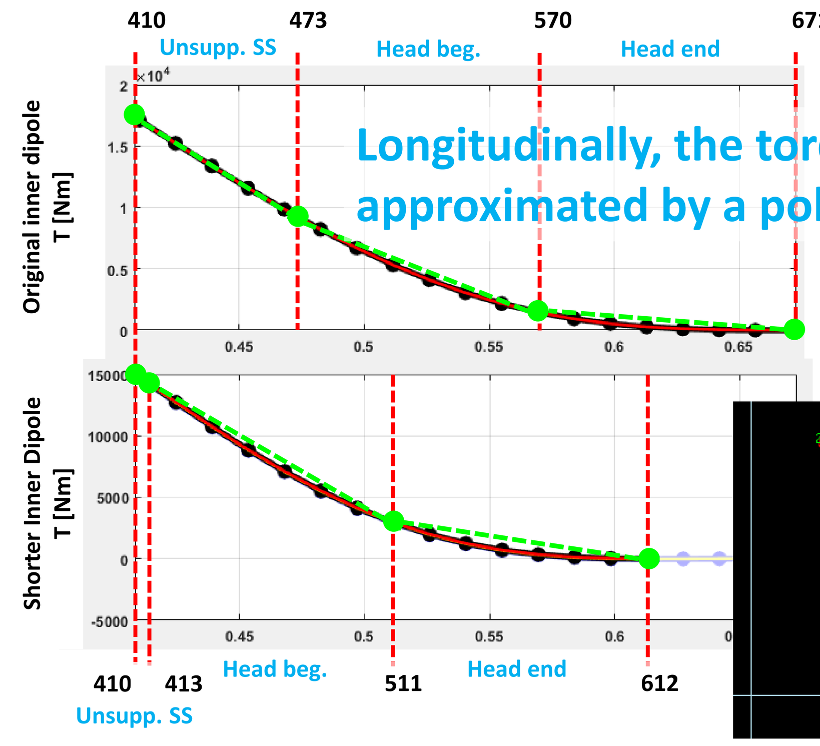
Is it really better?



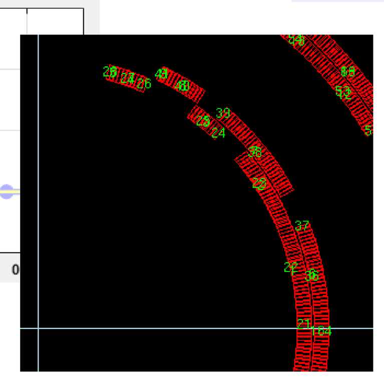
Endspacers legs are elongated to reach torque locking area in order to increase head stiffness



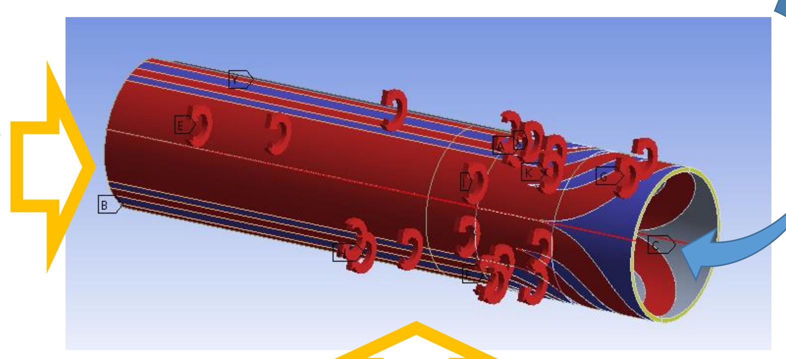
Simulation Results: Detailed Inner Dipole Inner Layer Models



Longitudinally, the torque is approximated by a polyline

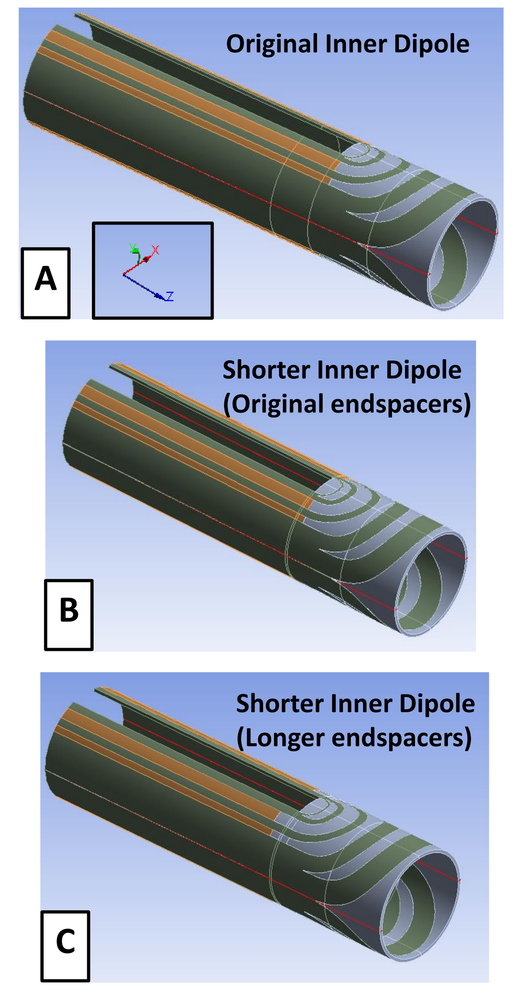


Lorentz forces



Azimuthally, the torque is distributed like in a 2D simulation

Same boundary conditions and simulation parameters



Main goal: Compare azimuthal deformations

Peak shear stress are reduced specially at wedge/endspacers and wedge/cable interfaces.

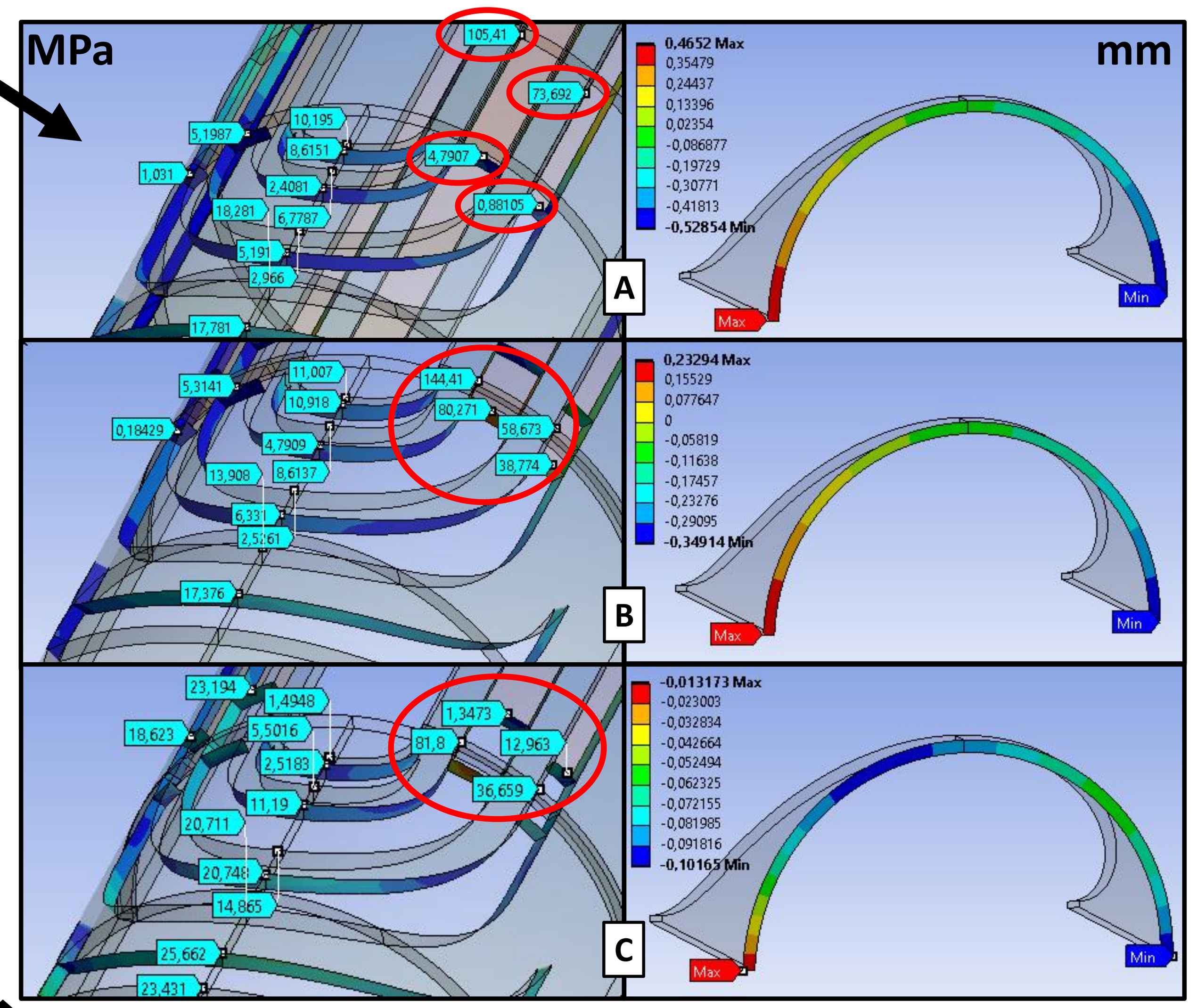
Maximum azimuthal displacement is reduced 50% by shortening the ID.

Assuming all parts have 29 Gpa, provide pretty accurate results for original endspacers models.

Original design using 15 GPa cables has 25% more azimuthal deformation (Worst behaviour of P2 at power tests)

Longer endspacer legs reduce maximum azimuthal displacement 70% vs original design, 50% with respect to not using them in a shorter inner dipole.

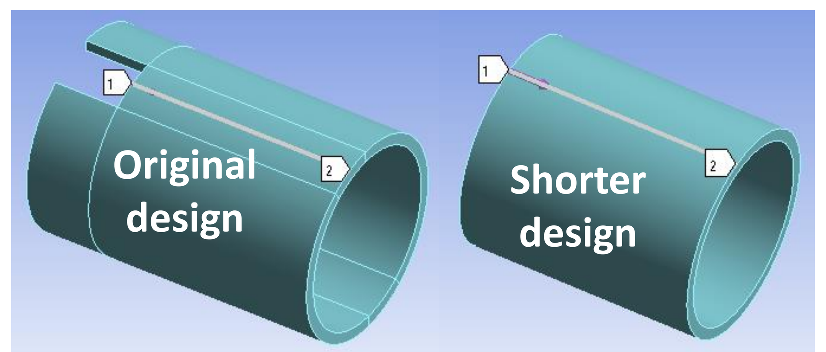
Shorter inner dipole + longer endspacer legs should be implemented in MCBXFB01



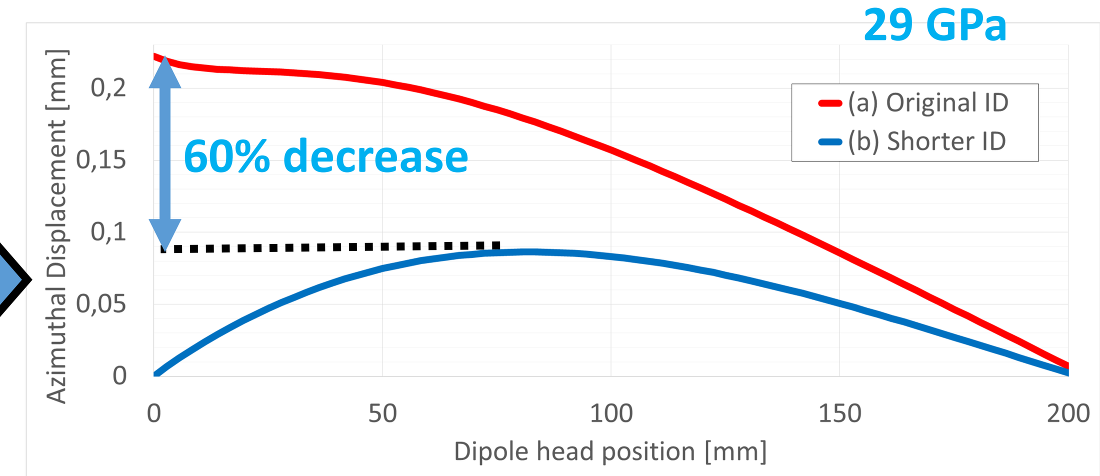
Longitudinal deformation is greatly reduced by inner dipole shortening

Longer endspacer legs make the coil head much stiffer, changing the torsion deformation pattern.

Simulation Results: Simple Geometries



P1 Straight section smeared-out Young's modulus assumed: 29 GPa



Analytical Analysis

$$d\theta = T(z)\,dz/(JG)$$

$$\theta(z) = \theta(0) + \int_0^z T(z)dz/(JG)$$

$$T(z) = T(0) + \int_0^z N(z)dz$$

Torque per unit length linear approximation

$$N(z) = N_{SS}(1 - z/L)$$

$$\theta(0)=\theta(L)=0$$

Rotation fixed at both ends

$$T(z) = N_{SS}(-z^2/2L + z - L/3)$$

$$\theta(z) = \frac{N_{SS}}{JG}\left(-\frac{z^3}{6L} + \frac{z^2}{2} - \frac{zL}{3}\right)$$

$$\boldsymbol{d_{\theta,max}} = (6\sqrt{3} - 11)\frac{N_{SS}L^2 r_{out}}{9JG}$$

$$\boldsymbol{\tau_{max}} = -N_{SS}L\,r_{out}/(3J)$$

Unsupported head length (L) dependence endorse inner dipole shortening

33% reduction

15% reduction

Conclusions

This inner dipole shortening has been analysed analytically and through FEM. All the results indicate that it is an effective way to reduce azimuthal displacement and shear stress at inner dipole heads. Endspacer leg elongation has also been proven beneficial, increasing head stiffness.

After implementing these design changes at the first series magnet, its power test was completely successful. The magnet was able to reach all its required operating range without any retraining [8].

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