MEASUREMENT OF YOUNG'S MODULUS AND SHIM CALCULATION FOR LHC PROTOTYPE DIPOLE MAGNETS

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Abstract

The superconducting coils of LHC prototype dipole magnets wound from a Nb-Ti cable of the Rutherford type are assembled in an Aluminium clamping structure, the so called collars. The coils have to be prestressed in order to avoid movements of the superconductor during operation, which may cause quenches. The exact value of the prestress and the uniformity of the prestress over the length are adjusted by the thickness of inserted shims.

The basis for prestressing the dipole coils is the precise measurement of the size and the Young's modulus of the winding. Based on the measurements shims are calculated ensuring the specified prestress of the coil. During shim calculation several corrections of the shim thickness have to be taken into accopunt e.g. corrections due to the deformation of collars.

The measurement of Young's modulus and the shim calculation will be presented.

1 INTRODUCTION

Superconducting coils have to be prestressed in order to avoid movements of the superconductor during operation. The value of the prestress is calculated by finite element analysis. The prestress is 55 MPa for the inner and outer layer of the actual prototype dipole magnets.

The coils are prestressed by inserting shims in the collaring structure. The thickness of the shims is based on the required prestress, the Young's modulus measurements and the actual size of the coils

2 MEASUREMENT EQUIPMENT

The coil will be compressed hydraulically in a special mould and the deformation measured by inductive gauges and recorded via PC.

Using different inserts of the mould the following positions are measured:

a) the straight part of a single layer
b) the coil ends of a single layer
c) the layer jump of the assembled

3 MEASUREMENTS

For prototype manufacturing the straight part and the coil ends of single layers are measured. After the assembly of a pole the layer jump of the assembled pole is measured.

This method has to be reviewed for series production.

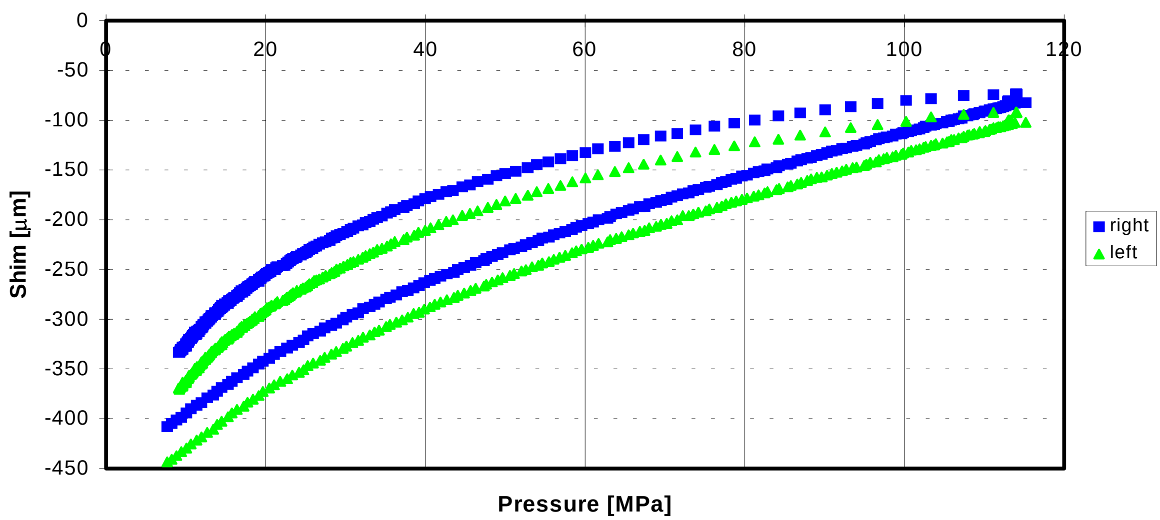

Figure 1: Measurement of inner layer

The coils are compressed five times and the fifth load cycle is recorded. The applied load varies between 0 MPa and 120 MPa for the straight part and the layer jump or 0 MPa and 30 MPa for the coil ends respectively.

The deformation of the left and right side of the coils is measured and recorded for increasing and decreasing load.

The coils are measured at nine positions of the straight part, at one position of each coil end and at one or two positions respectively of the layer jump.

Figure 1 shows a typical measurement graph of an inner layer with the curves for increasing and decreasing load.

4 CALCULATION OF SHIMS

There are two different ways of shim calculation with regard to the collar deformation.

The first way is to take for specified prestress of 55 MPa of the coil the shim thickness from each graph for decreasing pressure at 55 MPa. Then the values are averaged over left and right side and over the nine measurement positions of the length.

To this averaged shim thickness the corrections due to the collar deformation, the elastic behaviour of the ground insulation, the size of the gauge pieces and the tolerances of the collars are added.

A second way is to take from each graph the shim thickness at 110 MPa under consideration that there is a reduction of the prestress due to the collar deformation of approx. a factor of two (factor obtained by FE analysis and tests on models). The values are averaged and the remaining corrections for ground insulation, gauge pieces and tolerances of collars are added.

Both methods show the same results for the shim thickness within approx. 3/100 mm.

5 RESULTS

Figure 1 shows the measurement of an inner layer at measurement position 5 of the straight part. Negative values of the shim have to be subtracted from the nominal shim

The measured Young's moduli of the layers wound from superconducting cable with a prepreg insulation vary between 18,000 MPa and 22,000 MPa.

Fig. 2 shows the distribution of the coil size over the 10m length of 4 different outer layers. The tolerance of the coil size over the length is ± 4/100 mm.

The difference between the layers 009, 010 and 011, 012 is due to different superconducting cable. The cable of layers 009 and 010 is coated, the cable of layers 011 and 012 is not coated

The graphs of the 4 different coils are nearly parallel which indicates that the variations are caused by the tooling.

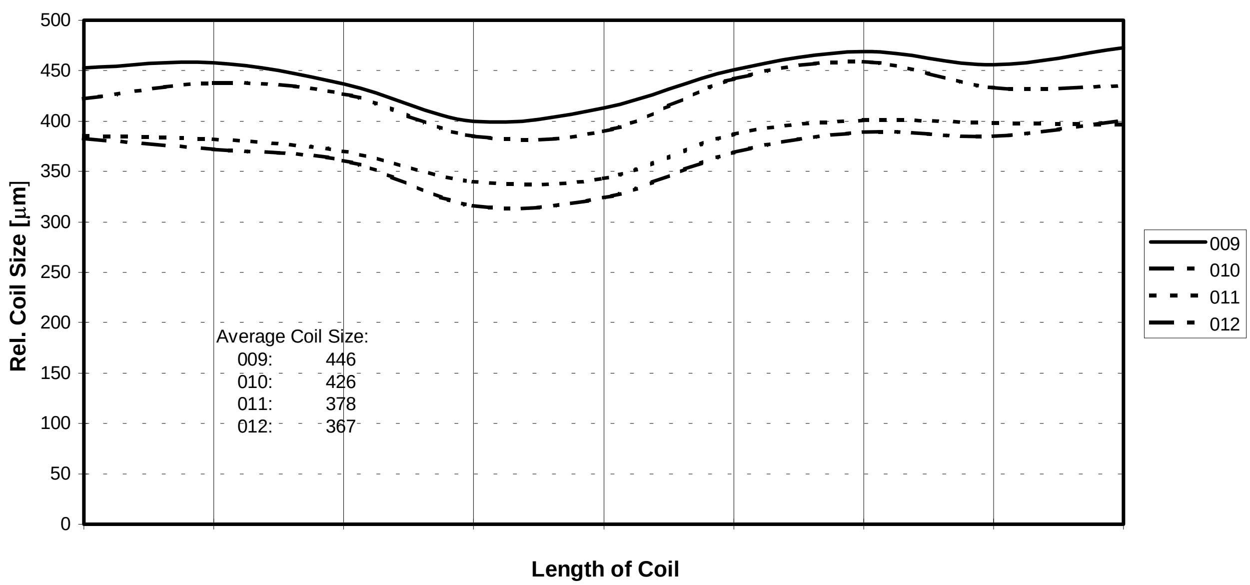

Figure 2: Distribution of coil size

The remaining prestress of the coil after collaring is verified by measuring the deformation of the collars. The higher the prestress of the coil the larger the deformation of the collars.

For this purpose the dependence of the deformation of the collars on the prestress of the coils was determined in several ways. Collars were loaded hydraulically or by screws and their deformation measured. Short models of coil sections were collared with different inserted shims for different prestresses and in each case the deformation of the collars measured. The measured datas resulted in a curve for calibration.

Figure 3 shows the measurement of the collar deformation over the length of the coil as an indication of the prestress of the collared coils. The distribution is homogenous over the length. The minor collar deformation in the coil ends shows the required lower prestress.

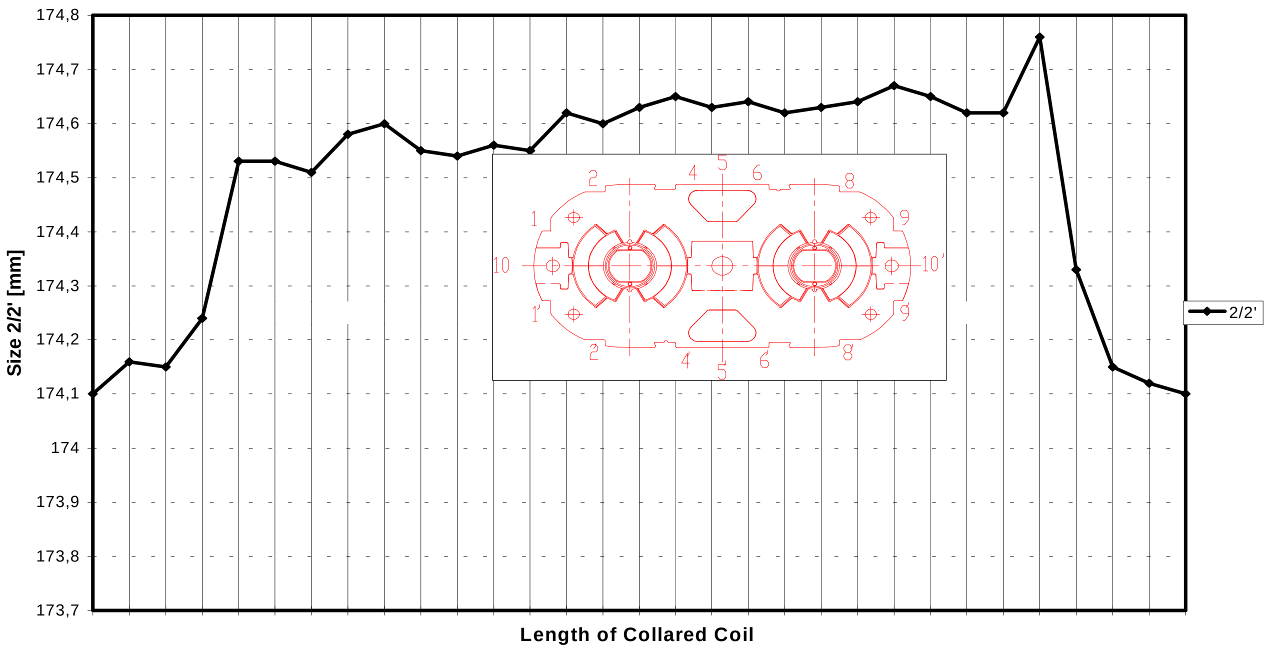

Figure 3: Deformation of collars

The measured collar deformation shows that the specified prestress could be achieved within the tolerances.

6 CONCLUSIONS

The presented method for Young's modulus measurements and shim calculation give reliable results for obtaining the correct thickness of the shims for a specified prestress of the collared coils.

By the measurement of the collar deformation the remaining prestress of the collared coil after collaring is controlled. The measurements show a homogenous stress distribution over the length of the coil.

It has to be checked if the measurement procedure has to be improved for series production of the magnets by measuring assembled poles.