A Strategy for Series Magnetic Measurements of the LHC Superconducting Magnets.

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The purpose of this talk is to present the main aspects of the strategy that has been proposed [1] for series magnetic measurements of the LHC magnets (slide 1).

INTRODUCTION: The LHC and the LHC magnets

The presentation starts with an introduction to the LHC Project [2] and a short description of the characteristics of the main dipole (MB) and quadrupole (MQ) cold masses (from slide 2 to slide 8) . The LHC accelerator will consist of two synchrotron rings installed in the existing 27 km LEP tunnel. Two superconducting magnetic channels will guide the proton beams at an energy of 7 TeV each. The machine will be constituted of eight bending arcs separated by eight insertions. The main parameters of the machine are shown in the slide number 2. About 8400 superconducting magnet units of different types (dipole, quadrupole, correctors), operating for most of them at a temperature of 1.9 K will be used to bend or to focus and defocus the proton beams (see slide 2). Each arc is composed of 23 cells containing six twin apertures dipoles and three 3.10 m long main quadrupoles and their associated correctors (slide 3) [2]. The schematic cross section and the main parameters of the LHC dipole and of the LHC Short Straight Section (SSS= twin aperture quadrupole plus octupole and dipole-sextupole correctors) are given in the slides 4 and 5. A list of three types of correctors is presented in the slide 6 with examples of corrector locations in the case of the dipole and of the SSS (slide 7 and 8). In the slide 10, the integrated deliveries of cryomagnets during series production are presented [3]. Almost all the dipoles and the SSS will be delivered at the beginning of 2005. The dipole and the SSS will be tested in cold conditions at CERN in a dedicated Superconducting Magnet Test Plant [3] where the cold masses will be attached to one of the 12 test stations (slide 11). The introductory part of the talk ends with a recall of the main components of the cold mass, critical for the field quality (slide 12) and a list of the field errors sources in the superconducting magnets (slide 13).

BEAM REQUIREMENTS

The second topic of this presentation concerns the requirements from beam physics to reach the nominal LHC performance (slides 15 and 16). The tolerances for key beam parameters (i.e. energy variation at injection $\delta p / p_0$, maximum orbit excursion, maximum tune variation δQ, coupling ΔQ and chromaticity tolerance $\delta\xi$ [4]) have been translated into a set of maximum field imperfections to be achieved at operation [5] (slide 17). The model used to quantify the expected field quality of the LHC magnets is the following: The magnets produced are expected to fall into a gaussian distribution centered around an average value (systematic) and with a specified standard deviation (random). Systematic effects that are associated with the lack of complete knowledge on the production methods and cannot be quantified are defined as the uncertainty on the average. By definition, the effect of the uncertainty is to shift the average of a production without affecting its standard deviation. The slide 18 displays the severe constraints to the alignment for the dipoles and the SSS components imposed by the requirements of the beam dynamics [6]. These values referred to the tolerances in displacements from the reference orbit. The errors that are thought to be realistically achievable during series production of the LHC main ring magnets are summarized in the field quality (error) tables presented in the slides 19 and 20 [7], [8]. It is clear that the required field quality cannot be met. For this reason the LHC is provided with a sophisticated correction system that will close the gap between the field errors in the magnets and the field quality required for the beam. This correction system can be effective only if the field errors are known at operating condition to the levels quoted previously (slide 21). This is particularly challenging for the contributions to the field and harmonics generated by thermal shrinkage, originating from the effect of the electromagnetic load and coming from the superconducting effects in the cables (persistent currents, coupling currents, field decay and snap-back) (slide 22) [9]. It is therefore necessary to establish a coherent warm and cold series test plan at CERN.

QUALITY CONTROL LEVELS AND SERIES TEST PLAN AT CERN

Three quality control levels have been proposed :

- Tolerance control, warm magnetic measurements and alignment in industry (slide 24).

- Warm magnetic measurements and alignment at CERN before and after the cold tests (slide 26 for the dipoles and 27 for the SSS).

- Cold tests measurements at CERN (slide 26 for the dipoles and 27 for the SSS).

The CERN test plan should be organized in accordance with the following principles (from slide 28 to slide 33):

- Warm testing should be done only on a statistical basis, as a quality control of tests in industry and to verify possible effects due to shipping and transport.
- Cold test should be performed systematically on all main ring magnets.
- Alignment of dipoles and associated correctors should be statistically verified in cold conditions, and systematically in warm conditions at the latest possible time before installation in the tunnel.
- Alignment of SSS should be measured systematically in cold conditions.
- Magnetic measurements of correctors alone are mainly performed in industry at warm. Warm testing and cold tests at CERN should be done only on a statistical basis (typically 10 %).

TARGET MEASUREMENTS AND EQUIPMENT

The slides 34 and 35 describe the accuracy targets for dipole and quadrupole measurements. Then an overview of the equipment that will be used for the tests and for the calibration is given in the slides 36 and 38. A summary of the equipment planned, ordered and operational is presented in the slides 37 and 39. Finally an overview of the acquisition equipment in the case of a test using the rotating coils is presented in the slide

40. The magnetic measurements are driven by a labview application developed at CERN (MMP) and the field quality analysis will be performed using a fast analysis system developed at CERN during the last two years (part of the Data Analysis Project). The results will generate a database (LHC database) that will be used by the correction algorithms for operation of the LHC.

CONCLUSIONS

The main conclusions are presented in the slide 41:
- Beam dynamics requirements impose severe constraints in field quality and alignment.
- Present state of knowledge calls for a strategy including 100% cold magnetic and warm alignment testing.
-The equipment for dipoles and SSS to absorb series measurements is procured or in process of procuring.

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