Steering Field and Current in the LHC Magnets

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Abstract

Recent measurements performed on prototypes of the main dipole and quadrupole magnets and of some corrector magnets confirm the need of a "Multipoles Factory" for the LHC. This engine will be based on magnet test and on-line measurement and give to the accelerator control system a knowledge and a prediction as accurate as possible of the magnetic machine. A case study based on magnet measurement tentatively defines a specification of this "Multipoles Factory". A frame is proposed to separate the number crunching part from the real time features.

1 INTRODUCTION

The stability and reproducibility of the strength value and the field quality of the LHC superconducting magnets have been extensively measured on prototypes. Measurement of the series magnets are still needed to confirm the expected perturbations [1] and to detail the implications for the beam control system. The start of the acceleration will be performed with an exponential increase of the ramp rate to divide by five the amplitude of the eddy current effects and the rate of change of the snap-back to the chromaticity [2]. Systematic cryogenic tests will be performed on the main and corrector magnets to quantify the field quality in all operating conditions. A multipoles factory will include the measurement database, the real time measurement in the reference magnets, and the current history in all power supplies in order to tune all feed forward and real time feed back loops needed.

This contribution analyses some of these perturbations in terms of type of corrections to apply. A frame is then proposed for the multipoles factory in order to clarify the management of the first series magnets soon to be measured and to define the real time needs for the control of the accelerator.

The term "unit" used below refers both to multipole errors in a given magnet and to the accuracy of the magnet strength as a function of current or current history. The expansion used to express the field harmonics is relative to the main field B_1 of the magnet at R_{ref} = 17 mm. Here n=1 is a dipole field, n=2 is a quadrupole field etc. The b_n and a_n represent the normal and skew errors and are given in units of 10^{-4} relative to the main field :

$$\mathbf{B}_y + i\mathbf{B}_x = B_1 \sum_{n=1}^{\infty} \frac{c_n}{10^4} \left(\frac{z}{R_{ref}} \right)^{n-1} = B_1 \sum_{n=1}^{\infty} \frac{(b_n + i a_n)}{10^4} \left(\frac{x+iy}{R_{ref}} \right)^{n-1} .$$

2 CONSTRAINS FROM THE SUPERCONDUCTING MAGNETS

2.1 Control of the Tune

The tune of the beam has to be controlled within 0.003 in all conditions for high luminosity beams corresponding to a steering of the main MB dipole and quadrupole MQ chains to within 0.4 unit. The first measurements performed with the prototype digital control of the power converter indicate a decay of the MB strength of 3 unit during the injection flat-top. The strength of the MQ is calculated to change by 16 unit with the nominal acceleration rate of 6.5 TeV in 20 minutes. An improvement factor of 5 is obtained with the slower exponential start-up of the acceleration ramp.

The decay of the MB strength or the effect due to current ramp on the MQ strength must therefore be predicted to within 10 % of their amplitude. To achieve this, we shall systematically measure these strengths on the LHC magnets with a current cycle as close as possible to the machine cycle and quantify the effects due to different cycles. The resulting data will tell whether a systematic current pre-cycle lasting about 1 hour will be needed after each physics run or even after the following preparation and access time slot or if correction based on the continuous measurement of the reference magnets will be representative enough.

2.2 Crossing the Hysteresis Loops due to the Persistent Currents

Reversing the direction of the current ramp in superconducting magnets provokes crossing of the hysteresis characteristic due to persistent currents. The overshoot of the MB power converters must be limited to about 50 mA to control the sextupole harmonic within 0.02 unit corresponding to 1 unit of chromaticity.

A change of ramp direction will be systematic at the start of the acceleration for the MCS sextupole correctors resulting in a jump of the chromaticity of 10 unit [3]. This jump of the sextupole term must be modelled and a corresponding correction fed forward to the MCS current steering.

Half of the MCB beam position correctors are expected to similarly change the direction of the current ramp at the start of the acceleration. This will be hardly noticeable on the tune.

2.3 *Stability of the sextupole term of the MB's*

Several factors are known to influence the stability of the b_3 sextupole term of the MB mainly by changing the amplitude of the decay and snap-back. These are :

- quenches,
- time spent at collision flat-top,
- temperature difference and variation during the decay (a systematic change of 50 mK gives a change of 4 unit of chromaticity).

It is planned to record these factors in the multipoles factory in order to better predict the sextupole term.

2.4 *Current in some Corrector Magnets influence other multipole terms*

The MCS and MCD correctors are due to correct the systematic b_3 and b_5 multipoles of the MB's. A misalignment, systematic or random, between these correctors and the MB axis will give by feed-down an effect on the coupling between betatron planes or on the anharmonicity (amplitude detuning).

These effects could be considered negligible if the MCS and MCD are respectively aligned within 0.09 mm and 0.4 mm. This alignment specification is however difficult to meet and a feed forward based on the systematic measurements of these misalignment may be necessary in the accelerator.

3 PROPOSAL FOR A MULTIPOLES FACTORY

3.1 *Specification*

The constrains detailed here above allow to tentatively define the off-line and on-line information needed for the “multipoles factory”. The low order multipoles of the main magnets will be fully described taking into account their random values from magnet to magnet and the bias over the production. Higher order multipoles degrade the beam dynamic aperture. The beam instrumentation can hardly measure their contribution and the relevant corrector magnets must be excited according to measurement data accumulated during the cold tests.

The proposition described below is able to include demanding correction schemes with flexibility and to keep real time needs separated from the “number crunching” part. The experience to accumulate during the cold measurement and the running-in of the machine will tell how much could be simplified.

3.2 *The "Current Forecast" Engine*

A feed forward of the current in all the magnet power converters relies on the database of the cold measurement performed before installation. It will include for enough accuracy, a model of all non-linearity's [5], the contribution from the persistent current depending on the current history of main and corrector magnets, and multipoles due to the main magnets or misalignment of correctors. A software tool connected to the measurement database is proposed as a "current forecast engine" [fig 1]. The inputs are the $B_{n,m}(t)$ curves specified for the whole injection or acceleration cycle in the main magnet chains m (n stands for the multipole order). The outputs will be the curves of current ramp $I_{m1,m2}(t)$ to preload in the main and corrector magnet power converters.

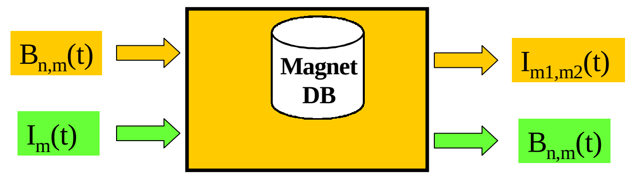

Figure 1: The "Current Forecast Engine" to deduce the current needed in the main magnet and associated correctors m1, m2, .. to obtain a field strength B(t) and field multipoles $B_n(t)$.

3.3 *The Reference Magnets*

On-line measurements of the reference magnets must complement the "current forecast engine" to get enough accuracy among others on the tune and chromaticity control. The experience from HERA shows the need to feed corrections just before beam injection and at the beginning of the acceleration ramp [4]. The possibility of more real-time control is however kept in the proposed scheme.

The reference magnets will be fed with exactly the same current as the ring magnets. The “Beam Forecast engine”, based on the inverse calculation of the “current forecast engine” and taking into account the current and temperature history will compare its output to the multipoles measured in the reference magnets and propose a correction to the current curves in the preloaded power converters.

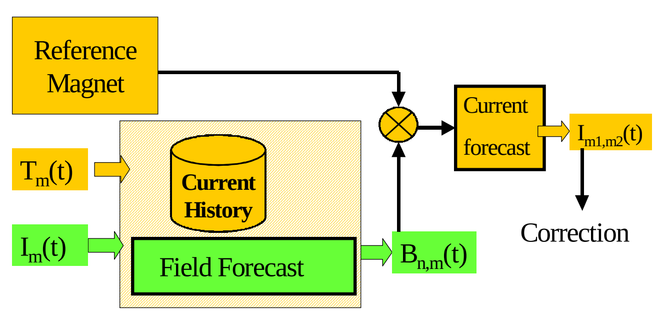

Figure 2: Frame for the "Multipoles Factory" : the current to apply to the corrector magnets depends on real time measurement of the reference magnets and on current and temperature history in the accelerator magnets.

3.4 Real Time Request

Closed loop control based on beam measurements requires an independent path to the power converters. These requests of field change will go where needed through a reduced "current forecast engine" to take into account hysteresis behaviour of the corrector magnets used. These correctors should be different from those steered by the reference magnet system to avoid cross-talk between the two systems.

4 CONCLUSION

A first proposition for the "Multipoles Factory" allows to clarify the needs for a real time control system for the LHC beam. Flexibility must however be kept in the specification and design since this system will dramatically evolve during LHC magnets production and measurement and during the accelerator commissioning.

REFERENCES

[1] L Bottura, "From the LEP warm magnets to the LHC superconducting magnets", Proc. of Chamonix X, CERN-SL-2000-007 DI, January 2000.

[2] L Bottura, P. Burla, R. Wolf, LHC project report 172, 1998.

[3] Z. Ang et al, "Measurements of the LHC corrector magnets at room and cryogenic temperatures", LHC project report 201, 1998.

[4] B. Holzer, C. Montag, "Reproducibility and predictability of persistent current effects in the HERA proton storage ring", proceedings of the 7th European Particle Accelerator Conference, Vienna, June 2000, pp 2142-2144.

[5] L. Bottura, "Superconducting magnets on Day 1", this workshop.