SUMMARY OF SESSION 7: MAGNET ISSUES AFFECTING BEAM COMMISSIONING

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AIM OF THE SESSION

At this moment in time, the cold mass production of the dipoles is passing the 50% level, the quadrupole production rate keeps increasing, and the many types of insertion magnets and correctors are in production or sometimes already produced. It becomes then possible to predict with a reasonable confidence the actual quality of the LHC machine. This is of importance for commissioning, as the LHC performance is primarily driven by the technology and performance of its magnetic system. The time as well has come to turn to magnetic issues relevant not only to beam dynamics but equally to the efficiency of machine operations. The goals were thus to put in perspective the present knowledge and identify the issues requiring special attention for the commissioning.

PRODUCTION OF THE MB & MQ [1]

The production of the main dipoles and quadrupoles is now in full swing. It is expected to finish on schedule even though so minor delays require constant attention and optimization. The quench behaviour is consistent with expectations for the MB's and even better for the MQ's. Several technical issues need constant attention, such as the collars quality and production rate, the electrical insulation (MQ's) and obviously the magnetic and geometric quality of the magnets, discussed in an other talk [7].

There is today no evident requirement to commission the machine below 7 TeV for the commissioning beam intensity.

A total of 40 spare dipoles and about 12 quadrupoles will be manufactured and a Magnet Rescue Facility organized at CERN for repairs. The time needed to change one isolated magnet is estimated to be 20 days.

GEOMETRY OF THE MAGNETS [2]

The most important issue is the control of the 15m long dipole magnet at the 0.1 mm level to fulfil three criteria: beam aperture, avoidance of feed-down effects from the spool-piece correctors, connectivity. The decision of blocking the central foot taken in 2004, which gave some concerns to the mechanical engineers, has much improved the magnet stability. Even after blocking, the dipole shape is observed to change at the 0.1 0.2 mm level. This is acceptable but requires follow-up on longer periods.

The quadrupole geometry is not anticipated to cause problems. The good alignment of the correctors on the quadrupole axis remains however an issue.

All data are centralized in a database and will be processed to allow a geometrical model of the machine.

LONG-TERM STABILITY OF THE DIPOLES [3]

This interim report of the "Dipole Long-Term Stability Task Force" shows basically that the cold mass does not appear to suffer from the outdoor storage. The field quality, quench behaviour and electrical integrity appear unchanged. The small changes observed in geometry may not be related to outdoor storage [2]. The outside of the cold mass however is exposed to humidity and a few corrosion points are observed (one on a magnet stored only one month). Three diode faults were observed but not related to the storage conditions.

So far, it seems that the unplanned outdoor storage will not degrade the machine quality but has a cost in human resources for investigations, conditioning for outdoor storage and possible repairs.

PRODUCTION OF INSERTION MAGNETS & CORRECTORS [4]

The challenge and complexity stems from the variety of these magnets and their number. The production is so far estimated to be on schedule. There is a serious concern that the in-house produced MQTL's might not be ready for the sector test. The quench behaviour is in all cases within or above specifications and consistent with 7 TeV operations.

On average, 6.5% of spare magnets will be available, often in parts, with at least one magnet of each type. A Rescue Magnet Workshop will be organized at CERN. Unlike the Main Dipoles or Quadrupoles, the time to change or repair a magnet is highly dependent on the access possibility of the insertion area, especially the collimation areas (radioactivity) and the time needed to build or repair a magnet and its ancillary correctors from parts. The time estimate ranges from 6 weeks to 6 months. A concern is the staff that needs to be in sufficient number to minimize radiation exposure and of high competence given the very large number of high-tech magnet types.

MAGNETIC BEHAVIOUR OF CORRECTORS [5]

The super-conducting correctors exhibit a significant hysteresis. This hysteresis is liable to create orbit, tune and chromaticity residuals up to about 10 times higher than allowed by beam tolerances. This is especially relevant to the design of the feedback systems. It is therefore of important to work out a field model including hysteresis and magnetic history for use by operations.

The field quality and transfer function accuracy of the correctors are somewhat less important due to their lower integrated fields. A minimal programme of cold measurements is still to be worked out and implemented to allow the construction of the field models and of possible cross-talks between beam channels and corrector layers.

EXPERIENCE WITH SLOT ALLOCATION [6]

The Magnet Evaluation Board is an executive Project unit in charge of allocating the accepted magnets to positions in the ring (slots). An installation algorithm has been worked out in collaboration with the relevant groups and working groups. The most difficult octant 7/8 (pre-series magnets, change of cross-sections,…) is allocated with a saving of about 1.4 mm in beam aperture, 1σ in dynamic aperture and a few percent of β-beating. This is by LHC standard significant. This further exercises the many machine databases and prepares them for use at commissioning time.

QUALITY OF THE MAGNETIC OPTICS [7]

The quality of the magnetic fields is a special issue as it is not contractual. The Quality Assurance & Control relies on warm magnetic measurements carried out in the firms for CERN. A `holding point' is managed at CERN where decisions are made for each magnet with feedback to the firms and call for action when necessary. After two cross-section adjustments for dipoles and one for quadrupoles, the dominant geometric component of the field quality is globally very good. The transfer function of the dipoles is remarkably equal amongst firms. The main quadrupole transfer function is somewhat above tolerance. The consequence on β-beating remains very small thanks to a limited sorting. Many insertion quadrupoles remain to be measured at cold. If the recommendations of the recent Cold Measurement Review are accepted, the β-beating is expected to be under control in all situations. The up-down strategy of dipole installation copes with some excess of the random b3 in the dipoles. Altogether, the resulting conventional dynamic aperture is reduced by about 2σ while a 2.5σ safety margin had been implemented at the beginning of the project. The latest effect of the beam screen on the field quality is planned to be measured this year. The difference with the former beam screen is expected to be small.

OPERATIONAL USE OF MAGNETIC MEASUREMENTS [8]

The Reference Magnetic System is conceptually the facility allowing the conversion of a field increment into a current increment, whatever its implementation and distribution. Three levels of implementation were contemplated:

- A semi-empirical field model using all magnetic measurements available (warm and cold, standard and extended)
- Off-line reference magnets.
- On-line reference magnets.

The last option will not be implemented, given the tight schedule and the added complexity requiring extra resources.

While all magnets are measured at warm, only a fraction (1% to 100% depending on their types) is measured at cold and a very small fraction will be measured with a non base-line magnetic history. The estimated resulting accuracy should meet the commissioning demand. One should however anticipate dedicated machine time with beam to check and possibly tune the magnet field models.

The deliverables will be a field model per magnet and a global magnetic and geometric model of the magnetic machine suitable for MAD calculations.

QUESTIONS AND ANSWERS

1. to L. Rossi

- ***Are the magnets trained above 8.33 T?*** Yes the dipoles are trained up to 8.4-8.5 T to have a safety margin. These magnets will work at 8.33 T.
- ***What is the policy for spares?*** The goal is to obtain spare magnets as much as possible. 30 spare magnets (in addition of the 10 foreseen) have been asked. As reference, the number of magnets which needed to be changed or repaired is 100 for the TEVATRON and 1 for HERA.

2. to K-H Mess

- ***Are the correctors tested during the dipole cold tests?*** Power tests of the correctors will be performed for 10% of the dipoles.
- ***Do we expect problems for the MQTL for the sector tests?*** Not for the performance. For the scheduling yes.
- ***Why will it take 3-6 months to repair the MQM and the MQY?*** The magnets have to be repaired and re-tested at cold.

3. to E. Wildner

- ***The discrepancies observed between WP08 and WP09 are worrying. Can we trace back what happened during the storage and the transport?*** To some extent: the magnet history can be found in MTF. However details concerning the transport restraints for instance cannot be traced back.
- ***Do we have a warm/cold correlation established for the dipole magnetic axis?*** Three magnets were measured at cold. The analysis performed by MTM is in progress. The indication is an expected downward contraction of about 1.5 mm.

4. to E. Todesco
   - ***Do we have knowledge of the snap-back variations in the inner triplet quadrupole?*** Measurements were done. Results are not issued for the moment.
   - ***is the contribution of the beam screen relevant and has it been measured?*** The contribution of beam screen is relevant, giving strong effects on b5 and b7 for the dipoles. This is the only part of the field quality estimates of the machine that rely on models and not on measurements. Measurements of a previous version of the beam screen have been proven to be in good agreement with simulations, but a final measure of the beam screen is not yet available.
5. to L. Bottura about the RMS:
   - ***When do we expect to have the off-line RMS system?*** The field model is foreseen to be ready at the end of the series tests. The available magnets could then be further measured to investigate special cycling conditions, if requested.
   - ***What will be the time resolution for cold measurements, in particular for the snap-back?*** Using the b3-b5 Hall probe device measurements at 10 Hz will be carried out. The estimated uncertainty will be about 1 unit on these local measurements.
6. to W. Venturini:
   - ***The hysteresis of the MO should be known precisely because the MO will be switched off at injection and switched on at 2 TeV. The residual octupole field at injection is of concern.***
   - ***Is this requirement on the MCB (few per 1000 on the transfer function) not too tough? The knowledge of the transfer function at a few percent level might be enough.*** The problem is that the transfer function is not monotonous. The correction algorithms may not converge with the required accuracy.
   - ***Why do we not use a degaussing cycle before the powering of the correctors?*** Even if the initial magnetic state is known, the trims are not predictable. Of course settings cycles must be defined. These correctors being super-conducting, they will remember the magnetic history.
7. to D. Tommasini:
   - ***What is the impact of the water/humidity on the cool-down of magnets?*** There is the capacity to pump the water inside the cryostat.
   - ***What happened to the interconnects after the storage?*** No damage was detected. In case of need the bus bar can be re-generated.
   - ***Did the diode suffer?*** We have never detected so far problems in the diode connections coming from storage since a new assemble procedure was introduced at the magnet manufacturers premises.
   - ***What is the stability of the vertical geometry?*** Small movements have been detected. The origin is not well understood.
8. to L. Bottura about the MEB:
   - ***Is a magnet with fast training and no detraining effect a guaranty for the allocation in sensible regions?*** It is still an open question. These bonus magnets are allocated in these regions because no training is expected after installation and various thermal cycles.
   - ***Is there a clear relationship between quench performance and robustness against losses?*** This issue is not solved for the moment.

CONCLUSIONS AND RECOMMENDATIONS

The performance of the magnet system seems today in line with the tight expectations set by the beam dynamics to reach the nominal machine performance level. For commissioning, there is no evidence today that the collision energy should be reduced below 7 TeV, except for prudence, of course. The availability of the MQTL for the sector test is presently an issue and should be investigated. The spare policy seems reasonable and Magnet Rescue facilities will be organized at CERN. Their staffing at the right level appears as a complex issue to be tackled. One should consider for the most exposed insertion magnets spare magnets in addition to spare parts to cut the long repair delays announced (3 to 6 months). The actual machine integrated performance will not only depend on a global assessment of the magnetic optics and geometry, but on its fine details, reliability and all bits and pieces. An important safety belt is the cold magnetic measurements to understand the detailed behaviour of the magnetic optics. It is under constant pressure to keep the schedule and should be preserved as much as possible and valued accordingly. The machine performance will be driven by the performance of the magnetic optics and geometry. It would seem appropriate at this stage to organize inter-departments multi-disciplinary teams for the (hardware + beam) commissioning to build up a concrete experience by exposure to the hardware.

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REFERENCES

[1]L. Rossi, “What are today’s Issues in the Production of the Main Dipoles & Quadrupoles”, this workshop.
[2]E. Wildner, “What will be the Geometry of the Main Dipoles & Quadrupoles”, this workshop.

[3] D. Tommasini, "Are there Issues due to the Long-Term Outdoor Storage", this workshop
[4] K.-H. Mess, "What are today's Issues for all other Magnets", this workshop.
[5] W. Venturini Delsaro, "Magnetic Behavior of the Correctors: Issues for Machine Operations", this workshop.
[6] L. Bottura, "How the magnetic measurements and Reference Magnetic System will be used?", this workshop.
[7] E. Todesco, "Estimates of the LHC Magnetic Optics versus requirements", this workshop.
[8] L. Bottura, "Installation Strategy of the MEB: what lessons from sector 7/8?", this workshop.