US-LHC MAGNET DATABASE AND CONVENTIONS*

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Abstract

The US-LHC Magnet Database is designed for production-magnet quality assurance, field and alignment error impact analysis, cryostat assembly assistance, and ring installation assistance. The database consists of tables designed to store magnet field and alignment measurements data and quench data. This information will also be essential for future machine operations including local IR corrections.

1 INTRODUCTION

The US part of the Large Hadron Collider (US-LHC) accelerator program is responsible for manufacturing superconducting magnets for the Insertion Region (IR) inner triplet and RF Region dipoles. Dipoles built at Brookhaven National Laboratory, quadrupoles built at Fermi Lab and Japan's KEK, and correctors built in Europe will be measured and assembled in cryostats in the US and then shipped to CERN for installation. In a multi-laboratory collaboration like this, it is necessary to unify the measurement and application conventions, and to establish a database structure commonly accepted by CERN and other collaborating laboratories. The US-LHC Magnet Database[1] is designed for production-magnet quality assurance, field and alignment error impact analysis, cryostat assembly assistance, ring installation assistance. The database consists of tables designed to store magnet field and alignment measurements data and quench data. This information will also be essential for future machine operations including local IR corrections.

The design of US-LHC Magnet Database is based on the existing structure used for the Relativistic Heavy Ion Collider (RHIC). Analysis and monitoring software for field quality[2] and alignment quality[3] have also been adapted for US-LHC magnet use.

2 DATABASE FUNCTIONS AND DATAFLOW

Fig. 1 shows the function of Magnet Database during the production stage, at installation, and after operation. After individual magnet elements (coldmasses) are constructed and measured, quench data, field quality data (integral transfer function, center offset and field angle relative to mechanical fiducials, field harmonics, etc.) and alignment data (fiducial positions, magnetic center, etc.) are collected. After processing (analyzing measurement conditions and statistics, correcting calibration and other systematic errors, etc.), a minimum set of representative data is transfered to the US-LHC Magnet Database. Based on these stored data, computer tracking and simulation is performed to assess the impact of errors; statistical and trend analysis is performed to monitor field quality and to assist in magnet coldmass acceptance; information of magnetic center and field angle can be used for alignment sorting [4] before cryostat assembly; and multipoles with signs defined according to the convention are used for future machine operation including IR correction. [5]

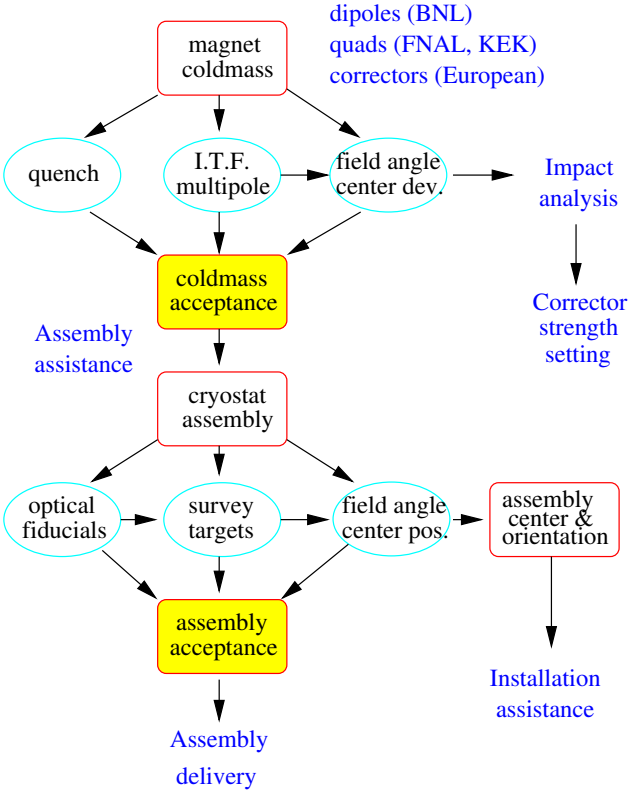

Figure 1: Dataflow for US-LHC magnet field and alignment analysis.

During cryostat assembly, survey and alignment data are extracted and stored in the database. Sufficient information is contained to provide the center and field angle of the assembly relative to the cryostat fiducials. Along with the completed assembly, this information will be delivered to CERN to assist in ring installation.

3 MEASUREMENT AND ANALYSIS CONVENTIONS

3.1 Measurement Convention

Conventions are established among BNL, CERN and FNAL defining the reference measurement coordinates. Magnetic multipoles are defined in the reference system[6, 7] illustrated in Fig. 2. The description is 2-dimensional

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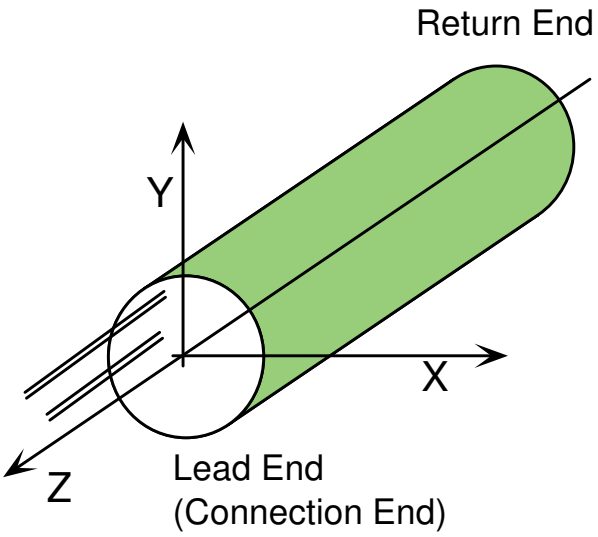


Figure 2: Reference frame for the measurement of magnetic multipoles.

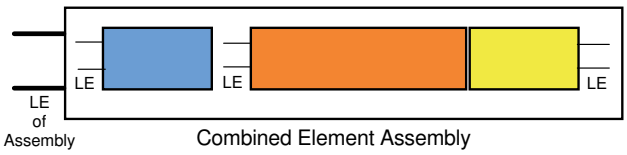


Figure 3: Lead end of a combined element assembly.

with $x-y$ axes chosen such that the skew (or normal) component in the main field of a normal (or skew) magnet is zero.

If the measurement is performed on a single magnet element (coldmass), the reference frame is defined with respect to the lead end of the element. If the measurement is performed on a magnet element contained in a combined element assembly, the reference frame is defined with respect to the lead end of the assembly (which may be opposite to that of the individual element), as shown in Fig. 3

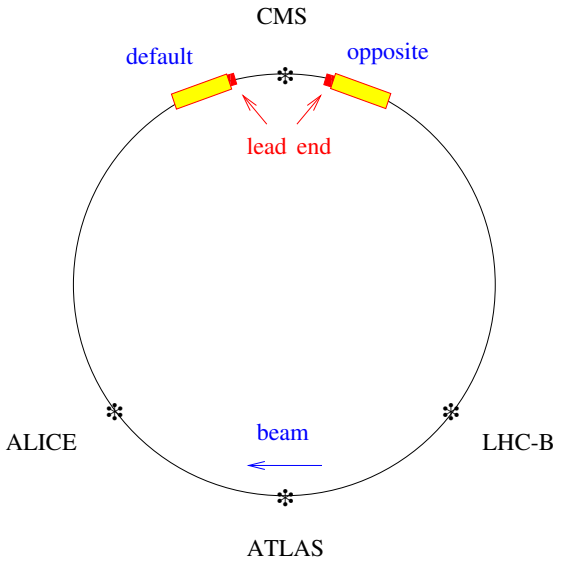
3.2 Multipole Sign Convention

Both the magnitude and sign of measured multipole errors are important for error analysis and for IR local correction[5]. For example, the systematic a_2 from the lead ends of the triplet quadrupole is significant. Since IR magnets at opposite side of the interaction point (IP) are oriented symmetrically towards the IP, the actual sign of a_2 seen by the beam changes accordingly.

Fig. 4 shows the change of magnet multipole sign from their measured value for a beam circulating counterclockwise. In general, rules for multipole transformation under 180° rotation around vertical (y) axis (orientation flip), longitudinal (z) axis (upside-down change) and radial (x) axis are summarized in Tab. 1.

4 DATABASE STRUCTURE

Presently, the database contains 17 tables as listed in Tab. 2. The first 13 tables are intended for quench and field quality



Multipole transformation for ‘‘opposite’’ orientation magnets:

quadrupole: $b_n \Rightarrow (-)^n b_n$; $a_n \Rightarrow (-)^{n+1} a_n$

dipole: $b_n \Rightarrow (-)^{n+1} b_n$; $a_n \Rightarrow (-)^n a_n$

Figure 4: Change of the sign of magnet multipoles from their reference measurement value for a beam circulating counterclockwise.

of individual magnet coldmass, while the last 4 tables are intended for survey and alignment data.

The Integral table contains the integral harmonics and transfer function information. In the case of short magnets, this information may be obtained from a single measurement with a suitably long measuring coil. For long magnets, e.g. the RF dipoles, the integral harmonics will be obtained from a sum of several measurements (a Z-Scan). In the case of a Z-Scan, one can also extract the harmonics averaged over the straight section as well as the integrated contributions from the two ends. If available, these results will be stored in the BodyHarmAvg and EndsHarm tables

Table 1: Transformation rule for magnet multipoles. It is assumed that the magnet polarity is adjusted, if necessary, so that the fundamental term remains positive. $N = 2$ is for quadrupole magnet, while $n = 2$ is for quadrupole order.

Item	Normal magnet of order N	Skew magnet of order N
Orientation:		
b_n	$(-)^{n+N} b_n$	$(-)^{n+N+1} b_n$
a_n	$(-)^{n+N+1} a_n$	$(-)^{n+N} a_n$
Upside-down:		
b_n	$(-)^{n+N} b_n$	$(-)^{n+N} b_n$
a_n	$(-)^{n+N} a_n$	$(-)^{n+N} a_n$
180° about x:		
b_n	b_n	$-b_n$
a_n	$-a_n$	a_n

Table 2: Summary of US-LHC Magnet Database tables.

Name	Content
Magnets	magnet name, ID, summary info.
Assembly	combined element assembly info.
Quench	quench performance
Integral	int. geometric multipole
LocalHarm	multipoles measured at one position
BodyHarmAvg	average body multipole
EndsHarm	lead and return end multipole
IntField	integral field strength
Magz	magnetization multipole
Eddy	Eddy current multipole
TDecay	time decay multipole
Centers	magnetic centering offsets
WarmCold	ITF & multipole warm/cold conversion
FidMagInfo	survey information summary
FidOpt	fiducial position from optical survey
CentMag	mag. center wrt external reference
Angle	mag. field angle wrt external reference

respectively. In addition, each individual measurement in a Z-Scan will be recorded in the table LocalHarm. The entries for various positions in the LocalHarm table can be used to identify any location which may be unusual from the field quality point of view. Such spots of concern are generally difficult to identify from the integral or the average body harmonics, and the information can be essential in establishing models for study of, e.g. magnet fringe field.

Tables Integral, BodyHarmAvg, EndsHarm contain transfer function, multipoles and field angle data of individual magnet coldmass. Both normal and skew Multipoles up to order 15 are recorded in accordance with the convention. Both the body and the ends harmonics are normalized to the value of the main field component in the straight section, whereas the integral harmonics are normalized to the integrated main field component. Thus both the body and integral harmonics are expressed in units. Since the ends harmonics are integrated values over a certain length of the magnet, these are expressed in unit·m rather than units.

The integral transfer function obtained by summing several measurements in a Z-Scan may not be very accurate due to small errors in positioning of the measuring coil. If this be the case, an independent measurement of integral transfer function is needed, for example with a long non-rotating coil, as was done for RHIC. With this in mind, a separate table (IntField) is created to store the most accurate measurements of integral transfer function.

For measurements in the superconducting state, measurements during the upward and the downward sweeps of current reveal contribution to harmonics due to superconductor magnetization. The difference between the up ramp measurements and the average of up and down ramp measurements will be stored in the table Magz. Similarly, if harmonic measurements are made while the magnet current is still ramping, then such harmonics will include any contributions from eddy currents generated in the superconductor. These harmonics will be stored in the Eddy table. Another superconductor related table is Tdecay, which will contain the time dependence of various harmonics at a fixed current (most important is the injection current) soon after a ramp.

Table Centers will contain the centering offsets and field angles from the magnetic measurements. These values are meaningful only when the measuring coil is well centered in the magnet yoke. In such cases, one can use this information, for example, to better align various elements in a combined element magnet.

Table WarmCold will contain the systematic values of warm to cold offsets based on data from all the magnets of a particular type for which both types of data exist. This table is only of academic interest if all magnets are measured cold. However, the table can be used to obtain the best estimates of cold harmonics if some magnets are only measured warm.

Tables CentMag and Angle contain information of assembly center offset and orientation relative to the external fiducials. This, together with Tables FidMagInfo and FidOpt containing information of fiducial positions, provides guidance to final ring installation of the magnet assembly.

5 SUMMARY

Along with the magnet assembly delivered for installation at CERN, magnet measurement data containing tables of quench performance, field quality, alignment and survey data will be transferred to CERN. This information is essential both for ring installation and for future machine operation including IR corrections. US-LHC Magnet Database has been designed to fulfill such tasks, and it will also benefit production stage quality assurance, error impact analysis, and assembly assistance including sorting.

We thank participants of the 1998 US-LHC Magnet Database Workshop for contributing to the establishment of the database structure.

6 REFERENCES

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