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Engineering Specification

THE ELECTRICAL CIRCUITS IN THE LHC REFERENCE DATABASE

Abstract

This document defines how the electrical circuits powering the magnets in the machine are described in the LHC Reference Database. It introduces the ideas of the circuit description language (CDL) and its interpreter, used to load the information into the database. A convention for a unique naming of the elements is proposed and applied to all the electrical circuit elements in the machine.

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1. INTRODUCTION AND OUTLINE

The superconducting magnets for the LHC accelerator, comprising 1232 main dipole magnets, about 450 quadrupole magnets and several thousand corrector magnets, are powered in 1612 electrical circuits, while in total 1712 power converters are connected to these circuits (e.g. the inner triplet circuit contains three power converters). The current feeding the magnets ranges from 60 A (for small correctors) up to 13 kA for main dipole and quadrupole magnets.

The powering layout is extremely complex with about 80000 high current connections. A minor fault in any of the circuits, or in one of the superconducting connections could obstruct operation of the accelerator, while an uncontrolled release of the total stored energy of 10 GJ in the magnets would lead to severe damage of accelerator equipment.

Therefore it is a necessity to ensure the correctness of connection of the superconducting bus bars around the 27-km long machine, especially as repair work in the cold part of the machine would result in substantial downtime of the machine.

Having the appropriate tools to describe the electrical system in an electronic format within the LHC Reference Database will help

- testing, commissioning and operating the electrical system in the presence of a complex interlock system that should ensure safe operation, in particular in case of an equipment failure such as quench or a power cut
- generating interconnection information and input files for optics programs such as MAD
- having a unique and coherent source for all the powering information for the machine

Up to now, the different groups were working with fractions of the complete available information, stored in various formats at CERN. Due to these distributed sources of information a lot of information was duplicated and thus becomes incoherent with time.

The decision to include the information of the electrical circuits into the LHC Reference Database was taken recently. This paper will detail the approach to describe the electrical part of the LHC in this database.

The most important information to be added and stored in the database is information about the sequence of connection in the different electrical circuits, which was only available in the electrical drawings[1].

These electrical drawings mostly describe the cold part of the machine, and only very little information is available about the electrical circuit between the power converter and the DFB.

To migrate this information into the Database, a description language will be introduced and described, as well as a prototype of an interpreter that will create the database entries. The electrical circuits are assigned to 28 Powering Subsectors [1], which represent independent areas of powering around the machine.

A second main input source for the circuit information is a FileMaker Pro database, describing in more detail the warm cabling in the different circuits as well as power converters, magnets, quench protection systems and various calculations for the electrical circuits (total resistance, total inductance…) and energy dissipation.

[1] Electrical diagrams of the LHC magnets; optics version 6.4 available on EDMS (LHCLSD%)

2. DEFINITIONS

Electrical Circuit

An electrical circuit is the connected sequence of electrical circuit elements, needed to connect the magnets to one or several power converters. Figure 1 shows an example of an electrical circuit, powering three magnets in one of the eight arcs. For normal conducting magnets (Figure 2) one will find a similar configuration, except the transition into the cold part at 4.5K through the current leads and the DFB's.

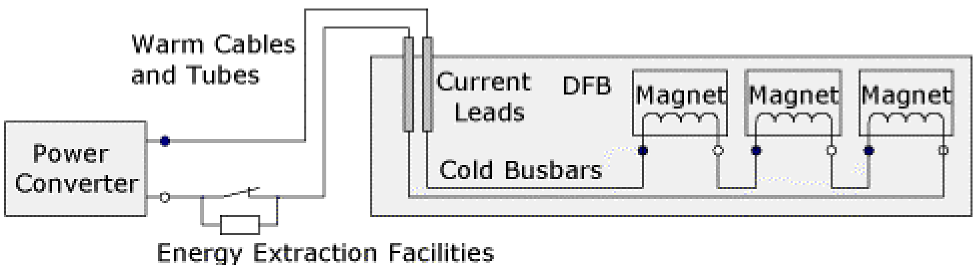

Figure 1: Electrical circuit feeding magnets in the cold part

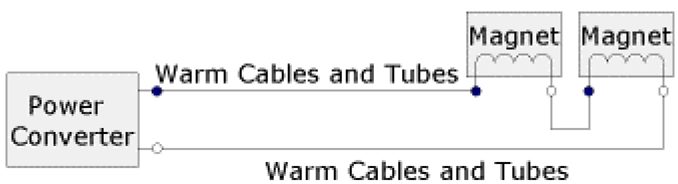

Figure 2: Electrical circuit feeding a warm magnet

Electrical circuit element

An electrical circuit element is a single component in an electrical circuit with two connection points. (e.g. Power converter, warm cable, warm tube, current lead, cold busbar piece, magnet, energy extraction switch or energy extraction resistor)

CDL

The CDL (Circuit Description Language) is used to describe the connection sequence of the electrical circuits in the LHC in an easy and compressed way.

CDL-Interpreter

The CDL-Interpreter uses the CDL as an input and is generating the data to be stored in the LHC Reference Database.

Cold

The term cold represents always a piece of equipment operated at 4.5 K or 1.9 K inside of a cryo assembly.

T-Junction A T-Junction is a term used to describe the junctions of the circuits. (e.g. for energy extraction facilities with parallel paths or embedded power converters in the inner triplet)

The T-Junction will appear in the CDL but is itself not an electrical circuit element.

Warm A warm piece of equipment operated at room temperature.

3. SPECIFYING THE REQUIREMENTS TO THE DATABASE

In order to support the assembly and commissioning of the electrical circuits in the LHC the following needs have been addressed when designing the database:

- Creating the interconnection information for all busbar types for a given interconnection plane
- Creating MAD input files to verify the correctness of data (this implies mainly information about magnet location, field strength and direction as well as PC ratings)
- Supporting the electrical integration and test procedures with tailored information (e.g. impedance calculations between two given points in the circuit…)
- Providing configuration information for the programming of the Powering Interlock Controller
- Introducing the concept of Powering Subsectors [1]
- Generating appropriate electrical drawings
- Implementing and in the end replacing the FileMaker Pro database

4. THE CIRCUIT DESCRIPTION

For translating the information stored in the electrical drawings, a circuit description language (CDL) was proposed to describe all occurring types of circuits in a fast, easy and compressed way.

An example for the CDL is shown in Figure 3 (for naming conventions see chapter 5), describing a part of the defocusing quadrupole circuit in Arc 78. The circuit description always starts at the positive terminal of a power converter and the corresponding circuit name is indicated in the first line of the description.

In the following lines, the sequence of electrical circuit elements is described, indicating every piece of equipment used in this circuit. As soon as the description will meet a bifurcation in the circuit, a T-junction is defined in the CDL and the description is continued with the main path of the circuit (the main path is hereby defined as the path including the magnets and power converters), until one will find the corresponding second T-junction, closing the circuit. The electrical circuit elements connected in the second path between the two T-junctions are described at the end of the CDL for this circuit as an additional SEGMENT of the circuit.

Main Defocusing Quadrupole Circuit in Arc 78

```
CIRCUIT
RQD.A78.UA83
RPHE.#RQD.A78.UA83.A
DWWCT.1.#RQD.A78.UA83
DWWCF.1.#RQD.A78.UA83
DFLA.7L8.1
DCQDD.7L8.R
DCQD.R
MQ.12L8.B1.B
DCQD.R
MQ.14L8.B1.B
DCQD.R
MQ.16L8.B1.B
DCQD.R
MQ.18L8.B1.B
DCQD.R
MQ.20L8.B1.B
DCQD.R
MQ.22L8.B1.B
DCQD.R
MQ.24L8.B1.B
DCQD.R
MQ.26L8.B1.B
%
DCQD.L
MQ.17L8.B2.A
DCQD.L
MQ.15L8.B2.A
DCQD.L
MQ.13L8.B2.A
DCQD.L
MQ.11L8.B2.A
DCQD.L
DCQDD.7L8.L
DFLA.7L8.2
DWWCF.2.#RQD.A78.UA83
DWWCT.2.#RQD.A78.UA83
T.DWWCT.2.#RQD.A78.UA83
DQS.#RQD.A78.UA83.A
T.DQS.#RQD.A78.UA83.A
DWWCF.3.#RQD.A78.UA83
RPHE.#RQD.A78.UA83.B

SEGMENT
T.DWWCT.2.#RQD.A78.UA83
DQR.#RQD.A78.UA83.A
T.DQS.#RQD.A78.UA83.A
```

Figure 3: The CDL for the Defocusing Quadrupole Circuit in Arc 78

The circuit description will then be uploaded to the LHC Reference Database using an Application Programming Interface (API), which is realised as a Web-Interface [2]. The circuit information will be stored in a table, using a circuit id and an element id (two unique numbers within the Oracle table) to identify an element within the different electrical circuits. Each element in this description will be linked to the existing electrical circuit element in the LHC Reference Database.

With the knowledge of the sequence of electrical circuit elements in any electrical circuit and the list of electrical circuit elements in the LHC Reference Database, we are able to represent the physical electrical circuit in the LHC Reference Database schematically as shown in Figure 4.

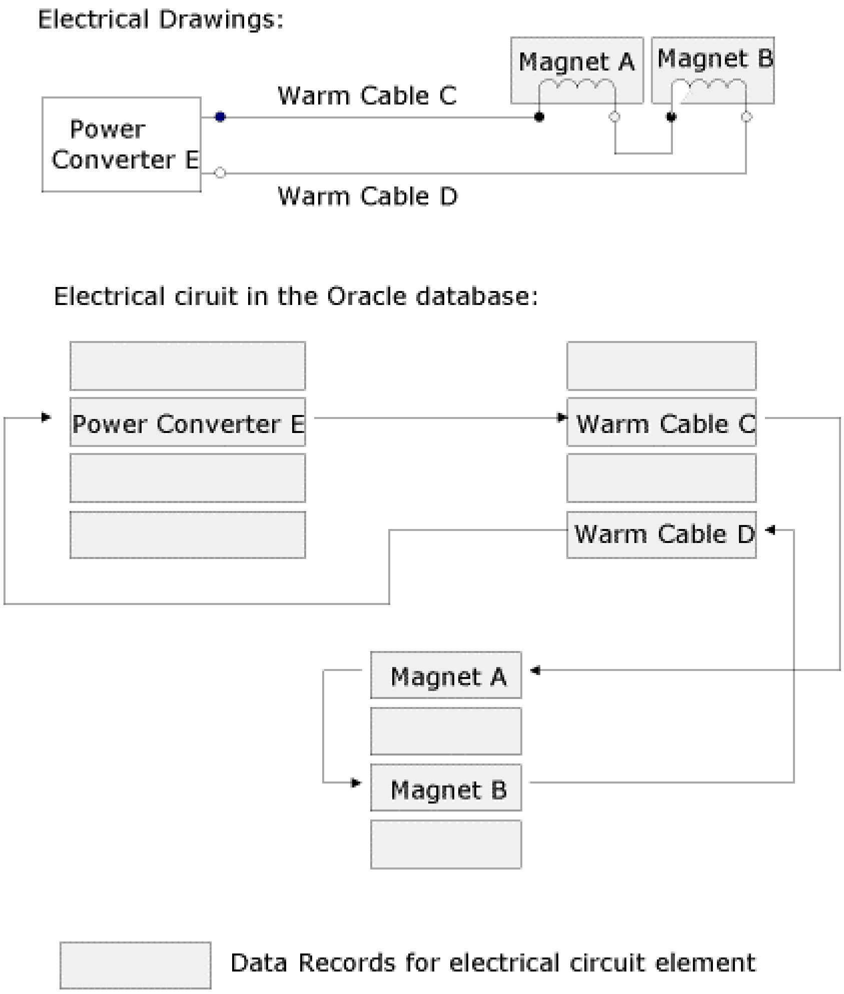

Figure 4: Comparison between the physical electrical circuit and the database entries

Note:

The electrical circuit elements are all together stored in one table in the LHC Reference Database, the connections in between them (pointers in Figure 4) can be found by looking at the uploaded circuit description. To verify the correctness of description, the presence of each electrical circuit element that is mentioned in the circuit description is crosschecked with the defined electrical circuit elements in the database.

4.1 THE CDL-INTERPRETER

To describe a circuit in the CDL, no detailed information about the busbar connections throughout the arc is entered. At this stage, only the type (and index if applicable) of the used busbar is mentioned.

Which connections in between the busbars have to be done in order to connect a magnet (that may be physically located somewhere in the middle of the arc) with a defined busbar is a task left to the CDL Interpreter. By using the circuit description and the geographical layout of the machine the interpreter will extend the original circuit description to the extended format of the circuit description and provide it as XML-files to the LHC Reference Database (see Figure 5).

The CDL Interpreter will at the same time verify the correctness and feasibility of the input, using existing data and knowledge about the circuits.

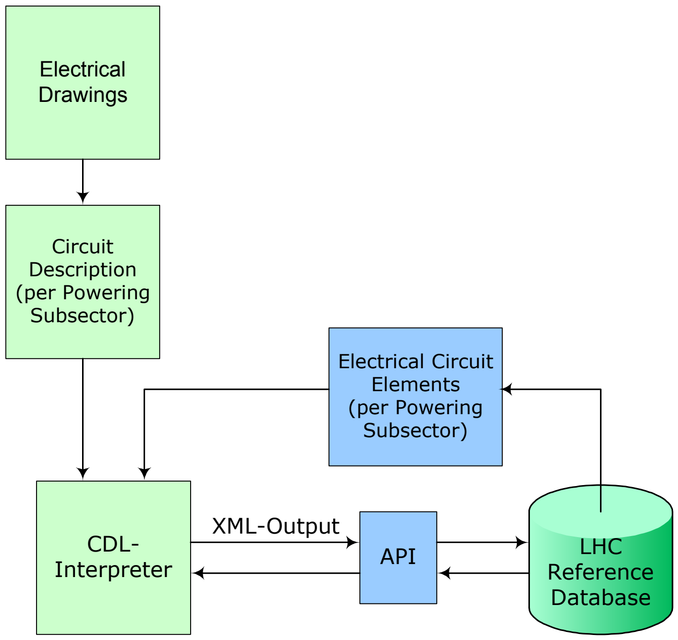

Figure 5: Extending and Uploading the Circuit Description

4.2 ADDING THE DATA TO THE LHC REFERENCE DATABASE

Some of the electrical circuit elements that will be required to introduce the connection information are already present in the LHC Reference Database (e.g. magnets) while others need to be created to provide the complete set of electrical circuit elements to the CDL interpreter [3]. Beside the information about name and location of an electrical circuit element, several fields for the connection information of the element are added.

These additional indices will help the interpreter to understand the usage of each electrical circuit element within the machine and provide information how and if it is already connected in any of the circuits.

There will be an index for the number of cryo assembly in the arc that an electrical circuit element is located in as well as an index for the number of electrical half-cell. Other parameters given for each electrical circuit element are the connection plane (the upstream connection plane is defined as the left connection plane of an assembly, seen by an observer standing in the centre of the machine), the half-cell length (for cables in Line N traversing through several electrical half-cells) and an index to indicate if an element already has been used in the description of any circuit (see Table 1 for the complete list of attributes):

- element name
- assembly index
- half-cell index
- connection plane
- half-cell length
- is used

Table 1: Attributes of an electrical circuit element

5. NAMING CONVENTION FOR THE ELECTRICAL CIRCUIT ELEMENTS

All naming conventions mentioned here are also available in [4]

5.1 ELECTRICAL CIRCUITS

The complete electrical circuit is indicated by a name as shown in (Table 2). It consists of a circuit identifier, information about the location of the magnets powered in that circuit and the location of the connected power converter. (The location of the connected power converter is not necessary for a unique circuit name, so it may not appear when accessing the Database via the foreseen user interfaces)

RB.A78.UA83	Main dipole circuit in Arc 78, PC located in UA 83
RQD.A78.UA83	Main quadrupole circuit in Arc 78, PC located in UA 83
RQTL7.R7B2.RR77	Circuit feeding MQTL7 in R7, acting on beam 2
RQ8.L8B1.UA83	Circuit feeding Q8 in L8, acting on beam 1

Table 2: Naming Convention for circuits

5.2 MAGNETS

Starting from the layout definition in the LHC Reference Database, it is already possible to derive the name and location of the electrical circuit elements for the magnets. The additional fields for the connection information are added in the table for the electrical circuit elements.

To remain consistent with the layout description in the machine (and also with the MAD input) it was decided to use a naming for the magnets in the standard half-cells of the arcs as shown in Figure 6 and Figure 7.

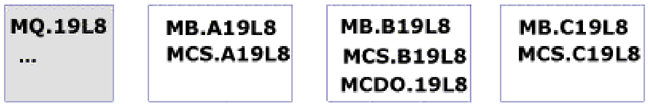

Figure 6: Naming Convention for Magnets in a Standard Half-cell with 2 LBB assemblies and 1 LBA assembly

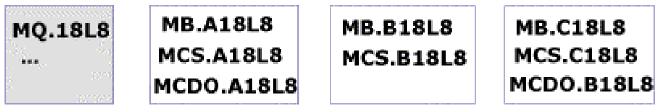

Figure 7: Naming Convention for Magnets in a Standard Half-cell with 1 LBB assembly and 2 LBA assemblies

Different to the MAD input, some magnet types such as the main dipole magnets appear as only one physical electrical circuit element (as both apertures are connected in series in the same electrical circuit). This needs to be taken into account when generating the magnet entries.

Information about turned cryo assemblies also has to be part of the stored information about magnets and is already included in the layout information of the machine. In such a case, the top assembly is installed by turning it 180° and thus having the interconnections of the magnets in the downstream connection plane. Such turned cryo assemblies affect the magnetic properties of the contained magnets with respect to the two beams as well as the connections of the contained busbars.

5.3 BUSBARS AND AUXILIARY CABLES

Busbars and auxiliary cables represent the electrical circuit elements in the cold masses and in Line N, connecting all the magnets to the shuffling module of the DFB's and via the current leads and warm DC cables to the power converters.

All magnets are connected via one of five different busbars types; busbars for the main dipole magnets (DCB), the main quadrupole magnets (DCQ), the spoolpiece corrector magnets (DCC), the lattice corrector magnets (DCA/DCE) and the individually powered quadrupoles in the arc cryostats (DCD) as shown in Figure 8.

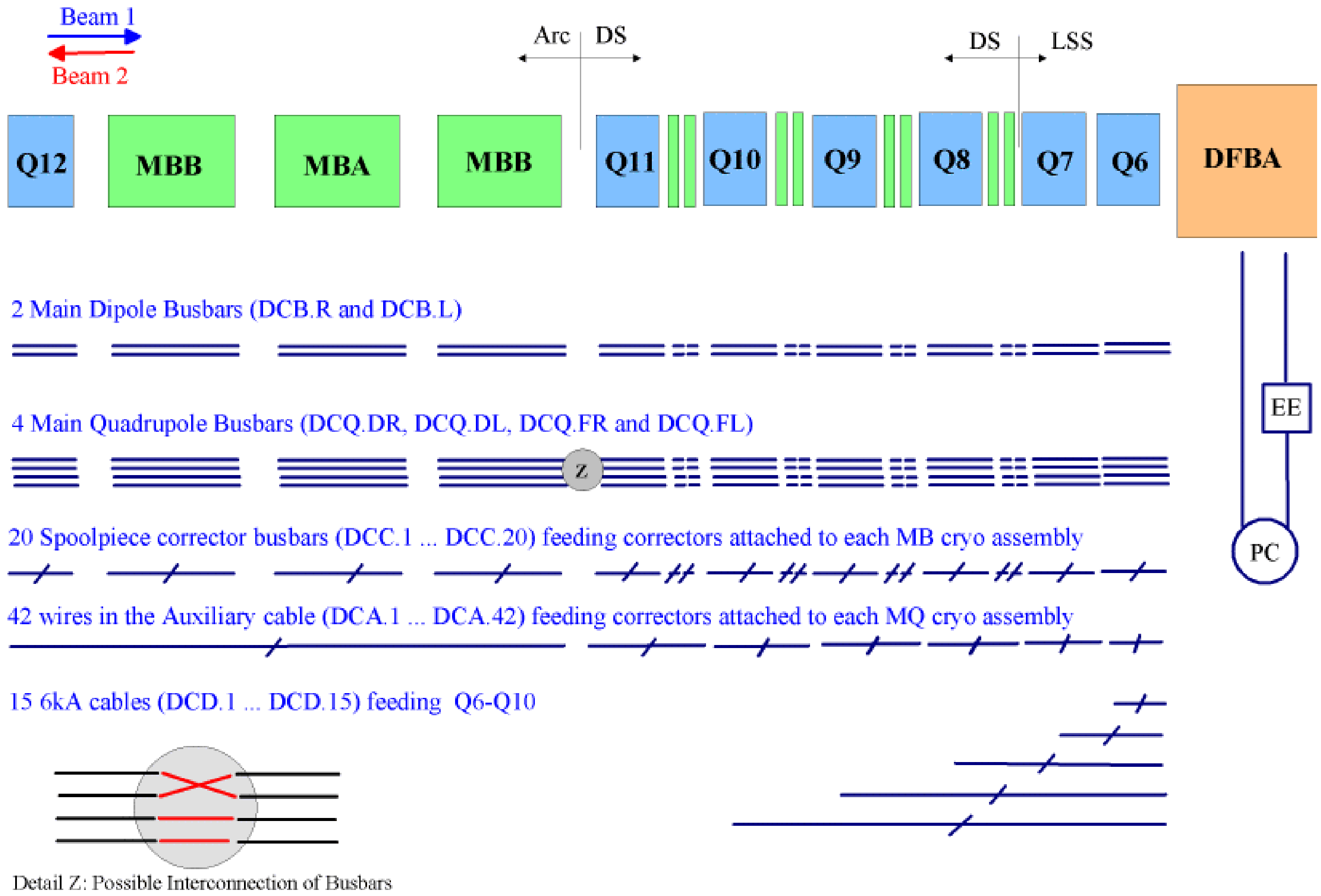

Figure 8: The cold busbars of the LHC

5.3.1 MAIN DIPOLE, MAIN QUADRUPOLE AND SPOOLPIECE BUSBARS

Three out of the five present 'busbar types' (main dipole, main quadrupole and spoolpiece corrector busbars) are physically mounted inside the cryo-assemblies (already before they are transported to the tunnel). Therefore these three busbars types will be present in every cryo assembly in the arc (LB, LQ and LE), while the busbars in Line N will be attached later onto the cold mass in a separate tube (see Figure 9).

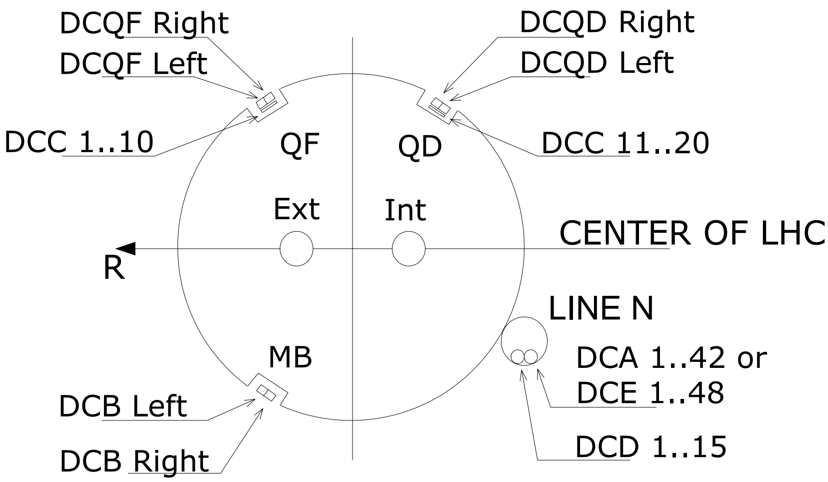

Figure 9: Cross-section of cryo assembly indicating the busbars types (seen from the connection end)

Each cryo assembly contains 2 main dipole busbars, 4 main quadrupole busbars and 20 spoolpiece busbars as shown in Table 3 for an LBB assembly in half-cell 19L8.

DCBB. A19L8.R	Main dipole busbar right
L	Main dipole busbar left
DCQBF. A19L8.R	Main quad busbar focusing right
L	Main quad busbar focusing left
DCQBD. A19L8.R	Main quad busbar defocusing right
L	Main quad busbar defocusing left
DCCB. A19L8.1	Spoolpiece busbar number 1
2	Spoolpiece busbar number 2
…	
19	Spoolpiece busbar number 19
20	Spoolpiece busbar number 20

Table 3: Busbars in an arc cryo assembly (e.g. for an LBB assembly in half-cell 19L8)

The fourth and fifth character in the naming of the busbar indicates the type of cryo assembly that they are located in. In case of several busbars of the same type in one half-cell, the location has to be extended by a character indicating the position of the element in the half-cell (A19L8, B19L8, C19L8) as shown in Figure 10 and Figure 11, while the letter A is given to the element that is located closer to the nearest IP.

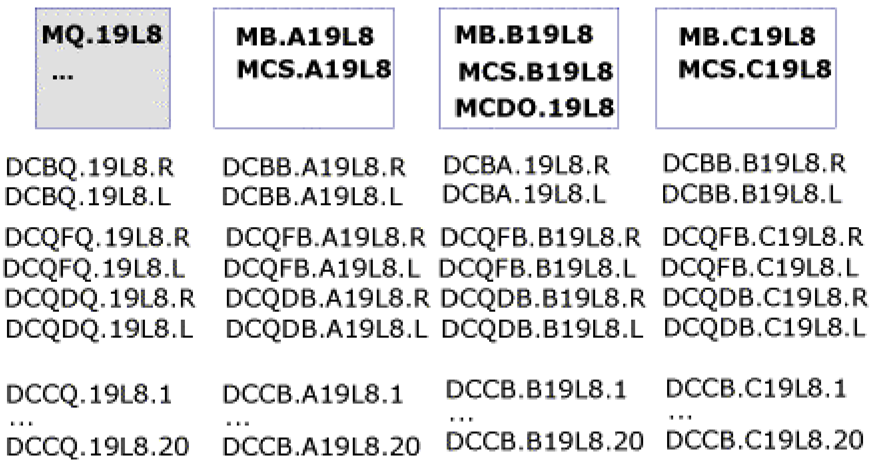

Figure 10: Naming of magnets and busbars in a standard half cell with 2 LBB assemblies and one LBA assembly (example for half-cell 19L8)

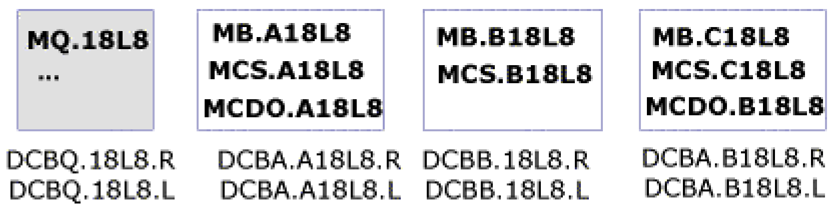

Figure 11: Naming of magnets and busbars in a standard half cell with 1 LBB assembly and 2 LBA assemblies (example for half-cell 19L8)

Empty cryostats (located always in half-cell 11 left and right of any IP) will be indicated by an 'E' as the fourth character of the busbar (e.g. DCBE.11L8.R). Like the quadrupole assembly, the empty cryostat is always unique in an arc half-cell and will not need any further letter to distinguish its location within a half-cell.

Finally, 26*n electrical circuit elements describing the main dipole, main quadrupole and spoolpiece busbars are present in each arc. (Where n represents the number of cryo assemblies in the different arcs and is given in Table 4)

	Arc 12	Arc 23	Arc 34	Arc 45	Arc 56	Arc 67	Arc 78	Arc 81
N	**211**	**211**	**211**	**211**	**210**	**210**	**211**	**211**

Table 4: Cryo assemblies in the Arcs

5.3.2 LATTICE CORRECTOR BUSBARS, 6kA CABLE

The two types of busbars that will be physically placed in line N (lattice corrector busbars and 6kA cables) are interrupted and connectable only in the upstream interconnection planes of the quadruple magnets of the arc.

The length of one unit of these busbar types is not a cryo assembly but always a half-cell, while busbars in the dispersion suppressor regions of the arcs can traverse several half-cells without any interruption (indicated by the attribute 'half-cell length').

The naming of the busbars in line N is shown in Figure 12 and Figure 13. As it can be seen in these figures, the layout is different for the IP's 3 and 7, as no special powered quadrupoles are present in these dispersion suppressor areas. Instead, a special type of cable with 48 wires (DCE) has to be inserted in the first half-cell of the dispersion suppressors in L3, R3 and L7 (in R7 the connection plane is located next to the shuffling module and thus no cable is needed there), which is replacing the DCA type in these half-cells.

The location appearing in the naming of such busbars does not always correspond to the definition of an optical half-cell as shown in the electrical drawings, due to the optically shared quadrupole in the centre of each arc. In general, the busbars adopt the name of the half-cell to which the dipole assemblies belong (as the dipole assemblies represent the major part of a half-cell).

The fourth and fifth character (LA, LB, LC… LZ) will specify the subtype of the busbar. Before attaching these letters the length of these cables are summarized all around the machine and stored in a table. Cables that have the same physical length will then receive the same fourth and fifth character, even though they may be located in different half-cells or may be of different types.

Applying this naming convention to elements e.g. in half-cells 19R7 and 7L8 will result in busbars as shown in Table 5.

DCALA.19R7.1	600A Lattice corrector busbar number 1
2	600A Lattice corrector busbar number 2
…	
41	600A Lattice corrector busbar number 41
42	600A Lattice corrector busbar number 42
DCDLE.7L8.1	6 kA cable number 1
…	
15	6 kA cable number 15

Table 5: Naming Convention for Busbars in Line N (example for half-cells 19R7 and 7L8)

These 3 busbar types contribute to the number of electrical circuit elements as follows:

42 electrical circuit elements in each half-cell for the lattice corrector busbars

48 electrical circuit elements in L3, R3 and L7

3-15 additional electrical circuit elements in the half-cells 6-10 on each side of the interaction points 1,2,5 and 8

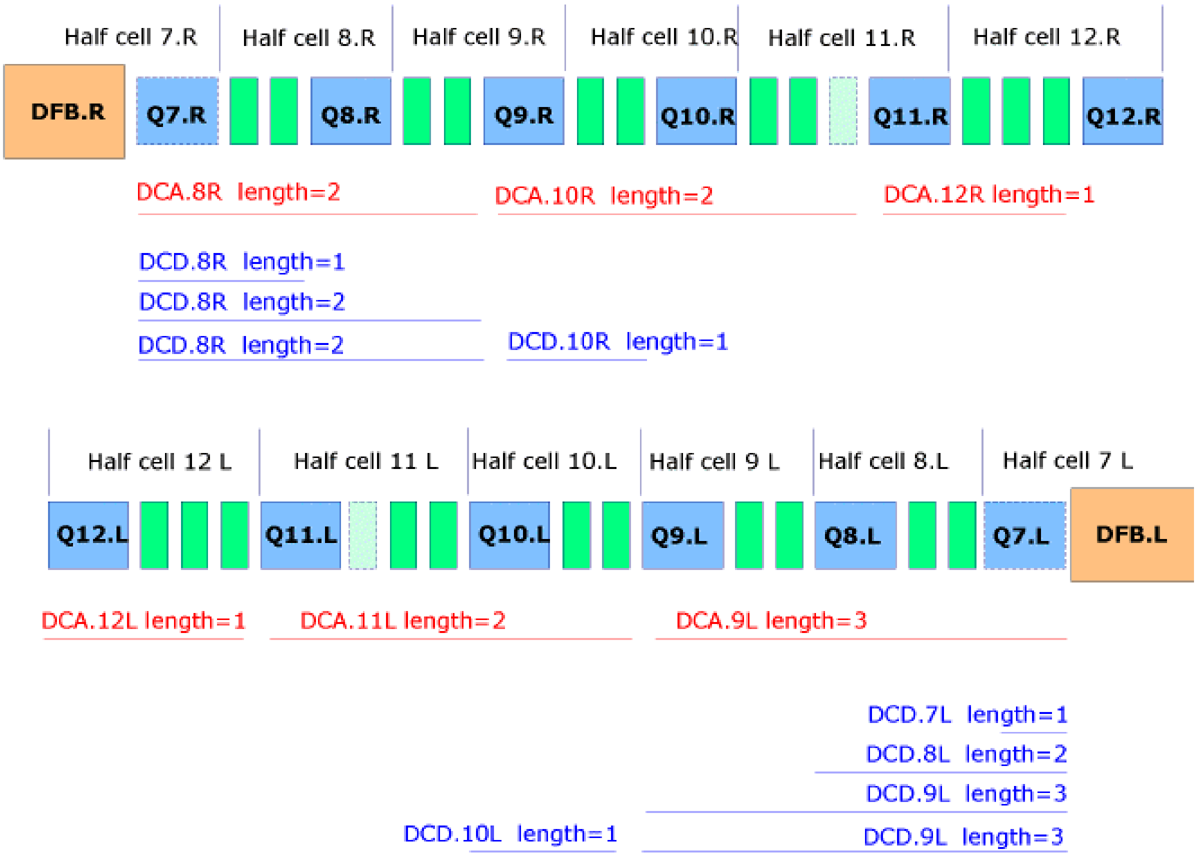

Figure 12: Naming of busbars in line N for IP's 1, 2, 4, 5, 6 and 8

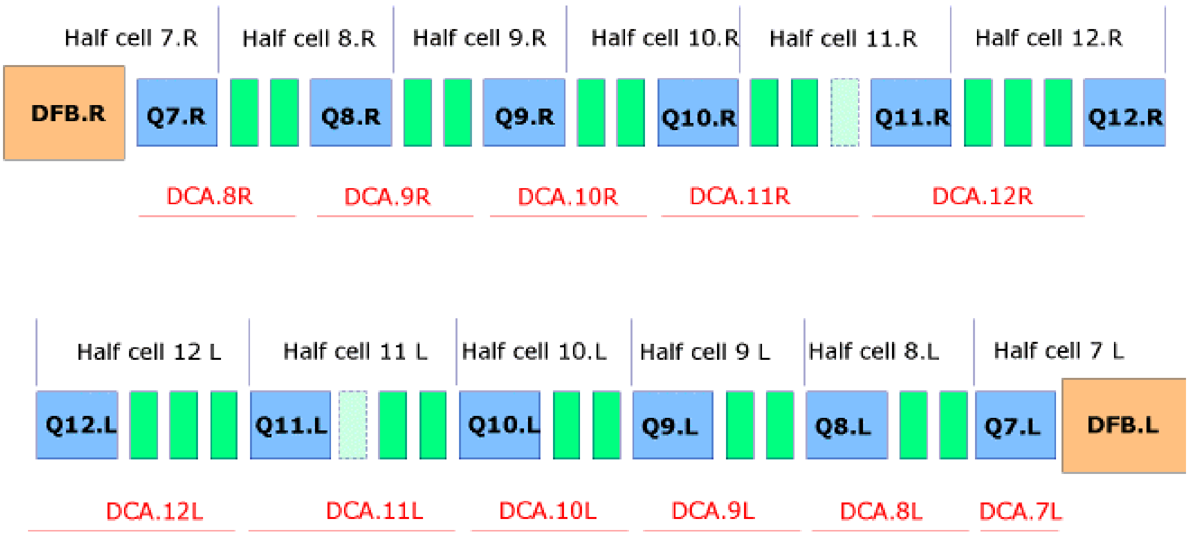

Figure 13: Naming of busbars in line N for IP's 3 and 7

5.4 BUSBARS IN THE DFB'S

The DFB's in the LHC can be treated from the electrical point of view like a number of electrical wires (with resistances according to their different length and type), leading from the connection flange of the CL down to the connection point in the cold part.

Depending on the number of electrical circuits connected to the DFB, the different DFB's will have a different number of electrical circuit elements.

Similar to the naming of busbars we will treat the DFB's as if they were cryo assemblies and indicate their location in a DFB with a character 'D' as shown in Table 6.

If there are several DFB's in the same half-cell, a letter in front of the location will distinguish busbars of the same type (e.g. DCAD.A7R5.1 and DCAD.B7R5.1)

DCBD.7R1.R	13 kA busbar for main dipole circuit in DFBAB
DCQDD.7L1.R	13 kA busbar for defocusing main quadrupole circuit in DFBAA
DCQFD.7L1.L	13 kA busbar for focusing main quadrupole circuit in DFBAA
DCCD.7L5.12	600 A spool piece busbar number 12 in DFBAI
DCAD.7R5.34	600 A busbar number 34 for auxiliary cable in DFBAJ
DCED.7L7.48	600 A busbar number 48 for auxiliary cable in DFBAM
DCDD.7R2.3	6 kA busbar for Q6-Q10 in DFBAD

Table 6: Naming of Busbars in the DFB's

5.5 CURRENT LEADS

Examples for the naming of the current leads on the different DFB's are given in Table 7. Each type of current lead on a DFB will start with the index one and will be increased following to the number of current leads. If there are several DFB's with the same type of current leads in the same half-cell (as in L6 and R6), again a character in front of the location will distinguish the two electrical circuit elements (e.g. DFLC.A5R6.1 and DFLC.B5R6.1). As there are also local current leads (e.g. for the orbit correctors in the arc), these current leads will indicate a half-cell as their location.

DFLA.7R1.1	13 kA current lead number one on DFBAB
DFLB.7R1.2	600A current lead number two on DFBAB
DFLC.7R1.3	6 kA current lead number three on DFBAB
DFLD.23R1.1	60 A current lead number one in half-cell 23R1
DFLE.6L2.1	120 A current lead number one on DFBAC
DFLX.3R1.1	7.5 kA current lead number one on DFBXB
DFLY.3L1.1	600 A current lead number one on DFBXA
DFLZ.3L1.1	120 A current lead number one on DFBXA

Table 7: Naming of Current Leads in the Machine

5.6 WARM CABLES

The warm cables represent the connections between power converter and the warm magnets or the current leads on the DFB's for the cold magnets.

Estimations about the length of these cables are stored in the File Maker Pro database.

For each of the 1712 power converters as well as for the eight energy extraction facilities in the machine an entry exists in this database, indicating the number and length of the according warm cables in the electrical circuit.

Due to different powering of the electrical circuits, each type of electrical circuit requires an appropriate warm cable in terms of cross-section area of the cable and cooling properties. Different types of cables and water-cooled tubes for current conduction are present in the machine. Three different types of connections can be defined, always using the indicated types of warm cables and tubes.

For 13 kA circuits: - a water-cooled tube (DWWCT)
- a water-cooled flexible cable (DWWCF)

For circuits with 1kA<I<13kA and for the energy extraction of the main dipole circuit in odd points:
- a water-cooled flexible cable (DWWCF)

All other circuits: - an air-cooled flexible cable (DWACF)

Examples for the naming of such elements are shown in Table 8.

DWWCT.1.#RB.A78.UA83	Water cooled tube of circuit RB.A78.UA83 in forward direction
DWWCT.2.#RB.A78.UA83	Water cooled tube of circuit RB.A78.UA83 in backward direction
DWWCF.1.#RB.A78.UA83	Water cooled flexible cable of circuit RB.A78.UA83 in forward direction
DWWCF.2.#RB.A78.UA83	Water cooled flexible cable of circuit RB.A78.UA83 in backward direction
DWACF.1.#RCBXV2.R1.UJ16	Air cooled flexible cable of circuit RCBXV2.R1.UJ16 in forward direction
DWACF.2.#RCBXV2.R1.UJ16	Air cooled flexible cable of circuit RCBXV2.R1.UJ16 in backward direction

Table 8: Naming of Warm Cables

With: forward direction representing the connection from the positive power converter terminal to the DFB

backward direction representing the connection from the DFB to the negative side of the PC

5.7 PC'S, ENERGY EXTRACTION FACILITIES

Information about the creation of these electrical circuit elements will be retrieved directly from the existing FileMaker Pro Database. There are 1712 power converters connected to the 1612 electrical circuits, while only 232 circuits are equipped with an external energy extraction system.

The naming convention for the power converters will include their type and the circuit they are attached to (see Table 9). The location of the power converter is hereby identical with the location mentioned in the circuit name.

RPHE.#RQD.A78.UA83	Power converter for circuit RQD.A78.UA83
RPHE.#RQF.A78.UA83	Power converter for circuit RQF.A78.UA83
RPLA.#RCBXV1.R1.UJ16	Power converter for circuit RCBXV1.R1.UJ16
RPLA.#RCBXV2.R1.UJ16	Power converter for circuit RCBXV2.R1.UJ16

Table 9: Naming of Power Converters

An energy extraction facility always consists of a switch (DQS) and an extraction resistor (DQR) (see Table 10). For each circuit providing energy extraction, we have to create these two electrical circuit elements.

DQS.#RB.A78.UA83	Energy extraction switch of circuit RB.A78.UA83
DQR.#RB.A78.UA83	Energy extraction resistor of circuit RB.A78.UA83
DQS.#RB.A78.RR77	Second energy extraction switch of circuit RB.A78.UA83 in RR77
DQR.#RB.A78.RR77	Second energy extraction resistor of circuit RB.A78.UA83 in RR77

Table 10: Naming of Energy Extraction Facilities

In case of the main dipole circuits there are two energy extraction facilities in the circuit, located at each end of the arc cryostat.

6. REFERENCES

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