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LHC PICS: WHAT ARE WE TALKING ABOUT?

P. Fessia, Geneva, Switzerland

Abstract

This paper will provide an overview of the PICs (Performance Improving Consolidation) providing a brief description of the system.

The contribution of the PICs to the machine reliability will be underlined as this is one of the key parameter to reach the HL-LHC target.

PIC TARGET

The target of the PICs intervention [1] on the LHC machine is to make possible achieve an accumulated integrated luminosity of at least 1000 fb^{-1} in the year 2035, assuming 10 years of operation and starting from an integrated luminosity of 300 fb^{-1}. Other assumptions are 160 days of physics per year and a minimum performance goal of 70 fb^{-1}/year. The different systems to be upgraded will be reviewed listing the necessary equipment and where, along the LHC ring, shall be installed.

INTERACTION REGION IR1, IR5

The interaction region will need to be consolidated because of the accumulated radiation damage [2] and the improvement target is to equip these area with units that would stand higher radiation dose, exploiting the advancement of superconducting technology in order to provide aperture and gradient to achieve stronger focussing.

The main equipment that will be improved are described in the followings paragraphs.

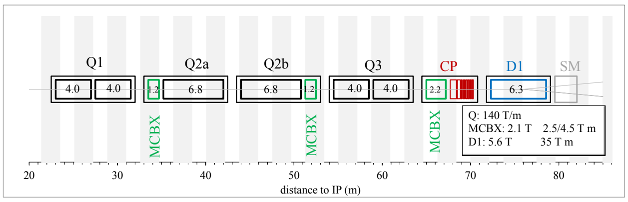

Figure 1: Magnet Layout for the HL-LHC upgrade from Q1 to D1.

The magnet system. The Q1 to D1 lay-out is shown in Fig. 1 [3, 4]. The present low-β quadrupoles in Nb-Ti will be replaced with Nb_3Sn based units. This new magnet (MQXF [5]) will have a coil aperture of 150 mm with an operational gradient of 140 T/m. They are based on the technologies and concepts developed in the past by the US LARP program (i.e. the HQ magnet, see Fig. 2). This unit is presently being designed in a collaboration between CERN (Fig. 3) and the US-LARP.

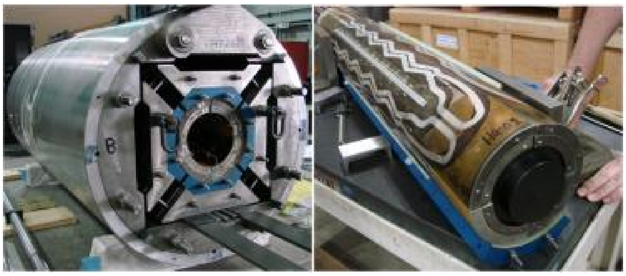

Figure 2: HQ magnet (on the left) and coils (on right) produced and assembled by LARP.

The present LHC uses normal conducting separation dipole D1. These elements will become superconductive in the new HL-LHC PIC configuration. The new D1 will be Nb-Ti based, with an operational field of 5.6 T and a magnetic length of 6.3 m. KEK in Japan is has taken the responsibility to develop the design of this type of magnet.

Figure 3: MQXF dummy coil wound at CERN.

The nonlinear corrector family (b_2, b_3, b_4, b_5, b_6, a_2, a_3, a_4, a_5, a_6) will be installed in one cold mass that will be called corrector package and it will be placed between the Q3 and the D1. They will superconductive, using Nb-Ti conductors and they will be based on the superferric technology tested by CIEMAT and CERN during the SLHC-PP program. INFN is presently involved in the design of these units.

The orbit correctors will be also Nb-Ti based. The central field will be 2.1 T and will be produced in two different lengths (1.2 m and 2.2 m) featuring an integrated strengths of 2.5 T·m and 4.5 T·m.

As mentioned the present LHC triplet has lifetime limited by his radiation hardness. In order to increase the radiation hardness [6] of the future units and to cope therefore with the debris of such high integrated luminosity, the magnet will be equipped with beam screens that will present a thick shielding very probably in

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tungsten alloy. The screen is designed to limit the absorbed dose on the coil to 10 MGy for the foreseen 1000 fb^{-1} and to reduce the heat deposition in the superconductor to a safe value of 1.5 mW/cm^3 for a peak luminosity of 3×10^{34} cm^{-2} s^{-1}.

The beam diagnostic will need also to be upgraded in order to cope with the new operation condition of the machine. New cryogenic Beam Loss Monitors (BLMs Figure 4) will be installed on the front face of the cold magnets in order to provide accurate measurements of the losses that could impact the coils. New Beam Position Monitors (BPM) will be installed between Q1 and Q5. The will be designed to minimise transverse impedance and will be equipped with tungsten alloy shielding.

Figure 4: Prototypes of cryogenic BLM installed on the front face of an LHC MQ cold mass.

The powering will be guaranteed via a dedicated **superconducting link** that will connect the magnet in the tunnel with electrical distribution feed-boxes on surface. Here the power converter will be installed in radiation safe area providing quick access for intervention and guarantee that the equipment will be safe from Single Event Upset (SEE) and radiation damage.

The protection scheme will need to be reinforced with new **collimators** and **masks.** The absorber protecting the experiments (**TAS**), the **alignment system** and the **Quench Protection System** (QPS) will also need to be redesigned.

THE COLLIMATION

The upgrade of the collimation system is linked to the operational evidences that will be collected during the run 2 of LHC at 6.5 TeV. This is particularly important for the IR7 system consolidation. The main actions for the collimation are described in the following paragraphs.

New secondary collimators (TCS) built using a more robust material coated with a highly conductive Mo layer. These collimators will allow halving the overall machine impedance budget (linked to the collimator system) from frequencies of the order of 1 MHz. These collimators will be mainly installed in IR7. In IR 6 **new TCLAs** will need to be installed to protect Q4 and Q5, while for the same reasons in IR1 and 5 new **TCTP**s will be necessary.

In IR2, to protect the superconducting magnet in the Dispersion Suppression area during the ion run [7], it will be necessary to install new collimators (**TCLD** Figure 5) in the section presently occupied by the continuous cryostat. In order to do that Nb_3Sn based dipoles with higher central field will be used. This will provide the same integrated field over a shorter length. Replacing therefore 2 LHC MB with these new units it will be possible to free and area where a cryo-bypass will be inserted, providing continuity to the cryogenic and electrical services and allowing space to install warm collimators.

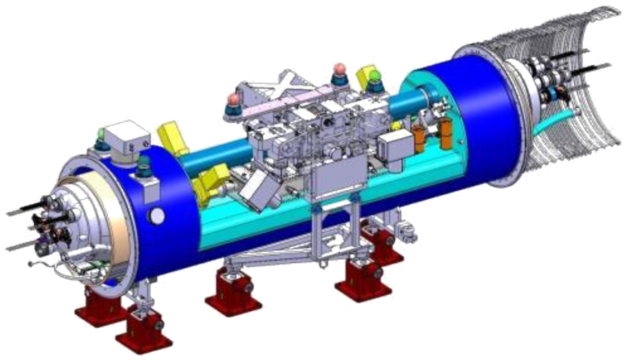

Figure 5: TCLD installed on its cryo-bypass dummy coil wound at CERN.

BEAM DIAGNOSTIC

The LHC beam instrumentation will need to be upgraded to face higher performance requirements and to stand the higher radiation dose

Radiation hard electronics will be installed in the IR3, IR7 and the LSS. Being radiation hard this electronics will be placed very near the measurement point, getting rid of the long cables that today collect severe noise. The present level of noise is such, that, today, it would be difficult to discriminate between it the signals to be read at 6.5/7 TeV.

The BLM electronics and the Synchrotron Light monitor will also need to be modified providing extra capabilities.

To enhance the emittance measurement capabilities, new Beam Gas Vertex detectors (**BGV**) and new **Fast Wire Scanner** will be installed in IR4.

SUPERCONDCUTING LINK

In addition to the superconducting link at IR1 and IR5, that will feed the magnet from Q1 to D1, a new superconducting link will need to be installed during LS2 in **IR7**. This will allow removing the 600 A power converters from the RR73 and RR77, placing them in the TZ76, a radiation safe area. This superconducting link will be only horizontal while the ones in IR1 and IT5 will be horizontal and vertical, but it will be installed already during the LS2.

CRYOGENIC SYSTEM

The first limitation of the present cryogenic system for the LHC will be encountered in sector 4-5, and in particular in the cooling capacity in the temperature range between 4.6 K and 20 K. This is due to the fact that the cryogenic installation of point 4 is also connected to the superconducting cavities that are installed there. Sector 4-5 will be therefore loaded not only with the power to be evacuated from the debris in the final focus in point 5, but also with the loads coming from the RadioFrequency system (RF). In addition, the two systems (magnets and superconducting cavities) are today strictly linked and warming, cooling and maintenance operation have to be performed on both large equipment at the same time. In order to get rid of this bottleneck in term of flexibility and installed cooling capacity, it has been decided to install a new cryogenic plant at point 4 to be connected only to the RF system that would be therefore separated from the other equipment. In addition, the two cryogenic plants would be provide extra redundancy the whole LHC system in case of malfunction of one of the two because the installation will be performed in order to allow connecting each of them to both the systems.

The next cryogenic limitations will be in the sector nearby the high luminosity experiments (IP1 and IP5) because the final focus will be loaded by the heat load coming from the collision point debris. As consequence the installation of two cryo-plants in these two locations to cool the two triplet is proposed. This will provide also easier operation thanks to increase flexibility and redundancy. It is also clear that HL-LHC (also including the three new cryo plants) will not have enough installed cryogenic capacity between 4.6 K and 20 K if the e-cloud effect in the dipoles of the arcs will not be suppressed.

WARM MAGNETS IN THE CLEANING INSERTION

In IR3 and IR7 the normal conducting magnets MQW and MBW will accumulate a very high level of radiation during the LHC and HL-LHC exploitation.

In order to guarantee the survival of these units till HL-LHC installation and beyond it has been decided to protect the most exposed units with tungsten alloy shielding to be installed during LS1. Thanks to this action only 4 MBW in IP7 and 4 MQW in IR3 will probably incur damaged before reaching the 3000 fb^{-1} foreseen by the full HL-LHC installation (US2 [8]) and they will be marginal for the PIC configuration. These units shall be changed with more radiation hard magnets during LS3. In addition it is important to remark that the activation of the equipment will increase while accumulating more integrated luminosity. For a total value of 1000 fb^{-1} and after 6 months of cooling we can still expect to have the magnets in IR7 emitting between 0.3 and 4 mS/h in IR7. These levels are 7 times more then what it was measured in LS1 and it will be about 3 times less (therefore ranges between 1 and 12 mSv/h) respect the values estimated for an integrated luminosity of 3000 fb^{-1} (HL-LHC US2 [7]).

CONCLUSIONS

The PICs, listed for the HL-LHC, target to substitute equipment that are not suitable to stand high radiation dose (i.e. the inner triplet) or would limit the machine operation capability (impedance budget due to TCS). Doing so the system will be upgraded in order to provide enhanced performance and the set of actions here described, is coherent with the objective to harvest 1000 fb^{-1} for 2035.

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REFERENCES

[1] G. Arduini et al. “PICS: what do we gain in beam performance?”, these proceedings.

[2] L. Bottura “What could stop us, when and how long?”, these proceedings.

[2] E. Todesco, et al., “Design Studies for the Low-Beta Quadrupoles for the LHC Luminosity Upgrade,” IEEE Trans. Appl. Supercond., vol. 23 no. 3, pp. 4002405, June 2013.

[3] E. Todesco, et al., “A first baseline for the magnets in the high luminosity LHC insertion regions,” IEEE Trans. Appl. Supercond. 24, submitted for publication.

[4] P. Ferracin, et al., “Magnet Design of the 150 mm Aperture Low-β Quadrupoles for the High Luminosity LHC,” IEEE Trans. Appl. Supercond. 24 submitted for publication.C. Petit-Jean-Genaz and J. Poole, “JACoW, A Service to the Accelerator Community,” EPAC’04, Lucerne, July 2004, THZCH03, p. 249 (2004); http://www.JACoW.org.

[5] L. S. Esposito, F. Cerutti, E. Todesco, “FLUKA Energy Deposition Studies for the HL-LHC”, TUPFI021, IPAC13 Proc., Shanghai, China.

[6] J. Jowett “Future heavy-ion performance of the LHC”, these proceedings.

[7] L. Rossi “How to implement all the HL-LHC upgrades (HL-LHC)?”, these proceedings.