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ESS-0092073 - Interface and Risk Management for the Cold Linac NPMs

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Abstract

This document presents the interface and risk management for the project NPM Cold Linac. The interface associated with the instrument NPM, its design and production, its installation and its operation is described at the conceptual level. It is intended to identify the interface so that risks for the project can be mitigated. At the stage of the conceptual design, the interface for the NPM are clearly understood. Mainly, they articulate around the production and installation of the instrument, and around the operation and maintenance. This main two points are described bellow, together with their associated risks.

Contents

1 List of Abbreviation

Table 1: List of Abbreviation

NPM	Non-invasive Profile Monitor
IPM	Ionization Profile Monitor
HV	High Voltage
RO	Readout
FOP	Fiber Optics Plate

2 Introduction

The NPM for the Cold Linac is a specific instrument designed to measure the transverse profile of the beam transported through the Cold Linac. This instrument supports the range of operation mode from tuning to production. It is selected to satisfy level 4 requirements (ESS-0078645) that stipulate the beam profile shall be measured for all pulses of any length and any current, with an accuracy of 10%, and measure the beam size in both axis, also for all pulses. The NPM, which is non-invasive and in principle could be used for all mode of operation is limited in its sensitivity, and cannot provide measurements for small current pulses. In addition, in the Cold Linac sections, the nominal residual gas pressure is 10^9 mbar. So the fluorescence based NPM is not sensitive enough to detect a nominal pulse. As a result, ionization based NPM is chosen for its sensitivity down to 10^{13} proton per pulse at the nominal pressure.

The instrument is composed of two IPM orthogonal to each other and thus enabling a vertical and horizontal profile measurement of the proton beam. The IPM is based on the interaction between the beam and the residual gas. The range of operation depends on the quality of the vacuum. Too few particles in the residual gas and the IPM might not see any signal. So the knowledge of the residual gas pressure and composition is essential to the design and to the operation of the instrument. The IPM has also a HV cage. Its implementation has to comply with safety aspects. Also the electric field induced by the HV should not deflect the proton beam significantly, and the deflection has to be compensated by the corrector magnets. Part of the IPM readout is in the vacuum chamber. So it has to comply with the vacuum handbook. But also since the readout will have a finite lifetime under radiation, maintenance scenario should be anticipated.

We present here the interface of the NPM for the Cold Linac that has to be clarified for its installation in the accelerator, and the interface required for its operation. Operating the

NPM is associated with risks; risks of not having the profile measurement during tuning and operation, but also risk hazards due to high voltage; finally, risk due to maintenance of part of the instrument in the vacuum chamber, in a particle free vacuum region of the accelerator.

3 Interface in Production and Installation

The NPM for the Cold Linac is composed of two identical and orthogonally placed IPM. Each of the IPM is composed of a HV cage, a RO unit, a Calibration Unit, a control unit.

- The HV cage, the RO and Calibration units are in a mechanical assembly in vacuum. So the first interface is with vacuum system. As such the design and construction of the IPM has to comply with the ESS vacuum handbook which can be found in the following documents: ESS-0012894, ESS-0012895, ESS-0012896, ESS-0012897. The procedure to deliver a particle free device that can be installed in the LWU in the Cold Linac sections has been discussed, and will continue to be discussed with the ESS vacuum group. Also, for the NPM to deliver any profile, a minimum gas pressure is required. Assessment of this pressure has been done and agreed together with the ESS vacuum Group.

- The HV cage may receive a potential in excess of 60kV. The cable from the unit delivering the HV, and the connectors have to comply with European/Swedish electrical safety regulation. For instance, some of the regulation that may enforce are:
  - 2014/30/EU EMC directive
  - directive 2006/42/EU on Machinery
  - SS-EN-61936-1 and SS-EN 50522 on Power installation

- Cable and Rack management: Cables should be ordered, pulled and terminated on site during the installation phase. The list of cables is still open, since the RO and Calibration has not yet been down-selected. However, an initial list of cables (based on possible designs of RO) have been communicated to the responsible persons for cables at ESS. The position of patch panels has been discussed and is now included in the mechanical model of the machine. The system may need intermediate electronics and controller close to the beam line element. This is also addressed by the design of a shielding enclosure for electronics in the Stubs. Documentation is found in the BD wiki: (`https://ess-ics.atlassian.net/wiki/display/BIG/BD+cables+for+CDB`, and `https://ess-ics.atlassian.net/wiki/display/BIG/BI+crate+and+racks`)

- Cooling: only one of the possible RO requires cooling. This is the TimePix3. The cooling can be provided by the cooling system pipes which will be used to cool the magnets. Discussion with the Cooling system lead as evidenced that this cooling system can be put in place at a later stage, and can even retro-fitting by adding another pipe derivation. Check of the cooling power has shown the proposed cooling system is well capable of cooling the 5W in vacuum generated by the Timepix3.

- Mechanical integration: the update of the machine design is done by exchange of mechanical drawings files between CEA mechanical engineers and ESS mechanical engineers in charge of the machine model. A procedure for updating the drawings is now in place, and has been experimented and the design of the LWUs has been communicated both ways successfully.

- EMC: there should be no EM-field in the volume occupied by the NPM. However the NPMs are between Quadrupole magnets, and Corrector magnets. The fringe magnetic field has been assessed using the IPM model code. The deflection of the electron / ions trajectories is negligible.
- Schedule: the planning of the project has been done before the installation schedule. As a consequence, the delivery of the NPM for the Spoke LWU installation will be late by 2 months in the current planning. This delay will be re-assessed along the detail design and production phases, making corrective measures in order to minimize the delays.
- Integration of the system into the control system is fundamental so achieve successfully this project. Interaction with ICS ESS and Controls Group at Saclay in on-going in order to clearly identify the resource and effort needed to achieve the control and software of the NPM within the planned schedule. This is documented on the following page

4 Interface in Operation

The RO and Calibration units are in vacuum, and also exposed to radiation during operation of the machine. As a result, they will degrade until it will be necessary to replace the damage parts for the NPM to operate within specification. The preliminary studies on the various components of each of the selected RO lead to an estimate of the lifetime and maintenance cycles frequencies for the NPM.

- Timepix3: its rated radiation dose is 10 MGy for the silicon chip, and 1 MGy for the digitizer and control electronics. The estimated radiation dose at the position of the NPM RO is the order of 200kGy/year[1]. This implies that the lifetime of the Timepix3 RO may be of the order of 5 years. As a result the maintenance cycle period to be planned is once every 5 years.
- MCP associated with metallic strips: The MCP lifetime under radiation is comparable to the Timepix3 chip, 10 MGy, if not better. So for this RO, the maintenance cycle is also expected to be once per 10 years or less.
  - Another cause of performance reduction of the MCP is simply the charge drawn in the MCP. Taking into account the source signal intensity per pulse at full power (5MW for 6000 hours per year), the total charge drawn by the MCP, with a gain of 10^6, is estimated to be of the order of 0.1C/cm^2. According data from MCP manufacturer[2], the lifetime of the MCP can be of the order of 10 years or more, depending on the arbitrary chosen threshold for the loss of gain efficiency.
- MCP associated with optical system: the system is composed of an MCP, a Fiber Optic Plate (FOP) to couple out of vacuum the MCP image. The FOP is composed of glass, and as such will degrades under radiation. However, FOP glass can be selected among several possible materials that can be radiation hard rated up to

[1] https://ess-ics.atlassian.net/wiki/display/BIG/Interface+and+Risk+Management+For+the+Cold+Linac+NPM

[2] data published by Hamamatsu, which shows that an MCP start to degrade its gain efficiency after 0.1C/cm^2, and remains above 80% after 1 C/cm^2

1MGy. This makes this system maintenance cycle comparable to the previous ones: 1 per 10 years.

- Scintillator associated with FOP: for this RO, the choice of the scintillator material impacts the lifetime. However, scintillators like for instance $CdWO_4$ or $PbWO_4$ start to degrade beyound 10 MGy. This leads to an anticipated maintenance cycle of 1 per 10 years.

The survey on lifetime of components of the down-selected RO systems shows that they all might have a long lifetime and therefore a long maintenance cycle period. However, the maintenance cycles draw here are estimated from the calculation of the dose based on 1 W/m beam loss. This calculation, which is the number on which PSS relies on, doesn't take into account the dynamic model of the accelerator. So it doesn't represent the dose that the NPM may receive during operation. However, this number should represent the order of magnitude of maximum dose rate, based on maximum beam loss. In order to mitigate the uncertainty on the radiation dose and associated degradation of the NPM, each of the two IPM will be also equipped with a calibration system. This will allow monitoring of the performance and degradation of the NPM. It will also permit correction to maintain the performance of the system and manage the planning for the maintenance periods.

5 Risks and Risk Management

The risks for performance degradation due to too low vacuum pressure will result in no profile measured, and thus not matching the level 4 requirement to provide beam profile and beam size for any pulse and any current delivered by the accelerator. This risk in low, but has been considered. A mitigation can be provided by the Calibration system. This will be specified during the detail design phase.

The risk do to radiation degradation is to shorten the maintenance period. It is addressed within the data available from the literature and within our best knowledge and predication for beam loss.

Additional risk for performance reduction is the space charge effect. This has been evaluated by means of a numerical model of an IPM and with the ESS beam - Space Charge based model of an IPM (ESS-0092068). it is shown that the nominal beam parameters can be accurately measured. However, very small beam sizes will induced distortion in the measured profiles, which can be recovered. However, the method to recover information from largely distorted distributions still remain to be demonstrated. A successful method has been developed at CEA Saclay. It has to be implemented for the ESS beam. This is to be done in the detail design phase. We conclude though that the space charge impact on the NPM measurement is under control.