A POSSIBLE SCHEME TO DELIVER 2 GeV BEAMS FROM THE CERN PS BOOSTER TO THE ISOLDE FACILITY

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Abstract

The CERN PS Booster (PSB) is presently undergoing an upgrade program to increase its beam energy from 1.4 GeV to 2 GeV. While this energy upgrade is targeted at LHC-type beams, the option of delivering 2 GeV beams to the ISOLDE facility has also been investigated. In this paper we present a preliminary study for delivering 2 GeV beams to ISOLDE including the physics motivation and the implications on the accelerator hardware.

INTRODUCTION

The upgrade of the CERN PS Booster to a top energy of 2 GeV [1] in the frame of the LHC Injectors Upgrade (LIU) project [2] is targeted at beams delivered to the LHC. Beams for the isotope separator ISOLDE have therefore not been included in this study. However, there is a strong demand from the physics community to take advantage of 2 GeV proton beams from an upgraded Booster. Therefore a preliminary study has been launched on the feasibility and impact of the transfer of 2 GeV proton beams to the ISOLDE targets. In the following sections we present the outcome of this feasibility study. The study comprises only the transfer of beams to ISOLDE, and does not cover any issues related to the ISOLDE targets, target area and the ISOLDE facility itself.

PHYSICS CASE FOR 2 GEV

The ISOLDE facility presently produces about 1000 different isotopes beams for over 70 different chemical elements. This is by far the largest offer in present ISOL-type facilities in the world. The ISOL method is based on a moderate- to high-energy light ion beam that impinges onto a thick target maintained at extremely high temperatures. The recoil products come at rest in the target materials, before being ionized and later separated in a mass spectrometer [3]. At ISOLDE, the beams are subsequently injected and accelerated by a linac in the REX-ISOLDE post-accelerator. The High Energy and Intensity (HIE-ISOLDE) project foresees the upgrade of the post-accelerator, and a design study is on-going to cope with the increased proton beam intensity which will become available with the start-up of CERN's new injector linac (Linac4).

The figure of merit of a given radioactive ion beam facility results from the combination of the following factors:

- Diversity of available beams.
- Beam intensity (referred to as ion or isotope yield when the intensity is normalized to a given primary proton beam intensity, namely ions/μC).
- Beam quality, for instance purity (i.e. presence of other ion components for a given isotope beam) and emittance.
- Yearly availability of the facility.
- Non-degradation of beam intensity over time, related to ageing of the production target or ion source that experience the harsh environment in the primary irradiation zone at the target station location.

Figure 1 shows the available beams at ISOLDE and the requested beams from a first series of Letter of Intents for HIE-ISOLDE. Since the gain in the secondary beam intensity is highly non-linear with the proton beam energy, the 2 GeV energy upgrade will notably improve the first two figures of merit for ISOLDE, providing a two to six fold increase of intensity for most of the beams [4]. In addition, it will better recreate the EURISOL conditions, for which 2 GeV has been shown to better fulfil the aim of this next generation facility [5].

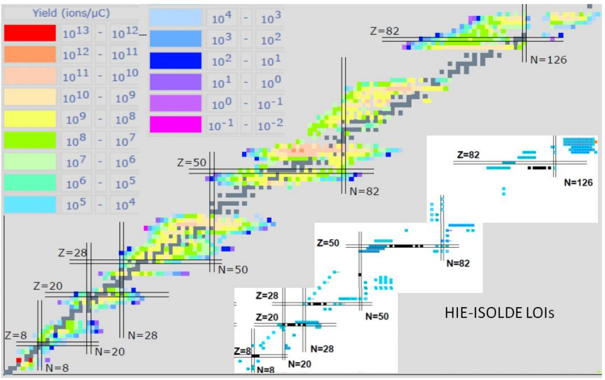

Figure 1: Available radioactive ion beams at ISOLDE (ISOLDE yield database, www.cern.ch/isolde, April 2013). Inset: Requested radioactive ion beams (blue squares) collected from the HIE-ISOLDE Letters of Intent submitted in 2010 to INTC. Vertical scale: Proton number Z. Horizontal scale: Neutron number N.

IMPACT ON MACHINE HARDWARE

The transfer line connecting the PSB to ISOLDE was originally designed for 1 GeV protons, the energy of the PSB at the time of the construction of ISOLDE in the beginning of the 1990s. Since then the proton beam energy has been increased to 1.4 GeV, and ISOLDE is currently using beams at 1.0 and 1.4 GeV. The transfer line consists of three sections: a vertical switchyard above the dump and measurement line of the PSB bringing the beam to the level of ISOLDE, a 60 m long transfer section bringing the beam through concrete shielding into the ISOLDE target area and a horizontal switchyard inside the target area to serve the two ISOLDE front ends HRS and GPS. The line is composed of three types of magnets. Four dipoles are used in the switchyards; they are of HB4 type, the horizontal benders of the former ISR transfer lines. 15 quadrupole magnets (type Q130), also from the former ISR machine, are used for the beam transfer and four larger quadrupole magnets (type Q100) are used for the final focus onto the targets. Seven horizontal and vertical corrector magnets are also employed throughout the beam line. In the last year, a study was undertaken to investigate the impact of an energy increase to 2 GeV on the transfer line elements. The following assumptions were made:

- Beam line geometry and optics remain unchanged
- Booster cycle length remains 1.2 s
- Only 1.4 and 2 GeV will be used in the future (no 1 GeV beams)

At 2 GeV the current settings for some of the quadrupole magnets (Q130) exceed the ratings of the magnets and power converters (220 A max for the magnets). A number of converters need to be upgraded. The magnets however can be reused if the mode of operation is changed. Currently all the quadrupole magnets are operated in DC mode, although both converters and Q130 magnets are designed for pulse to pulse modulation (ppm). In this mode of operation the nominal field is only maintained during the active cycles of the ISOLDE user and the RMS current can be lowered below the 220 A limit.

This also implies that the existing water cooling is sufficient and does not need to be upgraded. The focussing quadrupoles (Q100) can operate at 2 GeV without change but a replacement with laminated magnets could be envisaged to allow ppm operation and limit the energy consumption.

The four dipoles are already operating in a saturated regime and any further increase of the field would lead to unrealistic currents and cooling requirements. Magnetic field simulations also showed that the field quality would be severely affected (Figure 2).

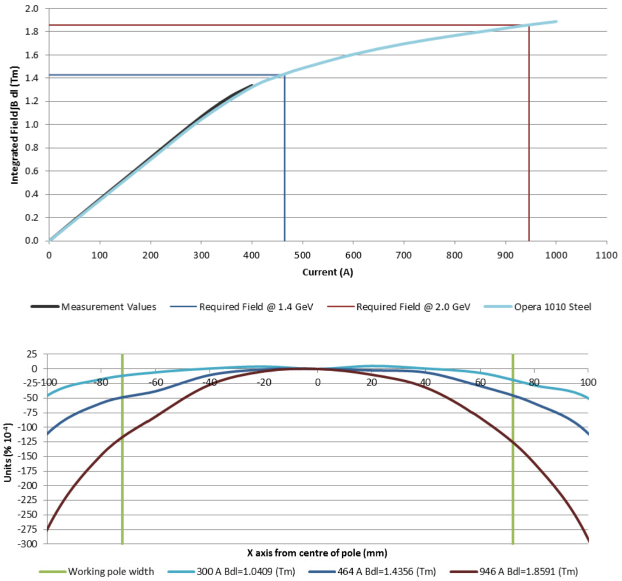

Figure 2: HB4 dipole excitation curve and homogeneity of integrated field along X axis, Y=0.

For this reason an alternative solution was proposed which consists in replacing the dipoles with new longer dipoles designed to match the specifications of the existing power converters [6]. In this way the power converter cabling and cooling could remain unchanged. A preliminary study showed the feasibility of such magnets. The main parameters are summarised in Table 1. A detailed integration study remains to be performed to define the available space for the new bending magnets.

Table 1: Main parameters of the proposed HB4 replacement dipoles

Magnet parameters	**Present HB4 magnet at 1.4 GeV**	**Proposed HB4 magnet at 2.0 GeV**
Iron length [m]	1.0	1.4
Total length [m]	1.59	1.91
Aperture height [m]	0.08	0.08
Aperture width [m]	0.32	0.32
Field in centre [T]	1.307	1.230
Integrated field [Tm]	1.429	1.859
Magnetic length [m]	1.09	1.51
Windings/pole	102	86
Total Windings	204	172
Current at peak field [A]	464	461
Resistance [Ω]	0.079	0.056
Inductance [H]	0.246	0.282
Coil current density [A/mm^2]	3.29	2.15

Some modifications in the beam lines around the dipoles will be necessary to accommodate these longer magnets with a larger bending radius. Transport and handling should also be studied carefully, as these magnets are installed in tunnels and areas with limited access. This is particularly true for the upper part of the transfer line which is accessed by a pit of 2.5 m by 2 m.

The corrector dipole magnets do not pose any problem as the currents are typically small and the magnets and power converters have sufficient margin.

Several other aspects such as the shielding and beam diagnostics need to be taken into account before an energy upgrade can be envisaged. The shielding of the transfer line was fortunately designed with very large safety margins [7]. It is composed of concrete blocks and iron blocs in the areas where space is limited. The assumptions made during the design of this shielding have proven to be pessimistic, for example losses leading to permanent activation of the beam lines with dose rates in the mSv/h range have been considered. This is several orders of magnitude larger than the dose rates currently measured around the beam lines at the beginning of the shutdown periods. In general it is unlikely that radiological protection will be an issue for the transfer line. The ISOLDE beam dumps however are clearly underspecified for 2 GeV. These beam dumps should anyway be replaced or upgraded for the increase of the proton beam intensities that are foreseen with CERN's new injector linac (Linac4). The design of new beam dumps and the adaptation of the ISOLDE front ends to the higher beam power are included in the HIE-ISOLDE design study. Beam diagnostics and beam intercepting devices in the transfer line have been considered as well. In general there is little concern with beam diagnostics as they are used throughout the injector chain and can withstand the beam power and radiation damage in other beam lines and accelerators. The ISOLDE beam stopper is a weak point as it was designed for a lower beam power and is not water cooled. This device together with other beam-stoppers in the injector chain will be upgraded as part of the LHC Injector Upgrade (LIU) project.

CONCLUSION

There is a strong request from the ISOLDE physics community to take advantage of 2 GeV proton beams from an upgraded Booster. The feasibility of an upgrade of the beam transfer line from the Booster to ISOLDE has been shown and an upgrade scenario been developed. Modifications to be done to the ISOLDE facility itself (e.g. target area) remain to be addressed in the frame of the HIE ISOLDE project.

REFERENCES

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