MULTIPARTICLE BEAM DYNAMICS SIMULATIONS FOR THE ESS-BILBAO SUPERCONDUCTING PROTON ACCELERATOR*

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Abstract

The paper reports on the first multi-particle simulations for the proton linear accelerator as proposed by the European Spallation Source-Bilbao. The new machine concept which complies with recommendations made at the ESS-Bilbao Worksop on "MW-Spallation Sources: Current Challenges and Future Prospects" held at Bilbao on March 16-18, 2009 profits from advances registered within the field of high power accelerators during the last decade. The design of such a new accelerator layout heavily relies upon the use of low-to-medium β superconducting spoke resonators and a high-β elliptical cavity section, both of which are already under development.

INTRODUCTION

The present contribution describes first multi-particle simulations on a revised layout for the proton linear accelerator proposed as a driver for the European Neutron Spallation Source (ESS). A recent workshop held at Bilbao (Spain)[1] has resulted in a thorough revision of the machine concept as described in the ESFRI fiche[2] and has arrived to an agreement between machine scientists and the final users of neutron beam lines[3] concerning the general *linac* parameters which are summarised in Table 1. The full reports and recommendations from the various working groups are also available at the source just referred to.

Table 1: General *linac* Parameters

Parameter	Value
Ion Species	H^+
Beam Power	5 MW
Repetition Rate	20 Hz
Beam Pulse Length	1.5 ms
Beam Energy	2.2 GeV
RF Frequency(Front end /High energy)	352.2 MHz / 704.4 MHz
Maximum peak power per cavity	1.2 MW
Cavity Gradient(@β=1)	15 MV/m
Average pulse current	75 mA – 100 mA
Warm-cold transition energy	40 – 50 MeV

Compared to previous specifications (5 MW|1.4 GeV|150 mA|16.7 Hz), the current parameter set proposes a stepwise increment of the proton current starting at 70 mA which has been decreased from the original proposal of 150 mA in order to simplify the *linac* design as well as to increase its reliability enabling the use of larger acceleration gradients. Apart from that, the final energy has been increased up to 2.2 GeV, keeping the footprint of the accelerator the same, the pulse length has been decreased down to a maximum of 1.5 milliseconds to ease the demands on beam physics as well as due to requirements from the neutron community, and the repetition rate has been increased to 20 Hz. The later modification enables to keep the average pulse current low and also serves to avoid possible problems related to operation at 1/3 of the grid power frequency. Finally, and for the users point of view, the pulse and repetition rate also suffice all their requirements.

High proton current at low energy is deemed to be one of the most severe bottlenecks limiting the transport of a useful beam into a radio-frequency quadrupole. The quote of 75 mA is taken as a first working limit within which space charge forces within the beam can be handled by means of well tested procedures.

The tentative *linac* parameters given above are consistent with SRF technology available today or that is expected to be in a 2 to 3 year period. No fundamental issue was identified even if there is still a large amount of work that remains to be done toward the engineering of various components.

The design of such a new accelerator layout will be critically dependent upon the development and/or adaptation of low β superconducting cavities already developed for some ongoing projects into those adequate for pulsed operation and high duty cycle. The current paper elaborates on concepts previously discussed[4, 5]. We here present the first multi-particle *linac* simulations that fulfil the recommended parameters during the mentioned workshop[1]. This new machine concept aims to incorporate advances which have been registered within the field of high power accelerators during the last decade, and particular synergies have become evident concerning efforts being carried out to provide a higher brightness injector for LHC at CERN within the LINAC4/SPL project.

BEAM DYNAMICS

Our current design profits from the considerable progress in the development of superconducting (sc) cavities for both low-to-medium and high β regimes—already in development towards IFMIF, EURISOL, EUROTRANS and SPIRAL2 projects. ESS-B current design considers a transition into a sc section composed by low β_g = 0.35 double-spoke

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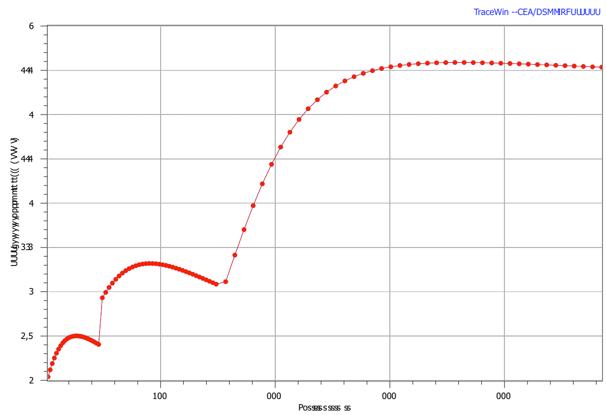

Figure 1: Voltage gain per meter along the sc Section: DSR ($\beta_g = 0.35$), TSR ($\beta_g = 0.59$) and ELL ($\beta_g = 0.87$).

cavities (DSR) after reaching an acceleration within the normal conducting *linac* of 50 MeV, followed by a set of triple-spoke cavities (TSR) with $\beta_g = 0.59$ which have and incoming beam of 150 MeV. After that a $\beta_g = 0.87$ elliptical cavity (ELL) section will accelerate the beam between 450 MeV and 2.2 GeV. Figure 1 shows the energy gain per length unit for such an arrangement. For more details, please follow our previous work [5].

The first multiple-particle beam dynamics for the ESS-B *linac* has been studied (see Figures 2 and 3) using the TRACEWIN code developed at CEA Saclay [6]. For doing so, a smoothed LINAC4 RFQ layout version and its correspondent initial particle distribution have been used. This initial distribution has been slightly modified moving from the nominal 64 mA to 75 mA as average pulse current in order to fulfil the requirements. The H^+ beam transport has been simulated from the exit of the RFQ to the end of the ELL cavity section. All the cavities have been simulated both with one gap approximation and with their computed EM field maps. On the other hand, the implicated quadrupoles have been characterised by their gradient/length instead of using the more refined multipole field map. From the simulation results based on these assumptions (illustrated on Figures 2 and 3), it can be reasonably deduced that the beam can be transported and accelerated to the required parameters using the proposed accelerator design.

CONCLUSIONS & FUTURE WORK

Once first ESS multi-particle simulations have been presented, it is necessary to refine the presented design in order to avoid parametric resonances, as well as to make sure that the phase advance per meter is sufficiently smooth, in order to ensure we can safety host future upgrades to handle ~100 mA beams (silhi[7] proton source has already been proven to be reliable for such a purpose).

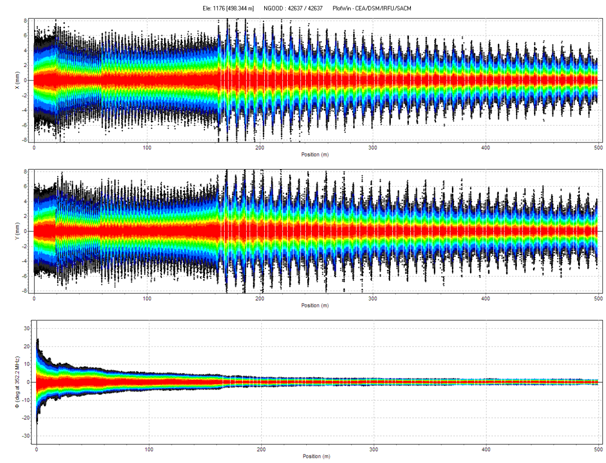

Figure 2: Multiple-particle simulation for the proposed *linac* design.

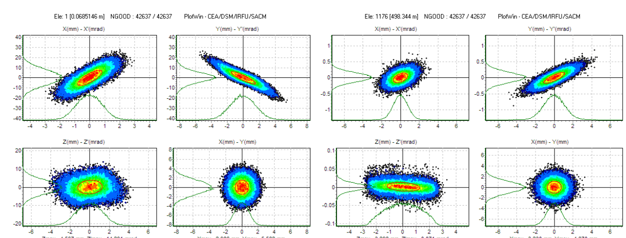

Figure 3: Proton beam at RFQ entrance (LEFT), and ELL exit (RIGHT) in the phase spaces.

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