LAYOUT OF THE ESS LINAC

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Abstract

The basic configuration of the European Spallation Source, ESS, linac has remained fixed since some time concerning, e.g., the type of accelerating cavities to be used. Details are still evolving, and changes during the last year have been influenced by factors like the geometry of the cryomodules, the maximum gradient in the cavities and the choice of phase advance in the superconducting linac. Top-level linac parameters have been decided upon and are under formal change control. Lattice parameters exist in preliminary form with the partners in the Accelerator Design Update Collaboration, and integration into a single end-to-end lattice is foreseen for the autumn of this year. The present paper describes the basic layout of the linac.

INTRODUCTION

The ESS linac [1] will accelerate 50 mA of protons to 2.5 GeV in 2.86 ms long pulses at a repetition rate of 14 Hz. This produces a beam with 5 MW average power and 125 MW peak power. Compared to the previous ESS design from 2003/2004 [2], this represents an increased beam energy, reflecting advances in superconducting RF and removal of the accumulator ring, while the current is decreased in order to ease the requirements on the linac front-end, reduce space-charge effects in the beam and provide headroom for future upgrades, keeping the 5 MW average power. Another major difference is the choice of protons rather than H^-, which again is as a consequence of the removal of the ring. Some of the top-level parameters [3] are listed in Table 1.

normal-conducting linac, France (IPN Orsay and CEA Saclay) for spoke resonators and elliptical cavities, Denmark (ISA, Århus) for the HEBT and warm magnets, Spain for infrastructure and services (Tekniker, Bilbao), Uppsala University for RF and Saclay and Bilbao for management

Table 1: Selected Top-level Parameters

Parameter	Unit	Value
Average beam power	MW	5
Proton kinetic energy	GeV	2.5
Average macro-pulse current	mA	50
Macro-pulse length	ms	2.86
Pulse repetition rate	Hz	14
Maximum cavity surface field	MV/m	40
Maximum linac length	m	392

The goal of the linac design is to achieve the parameters listed in Table 1, but a large number of other requirements, wishes and constraints also have to be taken into account. These include, just to mention a few, the cost, footprint at the site, energy consumption and operations costs, radio-protection and activation issues, reliability and upgradability. An interesting question at the beginning of a large project like ESS is also how to find the right balance between conservativeness and risk in the design. A conservative approach with substantial safety margins in all critical parameters should ensure a more smooth progress towards the goal of producing neutrons before the end of this decade, but it will increase the cost and possibly decrease the performance. A more offensive
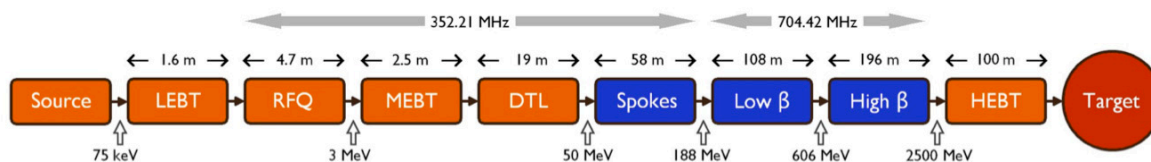

Figure 1: Schematic layout of the ESS linac, where dimensions and intermediate energies are those from the hybrid layout of ref [4]. Blue colour represent superconducting sections.

The linac will consist of the proton source, a magnetic LEBT, an RFQ, a MEBT, a DTL, a section of spoke resonators, sections of low-beta and high-beta elliptical cavities and the HEBT which includes room for an energy upgrade. The linac design is being thoroughly updated with respect to the 2004 version, and this work is performed within the Accelerator Design Update (ADU) Collaboration. This will result in a Technical Design Report at the end of 2012. Partners in this collaboration are, in addition to ESS in Lund, Italy (INFN) for the

strategy, relying for instance on continued advances within the field of superconducting RF or at least exploitation of the most recent progress to date, has the potential of a better cost-to-performance ratio.

LINAC SECTIONS

The design of the normal-conducting linac, with ion source, LEBT, RFQ, MEBT and DTL will be the responsibility of the Italian collaboration partners, although the RFQ to a large extent will be designed in

Saclay and the MEBT in Bilbao. The RFQ will be able to accelerate up to 100 mA of protons from the ion-source voltage of 75 kV to 3 MeV. Beam-dynamics calculations have been made assuming a 4D waterbag distribution with a normalized RMS emittance of 0.25 π mm mrad [5]. They show a transmission of nearly 99% at 100 mA and very close to 100% at 50 or 75 mA without transverse emittance increase. The RFQ and the DTL, as well as the superconducting spoke resonators, operate at a frequency of 352.21 MHz

There will be a chopper in the LEBT or in the MEBT, or possibly in both locations, to define the time structure of the beam. A rise and fall time in the range 0.1–1 μs is envisaged. The MEBT will also contain collimators with the purpose of reducing beam losses further down in the linac and in order to produce a more well defined beam distribution that more easily can be compared with simulations.

The design of the drift-tube linac, made in Legnaro, will be based on the design of Linac4 at CERN. Like Linac4 it will consist of three tanks, and it will accelerate the protons from 3 to 50 MeV.

After the DTL, a transition is made to superconducting accelerating structures. The first superconducting section uses spoke resonators designed in Orsay, still at 352.21 MHz. Although spoke resonators have not yet been used for acceleration of particles, they have the large acceptance and individual tunability of superconducting cavities combined with attractive mechanical properties such as a large inherent stiffness. The most recent optimizations of the linac layout [4], based on the so-called hybrid cryomodules (see below), favour double-spoke cavities with optimum betas of 0.50 and cryomodules containing two double-spoke cavities each. These cryomodules have one quadrupole magnet at each end and are separated by 500 mm long utility modules. With 14 cryomodules over 58 m length, the spoke section accelerates the protons to 188 MeV.

The remaining part of the linac uses elliptical 5-cell cavities in two families, designed in Saclay, with geometric betas equal to 0.70 and 0.90. There is also a frequency jump to 704.42 MHz for the elliptical cavities. The same optimization of the linac layout gives low-beta cryomodules with 4 cavities. With 16 cryomodules separated by the same utility modules, the length of the low-beta section becomes 108 m and the particles reach 606 MeV.

More than 75% of the energy gain is finally obtained in the high-beta elliptical section. Here 15 cryomodules with 8 cavities each and again the utility modules in between occupy 196 m of length. Also the cryomodules of the elliptical section are foreseen to have one quadrupole at each end. Fig. 2, from ref [6], shows the RMS beam sizes in the three planes. As concluded there, beam-dynamics simulations show that the transverse acceptance of the superconducting linac is an order of magnitude larger than the RMS emittance of the beam in an ideal linac, and also substantially larger than the envelope given by the outermost particles. Longitudinally, the acceptance is two
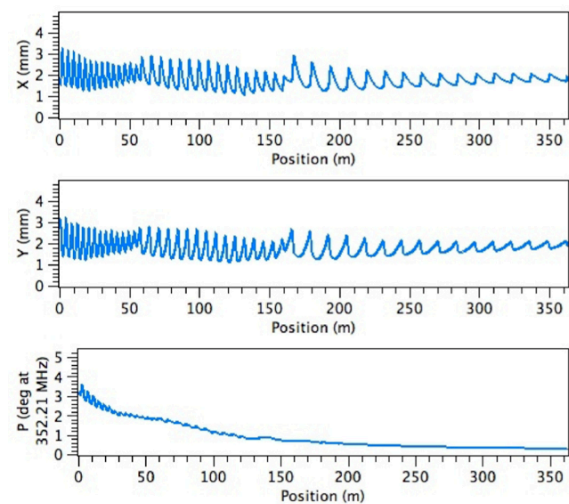

Figure 2: RMS beam size through the superconducting linac in the three planes, from [6].

orders of magnitude larger than the RMS emittance. Error studies investigating the emittance increase as a function of misalignments, RF phase and amplitude deviations, etc., are ongoing.

The linac will be powered by one klystron per superconducting cavity plus one for the RFQ, one for the first DTL tank and two each for the subsequent two tanks. The power sources will be chosen so that the linac is gradient-limited rather than power-limited at 50 mA of (peak) beam current [4], but not with a very large margin, so the beam current cannot be substantially upgraded without upgrading also the power sources (or, in the high-beta section, reducing the accelerating voltage).

Adding the different accelerating sections plus 2.5 m for the ion source, a linac length of 392 m from the source to the end of the high-beta section is obtained. The linac tunnel then will extend another 100 m before the beam line is split into one path continuing straight forward to a tune-up beam dump and another path bending upwards to the surface and the target station. This HEBT is reserved for future upgrades of beam power. According to the previous paragraph, not only an energy upgrade but also a current upgrade require additional acceleration cavities unless all the rf power sources are changed and the rating of the power couplers are increased beyond the currently specified 900 kW. Strategies for power upgrades are discussed in [7].

The choice of a rotating spallation target for ESS, made from tungsten and cooled by helium gas, was made only a few months ago. The exact requirements on the size and intensity distribution of the beam on the target have not yet been analyzed in detail, and the power dissipation and distribution on the proton-beam window (separating the linac vacuum from the target atmosphere) are also important parameters. An example of a flattened beam distribution on the target obtained using just two octupole magnets in addition to quadrupoles in shown in ref [8]. The design of the beam flattening and the HEBT as a whole is being elaborated by the Århus group [9, 10].

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HYBRID CRYOMODULES

Superconducting linacs are traditionally built with either continuous or segmented cryostats. In the continuous design, a long sequence of cryomodules form a single cryogenic unit with integrated cryogenic distribution lines. An example is the XFEL linac. Segmented cryomodules are independent cryostats having their own insulation vacuum. They require an external cryogenic distribution line with jumper connections to each single module. An example of a segmented design is the SNS cryomodule.

A continuous cryostat has the advantage of a lower static heat load on the cryogenic plant, reducing energy consumption and operational costs, which are important issues for ESS. A segmented linac has a higher heat load, both from the end plates of the cryostats, where thermal insulation may have to be simpler than optimal for reasons of available space, and radiation directly from the part of the beam pipe which is at room temperature. On the other hand, the segmented design has the obvious advantage of better serviceability, since individual cryomodules can be valved off, warmed to room temperature and repaired or exchanged. For ESS, a further major advantage of a segmented design would be the possibility to put beam instrumentation [11] in the warm spaces between cryomodules. Beam instrumentation is more challenging for a proton linac like ESS than for an H^- linac, and, for instance, the development of beam-profile monitors that operate efficiently at 2 K would require a significant R&D effort.

ESS is considering a hybrid between the two designs, where the cryomodules are built as separate cryostats, but where the space between the cryostats is enclosed by an interconnecting sleeve cooled to an intermediate temperature such as the 70 K of the outer thermal screen of the cryostats. Hereby, the heat load is reduced compared to the completely segmented design, and this holds true even if some of the intermediate sections are left at room temperature because of requirement from, e.g., beam instrumentation. However, this hybrid scheme is mechanically more complex, and it remains to be evaluated whether its advantages outweigh the increased complexity.

Figure 3: Schematic of hybrid cryomodule with one cold gap to the left and one warm gap to the right.

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