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STATUS AND PLANS OF THE SPL STUDY AT CERN

R. Garoby (for the SPL Study Team)

Abstract

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Status and Plans of the SPL Study at CERN

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Abstract. The study of the SPL (Superconducting Proton Linac), a 4 MW / 2.2 GeV H^- linac, began at CERN in 1999. Based on the large inventory of RF equipment decommissioned from the LEP (Large Electron Positron collider), it was originally proposed as an upgrade to the injector complex for the high energy accelerators. Since that time, the proposal has attracted the interest of an increasing number of physics communities and the design has evolved in consequence. The present design of the SPL is presented in this paper, together with a proposal for a staged realization.

INTRODUCTION

The SPL [1,2] was first proposed as a way of profiting from the decommissioned LEP RF equipment, to upgrade the characteristics of the beam delivered by the CERN complex of proton accelerators at low cost. The SPL would then replace the 50 MeV proton linac (linac 2) and the 1.4 GeV PS Booster, and inject directly into the PS. Moreover, thanks to the high flux of protons potentially available from such a superconducting linac, other users could easily be accommodated. For a second generation ISOLDE-like facility [3], the SPL beam is directly usable. For neutrino physics (first a “Neutrino super-beam” facility [4] and ultimately a “Neutrino Factory” [5]), accumulator and bunch compression rings have to be added. The design of the accelerator set-up has consequently evolved.

SPL DESIGN

The proton driver of a neutrino factory is the most demanding application for the SPL [5]. For this, a 150 m radius storage ring is used to accumulate the

linac beam. After accumulation, a $3\text{ }\mu\text{s}$ beam burst of 2.27×10^{14} protons is sent to a bunch compression ring before being delivered onto the pion production target. The resulting requirements for the SPL are shown in Table 1, and its overall layout is sketched in Figure 1.

TABLE 1. Main SPL characteristics		
Accelerated ions	H^-	
Kinetic energy	2.2	GeV
Mean beam power	4	MW
Repetition rate	50	Hz
Pulse duration	2.8	ms
Mean current during the pulse	13	mA
Number of H^- per pulse	2.27×10^{14}	
Bunch frequency	352.2	MHz
Chopping duty cycle	61.6	%
Bunch pattern (nb. of bunches / nb. of buckets)	5/8	
Norm. r.m.s. transverse emittances	0.4	π mm mrad
Longitudinal r.m.s. emittance	0.3	π deg MeV

FIGURE 1. SPL synoptic

Room temperature accelerating structures are used in the first 69 m of the linac (120 MeV kinetic energy). Above this energy and for most of the length of the accelerator, superconducting structures are employed. The parameters of the sections are detailed in Table 2.

Section	Final Energy (MeV)	Nb. of cavities	Peak RF Power (MW)	Klystrons	Te-trodes	Length (m)
Source	0.045					1
RFQ	3	1	0.5	1		2.4
Chopper	3	3	0.06		3	3.6
DTL	120	13	11.8	15		62
$\beta=0.52$	236	42	1.5		42	101
$\beta=0.7$	383	32	1.9		32	80
$\beta=0.8$	1111	52	9.5	13		166
$\beta=0.8$	2235	76	14.6	19		237
Debunch.	2235	4		1		13
Total		223	39.9	49	77	666

RFQ and Chopping line

The RFQ will be of the four-vane type, and its precise design is now expected to benefit from the development of the IPHI device actually in construction for the CEA and IN2P3 [6].

The proposed SPL chopper structure consists of a pair of deflecting plates with a meander delay-line printed on alumina (Fig. 2), without separating ridges [7]. Attenuation and dispersion measured on prototypes are in good agreement with computation. The printed meander on alumina has very good vacuum properties, easy implementation and good radiation resistance and heat transfer (water cooled metal ground plane). The high permittivity (ϵ) of the ceramic permits a meander width below 25 mm for particle velocity of $\beta=0.08$, and gives the possibility to install the deflectors inside quadrupoles. The 100 Ω characteristic impedance helps reduce the driver power. A prototype 500 V chopper pulse amplifier has been realised, and tests are in progress [8].

The chopper line is composed of two 1 m long double FODO sections, for transverse matching between a fast phase advance in the accelerators and a slow one in the chopper, plus a 1.6 m long FODO period in between. The latter houses the chopper inside the quadrupoles and provides the 90° phase advance at the dump placed at its end, needed for the separation of chopped and unchopped beam.

A test of the chopping line using a 3 MeV segment of the 352 MHz IPHI RFQ, presently being assembled, is in preparation with CEA and CNRS-IN2P3 (France).

FIGURE 2. Chopper prototype: double 100 Ω meander-line on ceramic substrate

By subsequently adding the second RFQ segment, acceleration will proceed up to 5 MeV. Beam tests up to 100 mA are foreseen, in pulsed mode with chopping and in CW without chopping. Beam measurements are planned to fully characterise chopping efficiency and halo development. The test stand will be located at CEA-Saclay.

Drift Tube Linac

The DTL section is based on a conventional Alvarez structure up to 40 MeV. From this energy, the focusing period is increased, keeping the longitudinal phase advance below 65° to avoid emittance exchange. A Cell-Coupled DTL design (CCDTL [9]) at 352 MHz is adopted, characterised by identical coupling cells. A 12-cell cold model (Fig. 3) has been realised and tested.

FIGURE 3. 3D drawing of a fraction of the CCDTL cold model

The advantages of this structure are easy access and alignment for the quadrupoles, low construction cost, stable $\pi/2$ mode operation, continuous focusing lattice, and simple RF distribution with one klystron per tank. However, at this relatively low frequency, the real-estate shunt impedance of the CCDTL remains similar to that of a conventional DTL.

Superconducting Linac

The superconducting part of the SPL begins at 120 MeV kinetic energy. Up to 383 MeV, multi-cell cavities optimised for $\beta=0.52, 0.7$ are used. To ease stabilization of the field in the cavities and minimize the energy fluctuation of the beam, each cavity is driven by its own tetrode amplifier. Above 383 MeV, $\beta=0.8$ 5-cell cavities are used. Unmodified LEP cavities are no longer employed, even at the highest energy. The additional cost is compensated by the higher accelerating gradient and transit time factor of the new cavities which allow to reduce the linac length. Housed in LEP cryostats, these 5-cell $\beta=0.8$ cavities are prepared at minimal cost. Four of them are driven by a single LEP klystron.

The beam dynamics design of the SC section is optimised for minimum emittance exchange, maximum stability against mismatch and simplified layout for minimum cost [9]. The length of the focusing periods, each containing a quadrupole doublet of 120 mm aperture diameter, increases along the linac to a maximum of eight cavities (two cryostats) per period above 1.1 GeV. This corresponds to 13 to 21 $\beta\lambda$ per period and keeps the maximum longitudinal phase advance below 65° . The relatively low longitudinal phase advance allows the full current tune ratio (σ_z/σ_x) to be kept below 0.8 thus avoiding emittance exchange between the longitudinal and the transverse planes [10]. At the same time, the maximum transverse phase advance can be held below 85° to avoid particle lattice instabilities. A smooth phase advance per meter in both planes ensures a minimum mismatch in the transition areas between sections, which are matched with existing beam line elements. Mismatch simulations with 50 M particles show only moderate emittance growth even for strong initial mismatch (30 % radial) [9].

A recent study having underlined the difficulty to properly control 4 cavities simultaneously [11], high power phase and amplitude modulators are now felt to be necessary to stabilize the field in each of the $\beta=0.8$ cavities individually (specifications in Table 3). The ferrite loaded waveguides and their external bias system are the only components that must be bought (Figure 4). Prototypes have been ordered and the first experimental results are expected by the end of 2002.

TABLE 3. Modulators specifications	
RF frequency	352.2 MHz
Peak power	350 kW
Phase modulation depth	± 25 degrees
Amplitude modulation depth	± 10 %
Rise-time (10 – 90 %)	1 ms

Phase /Amplitude Modulator Type B

FIGURE 4. Phase/Amplitude modulator

STAGED REALISATION

A staged realisation is necessary to comply with the limited resources available at CERN during the construction of the LHC. Effort is concentrated on the low energy part of the machine (up to a few MeV) in close collaboration with the CEA and IN2P3 [6]. In a second stage, the realisation of the 120 MeV room temperature front-end is envisaged as an improved injector for the PSB.

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