FEASIBILITY STUDY OF A 2 GEV SUPERCONDUCTING H^- LINAC AS INJECTOR FOR THE CERN PS

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Abstract

This preliminary feasibility study is based on the availability of the CERN LEP2 superconducting RF system after LEP de-commissioning. The option that is explored is to use this system as part of a high energy H^- linac injecting at 2 GeV into the CERN PS, with the aim of reliably providing at its output twice the presently foreseen transverse beam brightness at the ultimate intensity envisaged for LHC. This requires the linac to be pulsed at the PS repetition rate of 0.8 Hz with a mean beam current of 10 mA which is sufficient for filling the PS in 240 µs (i.e. about 100 turns) with the ultimate intensity foreseen for injection for the LHC.

The linac is composed of two RFQs with a chopping section, a room temperature DTL, a superconducting section with reduced beta cavities up to 1 GeV, and a section of LEP2 cavities up to 2 GeV. This study deals, in particular, with the problems inherent in H^- acceleration up to high energy and in the pulsed operation of SC cavities. Means for compensating microphonic vibrations in the SC cavities are considered, with the aim of reducing the final overall energy spread to the tight requirements for injection into a synchrotron. Other possible applications of such a machine are also briefly reviewed, that make use of its potential for working at a higher duty cycle than required for LHC alone.

1 INTRODUCTION

Most of the RF equipment of the CERN LEP-2 will be available after the year 2000. Among the possible re-uses of this valuable hardware [1-4] the realisation of a 2 GeV Linac injector for the PS is an attractive option with many benefits with respect to the present scheme for LHC injection [5].

As a result of the smaller emittance of the Linac beam and of the higher injection energy into the PS (at present 1.4 GeV), the LHC would profit from an increased brightness of the proton beam delivered by the PS injector complex. The peak beam intensity in the PS could be improved as well by filling the entire aperture. Beam losses would be reduced by the efficient charge exchange injection in the transverse planes, and by the chopped beam in the longitudinal phase plane. The injectors of the PS could be modernised and re-built with standardised equipment, with advantages in terms of reliability and maintenance.

Other potential applications of this facility at a higher duty cycle justify the use of SC cavities. They include: 1) neutron production with a spallation target, using the PS as an accumulator ring; 2) feeding a second generation ISOL facility for the production of radioactive ion beams; and 3) any physics application requiring intense secondary beams.

A small study group has concentrated on the main accelerator technology topics and on the most promising scenario. A first report indicating the feasibility of such a facility is being prepared [6].

2 PARAMETERS AND LAYOUT

The Superconducting Proton Linac, SPL, (Figure 1) is made of an H^- source, two RFQs with a chopper in between, a Drift Tube Linac up to 100 MeV and a superconducting section up to 2 GeV. The main design parameters are given in Tables 1 and 2.

Table 1: Linac Beam Parameters

Number of Particles / PS Pulse	1.5	10^{13}
Mean Linac Current during Pulse	10	mA
Pulse Length	250	µs
Repetition Rate	0.83	Hz
Filling Factor of Linac Buckets	½	
N. of Linac Bunches per PS Bucket	11	
SPL Micropulse (11 bunches)	59.6	ns
Chopping Factor	46	%
Mean Bunch Current (in an RF period, for a full bucket)	37	mA
Source Current	20	mA
Beam Duty Cycle (for PS filling)	0.021	%
Maximum Design Duty Cycle	5	%
Maximum Average Current	500	µA
Transverse Emittance, source exit, rms	0.2	µm
Transverse Emittance, PS input, rms	0.6	µm
Longitudinal Emittance (5 rms)	3	°MeV

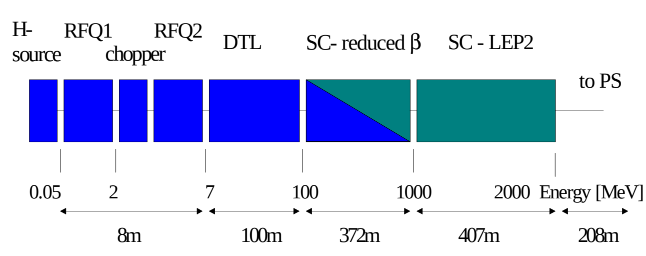

Figure 1: Schematic layout of the Linac.

Table 2: Linac structure parameters.

	W_{out} [MeV]	Freq. [MHz]	#of cav.	Power [MW]	# of klyst	Length [m]
RFQ1	2	176.1	1	0.45	-	2.3
RFQ2	7	352.2	1	0.5	1	4
DTL	100	352.2	29	5.8	6	99
SC - red. β	1027	352.2	152	13	19	372
SC - LEP2	2000	352.2	136	14.2	17	407
Line	2000	352.2	1	-	-	208
Total					43	1094

The facility is designed to provide 1.4 10^{13} particles at the exit of the PS, corresponding to the LHC beam-beam limit ("ultimate beam"). For a mean linac current of 10 mA, this number of particles can be obtained by injecting 110 turns into the PS, with a linac pulse length of ~250 μs. For the PS repetition period of 1.2 sec, the resulting linac beam duty cycle is only 0.021%. The injection energy into the PS, 2 GeV, has been chosen to use most of the existing LEP equipment, to improve transverse beam stability in the PS and to profit from the high accelerating efficiency of the LEP cavities at high energies.

The LEP RF frequency of 352.2 MHz is also used for most of the room temperature section. A significant number of klystrons with their power distribution systems can therefore be recovered, and a standard RF system can be used throughout the linac.

Due to the low duty cycle, the SC cavities need to be pulsed to minimise heat dissipation and wall plug power. The linac is foreseen for a beam duty cycle of 5%: up to this value the cryogenic system is dimensioned mainly to handle static losses and RF pulsing has no impact on the cryoplant. The main additional investment for this duty cycle comes from the shielding needed to cope with the higher activation due to losses in the linac.

The relative particle loss at 2 GeV and 5% duty must be smaller than 10^{-6}/m to allow hands-on maintenance; this is not a strong design constraint as a large fraction of the halo particles are transported through the large aperture of the SC cavities (>20 cm) and can be properly removed before PS injection.

An important design constraint is the high beam brightness needed by the LHC: this requires an emittance of 0.2 μm from the source because a factor 3 blow-up between the source and the PS has been conservatively assumed to account for space-charge, mismatch, and misalignment effects.

3 ROOM TEMPERATURE SECTION

The room temperature section is composed of a front-end (source, RFQs, chopper) injecting into a Drift Tube Linac (DTL). The 20 mA beam coming from the source is accelerated to 2 MeV by a 176.1 MHz RFQ. The beam is then chopped and injected, filling every other bucket, into an RFQ at double frequency (352.2 MHz), which brings the beam energy to 7 MeV. Matching to and from the chopper is performed by dedicated sections integrated in the first and second RFQ respectively.

A distance of 1.6 m is provided between the RFQs to house a wide-band electrostatic chopper of the BNL design [7] and some diagnostics. The chopper voltage required is 1.7 kV, and, to avoid partially filled buckets in the Linac, a 4.2 ns rise time is required: should it be too challenging, a chopper/antichopper line will be chosen.

The DTL has been divided in two sections. The first one (7-20 MeV) consists of one standard Alvarez tank, with FODO focusing. The second, up to 100 MeV, is of the separated-focusing DTL type, made of 28 8-cell tanks separated by 3 βλ drifts containing a quadrupole triplet. This structure offers higher shunt impedance and simpler mechanical construction than a standard DTL. Triplet focusing is preferred because of the resulting round beam inside the tank, which minimises the emittance growth due to RF defocusing. The transmission of the room temperature part is 99% (without taking into account stripping losses after the source) and the transverse emittance increase is 10%.

4 SUPERCONDUCTING SECTION

The superconducting part of the Linac consists of four different sections, with cavities optimised for beta 0.48, 0.6, 0.8 and 1. LEP-2 standard cavities (β=1) and cryostats are used between 1 and 2 GeV, while 5-cell cavities optimised for β=0.8 would be built and installed in the existing LEP-2 cryostats to cover the energy range between 450 MeV and 1 GeV [3]. Two additional sections of 4-cell cavities optimised for β=0.48 and β=0.625, arranged in shorter cryostats, cover the energy range between 100 MeV and 200 MeV, and between 200 and 450 MeV respectively. A development program is underway at CERN for the production of reduced-β (β=0.5 to 0.8) cavities with the niobium on copper technique [8]. In case the sputtering is not be feasible, the lowest beta cavities would be made of bulk niobium and the DTL energy increased up to 150 MeV. The layout of the superconducting part is given in Table 3.

Table 3: Layout of the superconducting section.

Sec.	Cryo stats	klyst rons	Cavi ties	cells / cav.	output energy [MeV]	length [m]	RF power [MW]
1	8	4	32	4	191	58	1.3
2	14	7	56	4	452	126	3.7
3	16	8	64	5	1027	188	8.0
4	34	17	136	4	2041	407	14.2
tot.	72	36	288			779	27.2

This layout makes use of 34 LEP2 4-cavity modules with their cryostats, i.e. 53% of the 68 installed in LEP. Including the cryostats used for the β=0.8 cavities, only 50 cryostats would be re-used, leaving some margin for reaching a higher linac energy if needed.

Due to the pulsed mode of operation, static cryogenic losses will dominate. Assuming a static loss of 180 W per 4-cavity module as in LEP [9], the 72 cryostats of the SPL would have an overall static loss of 13 kW, i.e. slightly more than the cooling capacity of a LEP-type cryoplant (12 kW).

The mean field used in this design is 6 MV/m although operation at a higher gradient should be possible in pulsed mode. The focusing for the superconducting section is provided by a doublet (two 400-mm long quadrupoles spaced by 100 mm) placed outside each cryostat. It has so far been optimised for zero current. For 40 mA the emittance increase is 45%, coming from the long focusing period at low (<1 GeV) energy and from mismatches between the different sections. A new layout for the low energy part and a more accurate matching should reduce the emittance blow-up.

5 ENERGY STABILITY

Mechanical vibrations in the SC cavities change their resonant frequency, leading to oscillations of the bunch in the longitudinal phase plane and finally to a pulse-to-pulse jitter in the mean bunch output energy. The effect of the vibrations can be greatly reduced by a self-excited loop and an RF feedback of the cavity voltage. For the SPL, a feedback scheme and calculation tools originally developed for the TESLA project [10] have been adapted for a proton beam. Since the correction is applied at the klystron input, the beam motion cannot be compensated completely when the klystron feeds several cavities as is the case in the SPL (8 cavities per klystron). In the simulations, the gains of the regulation loops are set to 100 and 500 respectively for the amplitude and for the phase. 20 % extra power is required for the amplitude loop and 20% for the phase loop.

The effect of the Lorentz detuning at 6 MV/m field is very small: the cavity phase can be cancelled by the feedback loops when the beam is injected, and the corresponding peak-to-peak energy error at 2 GeV is only 0.006 MeV.

The effect of mechanical vibrations has been studied assuming a pessimistic maximum cavity-to-cavity variation in resonant frequency of ± 40 Hz. The motions of the beam centre and the energy and phase errors at linac exit have been calculated for 500 uniform random distributions of frequency errors. The scatter in the position of the beam centre in the longitudinal plane at 2 GeV is shown in Figure 2.

Inside the single pulses, energy and phase are very stable (the period of the mechanical vibrations is much longer than the pulse length), while from pulse to pulse the rms energy variation is 0.3% (6 MeV). The energy jitter can be reduced to ± 3 MeV (total), by an energy-correcting cavity placed 200 m downstream, resulting in a good match to the PS bucket.

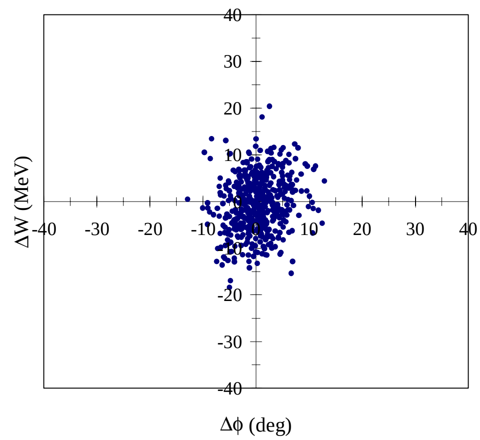

Figure 2: Relative position of the bunch centre in the longitudinal plane at 2 GeV for 500 random error distributions.

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