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A SLOW-CYCLING PROTON DRIVER FOR A NEUTRINO FACTORY

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Abstract

An 8 Hz proton driver for a neutrino factory of 4 MW beam power and an energy of 25-30 GeV is under study at CERN, in parallel with a similar investigation using a 2.2 GeV high-energy linac and an accumulator plus a compressor ring cycling at 75 Hz. At RAL, synchrotron drivers with final energies of 5 and 15 GeV cycling at 50 and 25 Hz, respectively, are being studied. With these four scenarios, one hopes to cope with all possible constraints emerging from the studies of the pion production target and the muon rotation and cooling system. The high beam energy of this scenario requires less proton current and could inject into the SPS above transition and upgrade LHC and fixed target physics. Its 440 kW booster would upgrade ISOLDE.

The main problems of the driver synchrotron are: the requirement of about 4 MV RF voltage at 10 MHz for acceleration and adiabatic bunch compression to the required r.m.s length of 1 ns; the sensitivity of the compression to the impedance of the vacuum chamber and to non-linearities of the momentum compaction of the high-γ_1 lattice.

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1 OVERVIEW OF PROTON DRIVER SCENARIOS

At the NuFact'99 Workshop, a consensus was reached on the beam power on target of 4 MW, independent of proton energy. In order to produce this beam power at 5–30 GeV, the approach of having a chain of "Rapid Cycling Synchrotrons" (RCS) is generally considered to be more economic than the combination of high-energy linac plus driver synchrotrons. Injection energies into the booster not exceeding 150–180 MeV facilitate the handling of the RF capture loss, which is very difficult to suppress completely. The linac and booster are similar to those being studied for MW spallation neutron sources. The driver is comparable to synchrotrons for a hadron facility. Apart from the known problems of these high-current accelerators, one is faced with the requirement of extremely short bunch lengths of 1 ns r.m.s.

Although the CERN study concentrated on an existing 2.2 GeV Superconducting Proton Linac (SPL) design, to which an accumulator and a compressor ring were added [1], a clear mandate was issued to study the more conventional RCS alternative. This is not only in order to find the most economic scenario, but also to anticipate unforeseeable constraints on the pulse frequency, and possible errors in pion production at 2.2 GeV which may be revealed by the forthcoming HARP experiment at the CERN PS. Limits to the pulse frequency may arise from unacceptable duty factors of the pulsed RF systems in the muon acceleration chain, and from a future upgrade towards a muon collider.

The CERN linac scenario [1] would upgrade the performance of the CERN PS, thereby increasing the luminosity of LHC, and also upgrade ISOLDE. On the other hand, a synchrotron of 25-30 GeV could inject into the CERN SPS above its transition energy, substantially upgrading its performance for LHC and fixed target physics. ISOLDE would equally profit from the 440 kW beam power of the booster. In the context of the collaboration, it was agreed that RAL would undertake a site-independent study. The result is two RCS scenarios of intermediate energies and pulse rates [2]. RAL also produced the design of a 180 MeV linac, derived from the ESS study, which is common to all three RCS scenarios.

2 MAIN PARAMETERS AND LAYOUT

The proton driver consists of a 180 MeV H^- linac followed by a booster and a driver synchrotron. The latter is designed to fit into the existing ISR tunnel (R=150 m, 15 m wide). The booster and linac, as well as the debuncher section and the momentum collimation arc, are located on the inside of the driver ring. Figure1 shows the layout of the complex and the Tables 1 and 2 give the essential parameters of the synchrotrons. The linac is described in Ref. 2.

Table 1: Booster beam and machine parameters

Parameter	Unit	Value
Kinetic energy	GeV	2.2
Pulse frequency	Hz	50
Pulse intensity	p/p	2.5×10^{13}
Number of bunches		2
Circumference	m	238
No. of injected turns (56 mA)		100
RF harmonic number		2
RF frequency	MHz	1.38-2.42

RF peak voltage	MV	0.35
Space charge tune shift at inj.		-0.18

Four booster batches of two bunches each are injected at 20 ms intervals on the 60 ms flat bottom of the driver, which then accelerates over 45 ms. 15 ms remain for the fall of the magnet cycle (cf. also Fig. 2).

Table 2: Driver output and machine parameters

Parameter	Unit	Value
Mean beam power	MW	4
Kinetic energy	GeV	25-30
Pulse frequency	Hz	8.33
Pulse intensity	p/p	10^{14}
Number of bunches		8
Bunch length (1σ)	ns	1
Momentum spread (2σ)		0.008
Transv. emittances, norm. (2σ)	µm	150 π
Longitudinal emittance / bunch	eVs	2
Circumference	m	952
RF harmonic number		32
RF frequency	MHz	9.7-10.2
RF peak voltage	MV	3.8
Transition energy γ_t		40
Sp.ch. tune shift on flat bottom		-0.22

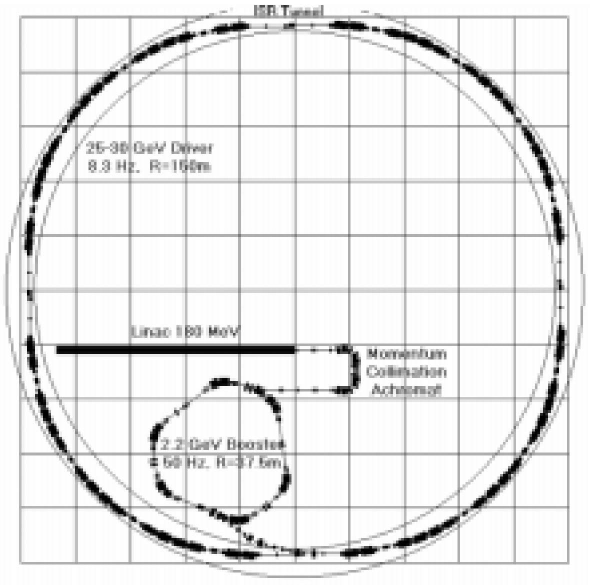

Figure 1: Layout of driver RCS in the ISR tunnel. Linac and booster RCS all fit inside. Grid size 30 m.

The peak RF voltage of 3.8 MV is delivered by ~20 RF cavities of a novel design [3]: An external mechanical tuner coupled to the cavity by 31/8" cables produces a frequency variation of ~ 4%. Each cavity (L = 2 m, r/Q = 42 Ω, Q = 5000-10000) should contribute 150-200 kV. The external tuner (mass = 1.3 kg, stroke = 10 mm) is actuated by a commercial shaker. An additional fast ferrite tuner provides the required tuning accuracy.

The 45 ms long rise fraction of the magnet cycle is constrained by the admissible acceleration peaks in the mechanical tuner and is flattened by the addition of a 2nd-harmonic component of 15% to the fundamental.

3 RF PROGRAM AND ADIABATIC BUNCH COMPRESSION IN THE DRIVER

The bunches in proton drivers of only a few GeV are subject to important space charge forces and are thus difficult to compress. Bunch rotation requires a sudden rise of high RF voltages, entailing problems with filling times that may require a separate ring as in [1]. At higher energies less space charge opposes the formation of short bunches and it is possible to approach transition to profit from naturally short bunches if the process remains quasi-adiabatic. This is not a priori evident as the synchrotron tune becomes also very small. In our case, ESME [4] simulations of the complete acceleration cycle of the driver were performed, indicating that with the RF voltage of 3.8 MV necessary for acceleration, bunches of 1 ns r.m.s. duration can be produced with a lattice of $\gamma_t \sim 40$ ($\gamma = 33$ at 30 GeV). Figure 2 shows the voltage programme and the bunch height. The latter is confined to a *dp/p* of 0.5-0.8%, even on the flat bottom, for the chosen emittance of 2 eVs, ensuring microwave stability over the whole cycle, if the dominant inductive impedance of the vacuum chamber can be limited to $Z/jn \leq 2\ \Omega$. This has been verified with ESME for a broadband resonator and a set of five narrow-band resonators at various resonance frequencies up to the pipe cut-off frequency.

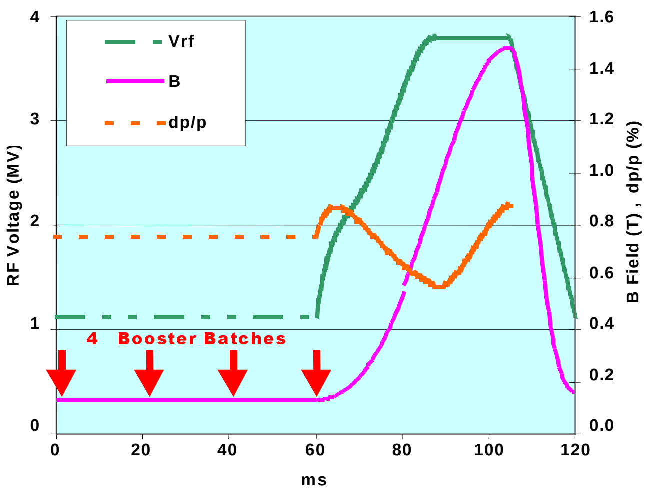

Figure 2: RF voltage programme and magnet cycle of the driver and evolution of momentum spread.

4 LATTICES

The tunnel radius of 150 m being very tight for 30 GeV, the specified high γ_t~40 is not easy to achieve in a lattice requiring long dispersion-free sections for RF, injection, extraction and collimation. A "resonant" lattice, similar to that proposed earlier for high γ_t values [5], was designed, which features reasonable beam envelopes and excellent dynamic apertures. Of superperiodicity S=4, it fits well into the ISR tunnel. More detailed investigations however revealed an unacceptable sensitivity of the momentum compaction to momentum deviations up to ±1% occurring in the driver. Also from ESME simulations, an upper bound of ±0.01 to the momentum compaction coefficient α_1 of the $(dp/p)^2$ term in the expansion, was established. Generally this condition is not met, except for a region of partial chromaticity compensation around $\xi_{x,z} \sim -6$, a value which is just acceptable. This is done with the usual two sextupole families; there are apparently no appropriate locations for a third one, allowing simultaneous compensation of both effects.

The booster lattice is a slightly stretched version of the lattice of the AUSTRON 500 kW/1.6 GeV/50 Hz RCS [6]. Its H^- injection layout uses the same momentum painting techniques as described in Ref. 5. Most results of the AUSTRON feasibility study are applicable. The ferrite-tuned 2 MHz RF cavities would be replaced by low-Q untuned Finemet cavities.

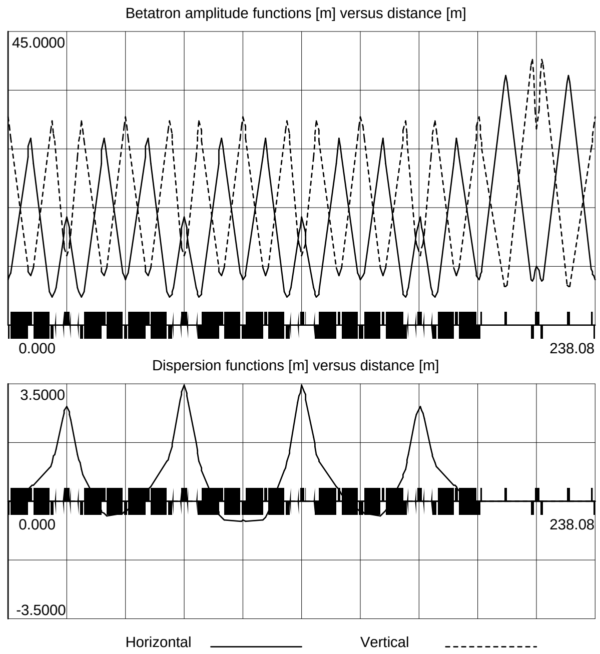

Figure 3: Lattice functions in one superperiod of the high-γ_t resonant lattice.

5 MISCELLANEOUS

5.1 Instabilities

Apart from the microwave instability, coupled-bunch longitudinal and transverse head-tail instabilities appear to be the most dangerous. The transverse resistive-wall driven growth rates are comparable to the dwell time of the booster batches on the flat bottom; the effect of the cavities on longitudinal stability remains to be assessed after a more detailed design.

5.2 Vacuum Chambers

The vacuum chambers for the booster have to be ceramic, of the type of the ISIS chambers with their wire RF shields. For the driver, the alternative DESY-type solution of a thin (0.13 mm) pipe reinforced by brazed ribs is not excluded and is being studied.

5.3 Power Converters

The main power converter for the 30 GeV machine is likely to be a cost driver. An array of IGBT converters would be preferable compared to a conventional dual-resonant converter; however at present IGBT converters are estimated to be more expensive by a factor two.

6 CONCLUSIONS

The alternative to the fast-pulsing 2.2 GeV / 4 MW proton driver, most useful for CERN, appears to be a high-energy synchrotron capable of injecting into the SPS above transition energy. For future requests of even higher proton beam power, it may complement the SPL to which its injection energy is matched. The top energy of 30 GeV may be lowered to 25 GeV in order to enable the design of a more realistic lattice.

REFERENCES

[1] R. Garoby, M. Vretenar, "Status of the Proposal for a Superconducting Proton Linac at CERN", CERN/PS 99-064 (RF).
B. Autin et al., “Design of a 2.2 GeV Accumulator-Compressor for a Neutrino Factory”, this Conference.
[2] C.R. Prior, G.H. Rees, “Synchrotron-Based Proton Drivers for a Neutrino Factory”, this Conference.
[3] W. Pirkl, Personal Communication
[4] ESME Reference: http://www-ap.fnal.gov/ESME/
[5] A. Iliev, Yu. Senichev, "Racetrack Lattices for Low-Medium-Energy Synchrotrons ", Proc. 14th PAC, San Francisco, May 1991, p.1904.
[6] P. Bryant et al., "The Accelerators for the AUSTRON Spallation Source", Proc. 4th EPAC, London, June 1995, p. 2667