

RF DESIGN OPTIONS FOR A 180 MEV H⁻ LINAC FOR MEGAWATT BEAM FACILITIES*

C. Plostinar, STFC/RAL/ASTeC, Harwell, Didcot, Oxon, UK

Abstract

Future projects like a neutrino factory or an advanced spallation neutron source require high power proton accelerators capable of producing beams in the multi-MW range. The quality of the beam delivered to the target is very much dictated by the accelerator front end and by the lower energy linac. Prompted by the Front End Test Stand (FETS) under construction at RAL, a new 180 MeV H⁻ linac is being considered as a possible replacement for the aging current 70 MeV ISIS injector, and the same linac has also been included in designs for the proton driver for a possible UK Neutrino Factory. In this paper, different RF design options are analysed and a general layout for the new linac is presented based on two accelerating structures to raise the beam energy from 3 to 180 MeV: a 324 MHz Drift Tube Linac (DTL), making use of commercial Toshiba klystrons, followed by Side Coupled Linac (SCL) with a triple frequency jump at the transition between the two structures.

HIGH POWER PROTON ACCELERATORS

The international community has been showing a growing interest in high power proton accelerators (HPPAs), capable of producing beams in the MW range. Many applications have been identified including drivers for spallation neutron sources, production of radioactive beams for nuclear physics, hybrid reactors, transmutation of nuclear waste, and neutrino factories for particle physics [1].

At Rutherford Appleton Laboratory (RAL), the development of a next generation HPPA represents a priority and is mainly driven by two important factors: the requirement of a high intensity proton machine as the driver for a future neutrino factory and the necessity to upgrade the aging ISIS Spallation neutron source.

Proton Drivers for Neutrino Production

After taking into consideration factors like the required production of 10²¹ neutrinos per year, the proton driver essential specifications have been identified: an average beam power of 4MW, a proton kinetic energy of 5-15 GeV and the ability to produce high intensity short bunches of protons with time duration of 1 – 2 ns (rms). Several designs options are under consideration at RAL, all consisting of an H⁻ linac followed by a series of synchrotrons or FFAG (Fixed Field Alternating Gradient)

* We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE, Contract No. RII3-CT-2003-506395).

accelerators [2]. A schematic layout of a 50 Hz, 4 MW, 10 GeV proton driver based on a non-scaling FFAG can be seen in Figure 1.

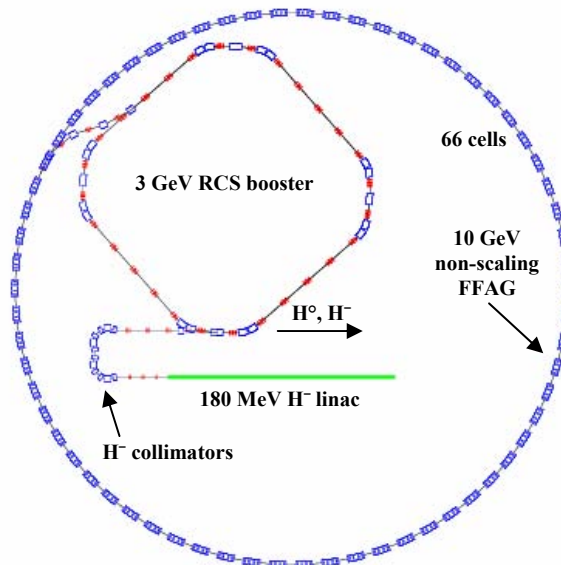


Figure 1: RAL 10 GeV, 4 MW, 50 Hz Proton Driver.

ISIS Upgrades

The ISIS facility at RAL has been delivering neutrons for users from all over the world for over two decades now, proving to be a very reliable and stable machine. However, ISIS is an aging machine and several upgrade options are being considered to increase the current beam power of 0.16 MW via a staged approach [3]. A second harmonic RF system is presently being installed at ISIS that will raise the operating current to 300 μA (0.24 MW). To increase the beam power even further up to 0.4 MW, a new 180 MeV linac [4] is foreseen to replace one of the oldest parts of the machine, the current 70 MeV injector. Adding a new 800 MeV synchrotron to operate in parallel with the current one will double the beam intensity, increasing the beam power up to 0.9 MW (see Figure 2). For higher beam powers (up to 6 MW) options are to increase the beam energy by adding a new 3 – 6 GeV synchrotron.

LINAC DESIGN FEATURES

The first critical stage of any HPPA is the low energy linear accelerator. The initial beam quality in terms of longitudinal and transverse beam emittances is defined in the linac and dictates the successful operation and reliability of the accelerators further downstream, that is

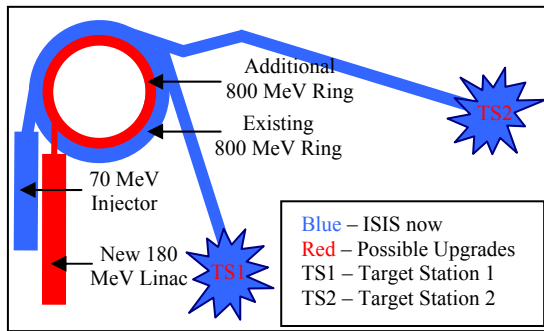


Figure 2: Schematic layout of ISIS with a possible 0.9 MW upgrade.

why, the design criteria have to be carefully considered, and often conflicting requirements have to be met.

The basic linac layout can be seen in Figure 3. It consists of an H- ion source based on the very successful ISIS Penning source that will deliver a 70 mA current and pulse lengths up to 2 ms at 50 pps. From the ion source, the beam will be matched into an RFQ (Radio Frequency Quadrupole) by a magnetic LEBT (Low Energy Beam Transport) based on a 3-solenoids design. The 324 MHz RFQ will create the bunching structure of the beam and accelerate it from 65 keV up to 3 MeV. The MEBT (Medium Energy Beam Transport) chopper line which follows, will transport and match the beam into the next acceleration structure. The chopper is one of the most important components in the low energy part of the linac, creating gaps in the bunch train, by removing the bunches that otherwise would fall outside of the RF bucket of the downstream accelerators [5]. The front end of the accelerator is now being built at RAL as part of the Front End Test Stand (FETS) project [6].

A 324 MHz drift tube linac (DTL) will accelerate the beam up to 90 MeV where the frequency is trebled and the accelerating structure is changed to a more efficient side-coupled linac (SCL), to accelerate the beam up to 180 MeV.

Choice of Frequency

In choosing the frequency, several conflicting requirements had to be taken into account:

- A higher frequency is equivalent with a better shunt impedance. A high shunt impedance is desirable, to reduce the power consumption, to simplify the cooling and thereby reduce the overall design complexity. At the same time, the accelerating cavities can be operated at higher gradients, the Kilpatrick factor (the electrical

discharge limit) being frequency dependent.

- On the other hand, a lower frequency will provide a long rise time for the MEBT beam-chopper, easing the chopper pulse amplifier specifications and ensuring that no bunches will be partially chopped. A lower frequency will also provide more space for the quadrupoles inside the DTL drift tubes.

The frequency choice of 324 MHz represents a good compromise between the requirements described above, the decision being eased by the readily available Toshiba klystron operating at this frequency.

RF Accelerating Structures Choice

For the low energy part of a high intensity proton linac, an Alvarez-type DTL is the structure of choice, proving to be very efficient. At around 50 MeV, the DTL will become less effective for acceleration and usually a more RF efficient accelerating structure is used instead, like in the CERN (LINAC4) [7] and J-PARC linac designs [8].

However, in the RAL linac, a different design approach has been adopted and the same DTL structure is used up to 90 MeV. Over the last years, developments in simulation codes and experience from machines already in operation have greatly increased our understanding of the beam dynamics in high intensity linacs. It is now well known that beam loss occurs mainly at the transition between tanks and between different accelerating elements, where mismatching can lead to emittance growth, halo development and emittance exchange between the transverse and longitudinal planes, effects that have to be avoided in high intensity linacs. We expect the choice of keeping the same DTL structure up to 90 MeV to have a positive effect on the beam dynamics, by avoiding an additional transition between two different accelerating structures, but a negative effect on the total RF efficiency of the linac by using a structure with a lower shunt impedance.

The transition energy to a SCL is 90 MeV. At this energy the space charge effects are lower and the matching between the two accelerating structures over a triple frequency jump is expected to be easier to achieve. Above 90 MeV the accelerating efficiency of the DTL structure is very low and so the more efficient SCL structure is adopted, operating in $\pi/2$ -mode. At the same time, the frequency jump from 324 MHz to 972 MHz adds a further increase in shunt impedance as well as the possibility to operate at higher accelerating gradients. Commercially available klystrons operating at 972 MHz have been another factor taken into account when

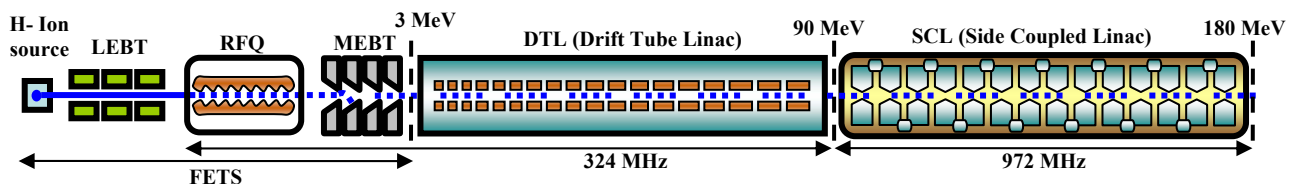


Figure 3: Schematic layout of the new 180 MeV linac.

choosing the frequency jump. Figure 4 shows the effective shunt impedance evolution along the linac, including a 0.8 correction from the calculated values to take into account the effects of surface imperfections, coupling holes, stems, etc.

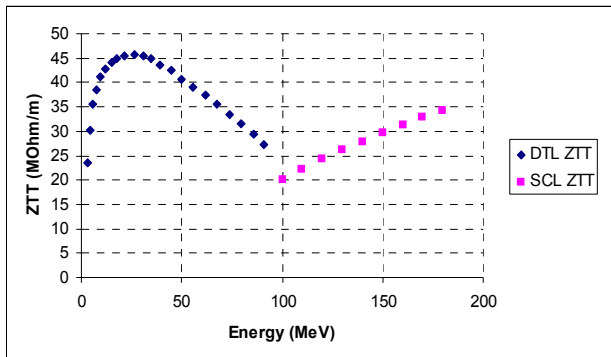


Figure 4: Calculated effective shunt impedance along the linac for the optimized DTL and SCL structures.

At 180 MeV the linac beam will be injected into a booster synchrotron. Simulation studies [9] suggest that the very short proton bunches (~1ns) and the required small longitudinal emittance, are best achieved by accumulating the beam around this energy.

Permanent Magnet Quadrupoles (PMQ) vs. Electromagnetic Quadrupoles (EMQ)

The type and design of quadrupoles to be used in the RAL linac merits special attention. EMQs produce high magnetic fields, and can be adjusted by varying the current flow in the conductors. In this regard, they are preferable to PMQs whose field cannot be changed once they have been installed in the linac. On the other hand, PMQs are much more compact than the EMQs and easier to fit in the small first drift tubes of the DTL. Their smaller length and diameter allows for smaller drift tubes and consequently higher shunt impedance. We have compared the shunt impedance in the DTL tank 1 when using 3 different quadrupole types currently in operation in proton linacs worldwide: a conventional EMQ, a SNS-type PMQ and the state of the art J-PARC compact EMQ [10], and as expected an increase in shunt impedance of ~20% has been observed in the case of the two more compact structures. Considering the technical difficulties and costs of developing a compact J-PARC type EMQ, the use of PMQs in the DTL becomes a viable choice for the RAL linac, backed by the increasing accuracy of the existing simulation codes and by the successful operation of the SNS DTL in Los Alamos (USA).

SUMMARY

A new 180 MeV high intensity H⁺ linac is being considered at RAL as a possible upgrade for ISIS or as part of a proton driver design for a future UK neutrino factory. The new linac will accelerate a 60 mA, 2 ms, 50 Hz, H⁺ chopped ion beam up to 180 MeV, which hasn't been achieved yet by the linear accelerators in operation.

The design approach takes into account often conflicting requirements from both beam dynamics and RF perspectives. Different RF design choices have been presented and justified: the operating frequencies, the accelerating structures and the transition energy between them as well as the choice of quadrupoles for the lower energy part of the linac. A summary of the main linac parameters is given in Table 1. The current design is open for further optimisations and extensive beam dynamics simulations have still to be performed in order to verify the feasibility of the scheme.

The existing collaboration with different European laboratories within HIPPI – JRA (High Intensity Pulsed Proton Injectors – Joint Research Activity) is expected to have a positive impact on the design progress due to the overlapping areas of research.

Table 1: Main linac parameters.

Parameter	Value
Ion species	H ⁺
Accelerating structures	DTL/SCL
Energy range	3 – 180 MeV
Frequency	324/972 MHz
Peak current	60 mA
Repetition rate	50 Hz
Duty cycle	>10%
Pulse length	2 ms

REFERENCES

- [1] R. Maier, "High Power Proton Linacs, Applications and Design Concepts", Proc. of EPAC'02, Paris, France, June 2002.
- [2] C. Prior, "Proton Drivers based on Rapid Cycling Synchrotrons", Proc. of NUFAC'T'05, Frascaty, Italy, June 2005.
- [3] C. Prior, "Upgrades to the ISIS Spallation Neutron Source", Proc of APAC'07, Indore, India, January 2007.
- [4] F. Gerigk, "A New 180 MeV H⁺ Linac for Upgrades of ISIS", Proc. of EPAC'04, Lucerne, Switzerland, July 2004.
- [5] M. Clarke-Gayther et al., "A Fast Beam Chopper for the RAL Front End Test Stand", Proc. of EPAC'06, Edinburgh, Scotland, June 2006.
- [6] A. Letchford et al., "The RAL Front End Test Stand", Proc. of EPAC'06, Edinburgh, Scotland, June 2006.
- [7] "LINAC4 Technical Design Report", CERN-AB-2006-084 ABP/RF Report, Geneva, Switzerland, December 2006.
- [8] "Accelerator Technical Design Report for J-PARC", KEK, Tsukuba, Japan, March 2003.
- [9] C. Prior, G. Rees, "RAL Proton Driver Studies for a Neutrino Factory", Proc. of NUFAC'T'00, Monterey, California, July 2000.
- [10] K. Yoshino et al., "Development of a DTL Quadrupole Magnet with a New Electroformed Hollow Coil for The Jaeri/Kek Joint Project", Proc. of LINAC'00, Monterey, California, July 2000.