SEPTA AND DISTRIBUTOR DEVELOPMENTS FOR H^- INJECTION INTO THE BOOSTER FROM LINAC4

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Abstract

The construction of Linac4 requires the modification of the existing injection system of the CERN PS Booster. A new transfer line will transport 160 MeV H^- ions to this machine. A system of 5 pulsed magnets (BIDIS) and 3 vertical septa (BISMV) will distribute and inject the Linac pulses into the four-vertically separated Booster rings. Subsequently the beam will be injected horizontally, using a local bump created with bumpers (BS magnets) to bring the injected H^- beam together with the orbiting proton beam onto the stripper foil. To accommodate the injected H^- beam, the first of the BS magnets will have to be a septum-like device, deflecting only the orbiting beam. This paper highlights the requirements and technical issues and describes the solutions to be adopted for both the BIDIS and BISMV. The results of initial prototype testing of the BIDIS magnet will also be presented.

INTRODUCTION

The 160 MeV H^- beam from the future LINAC4 linear accelerator [1], intended to replace the present 50 MeV LINAC2, needs to be distributed to the 4 superimposed synchrotron rings of the PS Booster (PSB) [2]. In the injection line a system of five pulsed ferrite core magnets (BIDIS), in combination with a fixed field iron magnet (DVT40), will kick time resolved slices of the beam with up to 4.75 mrad deflection sequentially into the appropriate aperture of 3 vertical electromagnetic septa (BISMV) producing the main vertical deflection for beam separation of ~30 mm. The BISMV further deflects the beam vertically into the 4 separate BVT vertical dipole magnet apertures to achieve the required PSB beam-level separation of 360 mm between each ring. So-called head and tail dumps, to which the rising and falling edge of the LINAC4 pulse are deflected, will be positioned just upstream of the BISMV yokes, allowing for maximum beam separation and optimum protection of the BISMV septa.

The LINAC4 beams will subsequently be injected horizontally into the PSB by means of an H- charge-exchange injection system using a graphite stripping foil. The local orbit of the PSB circulating beam is horizontally displaced by a set of four pulsed dipole magnets (BS) in order to meet the injected beam. The first BS magnet (BS1) must act as a septum, only deflecting the orbiting beam, with a field-free region for the injected H^- beam.

Table 1: Main BIDIS, BISMV and BS1 magnet parameters

	unit	DIS	SMV	BS1
Deflection angle	mrad	5	170	80
Integrated field	mTm	9.5	323	152
Gap field	mT	27	337	609
Gap height	mm	98	69	80
Gap width	mm	50	70	206
Magnetic length	mm	350	960	250
Septum thickness	mm	n.a.	4	<20
Peak current	kA	1.1	18.8	9.7
Peak voltage	kV	27	n.a.	1
Magnet inductance	μH	1.1	1.1	15
Magnet resistance	mΩ	15	0.2	0.4
Number of turns		1	1	4
Repetition rate	Hz	1.1	1.1	1.1
Rise / Fall time	ms	0.001	~1	~1
Flat Top duration	ms	0.420	~1	~1

BIDIS

The distributor will consist of 5 consecutive magnets, which will be powered individually. The main parameters of the BIDIS magnets are described in Table 1.

Simulations and Prototype Tests

The new BIDIS magnets are based on the present design. To improve its voltage hold-off capability and to improve the field homogeneity in the gap a new conductor was designed. The new coil geometry was validated using Vector Fields' Tosca software. In Fig. 1 the finite element model with the coil is shown. The calculations show that the required integral field will be reached at 1094A.

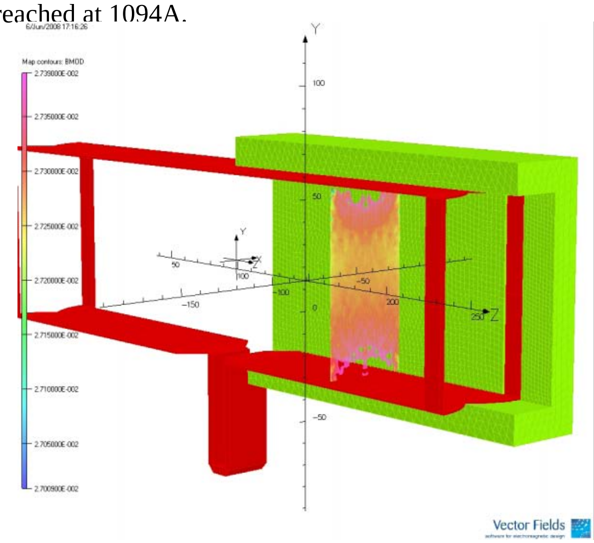

Figure 1: Finite element model of BIDIS with the 1 % field region plotted.

Following the simulations a spare magnet, still using the actual coil geometry, was tested. The magnet was successfully tested with a 5 μs pulse up to 30 kV. The magnetic length of the magnet was verified (using a 2 ms pulse, to reduce the voltage on the magnet). Its linearity proved to be better than the measurement accuracy of 5×10^{-3} between 500 A and 1200 A.

Mechanical Design

The existing BIDIS is mounted in an Ω cross section vacuum vessel which will be replaced with a UHV circular tank equipped with end covers at each end (see Fig. 2).

The 5-magnet stack can be inserted into the vessel using a temporary demountable rail guide system which is removed prior to closing the tank. Before insertion into the vacuum tank the magnets are pre-aligned on a rigid support plate and the complete assembly is then transferred to the rail guide system and rolled into the tank. The assembly is then transferred to a tank-mounted lifting system which positions and lowers the magnet stack on to the high voltage (HV) feedthroughs with the aid of precision location shafts. The vacuum tank can be baked if necessary and is equipped with ion pumps and independent vacuum gauges. All joints are of the OFE UHV type and the tank is fitted with UHV flanges which should allow for operational pressures in the region of 10^{-8} to 10^{-9} mBar to be attained.

In the existing BIDIS, an oil filled terminating resistor was used. However, in the new design the magnet will be short circuited and a dry connection box will be used. The HV cables from the pulse generator will use Lemo connectors, and the magnet connection boxes provide the link between these and the CERN MTE type HV feedthroughs on the vacuum vessel, while allowing the installation of a Pearson current transformer. The feedthrough will connect to the magnet coil using sets of concentric RF type finger contacts capable of passing the 1100 Amps during the magnet pulse.

The magnet yoke will reuse the existing design and is made using CMD 5005 ferrites manufactured by Magnetic Ceramics. The coil will be manufactured from stainless steel and will be assembled using a laser welding technique to minimize as much as possible the distortion during localized heating. A precision assembly tool has been designed which will allow precise alignment of all component parts of the coil prior to welding. In this way the strict geometric tolerances can be respected during the welding operations.

A scraper will be fitted to the upstream end of the magnet stack to protect the ferrites from stray particles in the beam halo.

The system has been designed to facilitate ease of exchange in the event of a magnet or HV failure. The complete tank, including the magnet stack, can be removed from the injection line and replaced by its spare assembly in a relatively short period of time. This will significantly reduce the downtime and radiation dose taken by equipment specialists during such an intervention. Although heating effects are considered to be minimal, a cooling system will be incorporated in the magnet support to stabilise the temperature of the distributor.

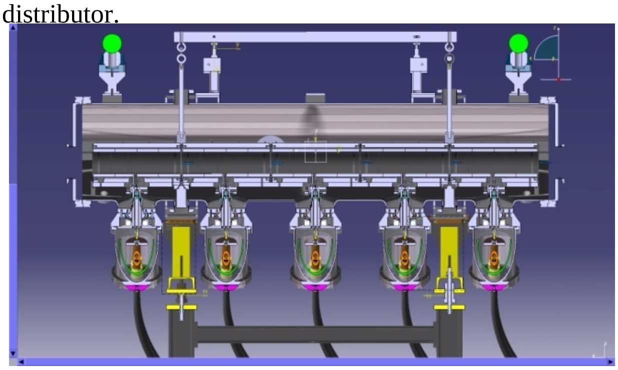

Figure 2: BIDIS assembly cross section, showing the 5 magnets inside the vacuum vessel and the associated feedthroughs and connection boxes below the tank.

Pulse Generator

Each magnet will be pulsed with a dedicated pulse generator of 25Ω characteristic impedance. To allow maximum re-use of existing equipment, which is limited to 30kV operation, the required increase in peak current in the magnets will be obtained by using them in short circuited mode, instead of the present terminated system. This has the disadvantage of doubling the risetime of the magnetic field however this will be accommodated by inclusion of 1 μs gaps in the Linac 4 pulse structure specifically for the BI.DIS field rise.

BISMV

The 3 vertical deflection septa will be installed in one vacuum tank, which will equally provide the space for the head and tail dumps. All magnets (see Table 1 for main parameters) will be identical, but mounted differently to allow the beams to be deflected to the different PSB rings which are not at the same height as the LINAC4.

Design of the Magnet Cross Section

The magnet cross section was optimised using Flux2D finite element software from CEDRAT. The magnets dissipate 50 W each, so water cooling is required. The resulting coil (made of OFE copper) has embedded cooling channels in raised edges and a small lip overlapping the yoke to reduce the stray field. The cooling channels in the return conductor will also be positioned close to the edges to reduce the provoked pressure wave in the cooling circuit by the energy deposited by the secondary particles originating from the head and tail dumps (for SMV3 and SMV1, respectively). For this coil geometry the simulations show that the stray field will be below 1% of the main field and its quadrupolar component is predicted to be 3 times less than the one of the gap field (see Fig. 3).

The magnetic core will be made of laminated silicon steel, and its cross section is designed to minimise the yoke cross section (reducing outgassing rates due to a lower surface exposed to vacuum) and reduce the stray field. A slot is foreseen in the back-leg of the yoke to embed a measurement coil for regulation of the power convertor. It will span one half of the yoke to simplify the connections and reduce potential interference with the magnet coil.

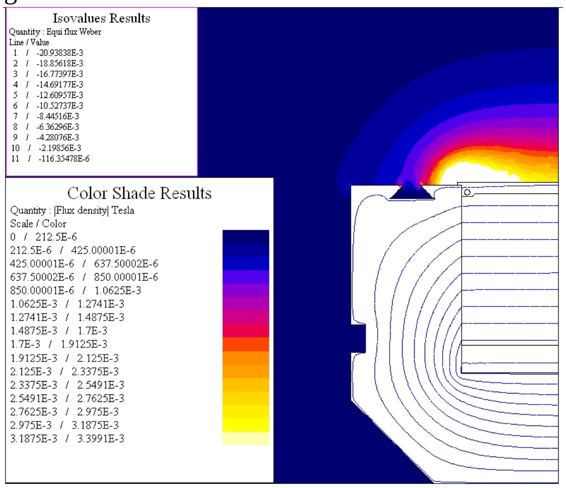

Figure 3: BISMV cross section showing the 1% (stray) field region.

The stable field flat top length needs to be 100 µs, but the current flat top was chosen to be longer to limit eddy currents induced in the yoke and stabilise the current from the power converter before the passage of the beam through the magnet.

Mechanical Design

The initial design is based on the manufacture of curved magnets which will be laminated and installed under vacuum. The critical design considerations include the coil fixation and the structural rigidity of the laminated yoke. The BISMV magnets will incorporate water cooled coils and proven high power vacuum feedthroughs. Due to the laminated construction of the magnets, the vacuum load will be significant and a substantial pumping system will be have to be integrated into the limited space assembly of the septum tank assembly. Water cooled head and tail dumps will be designed to cope with the rising and falling ramps of the Linac pulse. Since space is a major constraint within the vacuum tank, the beam dumps will have to be as compact as possible without compromising the operational performance and reliability of the complete assembly.

BS1

The present baseline design for the PSB injection foresees for the first closed orbit bump a fast dipole magnet under vacuum (BS1) with an eddy current shield between the orbiting beam area and the injected beam [3]. However, provided the beam injection scheme would allow for a slower bump, an alternative could be found in a direct drive septum magnet placed outside vacuum. To limit the voltage required to a manageable 1 kV, the magnet uses a 4 turn coil. The coil can be insulated using 2 mm glass fibre epoxy. The yoke can be made of standard 0.35 mm thick silicon steel. 2D finite element simulations of the magnet show that good field homogeneity can be expected in the gap: the quadrupole component of the field is 7×10^{3} times smaller than its dipole component. The stray field adjacent to the septum conductor, seen by the injected H^- been, is predicted to be less than 1% of the dipole field. However, by making the injected beam tube out of 2 mm mu-metal this can be reduced to below 10^{-4} of the gap field. To minimise the gap field deformation, the vacuum chamber will be made of corrugated 0.45 mm thick Inconel X750, measuring 67×195 mm internally and 80x206 externally. It can be shown [4] that the vacuum chamber will delay the field by approximately 68 µs, with a magnetic field fall time of 1 ms. To have to same eddy current induced field delay, the main challenge will come from the need to have all BS magnets to use vacuum chambers, which induce identical field delays for all 4 magnets. Moreover, to prevent induced current in the vacuum chambers, they need to be insulated from the magnet and space needs to be found for an insulator after each magnet in the vacuum chamber. This could be achieved with short insulating ceramic vacuum chambers, or enamelled vacuum flanges.

CONCLUSIONS

The BIDIS magnet design is presently frozen and the mechanical design of its vacuum vessel and support system well advanced. The procurement of long lead items, such as the ferrites, has started. The existing yoke design is shown to provide sufficient margin to provide the required ∫Bdl. The BISMV parameters are established. The magnet cross section has been designed and uses a non-uniform septum cross section to provide space for the water cooling channels as well as acceptable stray field levels. The impact on the beam of the present design still needs to be verified, in particular the impact of the higher order modes of the main and stray field. For the BS1 in the PSB injection region an outside vacuum direct drive septum magnet has been proposed. This design choice is acceptable only if the fall time of these magnets can be extended to beyond 1 ms, and if the impact of field distortion by the eddy currents induced in the vacuum chamber can be accepted by the orbiting beam.

REFERENCES

[1] L. Arnaudon et al. (Eds. F. Gerick, M. Vretenar), “Linac4 Technical Design Report”, CERN-AB-2006-084 ABP/RF, December 2006.

[2] W. Weterings et al., “160 MEV H^- Injection into the CERN PSB”, PAC’07, Albuquerque, June 2007, TUPAN109, p. 1628 (2007); http://www.JACoW.org.

[3] M. Barnes, B. Balhan, J. Borburgh, T. Fowler, L. Sermeus, A. Ueda, “Development of an eddy current septum for the new PS booster injection”, EPAC’08, Genoa, June 2008; http://www.JACoW.org.

[4] M. Chanel, private communication, 2008