High Current Density Septum Prototype for Accumulator and Storage Rings of DAΦNE, the Frascati Φ-Factory

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Abstract

DAΦNE is a Φ-factory, presently under construction at INFN, Laboratori Nazionali di Frascati. The injection/extraction magnetic system for both the accumulator and storage rings, composed of two septa, has been designed and is now under construction. A full size prototype of the 38 mrad thin septum near the machine has been built and completely tested at LNF. This septum is of high current density and edge cooled type. This paper describes the mechanical design and the results of the magnetic measurements in comparison with the FEM calculations.

1. INTRODUCTION

A 510 MeV electron/positron colliding facility known as DAΦNE [1], is currently under construction at INFN's Frascati National Laboratory.

The project consists of two storage rings and an energy injector system. Electrons and positrons will be injected into the DC accumulator alternatively from Linac at a frequency of 50 Hz. The storage rings will only have injection frequency of few Hz.

Figure 1 depicts the physical layout of the system. Injection/extraction of electrons and positrons is accomplished by two DC Septa [2].

The "thin" septum is a 38 mrad high current density, edge cooled type. Due to the fact that this element is the most critical one of the injection system, a full size prototype was built at Frascati Labs, in order to evaluate the magnetic and thermal characteristics.

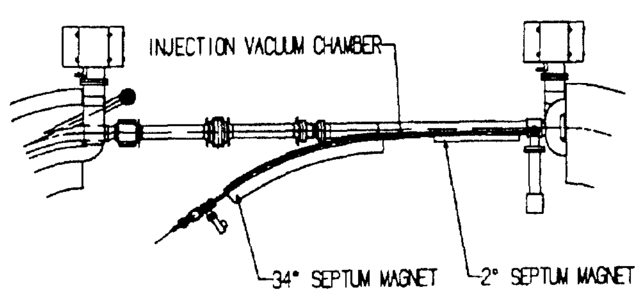

Figure 1. Injection/extraction Septum System

2. SEPTUM DESIGN

2.1. Septum Design

Figure 2 shows the cross section of the septum. The principal design constraint was the allowable maximum septum thickness set by machine physics group in the order of 4 mm. It of course includes the thickness of two vacuum chambers, reducing the thickness of the current carrying conductor to 1.5 mm. The resulting current density is in the order of 60 ampere per square mm. The septum coil is electroformed on two thin wall, rectangular tubings, to form an intimate thermal contact between conductor and cooling tubes for proper heat transfer. These tubings are of stainless steel AISI 304 L to avoid excessive current sharing with the conductor. The back coil is of conventional copper hollow conductor.

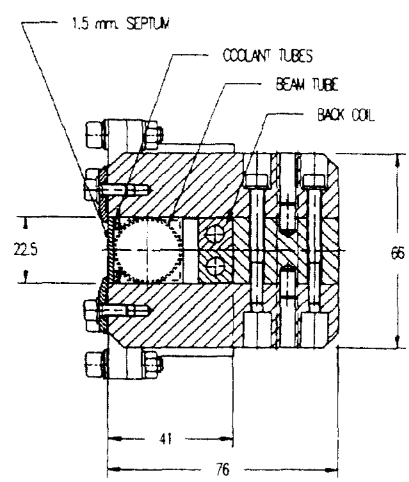

Figure 2. Septum Section

All the electrical insulation will be provided with 130 μm thick pressure sensitive Kapton tape. The additional function of the Kapton tape, due to its extreme low thermal conductivity, is to insulate thermally the beam chamber from high temperature septum, this will prevent the thermal outgassing of the stainless steel septum beam tube, so near to the machine that it is considered as part of the machine vacuum system. The iron yoke is of low carbon Armco steel type, it is detachable so that the septum can be installed or removed from its location easily. Table 1 shows some of the more relevant parameters of this septum.

Table 1. Septum Parameter List

Field	0.104	T
Bend Angle	38	mrad
Gap Height	22.5	mm
Magnetic Length	623	mm
Septum Cond. Area	33.75	mm^2
Current	2125	A
Current Density	63	A/mm^2
Resistance	0.33	mΩ
Power	1.49	kW
Voltage	0.7	V
N. of Water Circuit	1	
Water Flow Rate	0.1	L/s
Water Pressure Drop	3	Atm
Water Temp. Rise	5	°C

2.2 F.E.M. Analysis

The magnetic design has been carried out with POISSON code (2-D), taking into account the real current distribution within the septum and coolant tubes. Due to the small thickness (0.13 mm) it was impossible to mesh the Kapton electrical insulation. This fact involves that the computed lateral fringing field is surely lower of the real one. One of the aims of the prototype construction was the exact evaluation of the real fringing field that is required to be very low to avoid interference with the stored beams.

The thermal loading of the septum is rather severe due to high current density and edge cooled feature. Thermal analysis has been performed by using ANSYS code, with initial water temperature of 30 °C and assuming constant thermal characteristics of the materials. The computed maximum temperature along the median plane is ≈ 51 °C, there is negligible thermal gradient across the tube wall. Assuming tubings remain rigid, the maximum thermal compressive stress in the copper will be ≈ 440 kg/cm^2, which is below endurance limit of the copper.

3. SEPTUM PROTOTYPE CONSTRUCTION

All parts of the magnet with exception of the septum coil were constructed and assembled at Frascati Labs. The iron was worked with a digital controlled milling machine. The global machining tolerance measured after the iron assembling was less than 0.07 mm. The back coil was obtained starting from a 18x18 mm square holed conductor copper, and all the hydro/electrical connections were obtained from solid copper.

The septum coil was constructed by Tecnol (Florence-Italy) electroforming the copper septum on 2 rectangular pipes (inner dimension: 2x4 mm.) of stainless steel AISI 304 L. For a better fixation of the copper a layer of 10 μm of nickel was deposited on the stainless steel. The max. difference in the electroformed thickness was less than 0.17 mm.

An hydraulic test was performed on the assembled system with a test-pressure of 10 bar. The required water flow rate of 6 l/min. is obtained with a inlet pressure of 5.7 bar.

4. PROTOTYPE MAGNETIC MEASUREMENTS

The magnetic measurements were performed with a Hall Effect Digital Teslameter (from Group 3 - New Zealand) mounted on a X, Y, Z digital moving system (from Microcontrole - France).

The digital moving system permits the probe-keeper to be moved along 3 axes and to be rotated around 2 axes. A granite bench on which the positioning tables are mounted, and a Hewlett-Packard computer HP 9000/300 complete the system. Four of the five movements (X, Y, Z, ϕ) are automatized by means of stepping-motors. The movement resolution is 10 μm. Normally, the movements are remotely controlled by computer, so that dedicated softwares have been written to perform sets of measurements, i.e. the control of sequential steps of the stepping-motors that move the Hall probe along predefined paths. The calibration of the Hall probe is done comparing the instrument with a NMR teslameter (from Metrolab - Switzerland) in a stable and constant external dipole field.

We have done different set of measurements inside the magnet (paths parallel to the magnet axis) and outside in the fringing field region (paths parallel and perpendicular to the magnet axis).

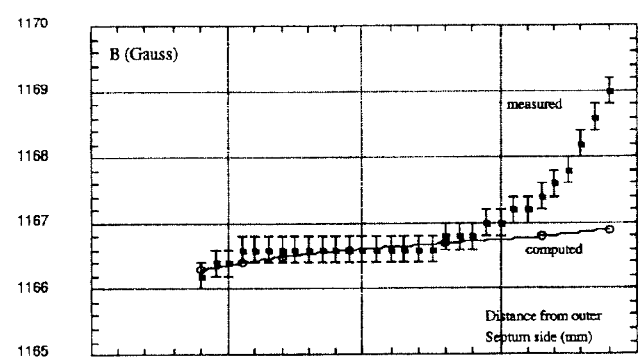

Figure 3. Septum Inner Field

Figure 3 shows the field inside the magnet comparing the measurement to the FEM calculation.

The measurements were done at different sections, showing some differences among different sections. These differences are probably due to the mechanical tolerances of the iron and copper pieces. The agreement between the measured and computed values is very good especially in the left side of the plot (septum coil direction). The discrepancy on the right side (back coil direction) of about 0.1 % is due to the presence of the Kapton insulation between the coils and the iron. The gap of this Kapton layer (0.13 mm), causing degradation of the field quality, was not taken into account in the FEM calculation.

Figure 4 shows the comparison between the measured and computed lateral fringing field.

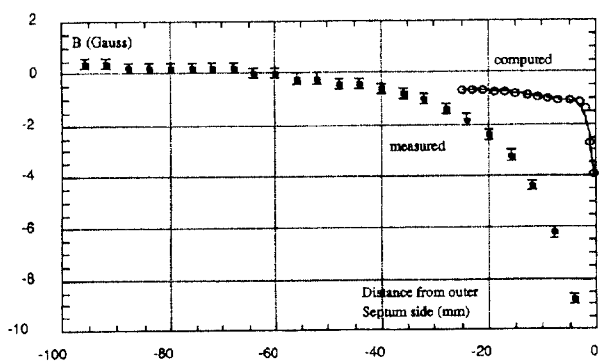

Figure 4. Septum Fringing Field

Also here the discrepancy is caused by the presence of the Kapton insulating tape gap between coil and iron, gap that is not present in the computer simulation. Nevertheless the measured fringing field is very low; less of 2 Gauss at 25 mm from the septum coil.

4. CONCLUSION

A full size 2° septum was built at Frascati Labs. The prototype was fully tested and measured. The results are satisfactory. The thermal loads, critical in these kind of septa, are acceptable. Also the magnetic behaviour (field quality and stray field level) is compatible with the requested one. The components are under series production for the construction of four septa needed for DAΦNE Accelerator Complex.

5. REFERENCES

[1] The DAΦNE Project Team : "DAΦNE Status Report", paper presented at EPAC 92, 3rd European Particle Accelerator Conference, Technical University of Berlin, Germany, March 24-28, 1992. Proceedings of 3rd European Particle Accelerator Conference, Vol. I p. 60.

[2] M. Modena, H. Hsieh and C. Sanelli: "High Current Density Septa for DAΦNE Accumulator and Storage Rings" EPAC 92, 3rd European Particle Accelerator Conference, Berlin - Germany, March 1992. Proc. p. 1472