A High Current Passive Septum Magnet for Elettra

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Abstract

The design of the septum magnets to be used for the injection of the electron beam into the 2 GeV storage ring ELETTRA is described. The magnets will be housed in a vacuum tank directly connected to the storage ring vacuum chamber. The septa are supplied by a solid state pulsed power supply producing a half sine wave current with 9.0 kA peak value. The results of the relevant tests are described and discussed.

1. INTRODUCTION

Two septum magnets will be used for the injection of the 2 GeV electron beam into the ELETTRA storage ring. The septa are used to deflect the beam coming from the transfer line into a direction which is parallel to that of the beam circulating in the storage ring. A description of the injection layout can be found elsewhere [1]. Due to space requirements in the injection section and to limit the thickness of the septum sheet it was decided to put the two septa in vacuum. In the same vacuum tank housing the septa, a separate chamber for the stored beam is allocated. The storage ring chamber is connected to the septum sheet by means of copper straps in order to maintain closed conductive loop all around the electron beam. At the same time this solution allows the septa to be moved up to 15 mm towards the storage ring chamber in order to optimize the injection optic during the commissioning of the ring.

The two septa will be identical, apart from the septum screen, which will be thinner for the septum which is closer to the ring. The two power pulsers will be identical, even if for beam optics reasons the current flowing in the two septa will be for the transfer line side septum and the storage ring side septum 9.0 kA and 8.0 kA respectively. Two septum magnets instead of one have been chosen in order to limit the peak voltage of the pulser below 2 kV, which must be considered an upper limit for a safe operation of solid state based switches. The solution of a short thin septum magnet inside vacuum and a thick septum magnet in air was rejected due to space problems on the storage ring side and to mechanical compatibility with the transfer line section. The solution of having a foil separating the storage ring vacuum environment from the septum magnets and the transfer line vacuum was also rejected due to the possible dangerous event of breaking the foil. Water cooling of the septum sheet is not foreseen in order to make the construction as reliable as possible. The cooling of the magnet will be provided by a series of copper straps connecting the magnet to a dedicated flange on the vacuum tank. If the heating of the sheet will be excessive due to possible collisions of electrons against the sheet, a water cooled screen has also been designed and will be ready to be mounted if necessary.

Table 1. Main parameters of the septum magnets.

Energy of the electron beam	2 GeV
Deflection	80 mrad
Magnetic length	720 mm
Peak magnetic field	0.8 T
Free aperture	30Hx15V mm
Nominal distance septum-closed orbit	25 mm
Minimum thickness of the septum sheet	2.1 mm
Magnet inductance	2.5 μH
Peak current	9.0 kA
Peak voltage	2.0 kV
Pulse duration	60 μs
Maximum integrated leakage field	10 Gauss·m

2. MAGNET DESIGN

The design of such a magnet has to meet many requirements in order to achieve a high reliability operation, some of them are of primary importance for the choice of the final magnetic solution, materials, electric circuit characteristics. Among them:

-septum sheet as thin as possible
-high magnetic field (due to geometrical limitations)
-low magnetic field leakage (due to beam optics)
-ability for operation in a U.H.V. environment
-resistance to radiation doses
-use of a solid state based power pulse circuit

The sum of these requirements can be meet with a series of two septum magnet, which are individually driven. A so called "eddy current" solution has been chosen for the septum sheet, in order to limit the septum thickness. Therefore the magnet is powered by means of a pulsed current, half sine wave shaped, with a peak value of 9.0 kA and a duration of 60 μs. Eddy currents flowing in the screen are able to shield the magnetic field produced inside the gap in a fraction which depends on the thickness of the screen and on the duration of the magnetic pulse. Extensive tests have been carried out in order to verify the attenuation of the magnetic field with a simple screen made only of copper and with a composite copper + ferromagnetic screen. The relevant results (Figure 1, Figure 2 and Figure 3) show that even if a composite shied would give the strongest attenuation, a simpler tapered screen made only of copper can also be used. From the results of Figure 1 and from some other measurements which have been made with some other different copper thickness, it was verified the accuracy in our conditions of the simple skin-effect relationship:

$$B=B_0e^{-d/\delta}$$

where:
B=magnetic field at a distance d from the inside of the gap
B_0=magnetic field inside the gap
δ=penetration depth for copper

It is remarkable that, as physically reasonable, the equivalent frequency relevant to the power pulse half sine wave must be taken for the skin depth calculations.

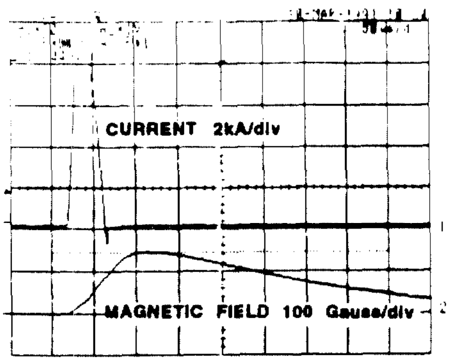

Fig 1. Current and magnetic field with a 1.8 mm thick copper screen.

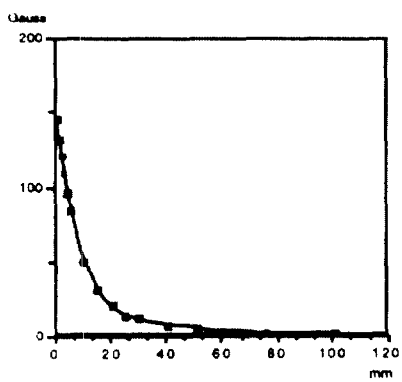

Fig 2. Variation of leakage field outside septum with 1.8 mm thick copper shield.

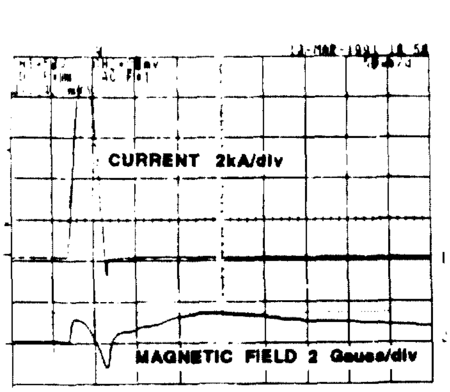

Fig 3. Current and magnetic field with a 1.8 mm thick copper screen + 0.2 mm ferromagnetic shield.

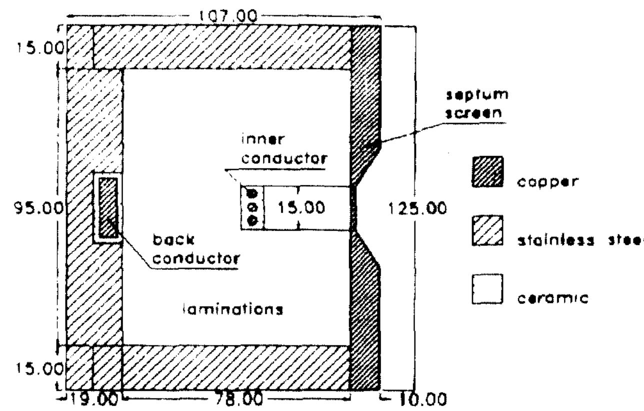

Fig 4. Septum magnet cross sectional drawing.

Therefore a design making use of a tapered copper screen with a minimum thickness of 2.1 mm and a maximum thickness of 10 mm was adopted. This solution still limits the magnetic field leakage integral to a value not exceeding 10 Gauss·m.

Due to the pulsed magnetic field to be produced, silicon iron 0.18 mm thick laminations have been used. The thickness of the laminations was chosen according to theoretical calculations [2], and it represents a safe value taking into account the equivalent frequency of the pulse and the need to limit the total surface of laminations due to vacuum requirements. The laminations are insulated by Carlite, in order to allow a very Ultra High Vacuum to be produced. Experimental tests which have been made on a septum prototype showed that the degassing rate of such a iron core remains below a limit still affordable for a pumping system making use of a combination of ionic pumps and getters.

The coil is made with three copper conductors which are connected in parallel to a solid bar on the back of the magnet. The increased section on the back is made in oerder to limit the heating of the conductor. The isolation between the coil and the core is made with ceramic spacers.

Fig 5. Septum magnet 3D view (half magnet).

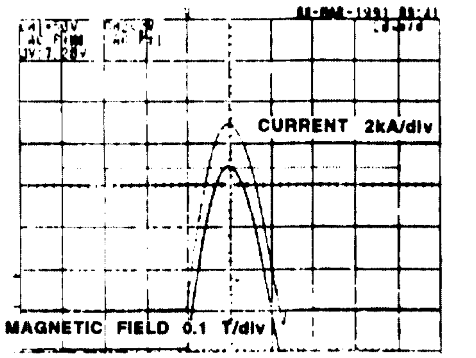

Fig 6. Nominal current and magnetic field waveforms inside the gap. The current was measured with a fast transformer, the magnetic field by integration of the induced voltage in a 50x2 mm rectangular coil. The waveforms were taken with a digital oscilloscope.

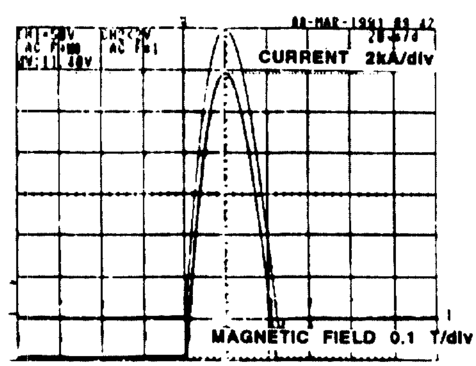

Fig 7. Current and magnetic field inside the gap at peak current = 14 kAmp.

In figure 6 and 7 the behaviour of the magnetic field produced inside the gap is shown with the nominal current and with a peack current increased by 50% with respect to the nominal peack value. It is remarkable that even for a such high current the magnetic behaviour of the Septum still remains in the linear region.

3. POWER PULSE CIRCUIT

The half sine wave pulsed current is provided to the magnet by a capacitor discharge like circuit (Figure 8).

The pulsed high current requires a load with an inductance not too much high in order to limit the charging voltage of the capacitor. This is why the septum magnet system is made of two different magnets: this solution allowed us to keep the supply voltage below 2 kV, i.e.,it allowed us to make use of thyristor switches.

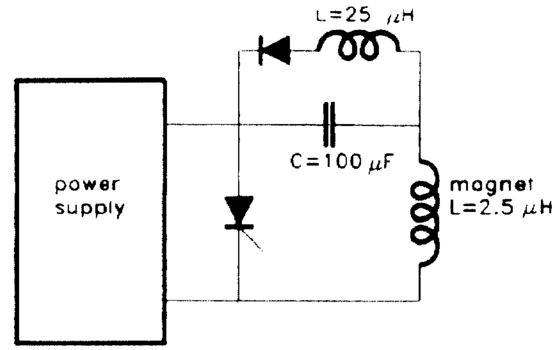

Fig 8. Power pulse circuit.

The capacitor bank is made of 20 capacitors, 5 μF capacitance each, metallized polipropylene, 2400 V D.C. voltage. The switch is a power fast turn thyristor, 2400 V, 40 μs turn off time.

The recovery chocke was designed in order to make the recharging time of the capacitor long enough to avoid a new firing of the thyristor after the pulse. A nearly complete recovery and optimum circuit performances were obtained with a recovery inductance value ten times that of the magnet.

4. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] D.Tommasini, " The ELETTRA fast magnets", D.Tommasini, this Conference.
[2] D.Tommasini, "Determination and Design of Septa Magnets for ELETTRA", Sincrotrone Internal Note 90/16.