A NEW DESIGN FOR AN *ACTIVE-PASSIVE* SEPTUM MAGNET

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Abstract

A septum magnet for synchrotron light sources of intermediate energy, like the Laboratory de Llum de Sincrotró de Barcelona (LLS), is presented. This septum is a hybrid between the passive and active types, which combines the advantages of both designs, especially with regards to the field quality, the stray fields and power losses, without significant technical complications. The performance of the proposed septum magnet is compared with that of an active and a passive septum magnet.

1. INTRODUCTION

The LLS, currently in the design stage, will be a third generation synchrotron light source. The LLS will consist of a linac, a booster and a storage ring with a triple bend achromatic lattice (TBA) of ca. 250 m in circumference. The stored beam current will be 250 mA, with energy of 2.5 GeV and an emittance of 8.4 nm-rad [1, 2].

Injection into the storage ring will be in the horizontal plane by means of a septum magnet and four bumper magnets at energy of 2.5 GeV. This method provides a smooth and continuous injection.

Injection efficiency is the main requirement of the LLS septum magnet. To this end we rely on the field produced by the magnet to have a maximum relative error, $\Delta B/B$, below 10^{-3} in the useful aperture and in the useful time interval.

There are several constraints on the design of this septum magnet (table 1). These are due to the accelerator geometry, the injection scheme and the materials used.

Table 1. Constraints on fundamental parameters of the LSB septum magnet.

Max. length	*[m]*	1.7
Max. septum thickness	*[mm]*	3.5
Deflection angle	*[rad]*	0.163
Min. vertical gap	*[mm]*	10
Min. horizontal gap	*[mm]*	20
Max. magnetic field	*[T]*	1
Max stray magnetic field	*[T]*	10^{-4}

In addition to the objectives and constraints defined above, the design of the LLS septum magnet must also take into account the needs of low cost and maintenance.

2. SEPTUM MAGNET TYPES

There are basically two types of septum magnets that could, in principle, fulfill the needs of the LLS injection scheme, namely: active type and passive type [3].

Active septum magnets require a very powerful cooling system due to the Joule heating. Increasing the septum thickness usually solves this difficulty, even though this solution is not always applicable, as the septum thickness must often be small (less than 4 mm). The stray fields in this type of septum magnet are in general of relatively high values.

Two main drawbacks are associated with the use of passive type septum magnets:

- The technology of the power supply is more complex.
- The field quality in the aperture is poorer.

2.1. *Active-passive septum magnet*

In this paper is presented a new type of septum magnet for the LLS. This magnet is a combination of the two types mentioned above. This septum magnet, which I call of the *active-passive* type, is active since the septum contains an active conductor, but it is also passive because it contains a passive conductor (fig.1).

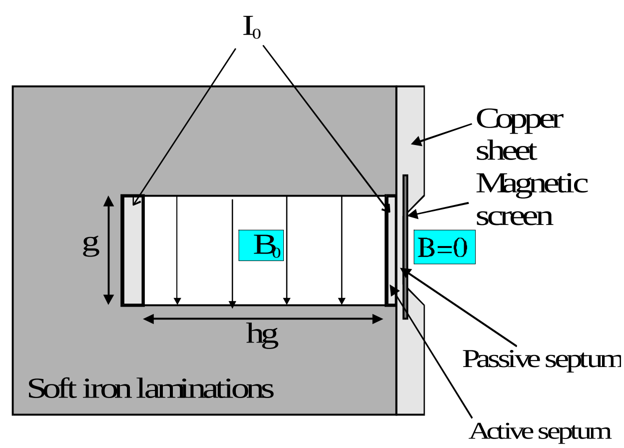

Figure 1. Cross-section of an active-passive septum magnet. The current in the coils, I, is pulsed. The stray fields are screened in the copper sheet by eddy currents and by the ferromagnetic screen. The cooling system is not shown.

The main features of the active-passive septum magnet type are:

- the active septum enhances the field quality;
- the passive septum screens the stray fields;
- the passive septum provides mechanical protection against magnetic forces;

- the current on the conductor is a half sine pulse of a few tenths of μs, which reduces heat losses typically below 250 W;
- the active conductor can be thin (2 mm) because the current flows in the surface with a penetration depth δ, δ~1 mm;
- the copper screen can be made thin because the magnetic field to be screened is orders of magnitude smaller than that in the aperture, and;
- to further reduce the stray fields a thin ferromagnetic screen is added to the copper screen.

3. OPTIMIZATION OF THE *ACTIVE-PASSIVE* SEPTUM MAGNET FOR THE LLS

This type of magnet has been optimized for the special characteristics of the LLS. The optimization process is a typical case of multiobjective optimization, where some conflicting objectives lead to an optimized compromise.

3.1. Defining objective functions and variables

The important parameters to take into account in the specific case of the LLS septum magnet are:

- the maximum voltage drop across the magnet, V;
- the maximum intensity in the magnet, I;
- the dissipated head, P, and;
- the magnetic force per unit length on the septum, F.

The variables of the optimization problem can be defined as:

- the pulse duration, τ, and;
- the magnet length, l.

Thus one must relate the four objective functions (V, I, P and F) with the two optimization variables (τ and l), so that the optimal compromise is found.

The maximum voltage drop across the septum magnet is given by:

$$V = \left(N \frac{\pi}{\tau} 3.3355 E[GeV] \right) \cdot \theta \cdot hg \qquad (1)$$

where N is the number of coil turns, hg is the horizontal aperture, E and θ are the particles energy and deflection, respectively.

The maximum current in the magnet is given by:

$$I = \left(\frac{3.3355 E[GeV]}{N \mu_0} \right) \cdot \theta \cdot \frac{g}{l} \qquad (2)$$

where g is the vertical aperture.

The dissipated power can be approximated by:

$$\frac{16.3 E^2[GeV]}{TN^2} \sqrt{\frac{\rho}{\mu^3}} \frac{g\theta^2 \tau^{1/2}}{l} \qquad (3)$$

where T is the time between pulses, ρ and μ are the copper resistivity and the magnetic permeability, respectively. Here I have only considered the power from the Joule heating in the coil and the septum because these are the main sources of heat.

The magnetic force per unit length on the septum is expressed by:

$$F = \frac{(3.3355 E[GeV])^2}{2\mu_0 N^2} \frac{g\theta^2}{l^2} \qquad (4)$$

Because the four expressions have to be minimized, it is clear that l must be maximum, i. e., l = 1.7 m (table 1).

Therefore the problem is reduced to only one single variable: τ, and two objective functions: the maximum voltage, V, and the dissipation power, P.

3.2. Optimised result

Figure 2 shows the maximum voltage, and the power losses (from (1) and (3)) as a function of the pulsed duration τ for the active-passive septum magnet proposed here.

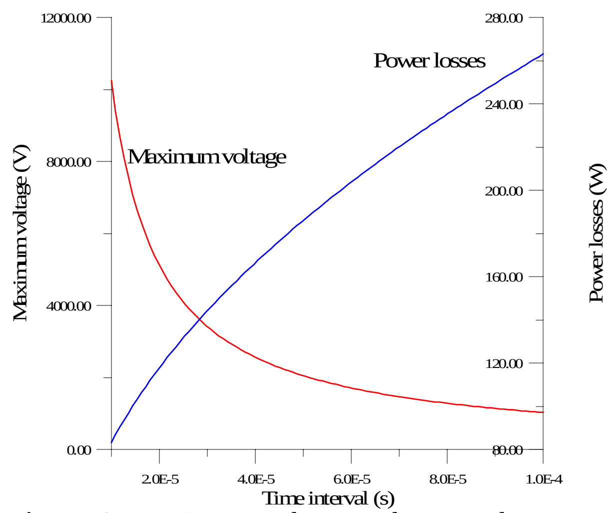

Figure 2. Maximum voltage and power losses as a function of the pulse duration τ for the active-passive septum magnet proposed for the LLS.

After consideration of the factors concerning the power supply and the cooling system, I have chosen a half sine pulse with a duration of 70 μs. The main reason for this choice is to remain under 1.7 KV in peak voltage so that a single solid state thyristor can be used in the pulsed power supply [4]. See in table 2 the main parameters for the proposed septum magnet.

Table 2. Main parameters of the LLS active-passive septum magnet.

Length	*[m]*	1.7
Magnetic field	*[T]*	1
Deflection angle	*[rad]*	0.163
Aperture	*[mm×mm]*	10×20
Self-inductance	*[μH]*	5.8
Peak current	*[A]*	8000
Peak voltage	*[V]*	980
Pulse duration	*[μs]*	70
Septum thickness	*[mm]*	3.5

4. COMPARISON OF THREE SEPTUM MAGNETS FOR THE LLS.

4.1. Field quality

Once the main parameters of the active-passive septum magnet are defined, a study of the magnetic field in the cross section must be carried out. A comparison of the active-passive model with an active model and a passive model, all suitable for the LLS, is presented in this section. For this purpose I used the OPERA-2d® package.

Figure 3 shows the field variation in the aperture as a function of the transverse coordinate for the active, the passive and the active-passive magnet models. One can observe that the transverse stability is much better for the active and the active-passive septa than that for the passive model. To obtain better field quality, especially for the passive septum magnet, the pulse duration should be shortened.

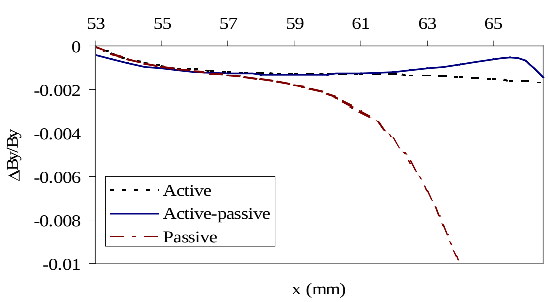

Figure 3. Relative variation of the vertical field in the aperture of the two LLS septum models: the passive and the active-passive. Note that the path of the electrons occurs in this region of the magnet aperture.

4.2. Stray fields

The stray fields are too high if there is only a copper screen in the passive and active-passive magnets; therefore the use of a ferromagnetic screen is mandatory. No ferromagnetic screen can be used in an active septum magnet. Figures 4, 5 and 6 show the field at different points in the magnet as a function of time for the three models calculated with OPERA-2d tr®. From these pictures one can conclude that the best solution to reduce the stray fields is to use whether a passive or an active-passive septum magnet with a ferromagnetic screen.

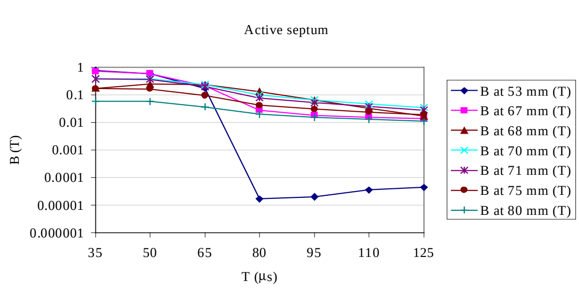

Figure 4. Evolution with time of the stray fields at different points of the active septum magnet model for the LLS, calculated with OPERA-2d® tr. The position with co-ordinate 53 mm is in the centre of the aperture. The septum is from 67 to 70 mm. The stray fields are calculated at the positions 71, 75 and 80 mm.

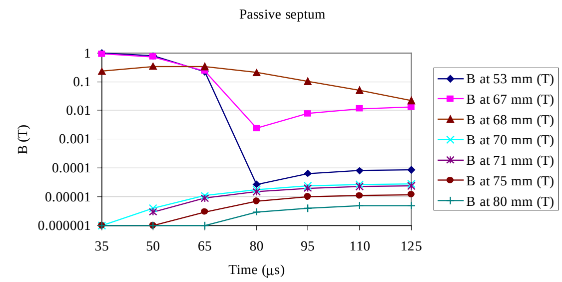

Figure 5. Evolution with time of the stray fields at different points of the passive septum magnet model for the LLS, calculated with OPERA-2d® tr.

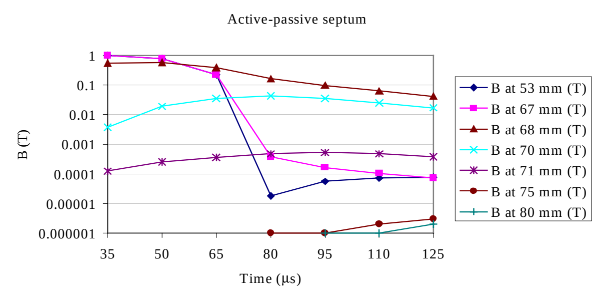

Figure 6. Evolution with time of the stray fields at different points of the active-passive septum magnet model for the LLS, calculated with OPERA-2d® tr.

CONCLUSIONS

In this paper I have presented a new type of septum magnet for synchrotron light sources of intermediate energy, like the LLS.

The main advantages of this *active-passive* compared with the more traditional active septum magnet are that the septum thickness can be thinner than 3.5 mm and that the power losses are greatly reduced. The penalty is a more complex technology for the power supply. With respect to the passive septum magnet the main advantage of the proposed *active-passive* one is basically its much better field quality.

ACKNOWLEDGEMENTS

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