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A MULTIPOLE WIGGLER MAGNET FOR DORIS

by

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1. Indroduction

Currently there is great interest amongst users of synchrotron radiation at ∿1.5Å to obtain higher photon fluxes at their samples. One way to achieve this is to use long curved mirrors to collect a large angular spread of beam from ordinary bending magnets and focus it onto the sample. Another method which is being persued at several synchrotron radiation laboratories is to use a multipole wiggler magnet which produces radiation into a small opening angle with an intensity which increases linearly with the number of poles. Such a device is currently under development at HASYLAB for installation in the storage ring DORIS.

This paper describes the magnet, the radiation it produces and discusses the effects it will have on the operation of DORIS.

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2. The multipole wiggler magnet

The magnet will be installed in the straight section of DORIS which includes the electron injection elements. This site was chosen because:

(a) there is sufficient free space available to install a magnet $\gtrsim$ 1 m long, and

(b) the radiation produced by the magnet will shine into an area of HASYLAB available for development (see fig. 1).

In order to service experiments requiring short wavelengths ($\lesssim$ 10Å) the field in the magnet should be made as high as possible. However, space restrictions in the chosen area make the use of electromagnets impractical and so a solution utilising rare earth cobalt (REC) permanent magnet arrays has been sought.

A magnet comprising the conventional four blocks/period array produces a sinusoidal field with a peak value Bo given by$^{1)}$:

$$Bo = 1.80\, B_r\, (1-e^{-2\pi L/\lambda o})\, e^{-\pi h/\lambda o}$$

where B_r is the remanent field of the magnet material
h is the gap
L is the block height, and
λo is the magnet period.

Fig. 2 shows a schematic view of a magnet period.

Therefore in order to maximise Bo it is necessary to select a material with high remanent field and design the magnet with a small gap and large block height. The value of λo is a compromise between the two exponential terms.

There are however constraints on the design, the most important being on the gap and on the volume of REC material.

The minimum aperture is determined from the vertical beta function, β_z, of DORIS II 2) and the restricting aperture of the vacuum vessel in the main dipole magnets (50 mms). This gives an aperture at the wiggler magnet of 37.5 mms for the standard synchrotron radiation optic for HASYLAB and 32.0 mms for the colliding beam optic. It is proposed that the magnet be built outside the vacuum chamber (for ease of removal and field manipulation), so an allowance must be made for chamber walls and tolerances, bringing the minimum gap to 42 mms.

Fig. 3 shows the fields which can be achieved from a magnet array with four blocks/period and a gap of 42 mms, as a function of period, λo, and block height. The curves assume a remanent field of 0.95 T which is readily available in blocks of samarium cobalt. Also shown in this figure are curves of constant K, the deflection parameter, which defines the opening angle of the radiation through $\alpha = K/\gamma$. Note that when K = the electron energy in GeV, the full opening angle ≃ 1 mrad.

Thus in order to achieve the maximum magnetic field one should choose the maximum possible period and maintain $L \sim \lambda o$. However, for a magnet with fixed overall length the number of periods must decrease as λo increases defeating the very purpose of the magnet. Also increasing the block height makes the required volume of REC prohibitive.

The compromise reached for the DORIS wiggler is a magnet with λo = 120 mms, $L = \lambda o/4$ (i.e. square x-section blocks), and with a width of 100 mm to give an acceptable field uniformity at the centre of the aperture. This

gives a sinusoidal field with a peak value of 0.45 T, and with 10 periods gives the intensity spectra shown in fig. 4.

These spectra were calculated by dividing a full wiggler period into 22 segments and assuming each segment to have a uniform field given by

$$Bn = Bo \cos \left\{ \frac{2\pi\ (n-1)}{22} \right\} \qquad n = 1,\ 22$$

The spectrum from each segment was then calculated using the HASYLAB code "SPECTRA" and these were summed to obtain the final curves. No interference (or undulator) effects have been assumed. This assumption is reasonable in the immediate area of interest ($\lesssim$ 10Å), however at the fundamental undulator wavelength (172Å at 3.5GeV) and harmonics up to the order $\sim$10, the spectrum will be enhanced by interference effects. The positions of these harmonics are marked on the graph.

Spectra from the DORIS dipole magnets are shown for comparison. The immediate gains, assuming that an experiment cannot collect more radiation than is given by the opening angle, ($=K/\gamma$), are given in Table 1, for some wavelengths of particular interest at HASYLAB.

The total power emitted by a 100mA electron beam passing through the magnet is:

189 watts into 1.4 mrads (horizontal) at 3.5 GeV

386 watts into 1.0 mrads (horizontal) at 5.0 GeV.

By opening the magnet gap it will be possible to operate the wiggler at a lower peak field. This has two immediate benefits for users in the VUV region of the spectrum.

(a) It will increase the photon flux still further, and

(b) it will eliminate the unwanted higher energy radiation.

It is clear that the wiggler is a very versatile source of synchrotron radiation indeed.

3. The effects of the multipole wiggler on DORIS

The effects on DORIS can be divided into three parts:

(a) Since the wiggler comprises a series of parallel ended magnets it will produce vertical focusing and so modify the β_z function, the vertical betatron tune, Q_z, and any vertical closed orbit distortions.

(b) The magnet increases the electron energy loss/turn, so changing the synchronous phase angle and the radiation damping times, which in turn alter the electron beam size.

(c) Like all other magnets it is a potential source of field error, the most important arising through $\int B d\ell \neq 0$, giving rise to radial closed orbit changes.

All these effects have been investigated and shown to be negligible to first order of machine operation. At 3.5 GeV, where the effects are most pronounced, the relevent parameter changes are:

Change in vertical betatron tune, $\Delta Q_z = 1.0 \times 10^{-3}$ for HASYLAB optic
$= 0.8 \times 10^{-3}$ for colliding beam optic

Increase in radiation loss $\Delta U = 1.89$ keV/turn
$\frac{\Delta U}{U} = 5 \times 10^{-3}$

Residual dipole field $\int B d\ell = 1.7 \times 10^{-3}$ T-m, which
gives a net deflection of $\Delta x' = 0.15 \times 10^{-3}$ radians.

4. Conclusions

It has been shown that a REC multipole wiggler magnet can be inserted into DORIS without undue disturbance. The radiation spectrum it produces will benefit users who work with wavelengths >1Å. Table 1 tabulates these gains for specific regions of interest. With a mechanism which permits the magnet gap to be increased the spectrum can be specifically tailored for VUV experiments and indeed, in this mode the magnet may begin to show interference effects which will enhance the spectrum still further.

For future development it may be possible to increase the field in the wiggler by concentrating the field with ferrous pole pieces thus extending the useful range of the device into the sub-Angstrom region of the spectrum³⁾.

Presently the engineering problems associated with the design of the wiggler are being persued.

5. References

1) DL/SCI/TM30A Some aspects of the design of plane periodic permanent magnets for use in undulators and free electron lasers by M.W. Fan, M.W. Poole and R.P. Walker.

2) K. Wille, DESY-Report 81-047 and private communication.

3) K. Halbach, Design of Focussing and Guide Structures for Charged Particle Beams using REPM, Proc. 5th Intl. Workshop on REPM, Roanoke, 1981.

6. Acknowledgments

This work has drawn heavily on the report, reference 1, and we should like to thank the authors for their assistance during the course of the initial design work. Thanks are also due to the staff of HASYLAB, in particular Dr. W. Graeff, the author of the program SPECTRA, without whose help the production of the all important spectral distribution would have proven very time consuming, and also Prof. Kunz for many useful discussions. We especially acknowledge the help of Dr. H. Nesemann and Dr. K. Wille from the DORIS machine group.
One of us (A.J.) would also like to thank Prof. Kunz and Dr. Koch for giving him the opportunity to work on this project and also for the hospitality of all staff during his stay at HASYLAB.

Figure Captions

Table 1: The intensities in Photons/s·mA·mrad in 0.1% bandwidth and the gain obtained with respect to 1 mrad from a bending magnet at several wavelength (energies).

Fig. 1 : A schematic overview of the HASYLAB-Hall and the first quadrant of the DORIS-storage ring showing the site chosen for the wiggler and the position of the wiggler beam line in the experimental hall.

Fig. 2 : A schematic drawing of the permanent magnet blocks in the wiggler. One period is shown with the magnetic orientation of the blocks.

Fig. 3 : The magnetic field Bo as a function of the periodic length λo with a gap height of 42 mm and a remanent field of 0.95 Tesla. The shaded area is obtainable with different block heights L varying from λo/4 to ∞ (which is nearly reached for L = λo). Also drawn are curves of constant K which means a constant deflection angle at a specific energy. The cross at λo = 120 mm indicates the condition we have chosen for the wiggler.

Fig. 4 : The intensity of the radiation of the wiggler at 3.5 and 5 GeV. The spectra from a bending magnet are shown for comparison. The bars indicate the harmonics of the "undulator wavelength" where peaks due to interference effects could arise.

Table 1

λ [Å]	E [keV]	Intensity x 10^{-10} 1) at 3.5 GeV	 at 5 GeV	Gain 2) at 3.5 GeV	 at 5 GeV
1250	0.01	90	75	45	38
125	0.1	180	150	43	36
12	1	250	250	33	29
2.5	5	100	190	14	17
1.5	8	40	130	7	12
1.0	12	15	80	4	8

1) Intensity in Photons/s·mA·mrad in 0.1% bandwidth.

2) Gain with respect to 1mrad from a bending magnet.

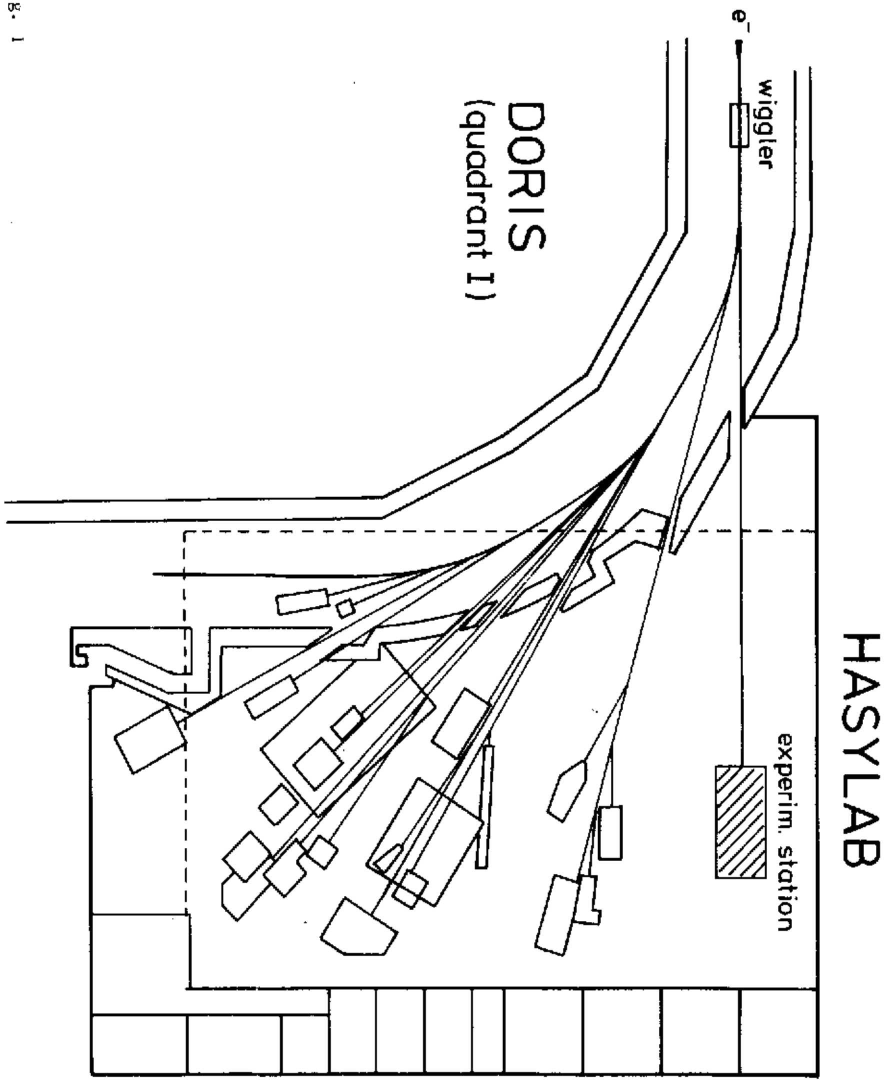

Fig. 1

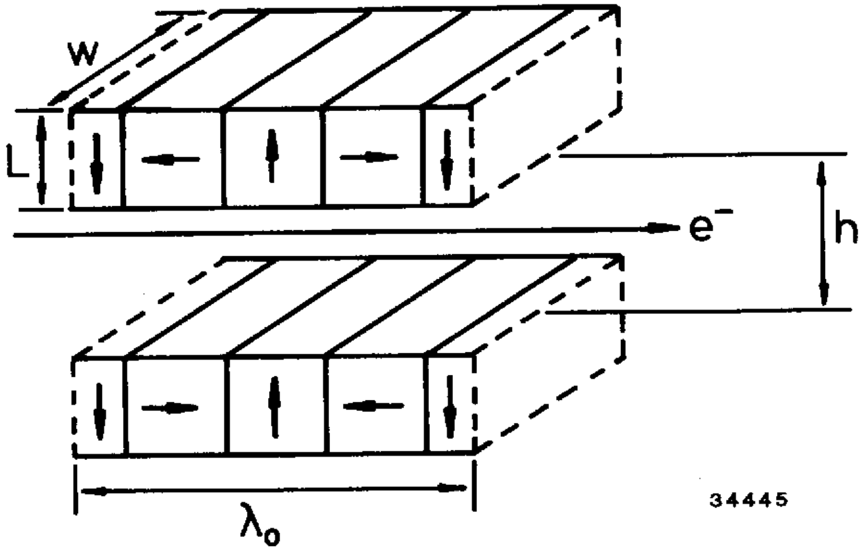
W
L
h
e⁻
λ_o
34445

Fig. 2

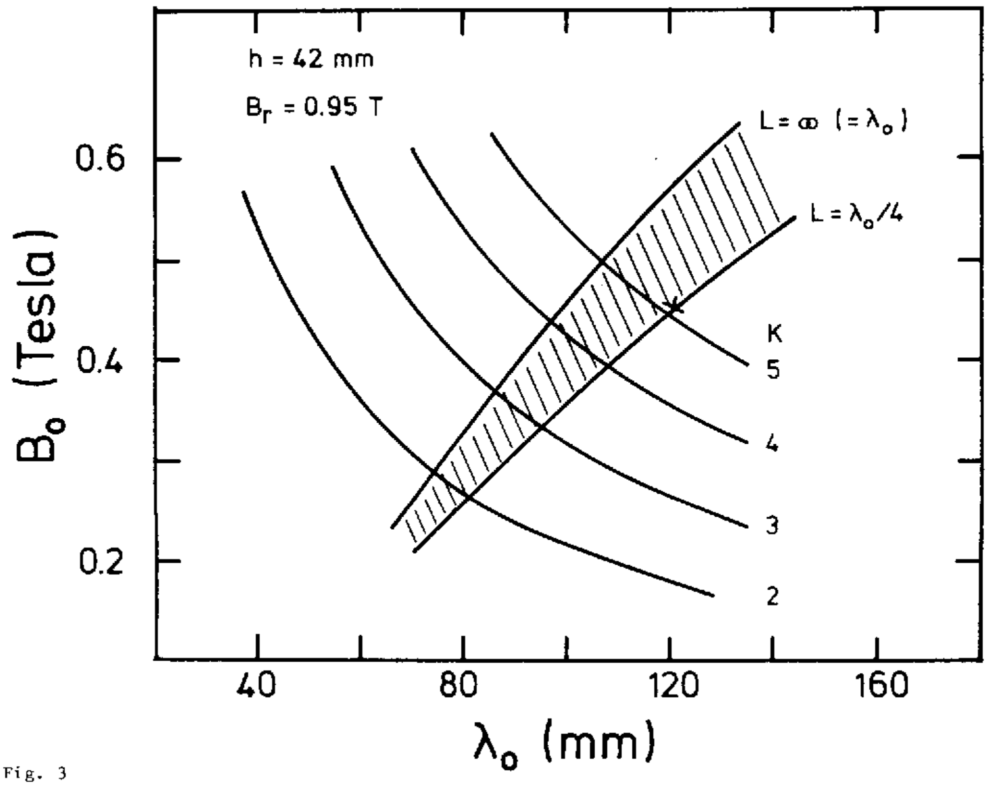
h = 42 mm
B_r = 0.95 T
$L = \infty$ $(= \lambda_o)$
$L = \lambda_o/4$
K
5
4
3
2
0.6
0.4
0.2
B_o (Tesla)
40
80
120
160
λ_o (mm)

Fig. 3

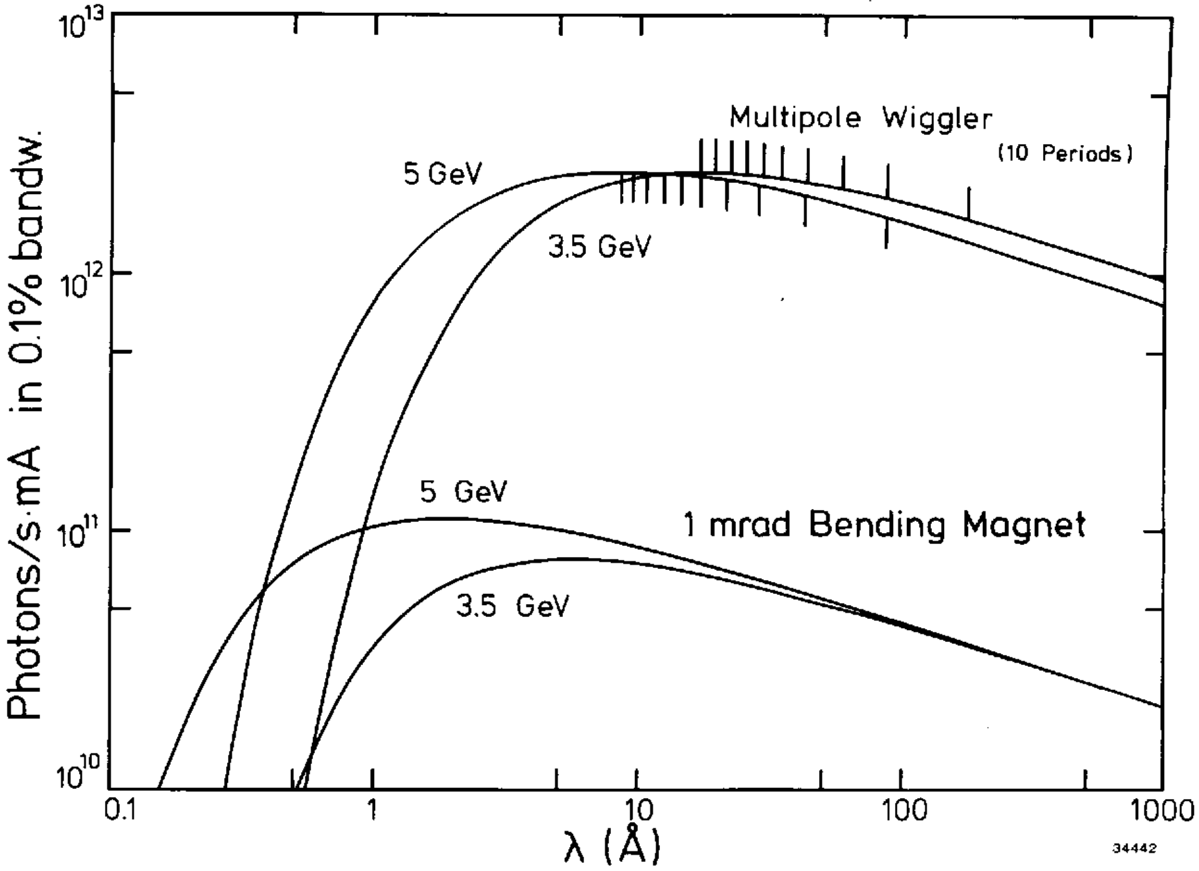
Photons/s·mA in 0.1% bandw.
10^{13}
10^{12}
10^{11}
10^{10}
Multipole Wiggler
(10 Periods)
5 GeV
3.5 GeV
5 GeV
1 mrad Bending Magnet
3.5 GeV
0.1
1
10
100
1000
λ (Å)
34442

Fig. 4