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THE 'ALL WIGGLER' SYNCHROTRON RADIATION SOURCE

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Abstract

The concept of wigglers as insertions in storage rings dedicated to synchrotron radiation is now old, but only recently have multipole wigglers for S.R. sources actually been brought into use. This confirmed the flexibility of such sources, though experience of matching experimental rigs to them is still somewhat limited. The flexibility arising from the use of wigglers, plus the fact that the radiation flux no longer depends only on the beam current and energy but can be adjusted, at each source point, by choosing the number of wiggler poles and the wiggler field, means that the efficiency of a synchrotron radiation source can be increased. Whereas a conventional x-ray ring may allow extraction of 10% of its radiated power, an "All-wiggler-Machine" (AWM) with 40 wigglers may allow 50% of its radiated power to enter the beam lines. This concept has been developed for the European x-ray source now under discussion and an example of an outline design is described in the paper.

1. Introduction

In 1979 the European Science Foundation published a feasibility study[1,2] of a 5 GeV storage ring which could be a European Synchrotron Radiation Facility (ESRF). As an extension to that study, this report describes a variant of the design in which all the ports are provided on multipole wiggler magnets.

Wigglers can easily be inserted into a magnet lattice at points where the dispersion is zero, and in this case they reduce the beam emittance. If inserted where the dispersion is non-zero the emittance is increased, but by balancing the two effects and restricting wigglers with the highest field to dispersion-free positions the total number of wigglers which can be inserted in a lattice of the ESRF type can be quite large.

Multipole wigglers have now been operated to produce synchrotron radiation in storage rings at Stanford[3] and at Frascati[4]. No difficulties have been encountered and it is clear that such devices can confidently be incorporated into designs for future machines. The main advantages are:-

a) The wigglers can provide the same spectra as bending magnets but each wiggler can be set to the optimum for a particular user and switched off if not in use.
b) Using multipole wigglers a given flux can be provided with a lower electron beam current, reducing the thermal load on vacuum chambers, the beam loading on the r.f. system, and instability problems.
c) The field in the dipoles can be decreased, reducing further the r.f. power and the vacuum loading. The magnet power can also be reduced.
d) The reduction in magnet and r.f. power will approximately compensate for the extra power demand of the wigglers.
e) The bending magnets can still be used as sources of lower-energy radiation.
f) Each wiggler can be considered as the first element in the beam line and specified to suit as regards maximum field, number of poles, length of poles, polarisation (horizontal or vertical) and so on.

However, the multipole wiggler presents an optical source which is considerably different from the arc of a bending magnet. The differences must be taken into account in the design of beam lines and experiments. Also, the spectrum from a wiggler varies across the beam line aperture (in the plane of the deflection) and may exhibit interference effects (as in an undulator).

2. Storage Ring Design[5]

Schemes have been examined for storage rings with energies from 2.5 to 5.0 GeV. Described below is a 5 GeV storage ring containing 48 wigglers. This particular example is based on the following assumptions:-

electron energy = 5 GeV (so as to provide the same spectral output from undulators as previously[1]);
total radiated power into the beam ports = 140 kW (as in the previous study[1]);
circumference = 909.6 m (to suit one possible location);
variation of λ_c across beam line aperture = ± 10%;

It is important to keep the length of the wiggler small for two reasons - for matching into the lattice; and to minimise the effective width of the radiation source. To achieve high values of intensity and brightness with a minimum beam current and minimum wiggler length it can be shown[6] that λ_c should be small. The wigglers are therefore divided into two groups: high field (W_o) which must be in dispersion-free regions, and lower field (W_p), which can be in regions of finite dispersion. For design study purposes the high field wigglers are all assumed to have λ_c = 0.5 Å, and the low field wigglers λ_c = 1.0 Å. The wigglers are all assumed to have six periods each 0.17 m in length.

The other general specifications are: (a) Beam emittance as low as possible. (b) Vanishing dispersion and low β_z in the short straights dedicated to high-field wigglers. (c) Long straights (~ 6 m) to be provided for undulators, with large values of the horizontal and vertical beta functions.

The lattice of one half superperiod is shown in fig.1; the lengths of all elements and the quadrupole

TABLE 1

ELEMENT LENGTH (m)		$K^2 (m^{-2})$	$K^3 (m^{-3})$
Q1 = 0.70	O1 = 0.20	Q1 = 0.668136	SF = 2.557
Q2 = 0.70	O2 = 0.30	Q2 = 0.787893	SD = 2.111
Q3 = 0.70	O3 = 0.25	Q3 = 0.781044	
Q4 = 0.70	O4 = 2.00	Q4 = 0.679090	
Q5 = 0.50	O5 = 2.80	Q5 = 0.635177	
Q6 = 0.70	O6 = 1.40	Q6 = 0.700000	
Q7 = 0.50	O7 = 0.40	Q7 = 0.210527	
SF = 0.20	O8 = 3.20		
SD = 0.40	M = 3.0185		

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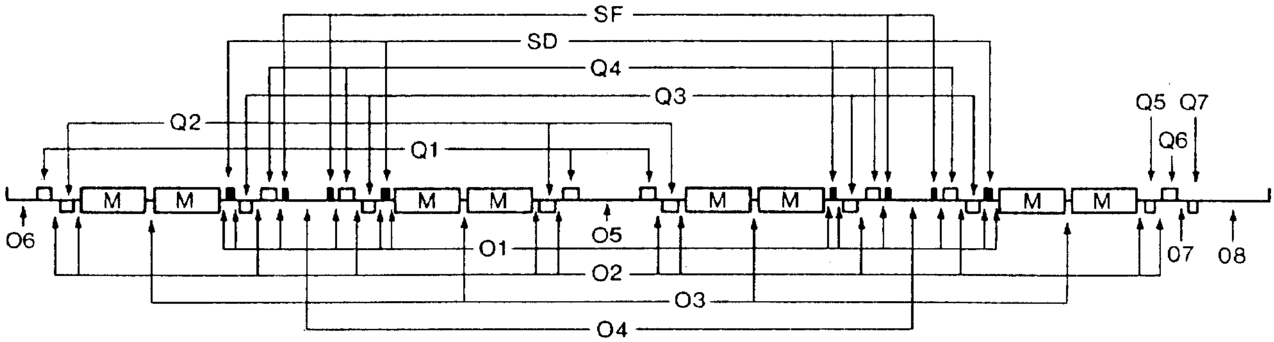

Fig.1 One of 16 half superperiods.

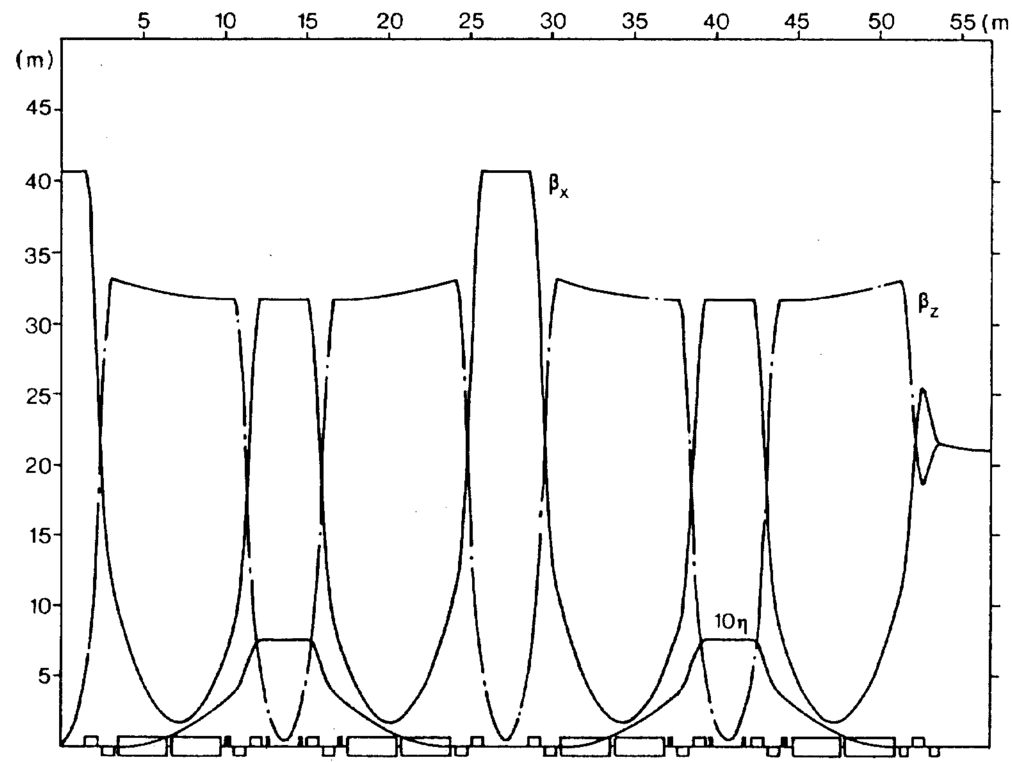

Fig.2 Optical functions β_x, β_z and dispersion η.

gradients are listed in Table 1, together with the sextupole strengths computed to give zero total chromaticity. The whole machine has 8 superperiods. Fig.2 shows the behaviour of the optical functions β_x, β_z and the dispersion function η.

Table 2 gives beam dimensions and divergences in the wiggler straights and at the centre of the bending magnets. The first figure given is for wigglers 'off', and the second for wigglers 'on'. Coupling is defined as $\varepsilon_z/\varepsilon_x = 0.1$.

Fig.3 shows the behaviour of the emittance as a function of the number of operating wigglers.

At 5 GeV, with all wigglers on, the current required to obtain 140 kW useful radiated power as in the previous study[1] is 132 mA.

A detailed parameter list is given in Table 3.

TABLE 2

	σ_x (mm)	σ'_x (mrad)	σ_z (mm)	σ'_z (mrad)
W_o	0.465 0.452	0.0114 0.0111	0.0146 0.0141	0.0364 0.0356
W_p	0.585 0.804	0.0129 0.0126	0.0150 0.0145	0.0354 0.0345
Undulator	0.335 0.325	0.0159 0.0154	0.106 0.103	0.0050 0.0049
Bending magnet 1	0.156 0.152	0.0572 0.0585	0.132 0.129	0.0041 0.0039
Bending magnet 2	0.149 0.197	0.0688 0.0866	0.131 0.127	0.0041 0.0039

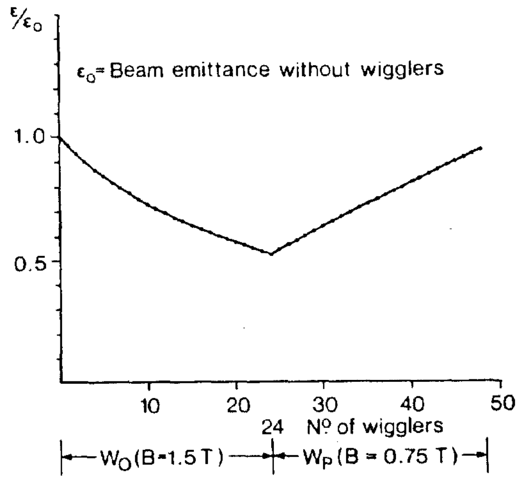

Fig.3 Beam emittance versus number of wigglers.

TABLE 3

Energy (GeV)	5
Circumference (m)	909.57
Bending radius(m)	61.49
Horizontal betatron wavenumber	26.20
Vertical betatron wavenumber	28.15
Horizontal uncorrected chromaticity	- 79.28
Vertical uncorrected chromaticity	- 106.13
Momentum compaction	7.25×10^{-4}
Horizontal beam emittance (m.rad)	5.31×10^{-9}
Horizontal beam emittance (wigglers on)	5.02×10^{-9}
R.m.s. energy spread (1 standard deviation)	5.47×10^{-4}
R.m.s. energy spread (wigglers on)	9.14×10^{-4}
Longitudinal damping time constant (ms)	1.69
Long. damping time constant (wigglers on)	0.75
Number of dipoles	128
Number of quadrupoles	272
Number of $\eta=0$ (W_o) wigglers	24
Number of undulators	6
Number of $\eta\neq0$ (W_p) wigglers	24
Number of sextupoles	128
R.f. frequency (MHz)	501
Energy loss per turn (keV)	899
Energy loss per turn (keV) wigglers on	2214
Total beam current (mA)	132
Beam power (kW) wigglers off	119
Beam power (kW) wigglers on	292
Total r.f. voltage (kV) wigglers off	1200
Total r.f. voltage (kV) wigglers on	3000
Max. Cavity dissipation (kW) (wigglers on)	125
Total r.f. power (kW) wigglers off	139
Total r.f. power (kW) wigglers on	417
Wiggler period (cm)	17.6
Number of periods	6
Maximum field (T) (W_o,W_p)	1.5,0.75
Critical wavelength (Å) (W_o,W_p)	0.5,1.0
Total radiated power per wiggler (kW)[7]	5.79,1.45
Useful radiated power per wiggler (kW)[7]	4.67,1.17
Full angle of extracted radiation (mrad)	4.0,2.0

4. The Wiggler as an Optical Source

The source is distributed non-uniformly along the length of the wiggler instead of uniformly along the arc of the bending magnet. This has to be taken into account in both the x and z directions.

To trace the source contour in the x, x' phase plane, consider the beam trajectory in the wiggler, in which the useful portions are where $B \geqslant 0.8\ B_o$ and fold all source points back so as to obtain a phase envelope at the centre of the wiggler.

By considering all source points and including phase space occupied by the beam itself, a phase space envelope as shown in Fig.4 is obtained. This envelope includes some approximations, but is in effect the envelope of the ellipses from each source point. It is most important to realise that the source intensity is not uniform inside the contour and, to explore more fully the consequences of using a multipole wiggler as a source, sample ray-tracing programmes should be tried using representative beam line optics. For comparison, Fig.4 also shows the equivalent diagram for the conven- 5 GeV machine.

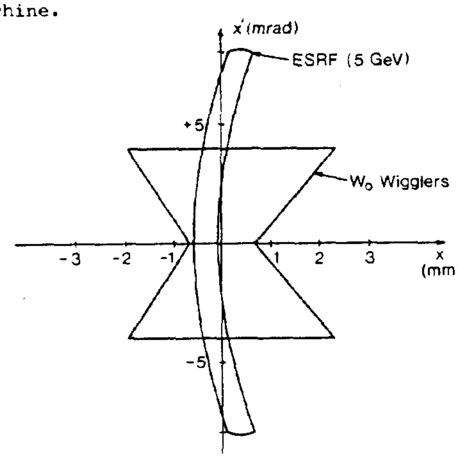

Fig.4

In the z, z' plane, each source point can be represented by an ellipse centred around z = 0, z' = 0, and these too can be folded back to the origin.

An additional complication arises, due to the focusing properties of the wiggler magnet in the vertical plane, if a vertical error in the closed orbit is present. The source distribution in physical space then becomes curved and this means that the centres of the various ellipses in phase space, instead of all being clustered around z = z' = 0, are now along a curve.

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