SOME DESIGN FEATURES OF AN ELECTRON STORAGE RING USED AS A PULSE STRETCHER

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Abstract

A storage ring designed for duty-cycle smoothing of a ~40 MeV linac beam is described. An energy-spread of only ~0.1% suffices for the coincidence-type experiments for which it is needed. This design is not basically achromatic but its performance is improved by suitably choosing the bending magnet second order field index[1] β; it has also appreciably fewer elements than earlier broad-band designs[2 3].

1. Introduction

While storage rings, in high energy physics, are usually planned for colliding beam experiments, an alternative application for temporary storage of a particle beam can be useful for increasing the duty cycle of a short-pulse linac; for the same mean current, an almost continuous beam may offer considerable advantages in experiments employing coincidence techniques. The ring technology used resembles that of higher energy rings in injection and beam storage, though the storage period is much shorter, and ejection techniques are similar to the "slow extraction" of synchrotrons.

For the Toronto linac (~40 MeV electrons), the researches planned[4] call for an incident electron beam with a narrow energy spread, so that monochromation is required. By putting this (or, at least, by arranging most of the energy-spread reduction) before the ring, a relatively simple ring design can be achieved. The linac beam current (within 2% - 3% in $\Delta E/E$) is initially over 0.5 A in a 365-ns. pulse, at 720 p.p.s., and a selection of a 35-50 keV range yields ~25 mA. Smoothed, this can give several microamperes, quite adequate for the experiments desired.

2. The "Basic" Ring Design

The injection and extraction points in both the ALIS[2] and the Saskatoon[3] rings were located in "achromatic" straight sections, i.e., where g = 0 (closed orbit position independent of energy). With $\Delta E/E$ (or $\Delta p/p$) ~25 times narrower, we abandoned this restriction. The basic design of Fig. 1 which then results is much simpler (fewer components) and probably cheaper. The orbit period is 73 ns. Fig. 2 shows the β-functions for horizontal (radial, or x) and vertical (z) planes and the g-function for half of this ring. The $\nu_x \approx 2.3333$ resonance was used for extraction, this value being approached from above, with $\nu_z \approx 2.12$. The 5-turn injection system needs perturbators to displace the closed orbit vertically; "coupled" injection is used, following closely the method proposed for Saskatoon[5]. However, with our lower particle energy a magnetic injection septum (v. Fig. 3) is proposed; an electrostatic septum, even a tilted one as proposed for the Saskatoon ring, appears unlikely to give as good lateral clearance for subsequent passage of the beam in the ring as Fig. 3 does. The field required inside the septum is only 100 Gauss; the design is basically similar to septa already used at much higher fields, although its small size puts it in the "watch-maker" class. It is important that the linac beam at this point be stable in position (as well as suitably matched), and these questions and the monochromation are still under study, for the proposed installation in Toronto.

3. Beam Extraction and X-plane Phase-Space

For the one-third integral horizontal extraction, a "hollow" beam in x-plane phase space is desirable. Injection occurs while the sextupoles ($H_{(+)}$, $H_{(-)}$, Fig. 1) are energized, without any deleterious effect on the stored-beam quality (v. Fig.4). Fig. 5 illustrates the cycle of operation, with the injection period shown on an expanded time-scale. Rapid de-energization of the perturbators is crucial; the electrostatic pulsed quadrupoles (p.q.) change strength only later and more gradually. Extraction begins when the plots like Fig.4 become triangular and touch the separatrices of the stability triangle; typically at injection the p.q. strength is 0.09 m^{-2}, ejection occurring within the range $+.028_5$ to $-.030$ m^{-2} (ν_x change during ejection about 0.006 for $\beta = 0$; see below for $\beta \neq 0$).

The storage period never exceeds the linac pulse interval (about 1.4 ms.) allowing about 19000 orbits for the last electrons extracted. It is possible to vary the p.q. strength non-linearly with time, to obtain a nearly-constant extracted current, although what is desired is also to have a time-independent extracted beam spectrum.

Fig. 6(a), for $\beta = 0$ bending magnets, gives curves for the area of the stability triangle vs. energy (with p.q. strength as

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a parameter), and quadrilateral ABCD, where AB and DC respectively plot vs. energy the total area and the hollow-portion area in x-phase-space (cf. Fig. 4, different plots needed for each E) for the stored beam. As extraction proceeds, the variation of p.q. strength leads to the sweeping out of the ring of successive parts of this "occupied" quadrilateral, and the early ejection of higher-energy electrons and later ejection of lower-energy ones is clearly apparent.

The behaviour can be improved rather simply. Due to having chosen an odd sub-harmonic resonance, $\nu_x = 7/3$ (7 being odd), extraction is caused by nonlinearities which must be anti-symmetrical ($H_{(+)}$, $H_{(-)}$ in Fig. 1) across the ring. A symmetrical term added (either by choosing sextupoles of numerically unequal strengths, or by varying the bending-magnet β) is found not to affect the area of stability S_Δ for the nominal energy, but to change the slope of constant-p.q. lines in Fig. 6. If all four bending magnets are designed to have β = 0.375 (a not uncommon value), we obtain the results of Fig. 6(b), and a further improvement, Fig. 6(c), is obtained for β = 0.475. For the latter case it is seen that the start of extraction for particles of all energies occurs together. Even for further energy-monochromation of the extracted beam a duty cycle in the region of 92% to 96% should be readily achieved. However, this advantage is obtained at the expense of some reduction of the change in p.q. strength during ejection, and an increase in precision of the magnetic quadrupole fields may be required in order that the onset of ejection should remain correctly timed. This precision, of the order of 1 part in 15000-20000, should not be too difficult to attain as a stability against drift, but special procedures may be needed when setting up the ring - e.g., one may have to widen the p.q. variation temporarily and observe the time-of-onset of ejection in order to adjust the fields of one or more quadrupoles to their desired values.

Two recent studies[6]) of the effects of sextupole terms on resonant extraction suggest that choosing $\beta \neq 0$ is undesirable. Our detailed particle tracking calculations appear to show that this problem does not arise in our ring. For example, Fig. 7 gives, for three energies, the triangles of stability for a typical p.q. strength, and points from particle tracking indicate the shape of the asymptotes along which particles emerge. Although these asymptotes are curved, the resulting extracted beam conditions (emittance, etc.) appear reasonable (e.g. horizontally we get ≈ 40 mm-mradians).

4. General Remarks and Conclusion

While further information on the Toronto linac beam is awaited, before a final design is computed, the present study promises good energy characteristics from a basically non-achromatic ring. Instability problems for a 1.4 msec max. storage period appear minimal, with a circulating current of say about 0.1A, and vacuum requirements will be modest.

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APPENDIX - Ring Constants

Orbit circumference 21.883 m (v. Fig. 1). For this design the admittance required at injection septum is 4(in x), 5(in z) mm-mrad.

Fixed magnetic quadrupole strengths:

F	D	F_1	D_1
5.45114	-5.09307	3.85255	-3.63934 m^{-2}
68.14	63.66	48.15	45.94 G/cm

(G/cm given for $B\rho$ = 0.125 T-m electrons)

Perturbator strengths (in milliradians)
P_1 = 2.5243 P_2 = 1.9199 P_4 = 6.1774

In Fig. 1: I,E are injection, ejection septa; each element lies to left of position shown.

Fig. 4 is for $\Delta E/E$ = +0.05%; scale 2.54 mm (0.1 in.) as printed = 1 mm or 1 mrad in x.

References

1. Notation: β (without subscript) as in J.J. Livingood, Optics of Dipole Magnets, Academic Press, N.Y. 1969, p. 222; all other notation is as in ref. 3.

2. ALIS, project report, R.A. Beck et al, presented by H. Bruck at 7th International High Energy Accelerators Conf., Erevan, 1969, and references cited therein (see also op. cit., vol. I, p. 629).

3. R. Servranckx and J.L. Laclare, pp 204, 207, IEEE Trans., NS-18, no. 3, 1971, and references cited therein.

4. J.W. Knowles, AECL report CRNL-511, 1971, (unpublished) and J. Goldemberg, priv. comm.

5. See Laclare and Servranckx, p. 207 (loc. cit. ref. 3), and reports cited therein, especially SAL-RING 17 and 22.

6. M. Month and E.D. Courant, Particle Accelerators, 2, p. 105, 1971, and R.W. Chasman and M. Month, ibid., p. 109.

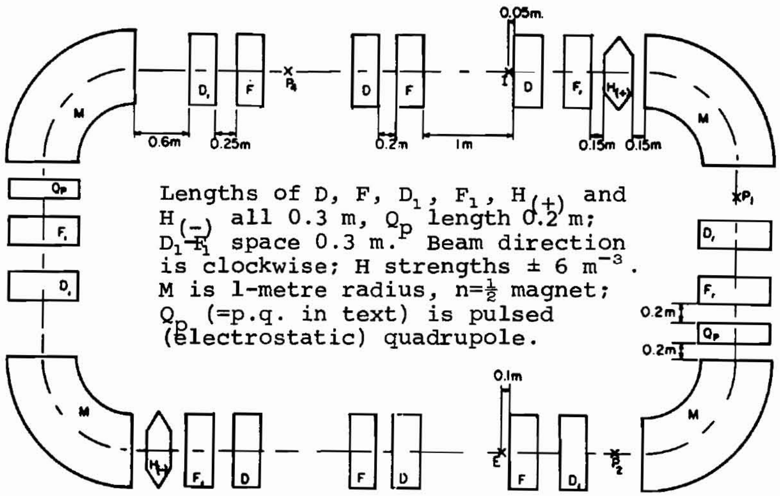

Fig 1. Schematic of Storage Ring

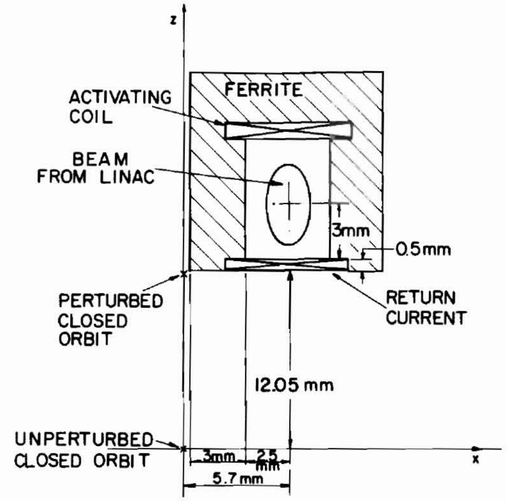

Fig 3. Injection septum; can be mounted from top or right hand side.

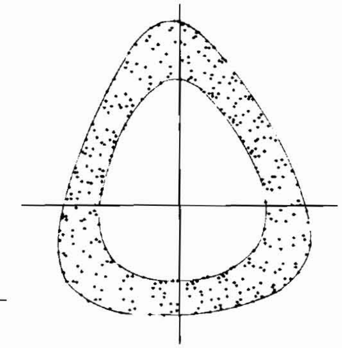

Fig 4. X-phase-space diagram for beam after injection.

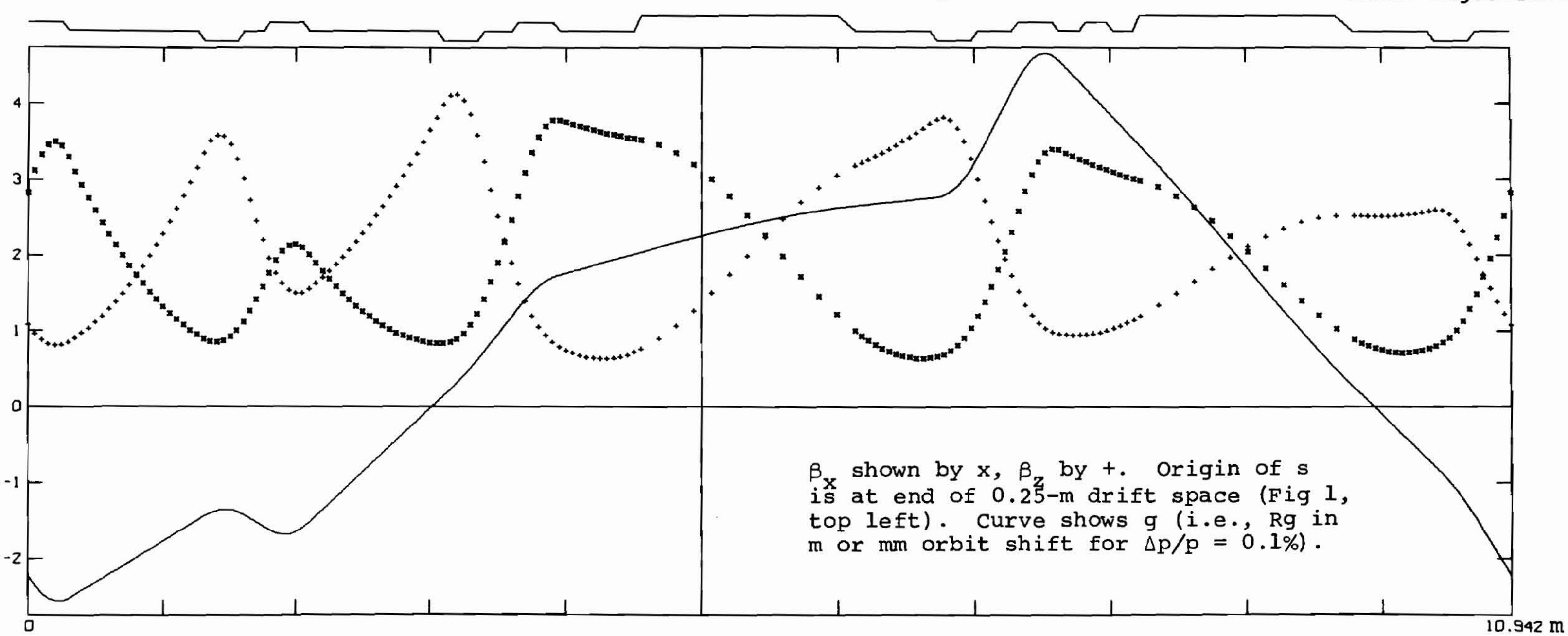

Fig 2. β and g-functions vs. s for half the ring (β and s in m). Line above graph indicates position of components.

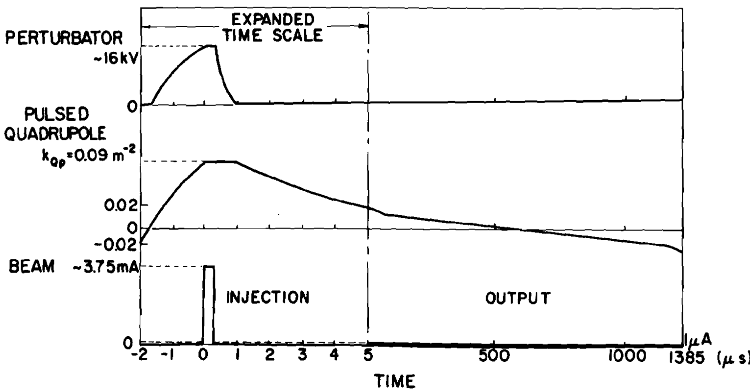

Fig 5. Mode of operation (schematic).

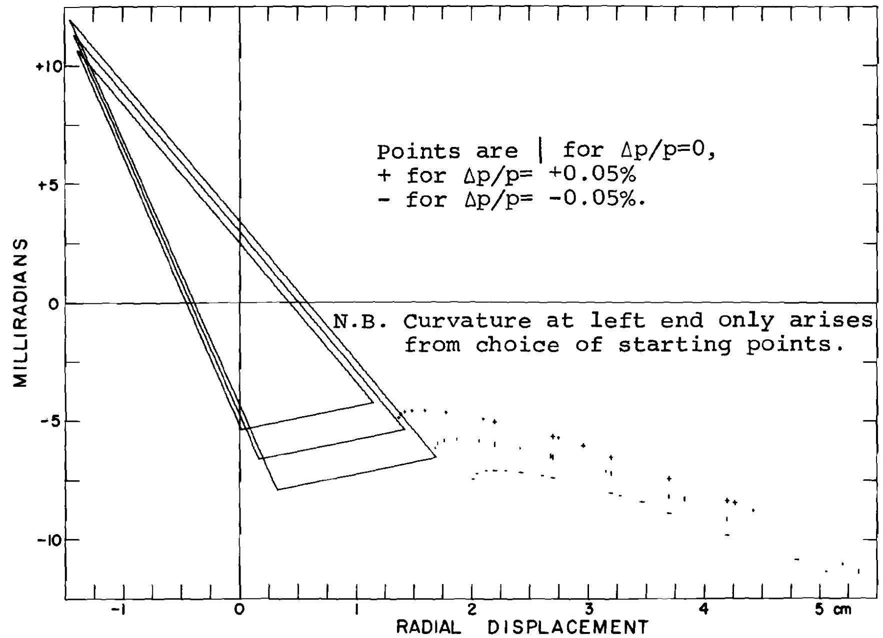

Fig 7. X-phase-space stability triangles and points showing trend of asymptotes (starting positions arbitrary).

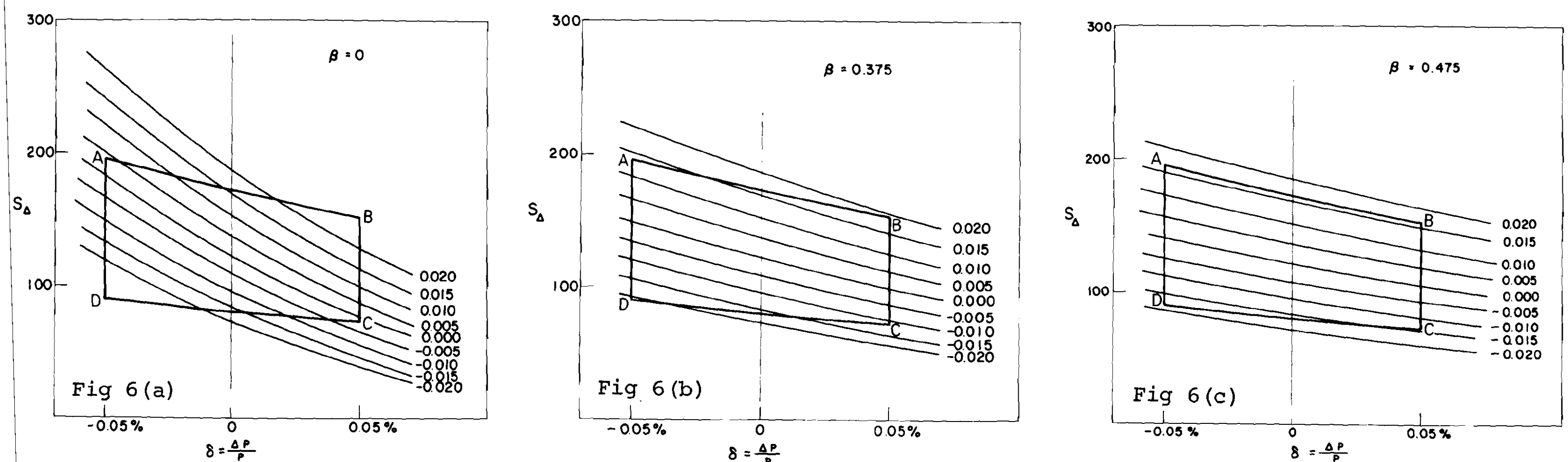

Fig 6. X-phase-plane areas (mm-mrad) vs. E; p.q. strength as parameter for s_Δ.