THE DESIGN OF DOUBLE SIDED MICROTRONS

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Summary

A severe problem in the design of double sided microtrons (DSM) which could supersede the race track microtron (RTM) in the 1-2 GeV range mainly because of its smaller magnet weight is the strong vertical defocusing in the bending magnets. Several possibilities to overcome this difficulty are discussed and a special beam optical design making use of the large longitudinal stability of the DSM is presented.

Introduction

The acceleration scheme of the double sided microtron (fig.1) has been mentioned by several authors many years ago but it was not considered to be promising because of its extremely critical beam optics. Because of the demand for a cw accelerator in the 1 GeV range its properties were recently investigated in more detail and a possible way to overcome the beam optical difficulty was shown [1]. After that the DSM has been proposed in a different design as a 2 GeV cw electron accelerator [2].

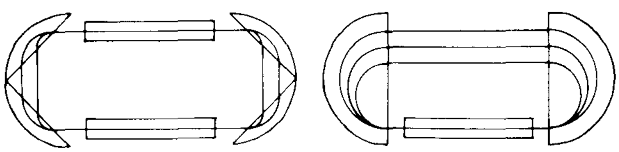


Fig.1 Scheme of DSM and RTM

General Properties

In tab.1 the general properties of the DSM and RTM are summarized. The bending system of the DSM originates from the 180° magnets by cutting two 90° segment magnets from each of them which leads to a reduction of the active pole face area by a factor $(\pi-2)/\pi = 0.36$ and consequently to a large saving of iron. Therefore, the end energy of a DSM is about twice the end energy of the RTM for the same magnet weight. Because of the coherence condition and the geometry of the system the energy gain per linac and the distance between successive turns is increased by the factor $\pi/(\pi-2)$ for the DSM. By the fact of having two accelerators on the circumference the longitudinal stability is considerably larger.

While the horizontal beam transformation in the segment magnets is simply parallel to parallel a severe problem, however, is given by the strong vertical defocusing in the fringe fields (fig.2). Since the DSM would be a relatively large device with about 20 m linac length stable particle motion seems not to be possible with focal length below about 1 m. As one can see from the diagram in fig. 2 acceleration would therefore only be possible with an uneconomical high injection energy of about 1300 MeV.

	DSM	RTM
pole face area (R_p = pole radius)	$2(\pi-2)R_p^2$	$2\pi R_p^2$
end energy for a total iron weight of 320 t	1.5 GeV	0.8 GeV
distance between subsequent turns (m = 1; λ = 12.24 cm)	$m\lambda/(\pi-2)$ (10.8 cm)	$m\lambda/\pi$ (3.9 cm)
energy gain per turn (B = 1.5 tesla; λ = 12,24 cm; m = 1)	48.3 MeV	8.8 MeV
first order longitudinal stability range for the synchronous phase (m = 1)	$-51.9^0<\phi<0^0$	$-32.5<\phi<0^0$
transverse beam optics	vert.defoc. hor.neutral	neutral

Tab.1 Main parameters of DSM and RTM

Reduction of Vertical Defocusing

A modification of the field distribution in the 90° segment magnets for a reduction of vertical defocusing leads in general to a non linear relation between path length and particle momentum (fig. 3). The coherence condition which requires a

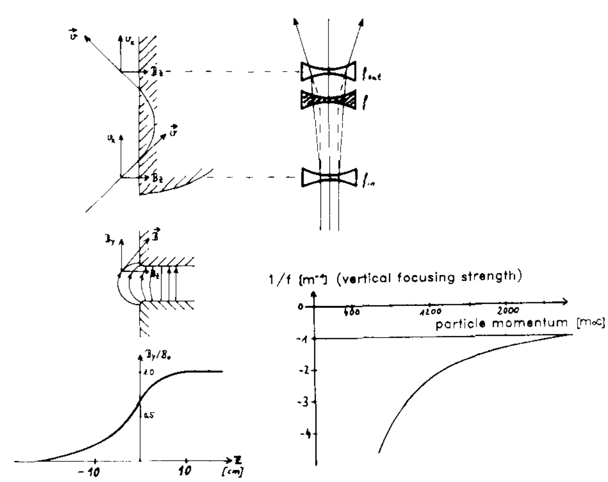


Fig.2 Vertical defocusing in a segment magnet

path length increase of one (or several) wavelength λ from linac to linac for successive turns can nevertheless be maintained if the momentum gain Δp varies in the right manner during the acceleration. The possible variation of Δp is determined by the allowed range of the synchronous phase Φ. In a DSM longitudinal oscillations are stable as long as Φ moves between 0° and -51.9° (the strong instability around Q = 1/3 is not important if the synchrotron frequency changes continuously in this region). Therefore, Δp and with it the longitudinal dispersion Δs/Δp may vary between 100 % and 63 %, in

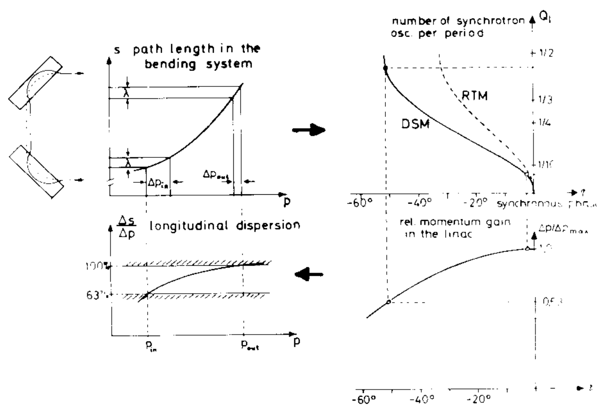


Fig.3 Possible variation of the longitudinal dispersion in a DSM

principle, during the accelerating process. If the variation is smooth enough one can find input phase and input energy combinations for which the synchronous phase varies slowly and without oscillations.

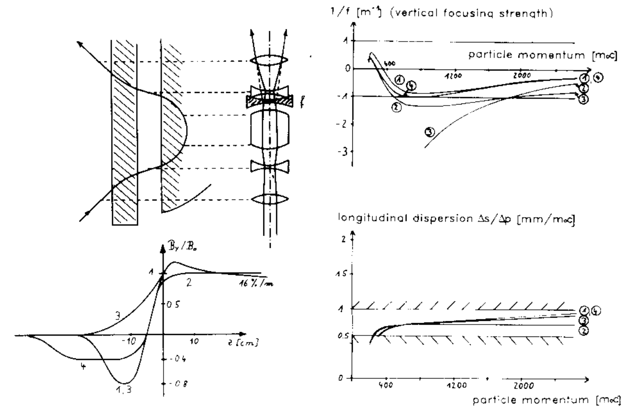
In fig. 4 a,several two dimensional field distributions are shown and the vertical focusing strength as well as the longitudinal dispersion as functions of the particle momentum p obtained from a ray tracing program are given. For the field curves 1 and 4 both with reverse field stripe and field gradient the focal length is always larger than 1 m for energies above 100 MeV. Of course, the longitudinal dispersion is no more constant so that a lower limit for the injection energy for the distribution 2 (without gradient) and limited energy ranges for the curves 1, 3 and 4 are defined.

Vertical beam optics can be further improved by adding a second reverse field stripe at a certain inclination angle in respect to the main pole edge which has more effect at medium energies (fig. 4 b). Unfortunately, the variation of Δs/Δp is relatively large in this case so that the possible energy range of the DSM is significantly reduced. Moreover, additional effort is needed in the horizontal plane to correct for the bending angle and for the angular dispersion.

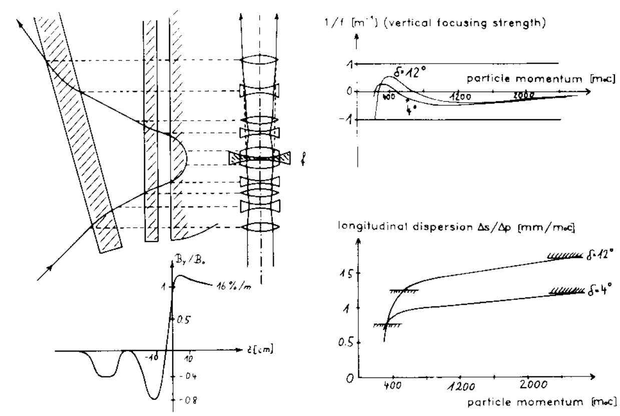
The use of pole face rotations on the entrance and exit of the 180° bending systems represents another very effective possibility for the reduction of vertical defocusing without influence to the longitudinal dispersion. As one can see from the diagrams in fig. 4 c, however, the resulting horizontal focusing is rather strong and additional measures are required for horizontal focusing and achromatic transformation. On the other hand, it would be obvious in this case to maintain a constant betatron frequency in the horizontal plane too.

Beam Optical Design Example

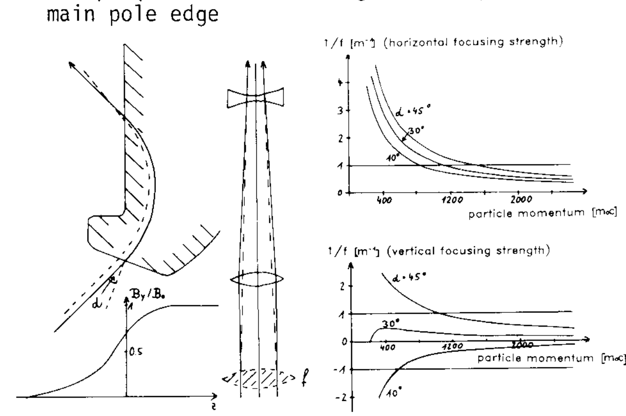
In fig. 5 the scaled scheme of a 1.3 GeV-DSM and its beam optical properties obtained from a ray tracing simulation program are represented. The rest defocusing of the two dimensional field distribution 1 (fig. 4 a) is compensated by a



a) two dimensional field with reverse field stripe, field enhancement and gradient



b) distribution a 1 with a second inclined field stripe (δ: inclination angle in respect to the main pole edge



c) homogeneous segment magnet with pole face rotation

Fig. 4 Focusing strength and longitudinal dispersion as functions of the particle momentum for different field configurations (B_0 = 1.24 Tesla)

horizontal parallel to parallel acting quadrupole doublet in such a manner that the shape of the acceptance ellipse taken in the middle of the linacs'is kept constant. Horizontal focusing is

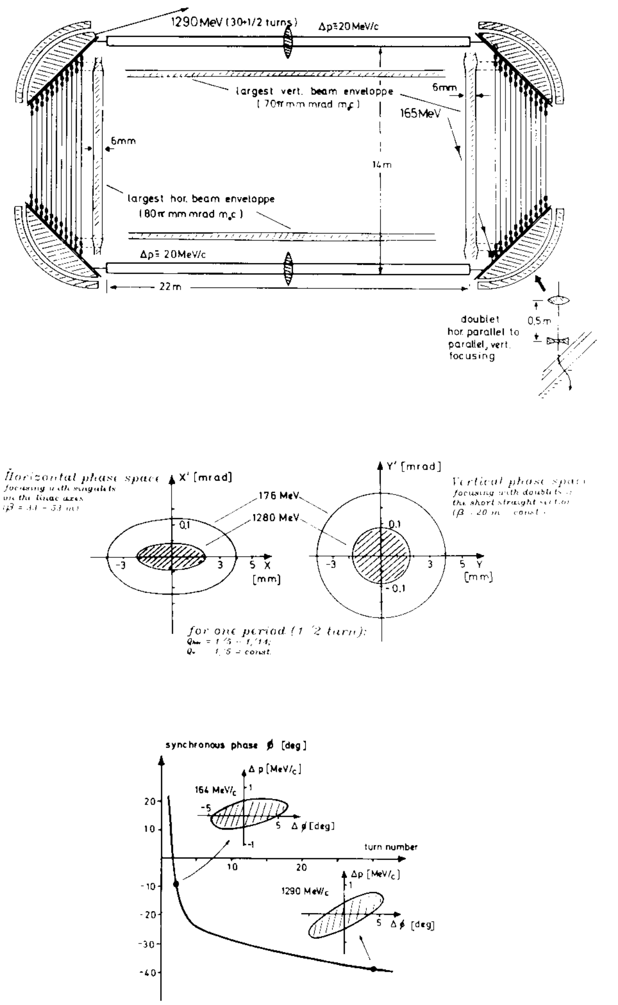


Fig. 5 Scaled scheme of a 1.3 GeV-DSM with phase space areas at input and output energy

done only with two singulets in the middle of each linac. The vertical acceptance is limited by geometrical aberrations in the segment magnets to about 0.8 π mm mrad at 176 MeV. The influence of chromatic aberrations is relatively small so that betatron oscillations are stable for the phase space area shown even for $\Delta p = \pm\ 0.5$ MeV/c. Due to the reverse field and the field gradient in the dipoles the synchronous phase is shifting from -10^{0} to -40^{0} during the acceleration with only a small change in the longitudinal acceptance area.

Conclusion

The problem of beam focusing in a DSM may be solved provided that the injection energy is not too low and the tolerances in the optical elements can be kept sufficiently small. The acceptance is much larger than the emittance to be expected from a RTM-injector. However, the problem of alignment and setting of the numerous quadrupoles is not yet discussed and would, at least, require a powerful beam diagnostic and control system. Further attention must be payed to beam diffusion effects by quantum synchrotron radiation and field imperfections.

References

1 K.H.Kaiser, Proceedings Conference on Future Possibilities for Electron Accelerators, Charlottesville, Virginia, 1979

2 H.Jackson et al., ANL-report, ANL-PHY-79-2, Argonne National Laboratory, 1980