EUTERPE, a ring facility for the Eindhoven cyclotron laboratory,

J.I.M. BOTMAN, H.L. HAGEDOORN,
Eindhoven University of Technology, The Netherlands

We present aspects of a proposed mini ring EUTERPE to be built at the Eindhoven University of Technology (EUT) for the study of atomic processes. The ring will be fed from the mini EUT cyclotron ILEC (3 MeV protons) or alternatively by a 25 MeV electron linac. The end energy of the ring is designed as 50 MeV for protons, corresponding to 300 MeV for electrons. Protons will be accumulated over many turns to provide very short beam pulses by suitable RF manipulations. The purpose of the electron beam is the production of synchrotron radiation (visible light, VUV, soft x-rays) in the bending magnets or in a superconducting wiggler. In the electron mode of operation the Compton back scattering of laser light for obtaining hard x-rays will also be studied. The ring has to be designed and built by students of our university. It also will serve as an experimental tool for investigating accelerator physics aspects such as space charge phenomena, non-linear beam dynamics, longitudinal phase space manipulations, etcetera. Apertures of dipoles and quadrupoles will be small for low cost.

Introduction

The Nuclear Physics Techniques group of the Eindhoven cyclotron laboratory has a long tradition of research of accelerator applications employing the variable energy, maximum 30 MeV proton cyclotron. Experiments include PIXE and micro-beam analysis, neutron activation, wear research, isotope production, and Rutherford back-scattering for depth profile measurements. A laser group investigates production rates of short-lived isotopes in gaseous targets. For PIXE and for the microbeam a special small 3 MeV cyclotron ILEC (Isochronous Low Energy Cyclotron) has been built (1), mainly by students of our physics department. It has an extraction radius of 17 cm, and operates at the second harmonic: 43 MHz. Moreover a flattop system will be added.

Plans have arisen to build a small accelerator and storage ring in order to be able to extend applications over a wider range of atomic physics research, and to have an instrument for investigating accelerator physics phenomena. The injector will be the ILEC cyclotron, the end energy is put to 50 MeV protons. This corresponds to a momentum of about 300 MeV/c, hence the ring can also contain 300 MeV electrons: quite useful for synchrotron radiation.

The electron injector will be a conventional 25 MeV linac as used in many hospitals for radiation therapy. Having a synchrotron radiation source fits with another tradition of our institute: former colleagues were involved in the design of the proposed PAMPUS light source (2). The name of the project is EUTERPE: Eindhoven University of TEchnology Ring for Protons and Electrons. She is the Greek muse of music and is often represented with two flutes, which is a good symbol of the dual character or our ring

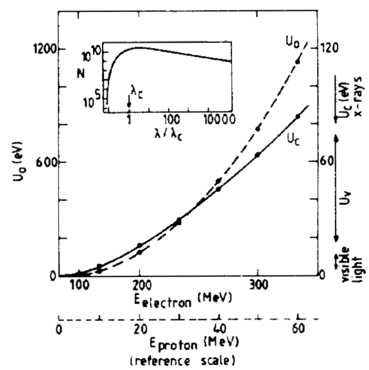

Fig. 2
Critical energy and energy loss per turn. Insert: universal synchrotron radiation spectrum:
N = photons/s/mrad/mA/GeV in 0.1% band-width

Deliberately a small scale project has been chosen. A fast construction time is not of prime importance. This means that construction of many parts can be done in the workshop of our university. This means a large portion of hidden cost (labour) and a relatively small capital investment of our group. Students design and calculate the components of the ring: bending magnets, cavities, injection and extraction devices, etcetera. The construction of ILEC has taken about five years, and has cost about k DFL 400 (k $ 200). EUTERPE is thought to cost double that amount. Due to the complexity of the small cyclotron (central region, magnetic field shape, RF) we think (and hope) that ILEC compares to EUTERPE like a wrist watch is compared to an alarm clock. Fig. 1. shows a proposed lay out of the ring in the existing experimental hall.
The kind of synchrotron radiation to be obtained with EUTERPE is illustrated in Figure 2 which shows the critical energy and the energy loss per revolution versus energy, for a bending radius of 1 m. With superconducting elements in the ring the region of x-rays is opened up even further.

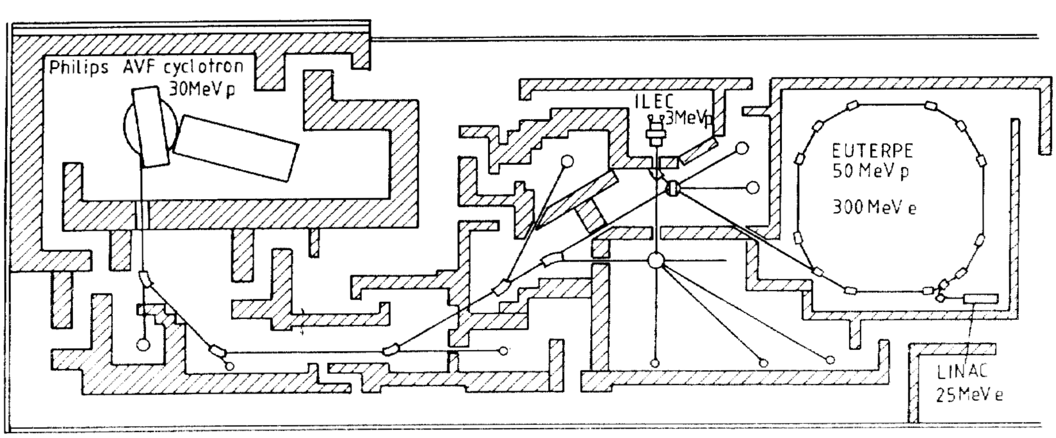

Fig. 1
Proposed lay out in the experimental hall

CH2387-9/87/0000-0488 $1.00 © IEEE

For protons, or other light ions, the aim is to make a very sharp energy definition, or alternatively very short pulses. This is illustrated in figure 3. Two bunchers, A and B, are located in the injection and extraction beam line. The synchrotron is used purely as drift and guides the ILEC bunch for say five revolutions. The action in longitudinal phase space is given in figure 3: in order to obtain short beam pulses buncher A is switched on, for a sharp energy definition buncher B is used. Details of this scheme still have to be worked out, but for instance beam pulses 100 ps wide should be obtainable.
In this status report we present initial design aspects and calculations. The parameters of the ring have not yet been finalized.

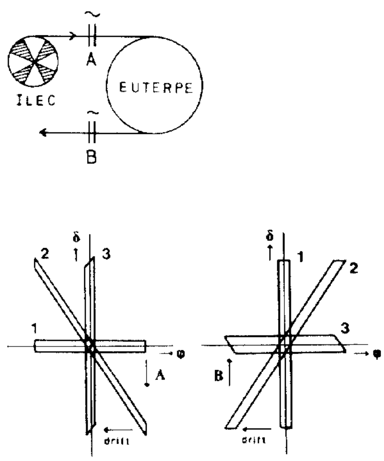

Fig. 3 Effect of buncher A and B in longitudinal phase space: A: short pulses, B: sharp energy. EUTERPE is purely drift.

Design aspects

The ring circumference is 30 times that of ILEC which is large for the maximum energy contained: 32 m. This leaves ample room for special devices such as undulators and wigglers, a free electron laser, a foton electron interaction region for Compton back scattering of laser light and also for cooling equipment when running protons.
A beam lifetime of a couple of hours is enough. Therefore we decided to use small apertures, hence reducing the cost. The aperture is much larger than the 12 σ requirement to garantee a long quantum lifetime. The Touschek lifetime and lifetime due to scattering with the residual gas still have to be estimated.
Dipoles have a gap of 2 cm, giving rise to a small overall magnet size: 40 cm long, 33 cm high, 26 cm wide.They will be laminated using transformer steel of 0.35 mm thickness. This allows for the highest repetion rates of synchrotron ramping. In future these elements can be used for a rapid cycling synchrotron as injector to a higher energy storage ring.

Lattice and beam dynamics

For simplicity of design and for operational flexibility and convenience a FODO type lattice was chosen. The phae advance per cell is relatively high in order to have a low emittance electron ring. Four superperiods with double achromatic sectors leave long dispersion free straight sections to be used for instance for the cavities to avoid synchrobetatron coupling, and for wigglers. Rectangular magnets are employed, causing some perturbations in the vertical betafunctions due to the edge focusing.

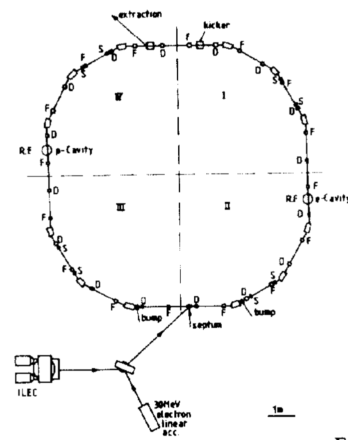

Fig. 4 Machine lay out.

Figure 4 shows the machine lay out, figure 5 gives the lattice functions in one superperiod. The working point (5.23, 4.22) is comfortably away from structural resonances. The nearest ones are: $\nu_y = 4$, which appears in all orders, the third order resonance $3\nu_x = 16$ and the fourth order resonance $3\nu_x + \nu_y = 20$. A parameter list of the machine is given in table 1. For the lattice studies we have made use of the code DIMAT (3).

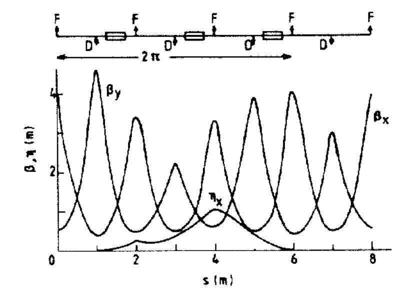

Fig. 5 Lattice functions

One pair of sextupoles per superperiod is sufficient for chromaticity correction. Figure 6 gives the tune dependence on momentum for the situation with sextupoles switched off, for one pair and for 6 sextupoles per superperiod. In the last case a focusing and defocusing sextupole is used in each "full" cell around the dipole. This gives the best tune dependence (curves 3a and b), however two sextupoles are in a region of zero dispersion so don't really function. Moreover induced geometric distortions are larger than for just one pair of sextupoles. For this case figure 7 shows the phase space area for tracking of protons over 400 turns at 3 MeV and at 50 MeV, where at 3 MeV they occupy the largest available aperture. This shows stable behaviour of the proton beam, which certainly garantees safe operation with electrons, the electron emittance being much smaller.

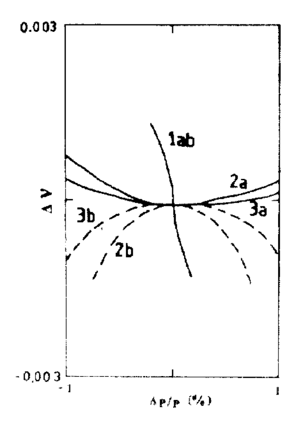

Fig. 6 Tune dependence per sector on momentum: 1ab no sextupoles, 2a,b: $\Delta\nu_x$, $\Delta\nu_y$ with 1 pair of sextupoles, 3a,b: for 3 pairs of sextupoles.

Five turn injection from ILEC in EUTERPE means 300 ILEC pulses corresponding to a maximum of $4.4\ 10^6$ particles, asuming ILEC gives 100 μA CW. This corresponds to a current of 0.5 mA in the ring. Direct space charge detuning is given by the equation:

$$\Delta\nu = -\ Nr_p/(2B_f\epsilon_v\beta^2\gamma^3)$$

where r_p is the classical particle radius, B_f the bunching factor (1/12) and ϵ_v the vertical emittance. Inserting numbers and using the full vertical aperture (~5 mm), we get $\Delta\nu = -\ 0.05$, which means that in practice operation is not near the space charge limit. For electrons, assuming 100 mA corresponding to $N = 6.67\ 10^{10}$, image terms are more important than direct space charge (4), however due to the large γ-factor the space charge detuning is still limited to $\Delta\nu = -\ 2.3\ 10^{-3}$, at 25 MeV. For injection of electrons we consider filling the ring during successive acceleration and deceleration, allowing the electrons to damp at 300 MeV (damping time ~60 ms in between two injected linac pulses. The gamma-transition value $\gamma_t \cong \nu_x$ is 4.43: the machine operates below transition for protons, above transition for electrons.

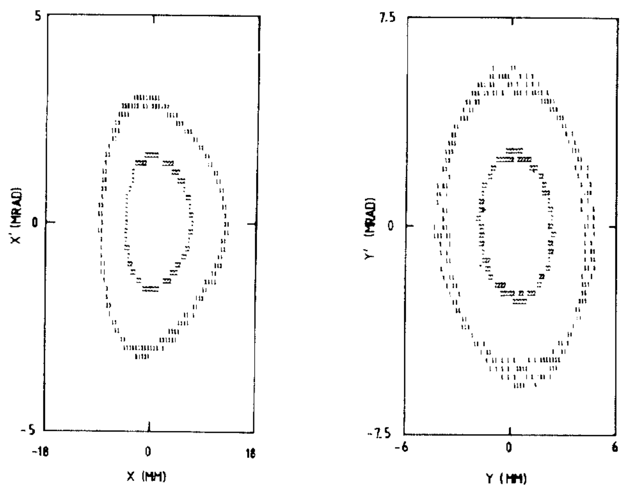

Fig. 7 Phase space plots from tracking 400 turns.

Modifications to the regular FODO lattice have been studied. A doublet lattice offers larger drift spaces and is preferred. Figure 8 shows the effect of changing the dipole position in the doublet cell on electron equilibrium emittance and momentum compaction factor, confirming the proportionality between these quantities (5). For lowest emittance the dipoles will be positioned near defocusing quadrupoles. With 10% coupling between horizontal and vertical motion the dipole gap is still sufficiently large.

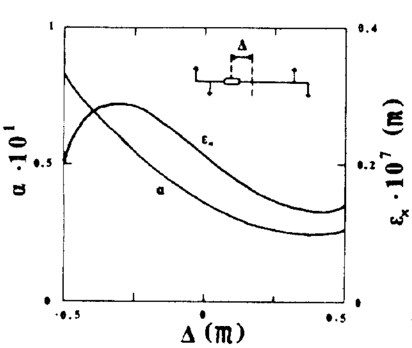

Fig. 8
Effect of changing dipole position in doublet cells.

Hardware

Initial POISSON (6) calculations have been done for specifying dipole and quadrupole dimensions. Since the dipole gap is small, the overall size is small and a large pole width, 10 cm, is taken. Without any tapering of the poles this still provides proper homogeneity: fig. 9. Nevertheless a small sextupole component is present. The dipoles will be constructed with laminated modules fixed together by iron rods, a fabrication technique common in transformer yoke design. The current necessary is 12 kA in a 30 cm^2 coil area, in order to have a magnetic induction of 1.4 T.

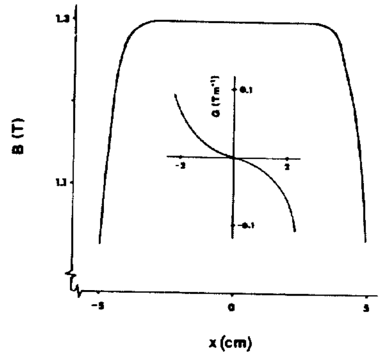

Fig. 9
Field homogeneity in dipole at 1.3 T

Table 1. Machine Parameters

Circumference		: 32 m
Proton energy		: 3 - 50 MeV
Electron energy		: 25 - 300 MeV
No of superperiods		: 4
No of cells		: 16
Focusing structure		: FOODOBO FOODOBO FOODOBO FOODOO
Maximum β_x, β_y		: 4 m, 4.6 m
Maximum dispersion η_x		: 1.1 m
Tunes ν_x, ν_y		: 5.23, 4.22
Momentum compaction factor		: 0.051
Proton revolution frequency		: 0.75 - 2.94 MHz
	Max RF voltage	: 200 V
RF electrons/harm. number		: 75 MHz/8
	MAX RF voltage	: 3 kV
Dipoles	length	: 0.40 m
	radius	: 0.74 m
	B_{max}/B_{min}	: 1.4 T/ 0.14 T
Quadrupoles	length	: 10 cm
	aperture radius	: 2.5 cm
	Max pole tip field	: 0.4 T
Sextupoles	.length	: 5 cm
	aperture radius	: 2.5 cm
	max pole tip field	: 0.1 T
Electrons 300 MeV:		
	emittance ϵ_x	: 20.10^{-9}m
	rad. damping time τ_x	: 58
	τ_y	: 60
	τ_e	: 30
	max beam size.....σ_x	: 0.26 mm
	σ_y	: 0.08 mm

Acknowledgement

We like to thank R. Queens, W. Dries, J. Uythoven and G. Brooymans for helpfull discussions and for calculations.

References

(1) J.A. van der Heide et al., Nucl. Instr. Meth. in Phys. Res. A. 240 (1985), 32
(2) W.H. Backer, Thesis Eindhoven University of Technology (1979)
(3) R.V. Servranckx et al., SLAC report 270 UC-28 (A) (1984)
(4) C. Bovet et al., CERN/MPS-SI/Int. DL/70/4 (1970)
(5) M. Sands, SLAC-121 (1970)
(6) A.M. Winslow, J. Comp. Phys. 2 (1967), 149