Injection Requirements for the EUTERPE Storage Ring

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Abstract

The injector chain for the EUTERPE electron storage ring consists of a 10 MeV linear accelerator, a 70 MeV racetrack microtron and two connecting beam lines. The aim is to store 200 mA beam current in the 400 MeV ring. The injection procedure, including the beam current requirements and the timing considerations for the pre-accelerators, will be described. Lifetime calculations of the circulating beam at the injection energy of 70 MeV will be given.

1 INTRODUCTION

At the Eindhoven University of Technology (EUT), a 400 MeV electron storage ring EUTERPE is being constructed[1]. The ring with a circumference of 40 m has 32 quadrupole and 12 dipole magnets, and 2 m long dispersion free straight sections useful for insertion devices (undulators and wigglers), see fig. 1. A special by-pass line for small aperture insertion devices is foreseen. The aim of EUTERPE is, on the one hand, to be a test instrument for accelerator studies in general, including the study of special insertion devices, and on the other hand, to provide possibilities for research employing synchrotron radiation. This is to be carried out in a university environment, with student involvement from any phase of their program.

The injector of EUTERPE is a 70 MeV racetrack microtron which is also being built[2] at EUT. This machine is injected from a 10 MeV (medical) linac. The beam current from the linac is too low to permit single turn injection into the ring. The common multiturn damping injection is possible for EUTERPE, however the damping action is small at 70 MeV. In order to collect 200 mA beam current in the ring multiturn injection with an adjustable closed orbit has been considered. The electron beam behaviour during the injection time has been simulated with the program DIMAD. The tracking results indicate that a small beam current from the injectors can continuously be injected into the ring in this low energy injection process. In this paper, the details about the injection procedure will be described. The beam current requirements and the timing considerations for the pre-accelerators will be discussed. The effects of beam-gas scattering and intra-beam scattering at the low injection energy will be given.

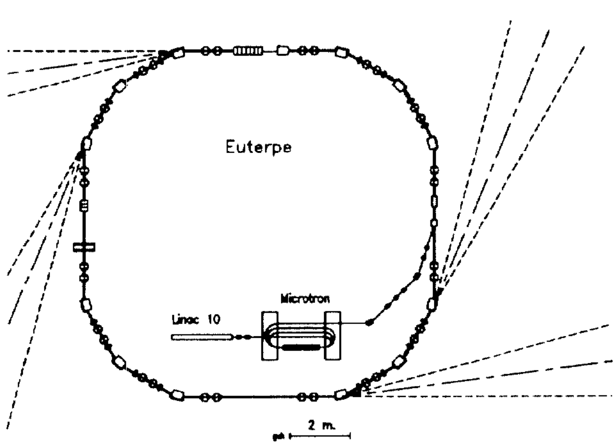

Figure 1: *Layout of the EUTERPE storage ring*

2 INJECTORS AND BEAM TRANSFER LINES

The racetrack microtron consists of two 180^0 bending magnets and a 5 MeV rf accelerating cavity. The injector linac provides 50 pulses per second with a pulse current of 30 mA and with a pulse duration of 2.2 μS. The microtron and the linac have the same operating frequency of 3000 MHz. They are each independently powered by separate magnetrons. We investigate the possibility to couple some power of the linac magnetron into the one for the microtron cavity, in order to phase lock this with the first one. This will lead to synchronous acceleration of electron bunches in both linac and microtron. Alternatively, acceleration through both machines is possible as long as the two magnetrons have a sufficient coherence time period. The linac emittance is 9 mmmrad at 10 MeV, however the relative energy spread is quite large, 10%. The microtron can only accept 1% relative energy spread; the absolute spread remains constant during acceleration[2]. The outcoming energy from the microtron is very insensitive to cavity voltage instabilities. The main parameters of the microtron and the linac are listed in Table 1.

The pre-accelerators and the storage ring will be connected with two transfer lines. Transfer line 1 connects the linac and the microtron. It is an antisymmetrical system with double achromatic behaviour consisting of two bending magnets and a quadrupole triplet. Two 30^0 dipoles translate the beam coming out of the linac by 40 cm in the vertical plane and into the microtron median plane. Transfer line 2 connects the microtron and the storage

Table 1: Main parameters of linac and microtron

	Linac	Microtron
Injection Energy		10 MeV
Extraction Energy	10 MeV	70 MeV
Average Pulse Current	30 mA	6 mA
Energy Spread	10%	0.15%
Pulse Duration	2.2 μs	2.2 μs
Rf Frequency	3000 MHz	3000 MHz
Emittance	9 mmmrad	0.6 mmmrad

ring. It consists of a symmetrical magnet system with achromatic behaviour and two quadrupole doublets. Since the microtron is at right angles with respect to the injection straight section in the ring, and since the beam exits the microtron at an angle of 9.5^0, a double achromatic section bends the beam by 67^0 towards the ring. The remaining bending is done by a magnetic septum, with an effective length of 10 cm, a field of 0.48 T and a deflection angle of 200 mrad, and by an electric septum in the ring. It has an effective length of 30 cm, a deflection angle of 32 mrad corresponding to an electric field of 75 kV/cm at 70 MeV. A quadrupole doublet is used for matching the injected beam at the entrance of the ring.

3 INJECTION PROCEDURE

Injection into the ring takes place in the horizontal plane. Three fast kickers will be installed in EUTERPE for shifting the closed orbit in the horizontal direction in the injection section. Table 2 lists the main parameters of the kickers. The kick action of the quadrupoles, resulting from the integral over the magnetic field with respect to the orbit location, has been taken into account.

3.1 *Multiturn Injection with a Fixed Locally Shifted Closed Orbit*

Prior to the injection the kickers have been switched on. The normal orbit is then displaced to the new position as shown in fig. 2. For betatron tunes ν_x=2.57, ν_y=1.63, and

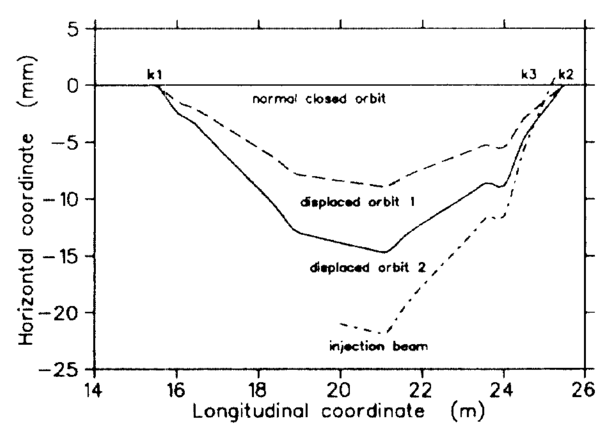

Figure 2: *The shifted closed orbits*

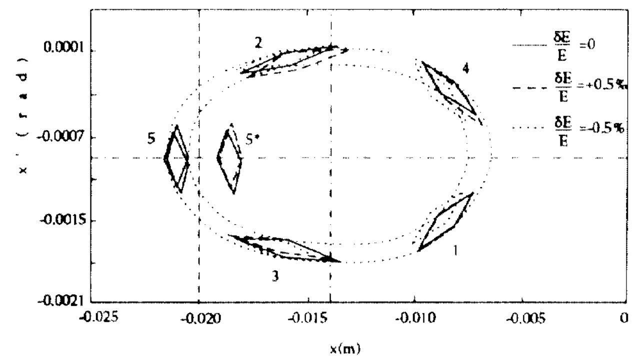

Figure 3: *The phase space contours of injected beam*

for kicker strength values corresponding to 5.0, 4.9 and 4.4 mrad respectively, the normal closed orbit will be shifted like the displaced orbit 2 in fig. 2.

The beam will be injected on axis in the vertical plane and off axis in the horizontal plane by a separation w.r.t the unshifted orbit of x=−2.1 cm. Fig. 3 shows the evolution of the injected beam in the horizontal phase space which is obtained by a tracking simulation. The emittance area of the injected beam is 0.6 mmmrad there. From fig. 3, it can be seen that the injected beam bunch will collide with the septum after five turns. If the fast kickers are switched off in the time interval between the fourth and fifth turn, the shifted closed orbit will rapidly return to the normal situation. Thus, the total five turn injection will be finished within this injection time.

3.2 *Continuous Injection with an Adjustable Locally Shifted Closed Orbit*

From fig. 3, it is clear that if, after four turns, the displaced closed orbit is shifted by about 2 mm or more towards the normal closed orbit, as depicted for the displaced orbit 1 in fig. 2, once more five turn injection can be realized without beam colliding with the septum. In this way a continuous collection of the low injection current can be obtained which facilitates the requirements for the current of the injector. If the shifted closed orbit is moved by 3 mm every 5 turns, more than 15 turn injection can be realized in EUTERPE in one pulse of the linac. For convenience the closed orbit can be shifted linearly. Then, the magnetic field of the kickers has a shape as shown in Fig. 4. In transverse phase space, the injected beam moves along a spiral with a centre moving towards the normal closed orbit.

4 THE REQUIREMENTS OF THE BEAM CURRENT OF THE PRE-ACCELERATORS

A circulating beam current of 200 mA in the ring is equivalent to 1.66×10^{11} electrons. The linac output, 30 mA macropulse current, where the macropulse is 2.2 μs long with a pulse repetition frequency of 50 Hz, implies

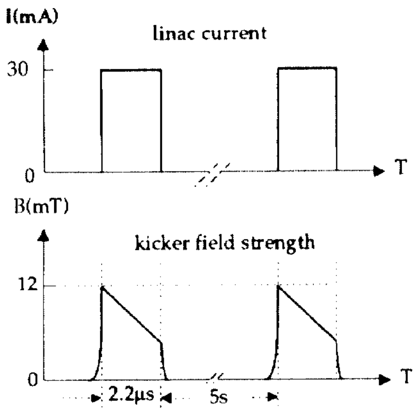

Figure 4: *The diagram for the timing control*

Table 2: Kicker Parameters

Quantity	3
Energy	70 MeV
Deflection	5–10 mrad
Magnetic Field	12–24 mT
Rise Time	100 ns
Down Time	50 ns
Pulse Duration	2.2μs
Effective Length	10 cm

4.2×10^{11} electrons per pulse. Hence the number of electrons in one linac pulse exceeds the number of accumulated electrons in the storage ring at 200 mA by a factor of 2.5. However these can not all be used. The energy spread (10%) and phase spread of the linac is too large to be accepted by the microtron. We estimate a factor of 5 will be lost (This is then done deliberately in a dispersive section of the beam guiding system from linac to microtron). This means we need 4 linac pulses for 200 mA assuming 50% injection efficiency in the ring. Moreover we want to use the full 2.2 μs injection time of each pulse. Since the electron revolution frequency in the ring is 7.5 MHz, this implies 15 turn injection for each linac pulse. This is only possible with a very good emittance of the linac and microtron beam. In the transfer line a switch directs the linac beam to the microtron during the few times it is used for injection into the synchrotron ring.

The estimated energy spread on the beam extracted from the microtron is 0.15%[2]. Another factor affecting the energy spread results from foil scattering. For the injection of EUTERPE an aluminum foil in front of the electric septum separates the storage ring vacuum system with a vacuum condition of 10^{-9} Torr from the vacuum system of the microtron and the transfer line with a pressure of 10^{-6} Torr. Electrons of a definite energy passing through a foil of matter lose energy due to inelastic collisions with atomic electrons and due to the emission of bremsstrahlung in the Coulomb field of the nucleus. This energy loss for the 70 MeV electrons has been estimated by means of the formulae and plot given by Knop and Paul[3]: $\delta E \approx 12.2h$ (MeV) where h is the foil thickness (in cm). Suppose the thickness of the aluminum foil is 0.1 mm, then $\delta E \approx 0.122(MeV)$. The energy spread because of this at the entrance of the ring is $\delta E/E \approx 0.17\%$.

In the tracking simulation a certain momentum spread ($\delta E/E = \pm 0.5\%$) has been taken into account. From fig. 3, it can be seen that the behaviour of these electrons will be slightly different during the injection process, because of the chromaticity sextupoles in the lattice of the ring. This indicates that the momentum spread is not sensitive for the injection in EUTERPE.

5 THE EFFECTS OF GAS SCATTERING AND INTRA-BEAM SCATTERING ON THE INJECTION PROCESS

The residual gas scattering and intra-beam scattering are the serious limiting effects on the lifetime of the beam for existing small and medium size electron storage rings[4]. At low energy, for high density circulating bunches, the scatting growth rates are large and the radiation damping rates are small. For EUTERPE the damping times are of the order of 5 seconds at the injection energy of 70 MeV. With the computer program ZAP[5] estimated equilibrium emittance values are about a factor of 400 larger than the natural ones. Correspondingly the beam size is about 4.5 mm and the beam lifetime is about 45 minutes due to the intra-beam scattering. The residual gas scattering mainly depends on the elastic scattering during the injection time. The calculated gas scattering lifetime is about 25 minutes assuming a pressure 1 nTorr of nitrogen gas. This offers enough time for acceleration to high energy. Therefore the effects of the gas scattering and the intra-beam scattering on the injection of the ring will not play an important role.

6 CONCLUSION

In this paper we have given a procedure for storing 200 mA beam in our ring, making use of a microtron and a (medical) injector linac providing 30 mA pulses. Lifetime and damping at the low injection energy are sufficient for this purpose.

7 REFERENCES

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