CONCEPT AND GENERAL DESIGN OF AN ELECTRON PULSE STRETCHER

R. Servranckx* and J. L. Laclare**

Saskatchewan Accelerator Laboratory, University of Saskatchewan
Saskatoon, Canada

1. Summary

This paper presents the project of an electron pulse stretcher (E.P.S.) for the 100-300 MeV electron linear accelerator of the University of Saskatchewan. We briefly outline the results of a previous study made by the particle optics division (S.O.C.) of Saclay for the project ALSI and show its relation to our design. The present E.P.S. machine design and characteristics are discussed and finally some remarks are made on tolerances and vacuum requirements. More detailed information can be obtained in our internal reports.²

2. General Principles

Previous studies on the problem of improving the duty cycle of accelerators have shown that a ring can be used as a relativistic particle pulse stretcher. A pulse lasting t us can be wrapped on itself c/L times (c is the velocity of light) in a ring of length L.

After a multi-turn injection in the ring, a slow extraction of the particles between successive pulses achieves the required increase in duty cycle. As was shown, in the studies of the French project ALIS a slow extraction is possible by the use of resonance phenomena. The 1/3 resonance was analyzed in great detail.

In Fig. 1 we show a layout of the E.P.S. The two curved sections act only as unit matrix transfer sections. Their tuned energy dependence is achieved by the adjustment of the quadrupoles F and D. Since the transfer matrix of these curved sections is the unit matrix, the straight sections are achromatic to first order. The two straight sections, which constitute the machine itself, are tuned to ωX = 1.333, and ωY = 1.13825 by the main quadrupoles F and D (ωX and ωY are the betatron wave numbers). To ensure the optimum conditions, the curved sections are matched as well as possible to the straight sections. In Fig. 2 we give the characteristic functions of the E.P.S.: F, D, and g = (p/R)/(dE0/dp), (p: momentum, R: mean radius of machine, E0: closed orbit corresponding to momentum p). The zero value of g in the straight sections shows the achromaticity of these sections and the regular pattern of the p-functions illustrates the matching.

The size of the machine is chosen so that the 1 us pulse of the linac can be injected in five turns. The radius of curvature is chosen so that the radiation loss at 300 MeV does not exceed a total of 3 MeV or 1%.

The non-linearities required for the 1/3 resonance extraction are introduced by the sextupolar pair h. A second order analysis shows that the shape and position of the triangle of the separatrices are highly energy dependent. By a suitable choice of the strengths of the other sextupolar pairs h, h4, h5, and h, it is possible to correct that second order chromatic effect and so to achieve achromat resonant extraction.

But in our project, due to a very precise injection procedure, which reduces considerably the energy spread, we may suppress the second order chromatic correction and so achieve chromatic extraction which has the interesting feature of delivering a beam with a narrow energy spectrum of 8 x 10^-2% and whose central energy varies linearly with time in the range of the energy spectrum of the injected beam.

As in the ALIS project we use a coupled injection, in the sense that the beam enters the machine along a trajectory situated off the closed orbit in both the vertical and horizontal planes. The perturbators P1, P2, P3, and P4 are used to displace the closed orbit vertically during the injection process. By tilting the injection septum (see Fig. 3), which makes the injection much more complicated, we are able to achieve a relatively much smaller beam than in the ALIS project.

Because of this small size, the coupling between the horizontal and the vertical movements, due to the sextupoles, is negligible and the sextupoles do not interfere with the injection procedure. Consequently, our sextupoles are not pulsed. The only pulsed elements in the machine are the two pulsed quadrupoles QQ that change the tuning for the extraction, the four perturbators and the two electrostatic inflectors.

3. Machine Description

a. Curved sections

The curved sections are made of four units. Each unit consists of one 45° bending magnet and two quadrupoles. The aperture needed is 10 cm high and 25 cm wide.

The magnets have a mean radius of 2 m and a field index of 0.5. At 300 MeV, the magnetic induction in the magnets is 5 kg. The quadrupoles are 50 cm long and the pole tip induction at 300 MeV does not exceed 2 kg. The hexapoles are 40 cm long and at 300 MeV their pole tip induction does not exceed 1 kg.

b. Straight sections

The straight sections are made of three units each containing two quadrupoles 50 cm long with a full circular aperture of 10 cm. At 300 MeV the pole tip induction does not exceed 1 kg.

c. Injection and extraction elements

Both injection and extraction take place through a magnetic inflector and an electrostatic inflector (labelled IMI, IFI, FMI, FII on Fig. 1). The electrostatic inflectors are 1.5 m long, have a radius of 120 m, a gap of 5 mm and preferably should be pulsed. At 300 MeV the electrostatic field is 25 kV/cm.

The magnetic inflectors have a radius of 3.33 m and a deflection angle of 0.3 rad. At 300 MeV they are not pulsed.
d. Injection canal

The injection canal is an achromatic transport system that shapes the beam so as to fit the injection requirements. It also has a point (near Q6) of high energy resolution where the energy spectrum of the injected beam can be reduced if necessary.

e. Extraction canal

The extraction canal brings the beam to the entrance slit of the existing spectrometer. It is an achromatic transport system which reduces the beam size to a spot of 1 mm diameter.

f. Overall size

The closed orbit for the nominal energy is inscribed in a rectangle of 23.2 m by 11.2 m.

4. Characteristics of the E.P.S.

a. Linear accelerator beam output

| Energy range: 100 to 300 MeV |
|-----------------------------|-----------------------------|
| Energy spectrum: 2% | Pulse length: 1 μs |
| Duty cycle: 6.25 x 10^-4 | Intensity: 190 mA peak current |
| Horizontal emittance: 3.2 x 10^-6 m.rad | Vertical emittance: 3.2 x 10^-6 m.rad |

b. Electron pulse stretcher stored beam

5 turns injection

<table>
<thead>
<tr>
<th>Horizontal emittance: 85 x 10^-6 m.rad</th>
<th>Vertical emittance: 25 to 30 x 10^-6 m.rad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity: 0.96 A</td>
<td>Total number of turns: 8,000</td>
</tr>
<tr>
<td>Total radiation loss at 300 MeV: negligible</td>
<td></td>
</tr>
</tbody>
</table>

Basic tuning: \( v_x = 3.3333 \) \( v_y = 3.13825 \)
Dynamic tuning

Injection: \( v_x = 3.319 \) \( v_y = 3.207 \) Extraction: \( v_x \) varies from 3.322 to 3.327 \( v_y \) varies from 3.144 to 3.14

5. Tolerances - Stability, Vacuum

To determine the precision of the alignments and of the tuning the following requirements were imposed:

a. The closed orbit displacements may not exceed a few millimeters.

b. The variation of the intensity of the output beam may not exceed 1%.

Under these conditions the alignment of the elements must be realized to 0.1 mm, the magnetic fields must be maintained to \( 10^{-8} \) in the curved sections and to \( 10^{-9} \) in the straight sections.

The transverse instability problem has been investigated and the computations have shown that under the worst conditions the e-folding time is greater than 1 ms.

An analysis of the residual gas diffusion leads to a vacuum requirement of \( 10^{-8} \) torr.

b. Acknowledgments

This work is the result of two years of research and computation.

During the initial stages of the study, Drs. H. Breuer, J. V. Kane and W. F. Stubbins contributed to the analysis of the existing literature and were involved in many exploratory discussions.

Dr. C. H. Westcott of Atomic Energy of Canada Limited, Chalk River, and Dr. E. N. Rowe of the University of Wisconsin have oriented our research by their advice and suggestions.

We are especially grateful to the members of the French particle optics group of Saclay who made all their files available to us. Our design is a direct application of their studies.

We would like to thank the National Research Council of Canada for the award of a Research Grant. The authors would also like to thank the Accelerator Laboratory of the University of Saskatchewan for the award of a Research Associateship to one of us (J.L.L.) and the Atomic Energy Control Board of Canada and Atomic Energy of Canada Limited for financial support.

We are gratefully to Dr. L. Katz, who initiated the project, for his continued encouragement and advice.

7. References


SOC-ALIS 1-32: Internal reports of the Service d’Optique Corpusculaire of the Commissariat à l’Energie Atomique. Saclay, France.

2. J. L. Laclare and R. Servranckx. Beam stretcher magnetic structure design. Internal report SAL-RING-16, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.
R. Servranckx. An electron pulse stretcher.
Injection. Internal report SAL-RING 17, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.

J. L. Laclare. Design of an achromatic extraction for the E.P.S. Internal report SAL-RING 18, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.

J. L. Laclare. Resonant extraction from the electron pulse stretcher. Internal report SAL-RING 19, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.

J. L. Laclare. An electron pulse stretcher. Higher order terms effect - Misalignment - Magnetic tolerances. Internal report SAL-RING 20, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.

J. L. Laclare. Designs of injection and extraction channels for the electron pulse stretcher. Internal report SAL-RING 21, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.

R. Servranckx. Injection in E.P.S. (II). Internal report SAL-RING 22, Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada.