THE USE OF A DEBUNCHER IN THE INJECTION PATH OF AN ELECTRON SYNCHROTRON

M. C. Crowley-Milling and G. Saxon
Science Research Council, Daresbury Nuclear Physics Laboratory
Nr. Warrington, Lancashire, England

Introduction

The principle of reducing the energy spread in a bunched electron beam by debunching and using a correcting r.f. cavity was first proposed a long time ago by K. W. Robinson (1), but the system described in this paper is believed to be the first application. Unlike the case for proton beams, where debunching in a drift space occurs due to the velocity variation, a magnetic system which provides a dispersion in path length proportional to energy error must be provided. In the original design of the electron synchrotron NINA, provision was made for the injection of positrons, and to avoid difficulties with the position system when injecting a large current of electrons, a magnetic bypass system was installed to take the electrons round the positron converter and accelerator as shown in fig. 1. The ends of the pole pieces of the bending magnets are cut at the appropriate angle to provide a unity transfer matrix from one end of the bypass to the other, so the system is achromatic, but it is not isochronous, giving different path length for electrons of differing momenta. This results in a tightly bunched beam of electrons becoming partly debunched, and to reduce the energy spread in the beam, a short length of linear accelerator waveguide is inserted in the path of the beam after the bypass. This waveguide is supplied with r.f. power at the same frequency as the linear accelerator. The power level and phasing are adjusted so that high energy electrons lose momentum whilst those of energy lower than the correct value gain momentum. In this way an initial energy spread in the beam of \( \pm 1\% \) can be reduced by a factor of about 10.

Design of the System

Calculations on the bypass system showed that the path difference for a 1\% momentum change is 13.6 mm corresponding to a phase difference of 47° at the linear accelerator frequency, 2856 MHz. The mean energy of the electrons is 43 MeV, so that the corrugated waveguide should be designed such that a particle off-momentum by 1% would gain or lose 0.43 MeV in traversing it, with the particle riding at 47° with respect to the zero of the wave. In the ideal case, in which the bunch phase width in the incoming beam is negligible, the energy error would be reduced in the manner shown in fig. 2(a). However, the NINA injector is designed for a high beam current, and space charge effects during bunching result in bunches of appreciable phase width, between 5 and 10°. However, a worthwhile improvement can be obtained even for a 10° bunch width, as can be seen from fig. 2(b).

A convenient level of power input to the guide was chosen to be 0.5 MW, derived via a directional coupler from one of the inputs to the electron linear accelerator. Consideration of the properties of iris-loaded waveguide (2) then led to the choice of an iris hole radius of 13.1 mm and a length made up of 8 corrugations operating in the 2\( \times /3 \) mode. Beam transmission effects have been considered and shown to be negligibly small for the maximum currents likely to be injected into the synchrotron.

The corrugated waveguide assembly is mounted in a vacuum tank on a pivot, so that it can be swung out of the beam line, when positrons are accelerated, as the small iris hole would collimate the larger emittance positron beam. Non-contacting choke joints are used for the input and output feeds. Power is obtained from a 10 dB directional coupler in one of the output feeders of the first high power klystron of the linear accelerator, with an isolator to minimize the effects of reflected power on the klystron. The other main elements of the waveguide feeder system include a phase shifter and a power divider made up of 3 dB couplers and a phase shifter, together with suitable waveguide loads. The rectangular waveguide and the corrugated waveguide are maintained at a constant temperature by water circulation to assist in maintaining phase stability. Additionally, a phase servo system is incorporated.

Operational Tests

It would have been desirable to use a high resolution spectrometer to check the operation of the debuncher system, but such a system was not available, nor would it have fitted in with the operational requirements. Estimation of the operation has been obtained using the momentum matching system in the remainder of the flight path to the synchrotron. The trajectories for particles of different momenta are shown in fig. 3. Near the inflector there is a horizontal displacement of 13.8 mm for a 1% momentum error. It is possible to measure the beam profile at that point by means of insulated collimator jaws. The system was set up by increasing the power supplied to the debuncher cavity in steps, correcting the phase at each step so that there was no net displacement of the beam at the inflector and measuring the beam profile. The result of one such test is shown in fig. 4, in which the points show the measured beam width as a function of r.f. voltage. The solid line shows the expected variation. This demonstrates the correct functioning of the system. It was also determined that deliberate variations of the linear accelerator energy over a ± 0.5% range made no detectable difference to the beam position at the inflector.

Conclusions

The debuncher system has been in continuous use since it was first commissioned in the middle of 1970 and has proved valuable in smoothing out energy variations in the injected beam, not only during the pulse but also longer term energy drifts, thus making the synchrotron less susceptible to variations occurring in the linear accelerator. There has also been some improvement in the percentage of injected current accepted by the synchrotron.

References


Fig. 1 Layout of bypass system for NINA injector.

Fig. 2 Reduction of energy error by debuncher system.

Fig. 3 Momentum matching system in the flight path.

Fig. 4 Variation of beam width at inflector with r.f. voltage in debuncher waveguide.