150-MeV Pulse Stretcher of Tohoku University

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150-MEV PULSE STRETCHER OF TOHOKU UNIVERSITY

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Summary

The present paper describes the Tohoku University 150 MeV pulse stretcher and the results of the test operation. The ring stores a pulsed electron beam from the electron linac and converts it into a continuous one. The test operation has proved that it works successfully. Broadening of the extracted beam in the vertical direction due to a coupling resonance was observed in the early operation. This problem was resolved by readjustment of the tune. And an extracted beam of 1 μA has been obtained with a duty factor of 80 %. The energy spread of the extracted beam was measured to be 0.2 %.

Introduction

The low duty factor (0.1 %) of the Tohoku University Electron Linac makes coincidence experiments difficult. The 150 MeV pulse stretcher has been constructed in order to supply a continuous beam for such experiments. It is used also to research the technical problems of a pulse stretcher, because a linac-and-pulse-stretcher system has been proposed for the next accelerator of Tohoku University. The system is considered to be a promising solution to realizing a high duty electron beam. The principle of the pulse stretcher is well known since the ALIS project,at Saclay.[1] However no pulse stretcher had actually been constructed. Thus it was thought to be necessary to confirm the feasibility of the pulse stretcher for the accelerator supplying the continuous beam. The construction of the ring was started early in 1979 and was completed at the end of 1981. Since then, it has been examined from various aspects, as well as supplying a continuous beam for the test operation of the tagged photon facility.

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Description of System

The stretcher is operated without RF acceleration and the beam is extracted from the ring by monochromatic extraction; the beam is injected with an energy width equal to the energy loss due to synchrotron radiation during the time between two successive injections. The lowest energy of the injected beam corresponds to the third integer resonance (ν_x=4/3). Electrons, losing their energy by synchrotron radiation down to the energy of the resonance, are extracted consecutively.

The stretcher was installed near the existing magnetic spectrometer for electron scattering, as shown in Fig. 1. The ring consists of eight bending magnets, with uniform field, whose bending angle is 45° and bending radius is 0.8 m. Edge focussing has been used with edge angles of 11.215°, because there is no space for quadrupole magnets between two adjacent bending magnets. The circumference of the ring is 15.472 m. A pulsed beam is bent from the present beam line to the ring by two bending magnets M9,M10 and is injected into the ring through two septum magnets (SMI,SM). During the time of injection, the equilibrium orbit is brought near the SM by two kicker magnets (KM1,KM2) and the off-energy function near the SM is made zero by a pulsed quadrupole magnet (PQ).

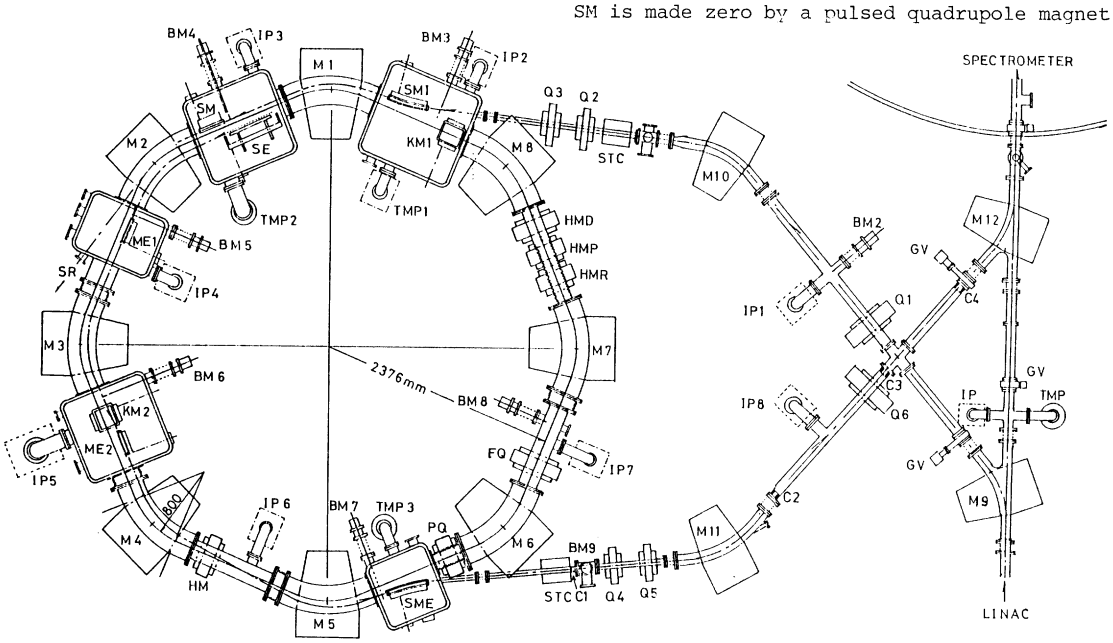

Fig.1 Layout of the 150 MeV pulse stretcher.

M;	bending magnet	SM,SMI;	septum magnet for injection	GV;	gate valve
Q,FQ;	quadrupole magnet	ME,SME;	septum magnet for extraction	IP;	spatter ion pump
PQ;	pulsed quadrupole magnet	SE;	septum electrode	TMP;	turbo molecular pump
HM;	hexapole magnet	BM;	beam profile monitor	STC;	stearing coil
KM;	kicker magnet	SR;	synchrotron light monitor	C;	collimator

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It also changes the betatron frequency down to ν_x=1.2 in order to give enough time for multi-turn injection. The quadrupole magnet FQ is used for a slight adjustment of the tune. The third integer resonance is induced by the hexapole magnet HMD. The strength of the magnet controlls the chromatic factor appropriate for making a resonant oscillation only for electrons with the extraction energy. The hexapole field distorts the injection orbit and makes a part of the injected beam hit the SM. To avoid this effect, another pulsed hexapole magnet HMP is set close to the HMD to cancel its hexapole field during the injection period. Electrons with an energy of about -1 % oscillate resonantly with the increasing oscillation amplitude, and finally enter into the gap of the septum electrode SE. After about a half revolution through three septum magnets (ME1, ME2, SME), the electrons leave the ring.

Operating Experience

Most of the test operations were made with an electron beam of 130 MeV from the linac. The energy width of the injected beam was adjusted to be 1.5 % and the pulse duration to be 20 nsec, whose length corresponds to 2/5 of the circumference of the ring.

Beam Broadening due to Coupling Resonance

Figure 2(A) shows the profile of the extracted beam first observed on a fluorescence plate (BM5) at the point immediately before the ME1. The beam broadening vertically was observed, and the efficiency of extraction was only around 10 %. The origin of the broadening was investigated and attributed to a third order coupling resonance ($\nu_x - 2\nu_y = -1$).

As shown in Fig. 3, the tune of the extracted point is on the resonance line. When the tune of the ring is close to the line, the vertical oscillation is coupled with the horizontal motion. In the case of our ring, the oscillation amplitude in the horizontal direction is much larger than that in the vertical direction. The coupling resonance transfers the energy of the motion from the horizontal direction to the vertical direction, and makes the vertical oscillation increase. The operation point should be moved far from the line in order to remove the broadening. It is difficult to do this by only two quadrupole magnet, PQ and FQ. Therefore the field clamps of the eight bending magnets were taken off, for the purpose of changing the working point. The consequent tune is also shown in Fig. 3. Figure 2(B) shows the beam profile after the reconstruction, which is a strong beam concentrated on a small area. The adjustment has improved the efficiency of the extraction up to 50-60 % and the extracted beam current reached to 1 μA at the operation of 300 pps when the beam with a pulse duration of 150 nsec was injected.

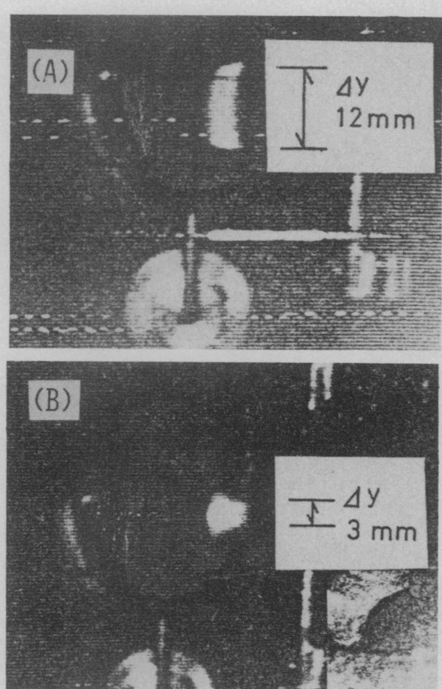


Fig. 2 Beam profiles of the extracted beam.
(A) Beam broadening observed in the early operation,
(B) Beam profile after improvement by changing the tune.

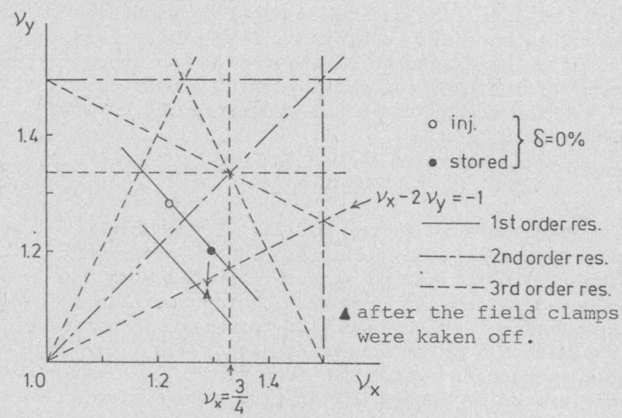
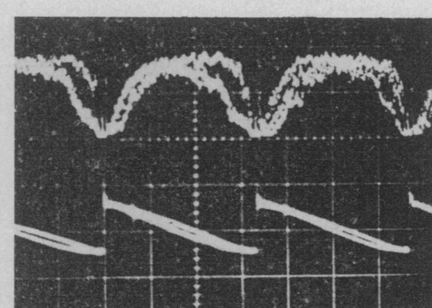


Fig. 3 Resonance lines and tunes in operation.

Duty Factor

The duty factor of the extracted beam was measured by using a plastic scintillation counter. The upper signal in fig. 4 shows the intensity of the extracted beam, which is the signal of the scintillation counter smoothed by an amplifier with a time constant of 30 μ sec. A duty factor of 0.7-0.8 was obtained at the operation of 300 pps. The lower signal shows the intensity of the synchrotron light emitted at the bending magnet M2 by electrons moving in the ring, which was measured by using a photocell. The synchrotron light increases rapidly at injection and decreases constantly up to the successive injection. It means a smoothed extraction of the electrons.



1 msec/div.

Fig. 4 Upper; extracted beam observed with a plastic scintillation counter, Lower; synchrotron light from bending magnet M2.

Micro-structures

Micro-structures in the extracted beam were measured by using tagged photon equipment and a time-to-amplitude-converter (TAC). The signal from one plastic scintillation counter started the TAC and the signal from another one stopped it. The time resolution of this system is estimated to be a few nano-seconds. If there are micro-structures in the extracted beam, the spectra from the TAC should have structures corresponding to them. First, the time spectrum was measured when a short pulse beam (∿20 nsec) was injected into the ring. Fig. 5(A) shows the output of the TAC whose gate was opened from 100 μsec to 600 μsec after the injection. A lot of structure can be seen in the spectrum, and the patern repeats at a period of 150 nsec. This period is equal to the time an electron takes to make three turns around the ring. This is a feature of the extraction due to the third integer resonance. In short, every 150 nsec structures derive from same bunches. Fig. 5(B) is the spectrum when the gate of the TAC was opened from 600 μsec to 1100 μsec. In this spectrum, the large structures in Fig. 5(A) disappear and a lot of small peaks appear on the increasing continuous part. The micro-structures in Fig. 5(A) and the transformation of the structures from Fig. 5(A) to Fig. 5(B) can be explained by taking account of the dilatation factor and the chromatic factor of the ring. On the other hand, when the long pulsed beam (∿ 150nsec) was injected into the ring, no apparent peaks were observed in the spectrum even from 100 μsec to 600 μsec. (Fig. 5(C)) These results imply that the micro-structures in the extracted beam scarcely disturb coincidence experiments.

Energy spectra

The energy spectra of the extracted beams were measured by means of the measurement of elastic electron scattering with a magnetic spectrometer at 30°. A foil of ^{90}Zr (49.97 mg/cm^2 thick) was used for the target. Figure 6(A) is the energy spectrum of the injected beam, which is centered at 130 MeV with an energy width of 1.5%. An example of the spectra of the extracted beam is shown in Fig. 6(B). The energy of the extracted beam is located at -0.8%, which is nearly equal to the lowest energy of the injected beam. Its energy width is estimated to be 0.1%. It is remarkable that no electrons were counted in the higher energy region beyond the peak. A slight tail in the lower energy part is attributed to the radiation loss of electrons in the target. Figure 7 shows an example of the time dependence of the energy of the extracted beam. In most case, spectra have an energy spread of 0.1 - 0.2% and

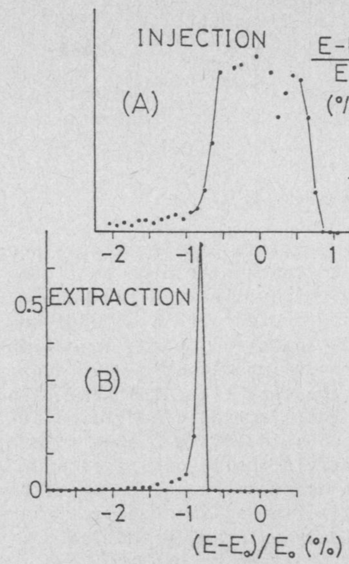


Fig. 6 (A); energy spectrum of the injected beam, (B); an example of the energy spectrum of the extracted beam.

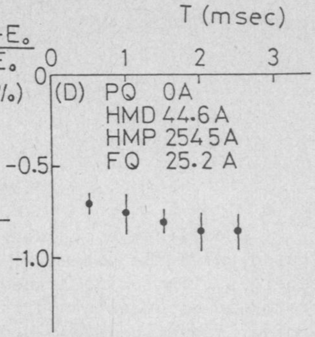


Fig. 7
Time dependence of the energy spectrum of the extracted beam.

an energy shift of about 0.2% is observed. These qualities satisfy the demands of experiments sufficiently.

Low energy electrons intermixed in the beam disturb tagged photon experiments. Such components increase the background as spurious electrons. The measurement of the background showed that the spurious electrons did not exceed 3% - 8% of the tagged electrons over the measured electron energy region (0.2 E_0 - 0.8 E_0) when a 10^{-3} radiation length Au was used for a bremsstrahlung target.

Acknowledgements

We wish to thank a large number of people in Saclay, Saskatoon, KEK and many other laboratories for sending us valuable reports and informations usefull to designing for the pulse stretcher. Most of devices were manufactured by Mitsubishi Electric Co.

Reference

1) R.Beck et al., ALIS, avant-project d'un anneau lisseur de cycle de l'accélérateur linéaire de Saclay, DSS/Soc-ALIS-32 (oct.1970).

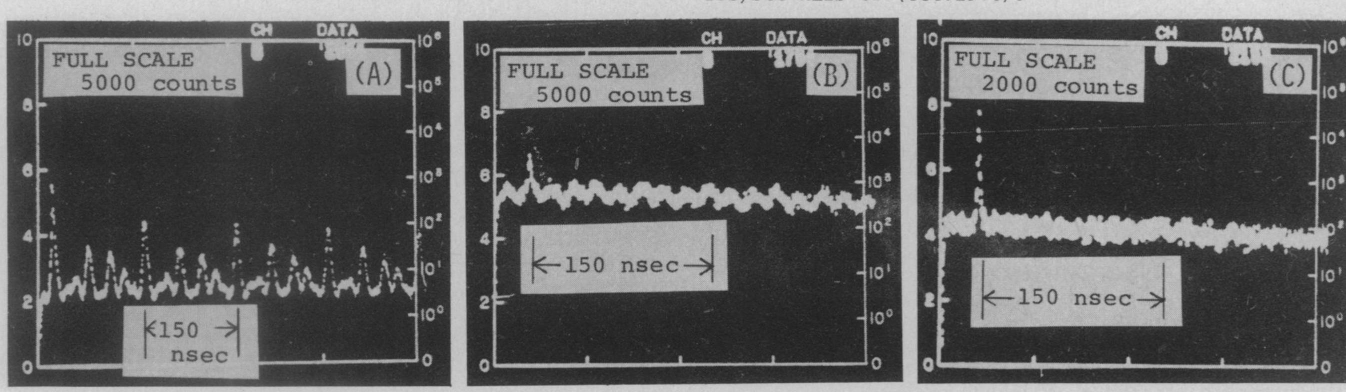


Fig. 5 Micro-structures in the extracted beam. Sharp peaks in (B) and (C) come from background.
(A) injection; short(∿20 nsec) pulse, measurement; 100-600 μsec after the injection.
(B) injection; short(∿20 nsec) pulse, measurement; 600-1100 μsec after the injection.
(C) injection; long(∿150 nsec) pulse, measurement; 100-600 μsec after the injection.