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MEASUREMENT OF ENERGY DISTRIBUTION IN MACROPULSE OF ELECTRON LINAC BEAM AT LNS

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Abstract

Both energy and time structures of the beam extracted from a pulse stretcher ring strongly depend upon the energy distribution in a macropulse of the injection beam. Measurement systems of the energy distribution of the macropulse accelerated by a linac have been developed at LNS, Tohoku University. Using the systems, energy profiles and spectra in the macropulse of the linac beam was measured.

1 INTRODUCTION

Operation of the STretcher-Booster (STB) ring at LNS [1, 2] began in 1997 for nuclear physics experiments, and the accelerator itself has been also investigated. The STB ring has two functions. One is beam acceleration of 200 MeV linac beam up to 1.2 GeV and beam storage to produce GeV γ rays [3]. Another function is a pulse beam stretcher to supply quasi CW-beam by employing a slow extraction method.

Using the STB ring as a pulse stretcher, the beam is extracted by the third order resonance in the horizontal phase space. The horizontal betatron tune reaches the third order resonance by the energy loss due to the synchrotron radiation. Simulation study for the extraction under the influence of the beam injection condition is also carried out and will be presented [4]. At LNS, the beam from the linac is injected into the STB ring with the repetition rate of 50 Hz or the multiples of it (max. 300 Hz). The beam extracted from the STB ring must be uniform in beam intensity during the extraction duration. The injected beam energy from the linac is normally 200 MeV, and the energy loss is about 0.5 % during the repetition period of 3.3 ms at the 300 Hz injection rate.

To produce the constant intensity of the extracted beam, the energy distribution of the injected beam must be uniform in a macropulse. In the case of existence of any structure in the energy distribution of the macropulse, the intensity of the extracted beam is possibly fluctuated and then the time structure of the spilled-out beam is never uniform.

The circumference of the STB ring is designed to be 49.75 m, and the three-turn injection is carried out. The pulse width of the injected beam of the uniform energy distribution is required to be 500 ns. The LNS linac is driven by five klystrons. The pulse width of the applied rf voltage of klystrons is fixed at 4 μs. The timing of the rf voltage of each klystron and that of the beam trigger can be changed independently. Therefore, the energy of the accelerated beam in the linac may be fluctuated. To produce the appropriate beam for the injection, the energy distribution of the macropulse must be investigated.

Measurement systems of the energy distribution in a macropulse have been developed at LNS. In this paper, the experimental apparatus and methods are reported in section 2. Results of the energy distribution of the macropulses are reported in section 3. In section 4, summary and future plan are reported.

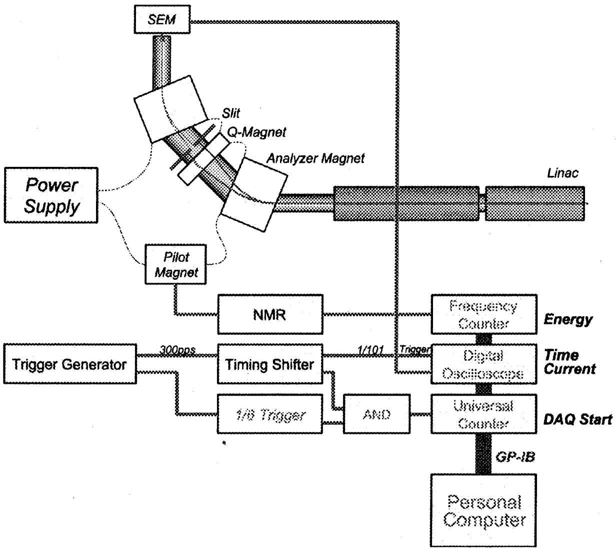

Figure 1: Schematic of the experimental set-up. The beam energy is determined by measuring the magnetic field of the pilot magnet that is connected in series with the bending magnets. The electric charge of the pulse beam is measured by an SEM that installed downstream of the energy analyzing system.

2 EXPERIMENTAL SYSTEM AND METHODS

The measurement system of the beam energy spectrum is shown in Figure 1[4]. The accelerated beam from the linac is selected by an energy analyzing system in the beam transport line. The energy analyzing system consists of two bending magnets, a quadrupole magnet that is located between the bending magnets, and a slit installed the place where the energy dispersion exists.

The beam energy is selected by changing the magnetic field of the bending magnets. The beam intensity is obtained by using the secondary electron monitor (SEM) installed downstream of the analyzing system. The beam energy can be accurately decided by the strength of the magnetic field, and the energy resolution is determined by the width of the slit.

The center energy of the analyzed beam is obtained by measuring the magnetic field of a pilot magnet that is connected in series with the bending magnets. The measurement of magnetic field is performed by an NMR method.

In these experiments, the NMR resonated rf output measured by a frequency counter are stored in a PC via a GP-IB interface and the center energy is calculated from the measured frequencies.

The SEM consists of 5 electrodes made of Al foils, and the secondary electrons produced by the pulse beam in the SEM is collected by applying high voltage. The output of the SEM from each pulse is measured by a digital oscilloscope. The results measured by the digital oscilloscope are saved by the PC via GP-IP interface. After the measurements, the amount of the electric charge in one macropulse is calculated by integrating the output signal.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Measurement by using SEM

Energy spectra of the macropulses were measured by changing the timing of the beam generated from the gun with respect to the rf timing of the linac. The results of the energy spectra and the energy profiles are shown in Figure 2. The accelerated beam energy was about 200 MeV. The width of the slit to decide the energy resolution was 2 mm. This corresponds to an energy resolution, *ΔE/E*, of about 0.1 %. Beam pulse accelerated at the flattop of the rf envelope became in an energy stable region because the supply of the rf voltage reduced by the beam loading is kept at a balanced state. In Figure 2(A), the beam energy in the beginning of the macropulse is low. It is obvious because the beam pulse was accelerated by a lower rf voltage at the rise up of the rf envelope. Although, as shown in Figure 2(B), the beam energy became stable from the beginning of the flattop of the rf envelope after the transit time passed. The transit time of the accelerating structures of the LNS linac is about 0.8 μs. When the macropulse length is longer, as shown in Figure 2(C), the beam energy is lowered at the falling down region of the rf voltage and then the beam is out of the stable region.

It is found that the beam loading and the rise up period of the rf voltage drastically affect the energy distribution of the linac beam. The timing of the rf voltage of five klystrons and that of the generation of the beam from the electron gun is considered to be adjustable by watching the energy distribution using this system. The uniform energy distribution in Figure 2(B) was about 500 ns at the center energy of 192 MeV with the energy resolution of 0.5%.

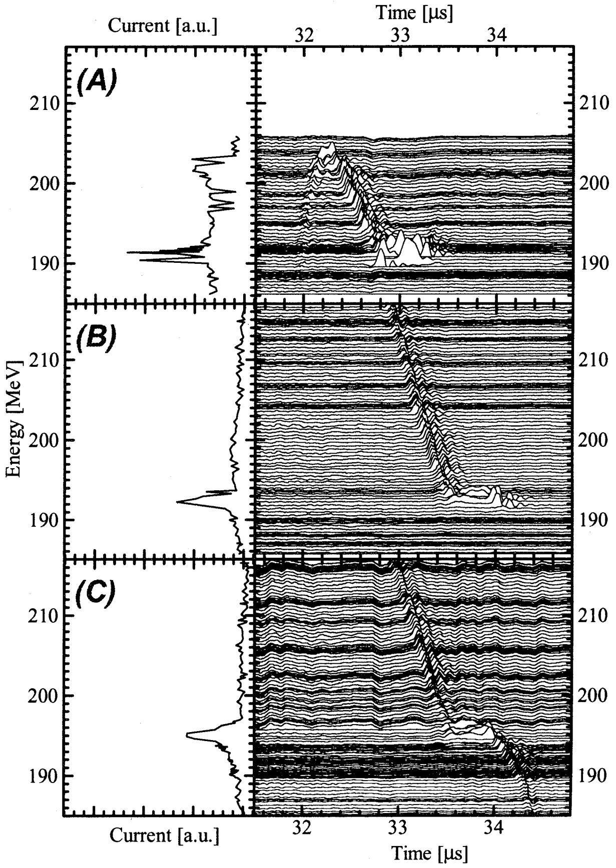

Figure 2: Results of the measured energy spectra and the profiles obtained by SEM. (A) Beam acceleration is started at the rise up of the rf envelope, and the pulse width is 1.5 μs. (B) Started at the flattop of the rf envelope. (C) Started at the flattop of the rf envelope, and the pulse width of 1.9 μs.

3.2 Measurement by using Cherenkov radiation

Another apparatus taking the place of the SEM is used for the measurement of the charge distribution in a macropulse, in which air Cherenkov radiation from the beam is employed. The photons are detected by an avalanche photodiode (APD). This measurement system was installed downstream of the SEM. The experiments were carried out to compare with the SEM.

The result of output signal of APD measured by changing the width of the energy slit is shown in Figure 3. The output of the APD corresponds to the beam intensity. In this figure, the macropulse has a uniform time distribution. However changing the energy width, it was found that the energy distribution was not uniform actually. This is caused when the timing between the rf envelope and the beam trigger is not matched.

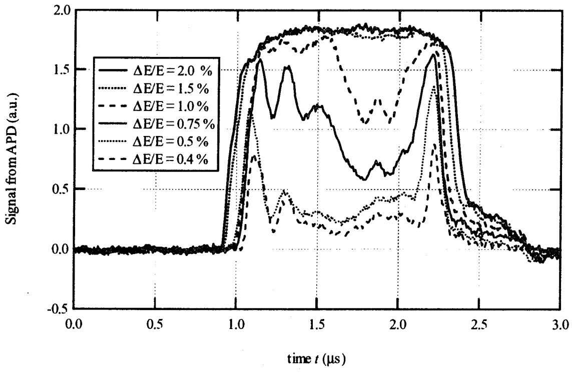

Figure 3: Output signal of the APD measured by changing the width of the energy slit. The center energy that is derived from the magnetic field of the analyzer was set to 149.98 MeV.

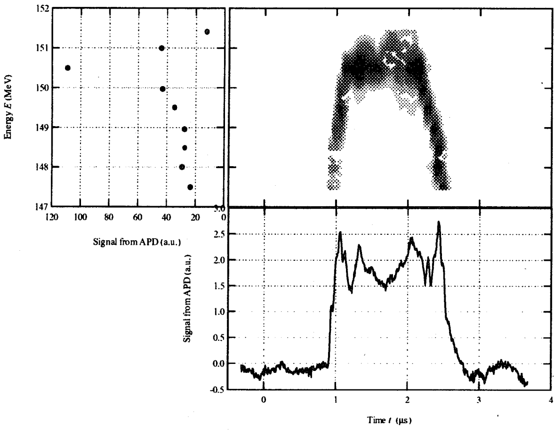

Figure 4: Energy spectrum of the macropulse measured by changing the magnetic field of the analyzer. The energy resolution was set to 0.25 %. The density in the center figure shows the intensity of the output signal of the APD.

To understand the variation of the energy distribution in the macropulse, the result is shown as a two-dimensional spectrum in Figure 4. This result was obtained by changing the magnetic field of the analyzer magnets. The width of the slit was fixed to the energy resolution of 0.25 %. The left side figure shows the energy distribution of the macropulse. From this figure, the center energy of the beam was 150.47 MeV, and the energy spread was about 0.46 % derived from Gaussian fitting. The downside figure shows the time structure of the macropulse. The beam intensity of the macropulse was apparently uniform for ~1.5 μs. The energy distribution was, however, much distorted and uniform at only narrower region as is shown in the center figure.

4 SUMMARY AND FUTURE PLAN

Two measurement systems of the energy distribution in a macropulse of the linac beam have been developed at LNS. The charge distribution in the macropulse was measured by an SEM detecting the secondary electrons and an APD detecting Cherenkov radiation. The identical measurement was able to be performed by both the charge detection apparatuses. The two-dimensional energy spectrum measured by these systems shows both the time structure and the energy distribution of the macropulse. The diagnostic and tuning of the injected beam are easily performed by using these systems.

However, using these measurement systems, the injected beam is destructed, and we cannot measure the energy distribution at the same time with operating the STB ring. Instead of these measurement apparatuses for the electric charge, it is planed that an electric charge is measured by using photons of synchrotron radiation emitted from a bending section in the beam injection line.

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