The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan 1993

LOW ENERGY RF ELECTRON ACCELERATOR FOR ELECTRON BEAM IRRADIATION

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Abstract

A re-entrant coaxial type electron accelerator named 'ELECTRON SHOWER' is developed for electron beam irradiation. The maximum beam energy is expected to be 900 keV and the maximum beam power 9 kW at the beam energy of 300 keV. The resonator is of 630mm in length and 500mm in diameter. The resonant frequency of the resonator is 180 MHz and the Q-value is 13000. The resonator is capacitively coupled to a feeder line and powered by a self-excited oscillator. This report describes the present status of the accelerator; mainly the radiofrequency system.

1. Introduction

Recently many electron accelerators are used in industries for electron beam processing(EBP). Particularly, the applications to the field of organic chemistry, for example, polymerization or curing of organic compound, vulcanization of rubber, and grafting are in practice among developed countries. Furthermore, electron accelerators are used for sterilization of medical tools , food irradiation, and environmental application, for example, SO_2 , NO_X removal from flue gas. These accelerators are usually classified in three groups as followings.

Low energy machine: beam energy is lower than 300 keV,
Medium energy machine: beam energy is between 300 keV and 5 MeV,
High energy machine : beam energy is between 5MeV and 10 MeV.

Most of accelerators used in industries are low and medium energy machines and recently are gradually increasing. However, the accelerators whose beam energy is lower than 5 MeV are mostly DC machine except for Russian machine. Then we are trying to develop an RF electron accelerator because an RF accelerator is much smaller than a DC machine in the energy higher than 300 keV.

2. Specifications and Outline of accelerator

We decided that the beam energies of the accelerator is lower than 900 keV , because we can use the electron machine whose beam energy is lower than 1 MeV without permission of the government. However, the DC accelerators whose beam energies are lower than 300 keV are very compact and already delivered by many companies. Therefore, we design the machine which can accelerate an electron beam to the energy higher than 300 keV.

The beam current is chosen below 30 mA because this machine is a proto-type and it is important that we prove the design concept of the machine. Also, the beam current of 30 mA is judged enough to study EBP in a laboratory. Table 1 shows the specifications of 'ELECTRON SHOWER'(ES).

Table 1. Normal specification of ELECTRON SHOWER.

Beam energy	300 -900 keV
Energy resolution	± 5%
Maximum beam intensity	30 mA
scanning width	30 cm
Beam spot size	<20mm in diameter.
Line power	3 phase, 200V, 35 kVA max.
Space for accelerator	Floor:1500*900 mm, Height:1850mm
Weight of accelerator	450 kg

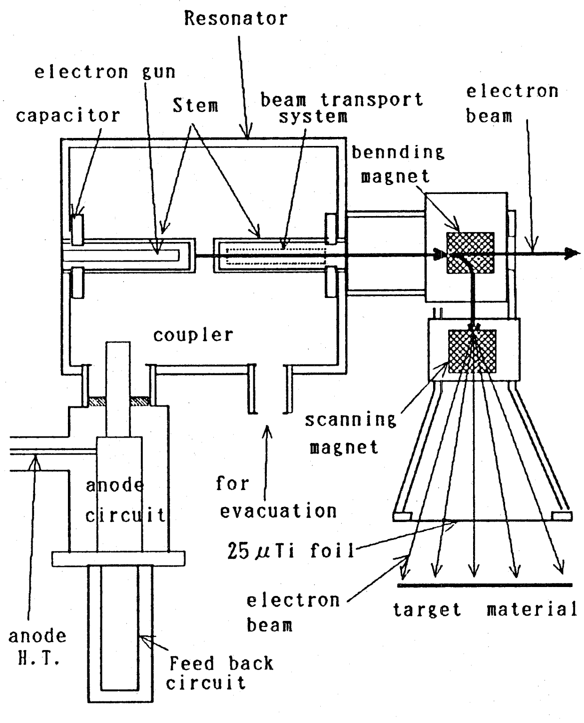

Fig.1 Cross-sectional view of ELECTRON SHOWER.

Figure 1 shows a cross-sectional view of ES. An electron beam is extracted from a hot cathode mounted in the stem by DC and RF fields. Velocity of the extracted beam is modulated by the superposition of DC and RF fields and electrons are concentrated in the narrow phase of the main acceleration field at the entrance of the acceleration gap. The beam accelerated at the gap is transported to a bending magnet and bent to the vertical direction. After that, the beam is scanned by a scanning magnet 30 cm in width and extracted into the N_2 gas or air through thin titanium foil(25-30 micro meters in thickness). Samples placed immediately below the foil are irradiated by electrons .

3. Resonator

The outer conductor of the resonator is made of aluminum plated with copper. The inner conductors(stem:270mm in length, 70 mm in diameter) made of copper are mounted on the flat end of the outer cylindrical conductor and faced to each other at the center of the resonator. The stem in which the electron gun is mounted is capacitively connected to the end wall so that the beam modulation field (RF) is derived from the main cavity through this capacitor. Also DC field for electron extraction is supplied on the stem. The DC field has the other role to suppress multipactoring of the main resonator.

Many resonances of the resonator, for example, 182 MHz, 250 MHz, 447 MHz, 565 MHz, and others are observed. In the fundamental mode(182 MHz), RF voltages of the stems are out of phase and in the second harmonics(250 MHz), the voltages are in phase and no acceleration field exists between the stems. Then the fundamental mode is used for beam acceleration. The measured Q-value of the fundamental mode is 15000 and consistent with calculation. However, this value decreased to 13000 when the whole instruments were installed on the resonator, as the capacitor at the stem end and an electron gun. The shunt impedance of the fundamental mode is estimated to be about 3.5 M ohm from the Q-value of 13000. As RF power is delivered by a self oscillator strongly coupled to the resonator, we have to tune carefully the resonator and oscillator so that the undesirable modes are not excited.

4. Self-excited oscillator

Recently, the resonators of RF accelerators are powered by a master oscillator and power amplifier system(MOPA). A MOPA system is very powerful and convenient to control finely an accelerator. However, a MOPA system is more complicated than a self oscillation system and require other components as a resonant frequency tuning circuit, an auto-impedance-matching circuit, and acceleration voltage stabilizer. For an electron beam irradiation system, high energy resolution and stability are not required. Then we chose a self oscillator system. Table 2 shows the specifications of the oscillator.

Table 2 Specifications of the oscillator.

Frequency	180 MHz
Maximum RF power (when duty<1/10)	100 kW pulse peak
Duty	from 1/5 to 1/50
Type	self-excited oscillation
Tube	4CW25000

To generate the acceleration voltage of 900 kV, it is estimated from the shunt impedance that an RF power of about 120 kW has to be fed to the resonator. Then, an amplifier system and DC power supply will be very big comparing to the resonator if the power is delivered by a CW oscillator. Furthermore, such a large power source is not economical because we can get the small beam power of only 9 kW. Then we chose the pulse oscillator whose duty is varied from 1/5 to 1/50. The oscillation is switched by the control grid bias.

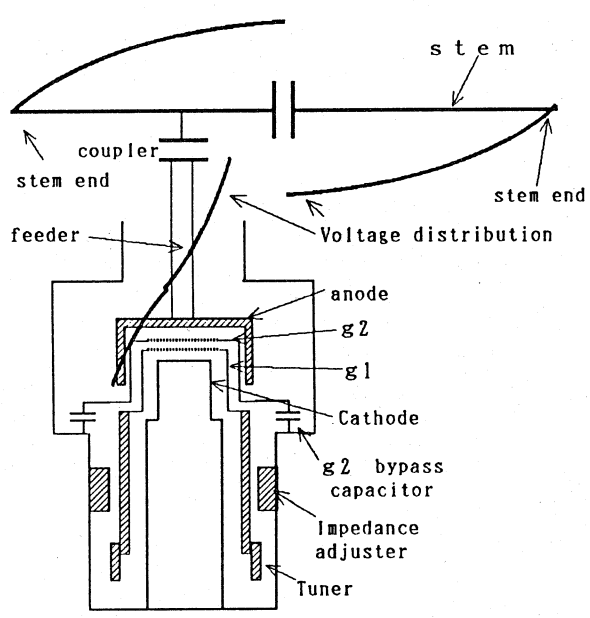

Fig. 2 Schematic view of the resonator and the self oscillator.

Figure 2 shows a schematic view of the self oscillation system and an typical voltage distributions of resonator and the anode circuit. The anode circuit is capacitively connected to the resonator and the voltage distribution of the anode circuit has a node near the center of the circuit. The cathode(feed back) circuit is a double coaxial line. An RF power from the anode circuit is fed back to the cathode circuit through a screen grid bypass capacitor and transmitted to the gap between the grid and cathode. RF voltage between the outside of the coaxial connected to the control grid and outer ground is different from that between the inside of the coaxial and the coaxial connected to the cathode. A difference of RF phase between the anode voltage and the control grid is nearly 180 degree when the circuit is tuned, and the amplitude of the feedback voltage is adjusted by a tuner and impedance adjuster.

5. Present status and remained problems

Fabrication of the whole system is already completed and the beam acceleration test has been done. Figure 3 shows the energy spectra of the electron beam which are analyzed by a bending magnet. An extraction DC voltage of the electron gun is 2.25 keV and RF modulation voltage is proportional to the main acceleration voltage. As the modulation voltage is adjusted to obtain the best energy resolution when the main acceleration voltage is about 250 kV, the energy resolution at 200 keV is better than the others. The typical result of acceleration test is summarized in Table 3. The energy resolution of about $\pm$ 1.5 % is sufficiently good for industrial irradiation applications. However, the maximum acceleration voltage of 300 kV and the beam current shown in the table are not enough. The reason why the beam intensity is so low is that power capacity of the DC power supplies of electron gun are not sufficient, and structures of electrodes of electron gun and of the acceleration gap and the beam transport system are not optimized yet. It is very difficult to see why the acceleration voltage is so low. Now we are trying to obtain much higher accelerating voltage and plan to reconstruct relevant parts identified to be responsible for the voltage limitation.

Table 3 Typical result of acceleration test.

Acceleration voltage	300kV
Beam intensity(160 keV, duty=1/50)	80 micro A
Energy resolution(200 keV)	1.5%

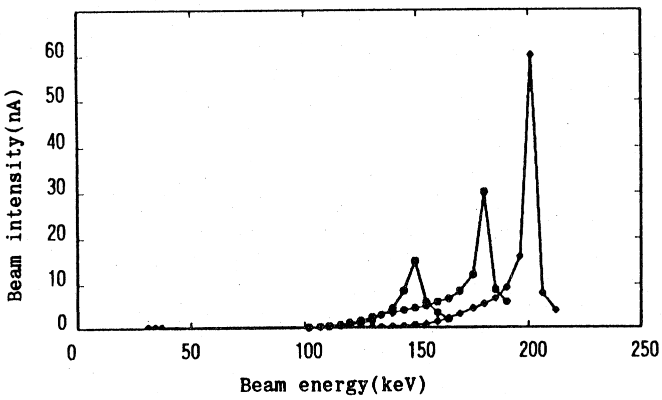

Fig. 3 Typical energy spectra of an electron beam.

6. Conclusion

We have not reached to a satisfactory result. However, the principle of the accelerator is established, that is, the self-excited tetrode oscillator works well and overcomes multipactoring in the resonator without DC bias on stem, and the new beam bunching system gives a sufficiently good energy resolution for industrial application of electron beam irradiation.