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DEVELOPMENT OF AN RF ELECTRON BEAM IRRADIATION SYSTEM

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Abstract

A prototype electron beam irradiation system using a re-entrant type RF accelerator(630mm in length, 500mm in diameter) has been studied to make a compact device for electron beam processing. The maximum beam energy is planned to be 900 keV. The resonator is powered by a self-excited oscillator. This report gives brief explanations and the present status.

1. Introduction

Recently many electron accelerators are used in industries for electron beam(EB) processing. Most of accelerators whose beam energy is lower than 5 MeV are DC type. The main reason why DC machines are used, is because the electric power efficiency of DC machines is much better than that of RF machines ,and principle and technology of DC machine are well established comparing to the RF machine. An RF accelerator, however, is much smaller and less expensive than a DC machine in the energy higher than 300 keV. Furthermore, RF accelerator is more reliable than DC machine because any insulator is not used in the area where strong electric field arises and no accessory is required such as a reservoir of SF_6 gas for DC machine. Then we studied a prototype RF electron accelerator to develop an electron beam irradiation system named 'ELECTRON SHOWER' for industrial use.

As shown in our previous report [1], the principle of the accelerator is established, that is, the self-excited tetrode oscillator[2] functions well and overcomes multipactoring in the resonator without use of the conventional DC bias scheme. The new beam bunching system[3] gives a sufficiently good energy resolution for EB processing. The maximum acceleration voltage, however, was 300 kV and the averaged intensity 0.1 mA. Then we have improved machine and increased the acceleration voltage up to 800 kV and the averaged beam intensity up to 10 mA. Now, a unit for industrial application based on the study is under construction.

2. Specifications and Outline of ELECTRON SHOWER

Table 1 shows the specifications of 'ELECTRON SHOWER'(ES) that were already described in our previous report [1]. These, however, are typical values and should be changed according to requests by a small modification of the prototype without change of fundamental construction.

Table 1. Specifications of ELECTRON SHOWER.

Beam energy:	300 -900 keV
Energy resolution:	± 5%
Maximum beam intensity:	10 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

Figure 1 shows a cross-sectional view of ES. An electron beam is extracted with DC grid voltage(5.5kV) from a hot cathode(LaB_6, 4 mm in diameter) of an electron gun mounted in the stem. Velocity of the extracted beam is modulated by the RF fields induced at a bunch gap and electrons are concentrated in the narrow phase of the main acceleration field at the acceleration gap. The beam accelerated at the gap is transported to a bending magnet and bent to the vertical direction. Then the beam is scanned 30 cm in width by a scanning magnet and extracted into the N_2 gas or air through thin titanium foil. Samples placed immediately below the foil are irradiated by electrons

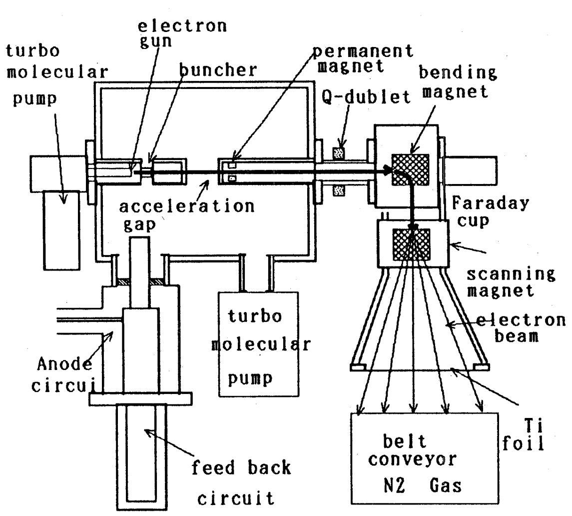

Fig.1 Cross-sectional view of ELECTRON SHOWER.

3. Radio-frequency system

The principle of radio-frequency system and structures of ES were already described[1]. Here, the brief explanation for RF system and for its modifications is given. The inner conductors(stem: 270mm in length, 80 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. As shown in Fig. 2 the, stem in which the electron gun is mounted, has slots to generate the electric field for the velocity modulation of the extracted electron beam.

The resonant frequency of the fundamental mode is 182 MHz, and the measured Q-value is 15000. The shunt impedance is estimated to be about 3 M ohm from the Q-value of the resonator coupled to the oscillator. The resonator is powered by self-oscillator system and the oscillation is switched by the control grid bias. Table 2 shows the specifications of the oscillator.

Table 2 Specifications of the oscillator.

Frequency	182 MHz
Maximum RF power	130 kW pulse peak (when duty<1/10)
Duty	from 1/5 to 1/50
Type	self-excited oscillation
Tube	4CW25000A

4. Increase of beam intensity

4-1. Electron gun

A triode type electron gun is operated in pulse mode by switching the grid bias in synchronous to the pulse mode of the main RF field. The cathode of electron gun made of LaB_6(4mm in diameter) is heated by pyrolytic-graphites set on both sides of the cathode. The grid made of molybdenum or tungsten mesh is set in front of the cathode with gap of 1 mm. The extraction electrode is one similar to a Pierce type as shown in Fig. 2.

4-2. Focusing system

The duty factor for normal operation of ES is 1/10. Then the peak current of 100 mA is required to accelerate the averaged current of 10 mA. Furthermore, the intensity more than 1A is concentrated in the narrow phase of RF acceleration field by velocity modulation. In such a case, very high tension as a few tens kV is usually applied to an extraction electrode to suppress the space charge effect. The low extraction voltage of 5.5 kV is ,however, supplied in ES because a machine for industrial application should be as compact and inexpensive as possible. For effective transportation of the low energy beam to the main acceleration gap, a beam focusing system consisting of cylindrical permanent magnets is mounted in the stem(see figure 2). The beam focusing system consisting of cylindrical magnets is also mounted in the other stem to transport the electron beam to the bending magnet.

4-3. Buncher coupled inductively to the main resonator

We developed a new type buncher system whose RF voltage is generated by an inductor in the middle of the stem[4]. Figure 2 shows a schematic view of the stem having the buncher. An electron gun and also a beam focusing system are installed in the stem. The RF electric field of the buncher is anti-phase with the main accelerating field.

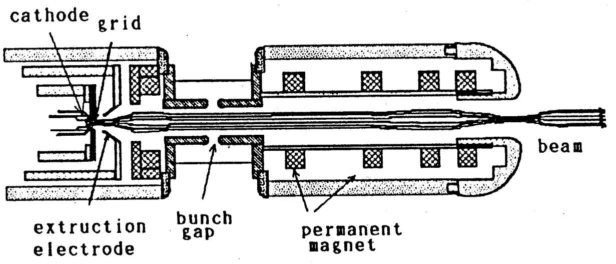

Fig.2 Cross sectional view of the stem with a beam focusing system and a buncher.

5. Present status

5-1.Beam loading

The insufficient maximum acceleration voltage of 300 kV in our previous report, was caused by poor adjustments of coupling between oscillator and resonator, and also of feed back elements. It is, however, difficult to optimize the coupling and feed back ratio, because these depend strongly on the acceleration voltage, biases of the tetrode and beam loading. Particularly, it is difficult to adjust the parameters when the beam is accelerated, because the shunt impedance of the resonator including beam loading is, for example, one thirds of the impedance without beam loading in a case of 300 keV 100 mA(pulse peak) acceleration. Figure 3 shows a time structure of the acceleration voltage when the beam is accelerated. Even if the self-excited oscillator were adjusted to operate under beam loading, the acceleration voltage decreased considerably when the beam was injected. Now, intensity of 100 mA(pulse peak) has been stably accelerated at 300kV.

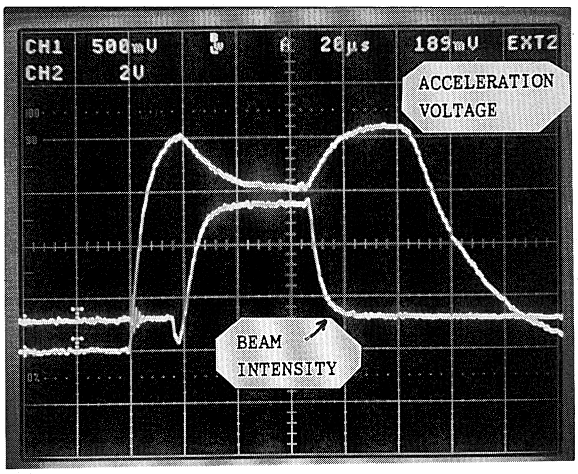

Fig.3 Typical beam loading effect.

5-2. Acceleration test

Figure 4 shows the typical energy spectrum of the electron beam analyzed by a bending magnet. The RF modulation voltage proportional to the main acceleration voltage is adjusted to obtain the best energy resolution at the beam energy of 250 keV. The typical result of acceleration test is summarized in Table 3. The energy resolution of 5% at 300keV is sufficient for EB processing.

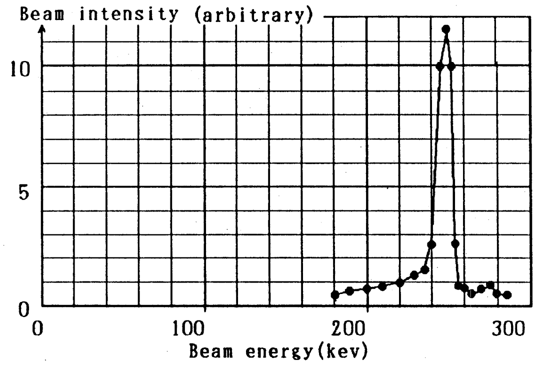

Fig. 4 Typical energy spectrum.

Table 3 Typical result of acceleration test.

Maximum acceleration voltage	820kV
Beam intensity(330 keV, duty=1/10)	100 mA
Energy resolution(300 keV)	5%

5-3. Irradiation test

It is required to irradiate sample uniformly in wide area. In the present case, as the machine operates in pulse mode(width:100 micro sec, period: 1m sec), the beam was scanned by so low frequency(50Hz) that a beam spot of a pulse overlaps with that of the successive pulse. The uniformity of ± 10% is obtained.

The depth dose curve measured by use of CTA films is shown together with one obtained with DC machine in Fig. 5. The disagreement between the data is little problem for EB processing.

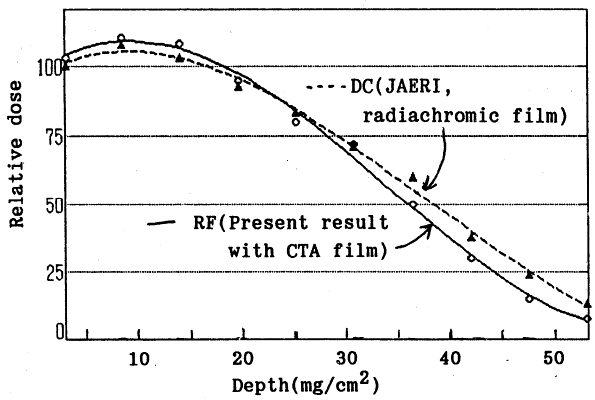

Fig.5 Depth dose curve obtained by ES

We usually estimate the effect of irradiation by dose(Gy). Most of data of electron beam irradiation ,however, are obtained by DC machine. Then we carried out preliminary experiments such as sterilization, cross linking of lubber, polymerization, coloration of glass, and etc. In most of the tests, we could not find out difference between effects of RF and DC machines, but found that one thirds of dose required for DC machine gave same effects on one of polymerization experiments. This result shows the typical example that irradiation effect depends on dose rate.

6. EB system for industrial use

Figure 6 shows the cross sectional view of electron beam irradiation system designed based on study for prototype machine. The reasons why the accelerator are set vertically are as follow:

1) The energy resolution obtained is sufficient for usual EB processing. Then the beam energy has not to be analyzed with a magnet.
2) Most of materials are irradiated in horizontal plane.
3) The transmission efficiency of beam is naturally better for a system without a bending magnet.

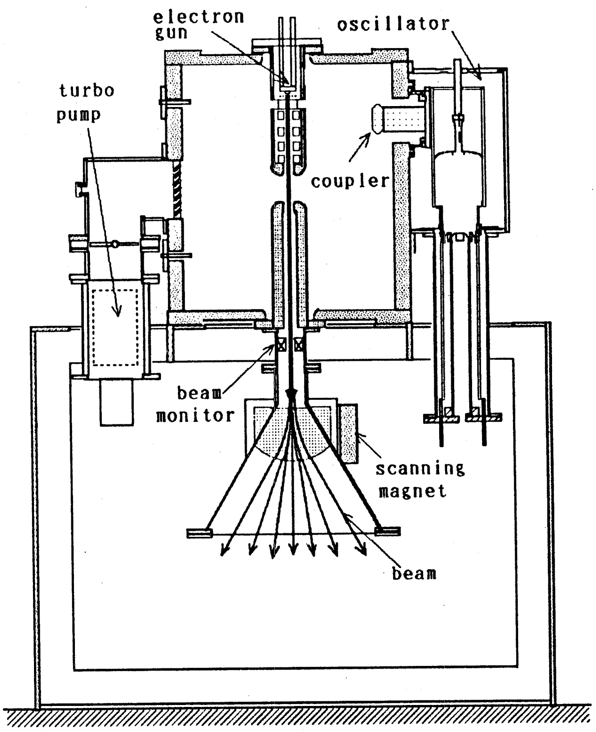

Fig.6 Cross sectional view of ES for industrial use.

7. Conclusion

The prototype electron irradiation system was successfully studied and also preliminary experiments have been carried out. Now the machine is installed in a university and used for several experiments. The system for industrial application based on the prototype is under construction.

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References

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