Design and Performance of the 40 MeV Linac and Beam Transport System for the 1 GeV Synchrotron Radiation Source at SORTEC

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ABSTRACT

A 1 GeV synchrotron radiation source (SOR) system has been installed and is now being adjusted at SORTEC corporation. This paper reports the configuration and the beam test results of the 40 MeV electron linac (pre-injector) and the beam transport line to the electron synchrotron used in this system.

The output beam from the linac must be low emittance, small energy spread, and stable in energy. The beam transport line must also efficiently lead the beam from the linac to the electron synchrotron. This linac produced the beam current of 130 mA, with an energy spread of 1.3% (FWHM), and an emittance of 0.7π mm·mrad. The beam characteristics were verified by various beam monitors on the beam transport line.

INTRODUCTION

The essential function of linac that serves as a pre-injector of the SOR system is to provide high quality beam. The value of both emittance and energy spread required for this linac are an order of magnitude severer than those for the conventional industrial or medical electron linac. This report includes measures taken in designing to meet these severe conditions and test results of beam quality. About the beam transport line, discussions center on design of the device configuration and beam trajectory.

LINAC DESIGN

In designing the electron linac, the following measures were taken to minimize the output beam emittance and energy spread, and to stabilize the energy.

(1) Generation of low emittance electron beam

To acquire low emittance output beam, it is important for the electron gun to emit beam with low emittance. A low-perviance electron gun is used to obtain electron beam with small divergence angles. The emitted electron beam is then forced to pass through a circular slit and thereby outer beam is cut out. The central electron beam of low emittance only is used.

(2) Enhanced electron beam trapping effieiency

For efficient use of electron beam, we employed a double-prebuncher system that has two single-gap prebunchers arranged in the direction of the beam acceleration axis.

The above two measures are major means to minimize the emittance.

(3) Use of a buncher accelerator tube with excellent bunching characteristics

Reducing the energy spread of incident electron beam into a small angle is more effective in minimizing the output beam energy spread. This prompted us to use a $\pi/2$ mode standing wave buncher as the buncher accelerator tube in place of the conventional traveling wave type. For the main accelerator tube, a $2\pi/3$ mode traveling wave type is employed.

(4) Stabilization of dominant parameters for output beam energy

The parameters are stabilized with respective minor loops. The klystron output is stabilized by using a shunt regulator type pulse modulator. This modulator stabilizes the output pulse voltage below $\pm 0.1\%$ by directly controlling the P.F.N charging voltage.

These two measures are major means to minimize the energy spread and stabilize the energy.

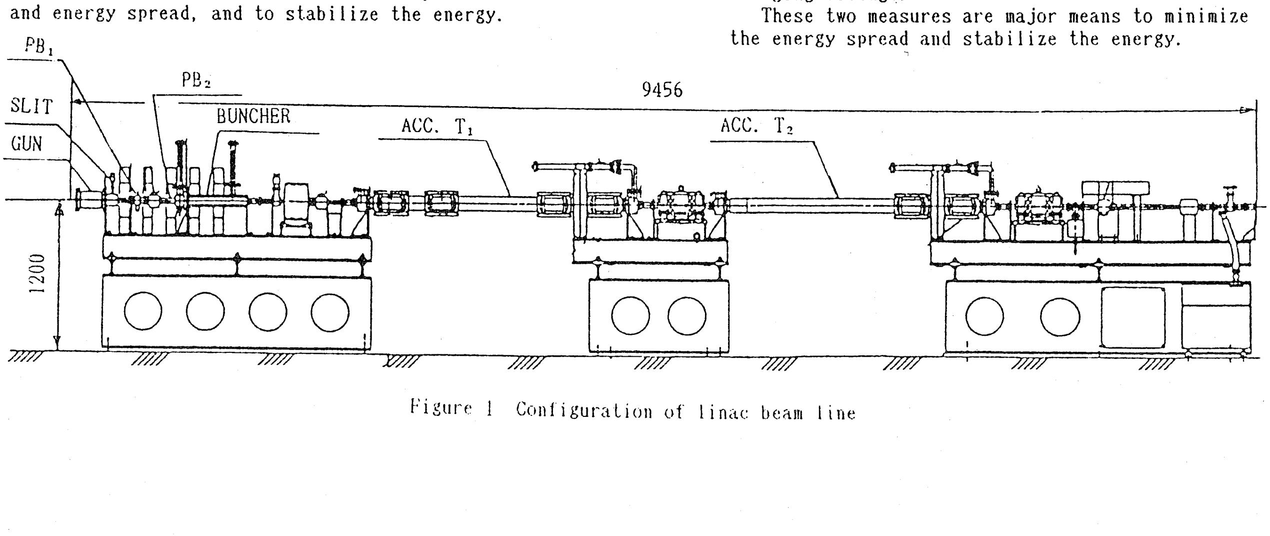

Figure 1 Configuration of linac beam line

LINAC CONFIGURATION

Figure 1 shows the configuration of linac beam line designed as described above.

It is designed to produce the current of 200 mA or more through the 2ϕ slit at the anode voltage 90 kV using a triode type electron gun.

The double-prebuncher in which RF voltages 5 KVP and 15KVP are applied to the first and second prebunchers, respectively, bunches 75% (corresponding to 270°)of the electron beam into 50° in phase angle.

The buncher accelerator tube is a side coupled standing wave type which has nine cavities. The calculation of beam dynamics shows that the output energy 5.3 MeV, energy spread 4%, and beam current 150 mA are obtained at the input power of 2 MW. It is also proved that the incident beam with the bunch width of 50° is bunched into 5° .

The main accelerator section consists of two quasi-constant gradient traveling wave accelerator tubes(2π/3 mode), can accelerate the beam current 150 mA up to 40 MeV at the input power of 8 MW. Each accelerator tube has 63 cavities.

A single S-band pulse klystron (PV-3035A)is used as the RF source. Although the rated peak power of PV-3035A is 35 MW, the RF source is designed to produce about 20 MW. The klystron output is distributed to five systems, where a phase shifter and an attenuator are installed as required.

Table .1 Results of output beam performance

I t e m	Measured value	Design value
Gun emission	210 mA	200 mA
Energy (buncher)	6.5 MeV(2.4MW)	5.3 MeV (2MW)
Emittance(buncher)	2.4π mm·mrad	————
Energy (output)	40 MeV	40 MeV
Beam current(total)	130 mA	150 mA
Beam trapping effi.	62 %	75 %
Beam current (useful)	60～80 mA	30 mA
Pulse width	1.7μs	1.5μs
ΔE／E (FWHM)	±0.67%	±1.5%
Beam size	±1.5 mm	±2 mm
Beam divergence	±0.6mrad	±3 mrad
Emittance(output)	0.7π mm·mrad	3.8π mm·mrad

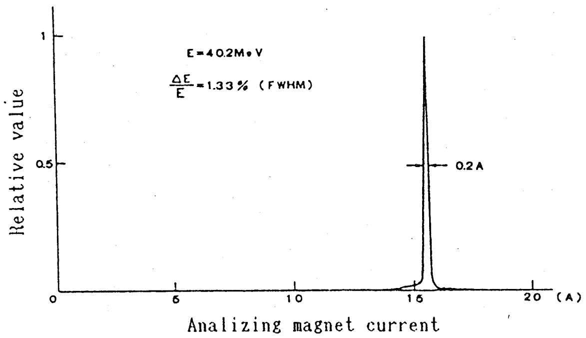

Figure 2 Energy spectrum

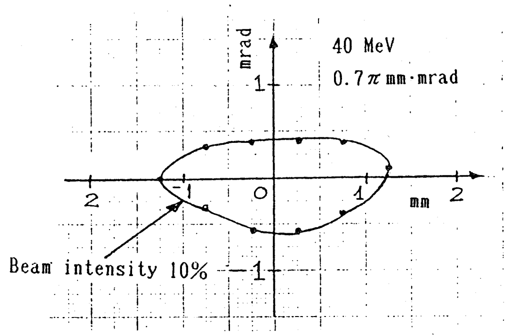

Figure 4 Emittance of linac output

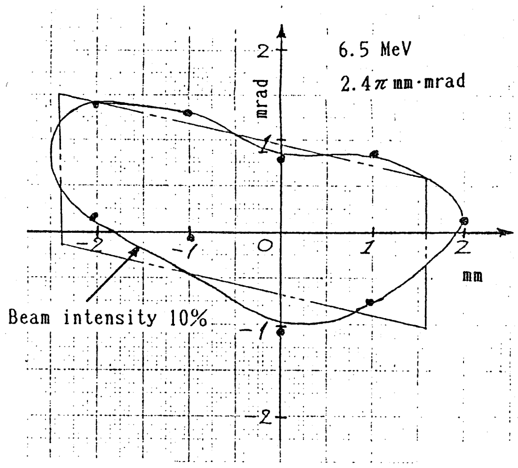

Figure 5 Emittance of buncher output

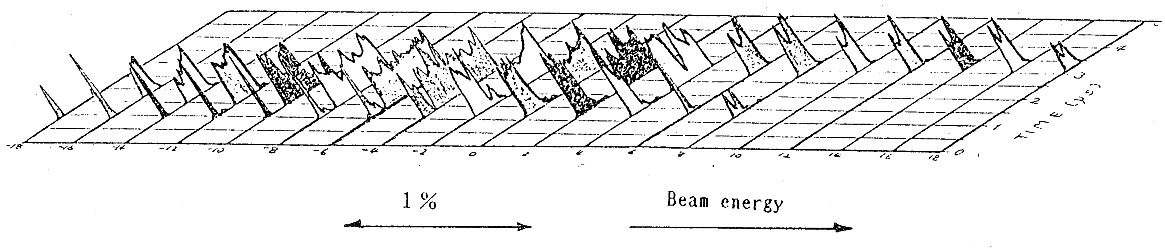

Figure 3 Finestructure of beam energy

LINAC BEAM PERFORMANCE TEST

Table 1 lists the results of output beam performance tests that agree well with the design values.

The measured energy spread proves that $\Delta E/E$ is $\pm 0.67\%$, within 1/2 of the design value.
Figure 2 illustrates an example of measurement charts.
Figure 3 shows the finestructure of beam energy.
The beam emittance obtained from the area of the phase chart in Fig.4 is about 0.7 π mm·mrad.
The beam emittance at buncher outlet obtained from area of the phase chart in Figure 5 is about 2.4 π mm·mrad.

In addition to above results, the fact that the obtained beam current has attained double or more value shows that these comprehensive beam characteristcs fully meet the requirements of the pre-injector to an electron synchrotron.

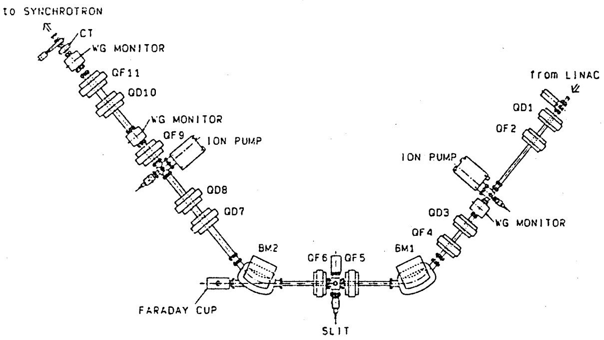

Figure 6 The layout of low energy beam transport line

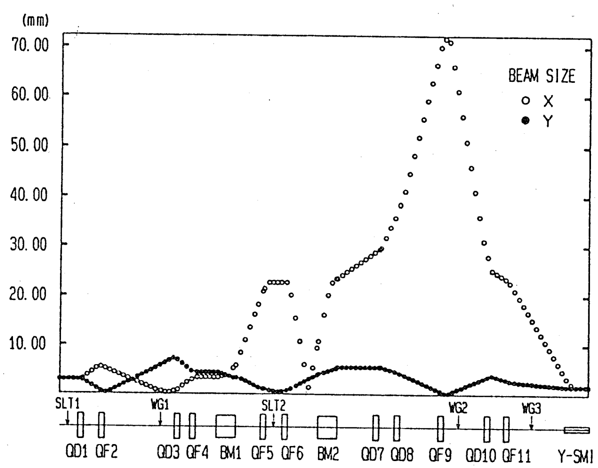

Figure 7 The beam size

LOW ENERGY BEAM TRANSPORT LINE (LBT)

The layout of the LBT is shown in Figure 6. Two dipole magnets, nine quadrupole magnets and correction coils are involved to constitute a favorable beam optics. This line can be divided into three sections from the standpoint of the optics.

(Ⅰ) The straight section from the linac.
(Ⅱ) The bending section of 101° .
(Ⅲ) The straight section to the synchrotron.

The straight section (Ⅰ) consists of four quadrupoles to have a flexibility to optimize the beam dynamics into the bending section, whenever the incoming beam shape from the linac is distorted.

At the bending section (Ⅱ),a non-dispersive deflection system (which means telescopic as well as achromatic system) are constructed with two focusing quadrupoles and two 50.5° bend dipoles each of which has edges of 13.87° . The beam should be so focused at the center of this system with the maximum momentum dispersion that we could, if necessary, make energy-distribution analysis of the beam as well as energy selection, using a slit.

The straight section (Ⅲ)is similar to the section (Ⅰ)in respect of the beam matching and consists of five quadrupoles, which enables us to adjust not only betatron functions but dispersion function with the reduction of the focusing strength of the downstream quadrupole of section (Ⅱ). It provides, therefore non-dispersive transport as well as dispersive one.
Figure 7 shows the beam size of the LBT calculated with an estimation of the emittance of 0.7π mm·mrad and momentum spread being not greater than $\pm 1.5\%$.
The large beam size at the downstream is mainly attributed to the large dispersion function.

Distortions of the beam orbit should be adjusted with five correction coils followed by wire-grid monitors.

The parameters of these magnets are summarized at Table 2.

According to the above classification in optics, three kinds of apertures are adopted to the beam chamber. Their dimensions are 56.5mm in inner diameter, 40mm×80mm cross section, and 97.6mm in inner diameter, downstream along the line. The main pumping is achieved by two sputtering ion pumps with the pumping speed of 140 ℓ/s each, associated with a turbo-molecular pump(100 ℓ/s) and a rotary pump (100 ℓ/min) for rough pumping. The beam-on operating pressure of 1×10^{-8} torr, or less is realized by the system.

Table 2 The parameters of the LBT magnets

T y p e	Number	Length	Field strength (max.) etc
Dipole	2	44.07 cm	0.27 T 13.87° edges
Quad. (1)	6	10.0 cm	4.0 T/m
Quad. (2)	5	10.0 cm	3.0 T/m
Correc.	5	5.0 cm	0.055 T

REFERENCE

(1) S. Nakamura et al. : Proc. of the 13th Linear Accelerator Meeting in Japan (Sept, 1989)