DESIGN STUDY OF 150-MeV RACETRACK MICROTRON

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ABSTRACT

A 150 MeV racetrack microtron was designed and is being constructed. This machine will be used as an injector for a superconducting electron storage ring. The racetrack microtron consists of an injection system, an accelerating column, two main magnets with reverse-field magnets, beam focusing elements, and a vacuum system.

A pulse width of the beam extracted from the racetrack microtron is designed from 0.5 to 2 μsec, and the repetition rate is adjustable up to 180 Hz. The designed emittances are as good as 1 π mm·mrad in both the horizontal and vertical directions, and the energy spread is less than 0.1 %.

INTRODUCTION

A 650 MeV superconducting single-body electron storage ring is being constructed by Sumitomo Heavy Industries, Ltd.(SHI-SOR)[1-3], as a light source for an X-ray lithography and other applications. SHI-SOR requires the 150-MeV injection energy. The injector is necessary to be compact and economical, same as the SR ring. Linacs, synchrotrons or microtrons are usually devices as an injector for SR rings. In general microtrons have advantages of good beem quality and small machine size compared with the others. These advantages are particularly suitable for the injector of the SHI SR ring. There is a case using a racetrack microtron (RTM) as an injector for a SR ring at the Wisconsin University (WU-RTM).[4] This microtron provides 108 MeV electrons which is the highest energy as an injection microtron. This machine is characterized by reverse-field magnets (RFM), a chicane magnet, and slightly inclined poles of the main magnets. Furthermore, it has an acceleration column with the bore apertures shaped as a racetrack.

Our RTM (SHI-RTM) conceptually follows WU-RTM, although some difficulties are encountered when extend

Table 1. Designed specification of the 150-MeV racetrack microtron.

Injection energy	120	keV
Extraction energy	150	MeV
Intensity	5	mA
Pulse width	2	μsec
Repetition rate	180	Hz
Energy spread	< 0.1	%
Emittance	< 1 π	mm·mrad
Turn number	25	
Linac acceleration	6	MeV/turn
Magnetic field	1.2	T

the extraction energy to 150 MeV. One of them is a precision of the magnetic field. A required precision of the magnetic filed increases by square as a number of turns increases.[5] Fortunately this difficulty can be cleared by taking the pole-gap to be larger and manufacturing its surface more accurately. Also the effect of steerers can be taken into account. Another difficulty appears in a transverse focusing. The 150-MeV RTM cannot be built with an adequate focusing power by the racetrack shape bore apperture without knowing effects of the higher orders of the electromagnetic field in the acceleration column. For SHI-RTM a cylindrical acceleration column used conventionally in the industrial and medical applications is adopted, since the accurate electromagnetic field is either known or measurable. In this case other focusing elements are required, thus we employed permanent quadrupole magnets. Beam dynamics are analyzed by a computer code PARMELA for the injection system, and we have developed an original code to analyze the RTM whole system based on the field analysis codes SUPERFISH and TRIM. Consequently, it became clear that an intensity of at least 1 mA of the 150-MeV electrons
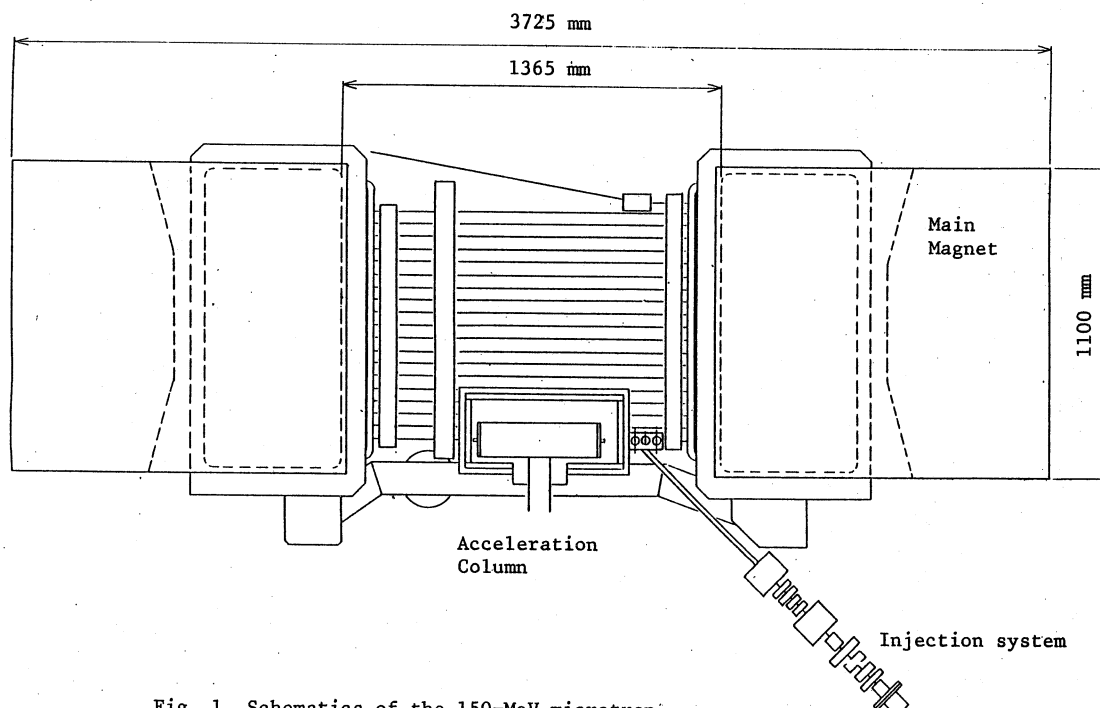

Fig. 1 Schematics of the 150-MeV microtron

can·be supplied from SHI-RTM. The designed specific-
ations are listed in Table 1 and the schematic drawing
is shown in Fig.1. In the following sections more
details are described.

INJECTION SYSTEM

The injection system consists of an electron gun,
a single-gap cavity (SGC), a chicane magnet, two
bunchers, and focusing elements. The electron gun
supplies 20 kV electrons. The current is 800 mA and
the pulse width is shorter than 3.5 μsec. The
repetition rate of the pulses is 360 Hz at maximum,
whereas external triggers can start up the electron
gun. The SGC boosts the electrons from 20 keV to 120
keV. The SGC made of high conductivity copper has a
similar geometry with the coupling cell of the linac
described later. The two identical bunchers, which
have 34 mm in·inner length and 43 mm in inner diameter,
have a conventional re-entrant shape.[6] They are made
of stainless steel and cupronickel and have the low
loaded Q-values as 300 and 800, respectively. The
bunchers work at the energies of 20 keV and 120 keV,
respectively. The chicane magnet bends the 120-keV
electrons at the angle of 45° from the injection line
to the linac line, and cancels the effect of bending
for the beam already accelerated by the linac.
The focusing elements are two solenoid magnets, two
X-Y steerers, and two doublets of electrical quadrupole
magnets.

LINAC and RF SYSTEM

The linac has side coupled structure, and
accelerates the electrons by the gain energy of 6 MeV.
The acceleration column, made of high conductivity
copper, is composed of 2 of half and 7 of full
acceleration cells, and 8 coupling cells. Its dimension
is 50 cm in length and 10 cm in diameter. Rf power is
fed into the acceleration column through a coupling
iris of the coupling cell which is connected to the
center cell. The main parameters of this linac is
listed in Table 2, and a typical axial electric field
distribution is shown in Fig. 2.

In the rf system a klystron which is driven by
an rf driver and a modulator provides 5 MW peak power.
The rf driver supplies 400 W peak power, and the
modulator generates 6 μsec pulses at a repetition rate
of 180 Hz. This peak power is divided into 4 power
lines. The schematic layout of the power delivering
system is shown in Fig.3. The wave guides are
pressurized to 2-atm in gauge pressure by SF6 gas.

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FREQ. (MHZ)  - 2875.625              ----------- RAV (CM) -  0.398
BETA (X)     - 100.678               ----------- RAV (CM) -  0.354
T.T.F.       -    0.7768             ----------- RAV (CM) -  0.309
EMAX (MV/M) -     3.024              ----------- RAV (CM) -  0.265
                                     ----------- RAV (CM) -  0.221
                                     ----------- RAV (CM) -  0.176
                                     ----------- RAV (CM) -  0.132
                                     ----------- RAV (CM) -  0.088
                                     ----------- RAV (CM) -  0.044
                                     ----------- RAV (CM) -  0.000
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Fig. 2 Axial electric field of a right half
cell near the axis and flux curves.

The supplied power of the each lines is adjustable and
the phase difference between any two lines can be set
and kept constant. The operating frequency is tuned by
an automatic frequency controller following the drift
of the linac resonant frequency. On the contrary, the
SGC follows the operating frequency using the motor
driven movable tuner, whereas the bunchers are left
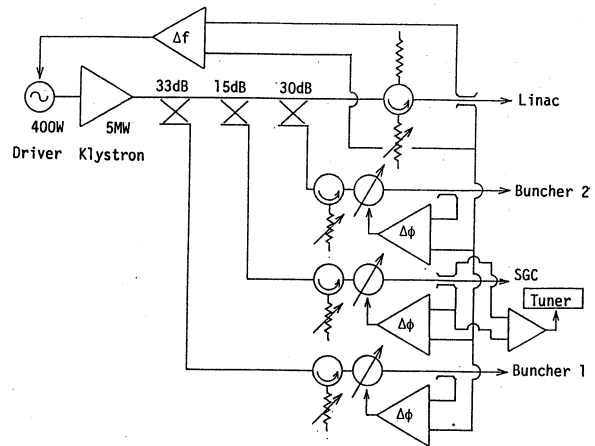alone because of their rather low sensitivity.

Fig. 3 Schematic of rf power delivery.

MAGNETIC SYSTEM

Two main magnets are located on both the sides of
the linac at the distance of 1.36 m. A designed
maximum magnetic field is 1.3 T and an operation point
for 150 MeV is 1.23 T. The dimension of the poles is
1100 mm wide and 530 mm long. The pole-gap is of 10 mm
at the entrance edge and of 10.6 mm at the other edge.
This difference gives the field gradient of 0.14 T/m.
The main magnets have air gaps of 2 mm between the
poles and yokes on purpose to avoid a distortion of
a medium plane caused by a strong magnetic force
between the poles.

The RFM has yokes of common use with the main
magnets as shown in Fig.4-a). The operation magnetic
field of the RFM is about 0.133 T. The size of the
poles of the RFM is 20 mm long in the longitudinal
direction, and in the transverse direction 40 mm and
20 mm wide for the first turn and the other turns,
respectively. Each pole has an independent coils in
order to adjust beam trajectories.

Two doublets of the quadrupole magnets are
installed on each beam line. One of the doublets is
electrical but all the others are made of permanent
magnets. Each permanent quadrupole magnet is composed
of 8 pieces of SmCo and ferrite magnets. The poles are
20 mm long and 30 mm in outer diameters. The strengths
of the field gradient are distributed between 1.2 and
8 kG/cm. It is impossible to obtain such strengths of
the field gradient by conventional electrical
quadrupole magnets of such small size. Effective K
values of the quadrupole magnets are adjustable by
changing effective length with field clumps.

BEAM DYNAMICS
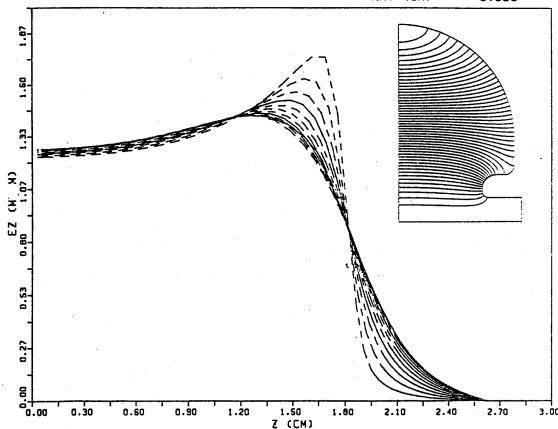
Electromagnetic fields in the bunchers and the SGC were calculated by SUPERFISH. The obtained values were Fourier transformed for the use in the calculation of the beam dynamics with a computer code PARMELA. In order to achieve a high efficiency, parameters of the injection line should be oetimized. Because the space-charge effect can not be ignored for the range of electrons at low energies and high intensities, PARMELA was introduced to simulate beam dynamics in the injection line.

Beam dynamics in the RTM are analyzed using the 10th order Runge-Kutta method[7] in the same manner as WU-RTM[8]. Initial conditions of the beam are derived from the analysis of the injection line. The effect of the chicane magnets are ignored in this analysis. Coordinate system and dimensions of spaces, time, fields and the other physical values follow ref. 8. Physical regions are divided into 4 parts as follows,

i) Linac (Cylindrical rf electromagnetic fields)
ii) Main magnet and RFM
   (Two dimensional static magnetic fields)
iii) Quadrupole magnets
   (Longitudinally homogeneous magnetic fields)
iv) Straight sections.

Electromagnetic fields in the linac are obtained by calculation with SUPERFISH both for the half-cell cavities and for the full-cell cavities. SUPERFISH generated magnetic flux density of each mesh point, normalizing them for the averaged strength of the electric fields on the center axis to be 1 MV/m. Electromagnetic fields on an arbitrary point and time in the cavities are obtained by linear interpolation of triangle data of the mesh generated by SUPERFISH, using the Maxwellian equations in the manners of the different equations in spite of the differential ones. The
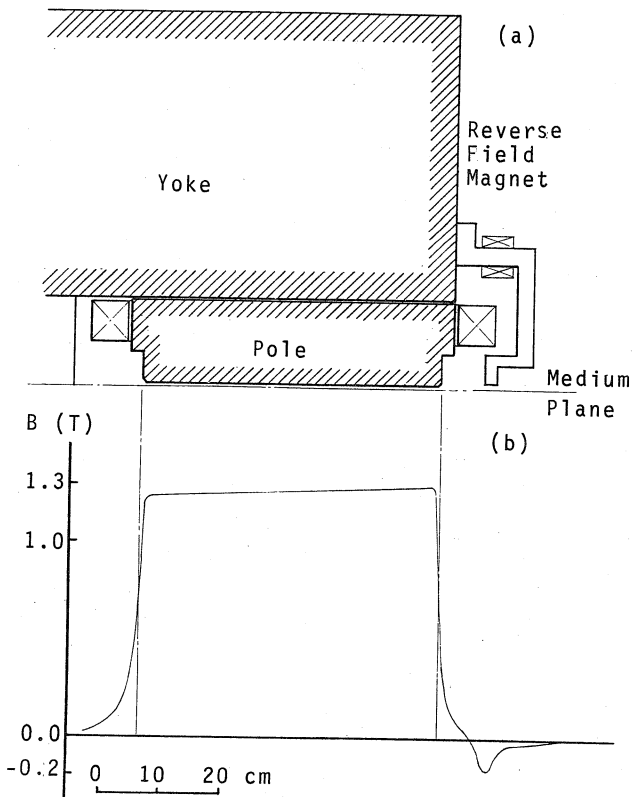
Table 3. Acceptances of SHI-RTM

Direction	Acceptance	
Horizontal	30	π mm·mrad
Vertical	40	π mm·mrad
Longitudinal	60	π keV·degree

normalization factors of the fields are changed in order that an on-axial electron which has a relativistic velocity is accelerated by an energy just of 6 MeV at the phase of 18° when the electron passes longitudinally the center of the full-cell cavity.

Magnetic fields in the main magnets and the RFM are obtained by a two-dimensional computer code TRIM. The both are calculated simultaneously for several different currents of the RFM coil. A typical result is shown in Fig.4-b). Two dimensional magnetic field on an arbitrary point in the main magnet and RFM is obtained by linear interpolation of triangle data of the mesh generated by TRIM. Magnetic fields in the quadrupole magnets used in the calculation are ideal ones, that is, nonlinear components and fringing fields are ignored.

Through these analyses we found that the injected beam can be accelerated in the efficiency of 2 %. Almost of them are lost within the first 3 turns because of their energy spread which is originated not only by the initial phase of the first turn but also by the pass difference from the central axis of the linac. The initial energy spread is allowed to be around ±5 %. The obtained acceptances of SHI-RTM are listed in Table 3. Since the main magnets have a dispersion, the longitudinal and horizontal emittances are strongly coupled. This is one of the difficulty for us to optimize quadrupole strengths easily. We are expecting more efficiency after further optimization is done for parameters of the injection line and the quadrupole magnets.

SUMMARY

A design study of a 150-MeV racetrack microtron was almost completed. From the beam simulation SHI-RTM can provide electrons of the intensity of at least 1 mA and of the energy of 150 MeV. At present SHI-RTM is on the stage of construction. Beam intensity will increase according to further optimization of the parameters.

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Fig. 4 (a) Schematic of the upper half of the main and the reverse-field magnet.
(b) Vertical magnetic field on the medium plane.