Improvement of 150 MeV Racetrack Microtron

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Abstract- A 150-MeV pulsed racetrack microtron (RTM) which was developed as an injector of an electron storage ring, succeeded in first-beam acceleration in April 1989. However, the output beam current of the RTM was far less than the designed value, and insufficient for the storage ring to accumulate the designed current. Therefore, the improvement program of the RTM started soon and the remodeling was finished in Octorber 1990 which brought a quite good result. The essential features of the improvement are simplification of the injection system and focusing magnets in the recirculation system. The new RTM has achieved the design specification with ease, proving its reliability by very stable operation.

1. Introduction

A simplest and smallest synchrotron-radiation (SR) source has been developed by Sumitomo Heavy Industries, Ltd. for industrial use, especially for X-ray lithography. The storage ring consists of a single cylindrical superconducting weak-focusing magnet having the circular electron orbit of 1-m diameter. The system, called AURORA[1] parameters of which are listed in Table 1, consists of a 150-MeV RTM injector and 16 SR light channels at the maximum.

Table 1. Main parameters of the electron storage ring in the SR source system AURORA.

Energy	650	MeV
Beam currents	300	mA
Critical wavelength	1.02	nm
Beam lifetime	> 24	hours
Magnetic field	4.34	T
Vacuum pressure	6×10^{-10}	Torr

Generally, linacs or synchrotrons are used as injectors in conventional SR rings, especially for high-energy-beam injections. There are systems using RTM as an injector such as that of the University of Wisconsin (UW). The RTM has the advantages of good beam quality and small machine size. We adopted the concept of UW-RTM[2], but opted for an alternative cylindrical acceleration column and a permanent-magnet (PM) focusing system. This type of the 150-MeV RTM[3,4] succeeded in the first-beam extraction in April 1989[5], and the first SR light was observed from the storage ring in November 1989[6,7]. However, achievement of the AURORA's full specifications seemed difficult because of a lack of beam intensity from the injector RTM, normally ~10 μA and 0.1 mA at the maximum[5]. Therefore, the remodeling of the RTM was started, and completed in October 1990. The result was very successful. The RTM is routinely operated since then satisfying the needs of the storage ring.

2. Main Modifications

The essential features of the improvement are; 1) simplification of the injection scheme substituting DC 120 keV beam for RF preaccelerated one, and 2) removal of PM quadrupole-doublets (QD) from return paths to eliminate dispersion from the linac line. The parameters of the new RTM are listed in Table 2.

Table 2. Design parameters of the injector RTM in the SR source system AURORA.

Injection energy	120	keV
Final energy	150	MeV
Beam currents(peak value)	5	mA
Pulse width	0.5-3.0	μsec
Repetition rate	1-180	Hz
Emittance(ϵ_x, ϵ_y)	<1π	mm·mrad
Energy spread(ΔE/E)	0.2	%
Number of orbits	25	
Energy gain per pass	6	MeV
Main magnetic field	1.23	T
Main field gradient	0.14	T/m
Reverse magnetic field	0.29	T
RF frequency	2856	MHz
RF pulse width	6	μsec
Accelerating gradient	15	MV/m
Bore diameter	1	cm
Wall loss(peak)	<1.3	MW
Beam loading(peak)	~1.3	MW

Except the reverse magnetic field strength and energy spread, nothing has been changed since the old parameters were fixed[3]. However, the outlook of the new RTM (Figure 1) became fairly different due to the remodeled structure preventing leakage of magnetic flux effectively and more vacuum-tight constitution. The whole size shown in Figure 2 is almost the same as the old one.

2.1. Injection System

In the old system, the 20-keV gun and three cavities; prebuncher, preaccelerator and buncher, were aligned to boost a beam 100 keV up keeping the bunching effect simultaneously[3]. The old one had the advantages of compactness and easy-handling of the high voltage power supply. But the disadvantages such as difficult clarification of the beam quality owing to the RF preacceleration and bunching, and a lack of stability derived from too many RF parameters were crucial.

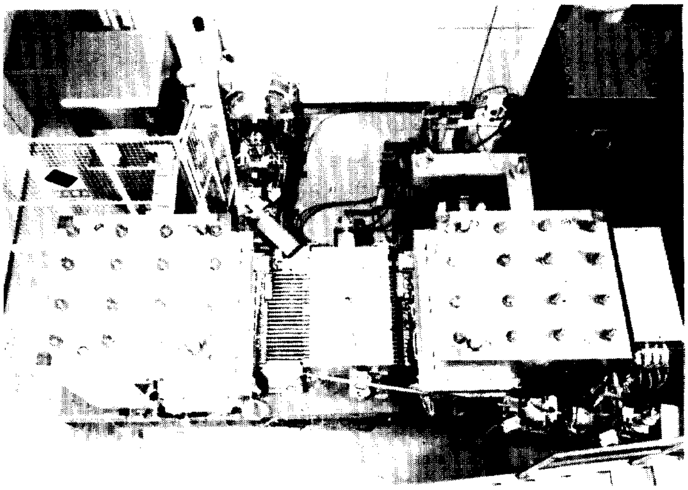

Figure 1. An overall view of the AURORA injector 150-MeV RTM after improvement.

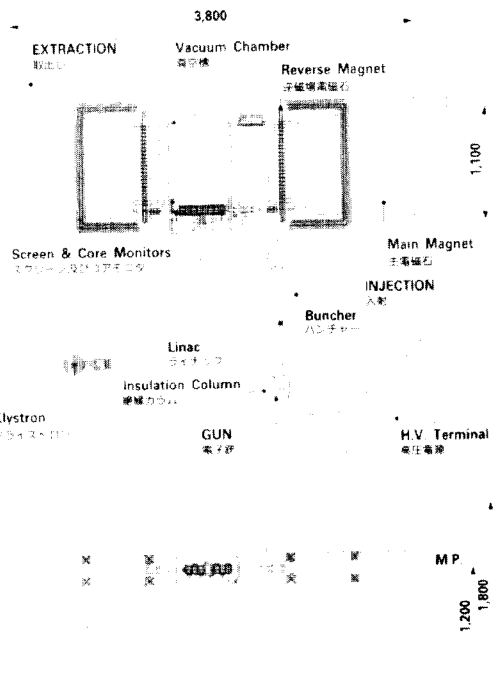

Figure 2. Schematic drawings of the new RTM with its outer dimensions.

The new system is designed to make the beam optics clear by simple DC acceleration. The parameters of both injection and recirculation systems are separated, and decided each other independently. Practically this makes the RTM tuning very easy, which was proved on the initial commissioning of the new RTM. Emittances of the new 120-keV gun were measured for the various cases and 80 mA was obtained within 60π mm·mrad for both ε_x and ε_y, as shown in Figure 3 for ε_x, and 220 mA in 100π mm·mrad at the entrance of the linac, where the beam size was restricted within $\phi 6$ mm. Actually 20 mA is enough to operate the RTM as the AURORA injector.

2.2. Recirculation System

The constitution of the auxiliary magnets in the recirculation system has been changed completely. The design strategy is to remove PMQD placed on every return paths, which makes the linac line dispersionless.

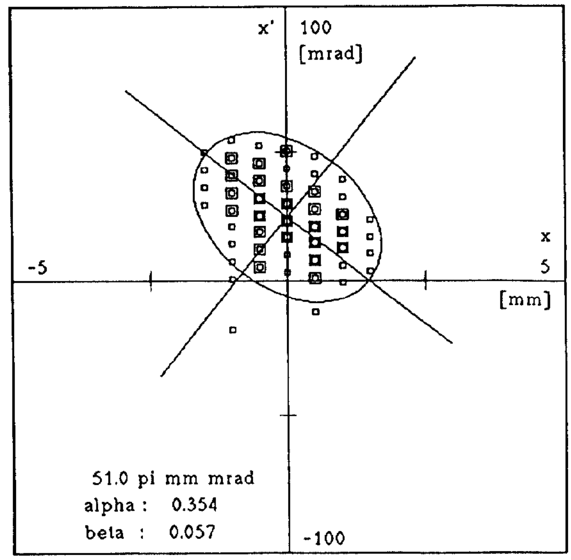

Figure 3. Measured horizontal emittance of 120-keV beam at the entrance of the linac.

Another advantage is simplification of the focusing parameters due to missing of all PMQD's. One can avoid confliction come from combined effect; focusing and steering of PMQD, which makes beam tuning very complicated. On the design stage, main concern was paid to vertical focusing, especially to the 6-MeV beam which is reflected back into the linac.

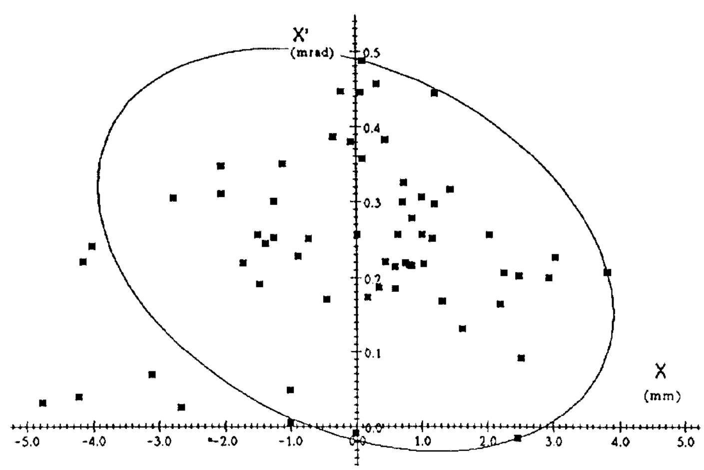

Figure 4. Calculated horizontal emittance of 150-MeV extracted beam. Ellipse of 1π mm·mrad is shown.

According to the careful beam simulation, it was found that horizontal focusing is achieved by the only Q-singlet placed on the linac line adjacent to the chicane, and vertical focusing by the reverse field can compensate all the vertical defocusing in the low energy region. In the result, more than 100π mm·mrad acceptances are obtained in the both horizontal and transverse directions, which are quite large compared with the designed emittances of the injected beam. Calculated results of the 150-MeV extracted beam are shown in Figures 4 and 5. The horizontal emittance is less than 1π mm·mrad including the dispersion effect[7], that means it is reduced to about a half at the linac exit where no dispersion exists. The energy spread $\Delta E/E$ of the 80% beam is within $\pm 0.1\%$.

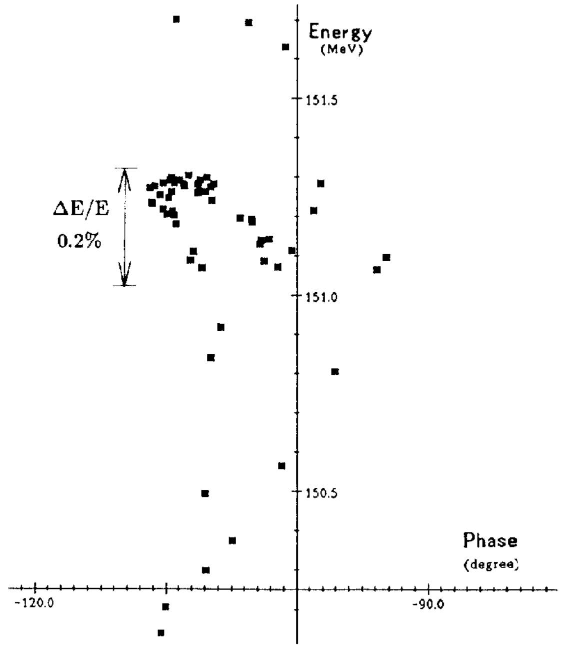

Figure 5. Calculated energy spread of 150-MeV extracted beam. About 80% of the beam are within 0.2% $\Delta E/E$.

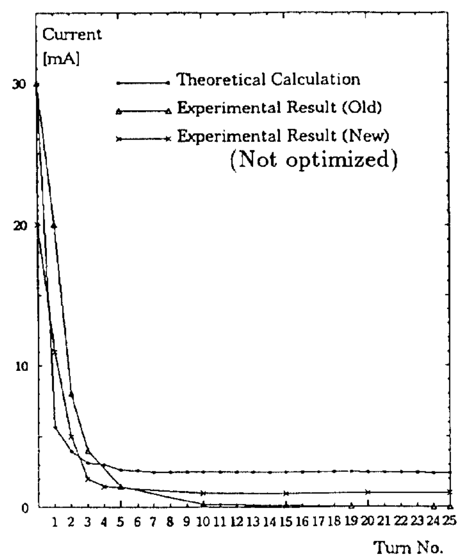

Figure 6. Transmission efficiency at each lap. Null turn no. correspondes to 120-keV injected beam and turn no. 25 to 150-MeV extracted one.

Various transmission efficiencies, calculated and measured ones, are seen in Figure 6. On the contrary to the old data, not so much decreasing after fifth lap appears in the new RTM's, which agrees well with the simulation result. A series of SR light spots from the RTM shown in Figure 7 is used as a powerful monitor whenever the RTM is tuned or operated[5].

3. Performance

The result of improvement is quite satisfactory. About 1 mA of a 150-MeV beam was extracted only after a-few-hours initial-tuning. This intensity is sufficient to accumulate the specified current in the storage ring, and the RTM is to be operated routinely as the AURORA injector with this rather-a-low intensity. Up to ~3 mA, the machine capability is proved without the buncher, and more than 7 mA with the buncher on the injection line. To achieve 10 mA is not difficult if the RF source could provide enough power to compensate the equivalent beam loading.

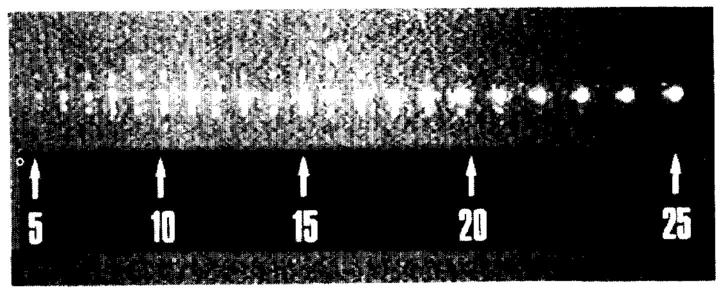

Figure 7. SR light spots emitted from the beam on the circular trajectories in the 180° end magnet, which are observed from the pole gap, 10 mm in width, through a view port. The spots from the fifth lap to twenty-fifth lap are seen from left to right in sequence.

Operability of the new RTM is so well-improved that the daily operation is on a full turnkey basis as the injector. Restoration of an operating condition is also well. Even when all the magnets are re-excited after shutdown, there is almost no need to change the magnets' parameters once they are determined. Thus the reliability of this stable machine is proved.

References

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