CONSTRUCTION OF A 35 MeV DOUBLE SIDED MICROTRON (DSM)

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Abstract: Construction of a CW 35 MeV double sided microtron (DSM) was started at Nihon University in 1984. Assembly and alignment of magnets, accelerating tubes and vacuum chambers have already been completed. The 5 MeV injector, the injection beam transport line and the first turn acceleration orbit have been tested with a pulsed electron beam of peak 10 μA.

Introduction

A CW 35 MeV double sided microtron (DSM) has been designed and constructed as a prototype of a 1 GeV CW 300 μA double sided microtron for medical use and as a test machine for free electron laser experiments.[1]

The basic configuration of the DSM, which is shown in Fig. 1, is the same as that reported at LINAC 84.[2] However, detailed parameters were changed for easiness of construction and operation of the machine, as listed in Table I. Assembly and alignment of magnets, accelerating tubes and vacuum elements have been completed. The RF systems have been operated with pulse mode of 50 % duty factor except the injector linac because of the breakdown problem of RF windows. Before completing all the recirculating systems, acceleration in the first turn orbit of the DSM has been tested with pulsed beam of peak 10 μA and pulse width 100 μs.

In the following sections, details of individual systems and beam test are reported.

TABLE I
DSM design parameters

Injection energy	4.55 MeV
Extraction energy	34.5 MeV
Beam current	300 μA
Field of sector magnets	0.1867 T
Accelerating gradient	0.773 MeV/m
Synchronous phase	25 °
Energy gain per turn	6 MeV
Number of recirculation	5 turns
Operating RF frequency (at CW)	2449.77 MHz
Accelerating tubes	4.283 m x 2
RF power dissipation	100 kW

The Injector Linac

All the RF systems have been designed so that they operate at 2450 MHz. There are four 50 kW CW klystrons made by Thomson CSF, two of them are used in the injector linac. Each klystron is isolated from the accelerating system by a circulator.

The injector linac consists of 100kV gun terminal, RF chopper, prebuncher, buncher and pre-accelerator. The output power of one of klystrons is divided among chopper, prebuncher and buncher via series of directional couplers. The chopper system, which is the same as

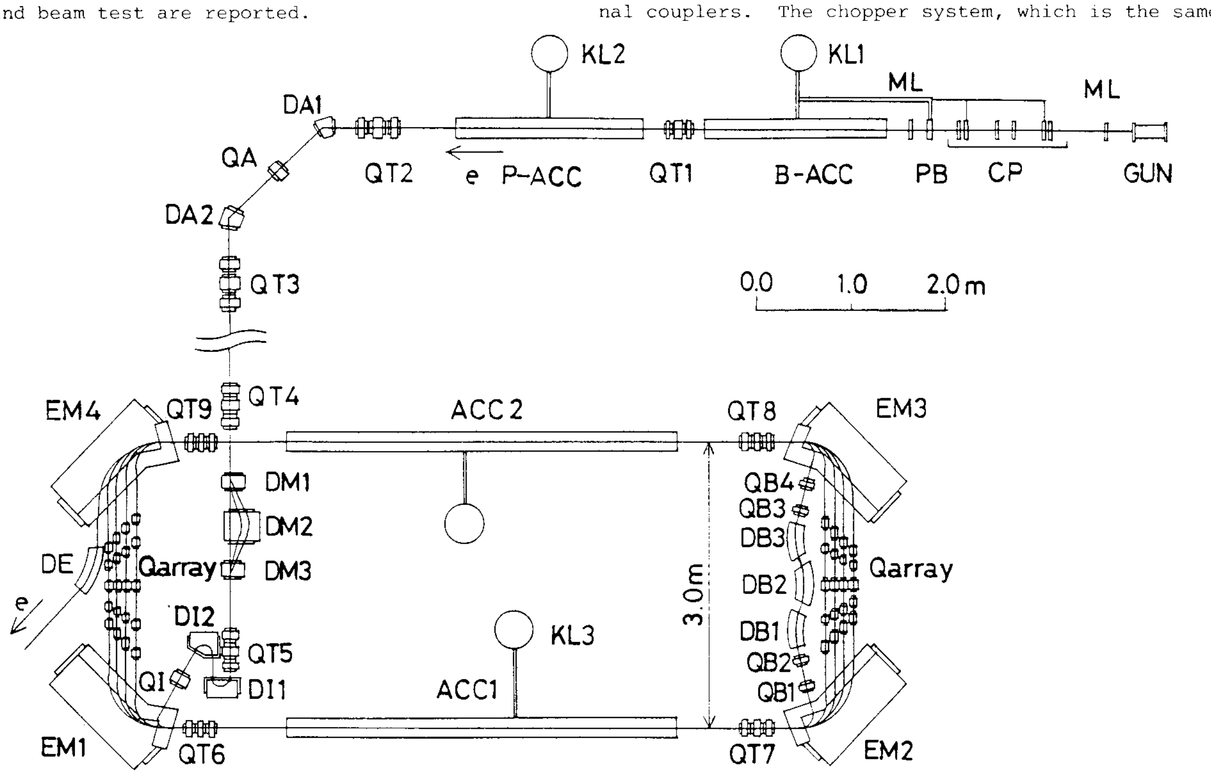

Fig. 1. Layout of the 35 MeV CW double sided microtron and the 5 MeV injector. KL:klystron, ML:magnetic lens, CP:chopper, PB:prebuncher, B-ACC:buncher, P-ACC:pre-accelerator, DA and QA:analyser magnets, DM:longitudinal matching magnet, DI and QI:injection magnets, EM:sector magnet, ACC:4m tube, DB and QB:phase matching magnets, DE:extraction magnet, QT:Q-tripet.

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one in the NBS-Los Alamos race-track microtron,[3] consists of two chopper cavities, a sector shaped slit at the mid point of two cavities and two magnetic lenses placed in symmetry near the slit. At the position of the slit, a circular beam profile is obtained according to input RF phase and power. The beam in relative phase width of 300° is removed at the slit and only residual beam within 60° is used.

The beam is accelerated 2 MeV in the buncher tube, and further accelerated 2 MeV in the pre-accelerator. Total energy of 4.55 MeV is required in the injector.

The buncher is a 2 m long graded-β accelerating tube of DAW structure. Combination of values of β and number of cavities was decided by a computer simulation using field distribution obtained by SUPERFISH,[4] which is shown in Table II. The pre-accelerator is a 2 m long constant β tube of DAW structure. Each tube was constructed separated into half parts for convenience of construction, and joined together near the center of the tube with vacuum flanges. There are six movable tuners opposite to washer support stems for fine tuning of the resonance frequency.

TABLE II
Combination of cavities in the injector tubes.

	β	number of cavities
Buncher	0.700	3
	0.850	5
	0.925	10
	0.974	17
Pre-accelerator	0.994	32

Injection Beam Transport Line

The beam from the injector is deflected 90° in the achromatic bending system, where energy spread is defined by a slit near the Q-singlet QA. The beam with energy spread of 2 % is transported to the DSM.

In order to keep stable acceleration in the DSM, both longitudinal and transverse emittance ellipses have to be matched at the injection point.

The longitudinal emittance is adjusted to an optimum shape by means of the longitudinal matching magnet system on the injection beam transport line so that the energy spread is kept minimum during acceleration in the DSM. Adjustment is only made by use of difference of orbit length according to different beam energy and magnetic field in the magnets DM1, DM2 and DM3. There is no accelerating element in the system.

The transverse emittance is adjusted by means of quadrupole triplets on the injection transport line so that the beam size in the DSM is minimized.

The injection point is the dispersive side of the first sector magnet EM1, where 4.55 MeV electron beam is deflected 120° with orbit radius of 8.077 cm. Energy dispersion is matched by means of two injection magnets DI1 and DI2, and Q-singlet QI, then an achromatic beam is injected on the center line of the first accelerating tube ACC1.

Accelerating Tubes in the DSM

Two accelerating sections placed in parallel at a distance of 3 m from each other, consist of 4.28 m long accelerating tubes with $\beta = 1$ DAW structure cavities. Each tube is fed with 50 kW RF power from one klystron. Coupling coefficient was chosen to be about 2.1 of over coupling in order to reduce the fluctuation of RF field in the cavities caused by beam loading, which is a possible maximum value when accelerating field necessary for operation is taken into account. The tube has been constructed separated in four parts and joined together with vacuum flanges. The resonance frequency is tunable more than 2 MHz with a total of 12 movable tuners in each tube.

At CW mode operation, the resonance frequency of the buncher tube is tunable below 2449.77 MHz, while those of the other tubes are tunable even above that frequency. Therefore, all the tubes were tuned in those expected to be 2449.77 MHz at CW mode, nominal RF power operation.

Since the temperature of cooling water supplied to the tubes is kept constant with accuracy of ± 0.1 deg, the resonance frequency decreases as increase of average input RF power, which amounts about 250 kHz at CW 50 kW, corresponding to increase in tube temperature by 6 degs. The resonance frequency has not been tuned during the operation so far, but the RF frequency has been adjusted so that VSWR could be minimized, which is a simple way of tuning when all the tubes are tuned in identical frequency and cooled using the same kind of cooling system. However, a remote tuning system using movable tuners will be made so that the change of the resonance frequency in each tube caused by change of input RF power will be compensated automatically.

Magnet Systems

The electron beam is extracted after accelerated ten times. The beam recirculation systems between two accelerating tubes were designed with the aid of computer programs TRANSPORT,[5] TRIM[6] and original program BEAM.

The sector magnets were constructed on the basis of results of field measurement on a model magnet which has the same dimensions as practical ones. A layout of the sector magnet EM4 is illustrated in Fig. 2. Each sector magnet is equipped with auxiliary, field clamp and auxiliary field clamp coils besides main coils so that all the sector magnets are excited at an identical field strength and that vertical defocus and horizontal orbit displacement in the fringing field are controlled precisely.

Field uniformity of flat regions in all the sector magnets were measured by means of a Hall probe in the symmetry planes of pole gaps, which was estimated to be within ± 0.07%. Additional correcting coils on the pole surfaces will be assembled in order to suppress within ± 0.01 %. However, there may be no problem even if no improvement is done, since estimated small displacement of beam orbit and deflection angle will be corrected by means of steering coils in the short straight sections.

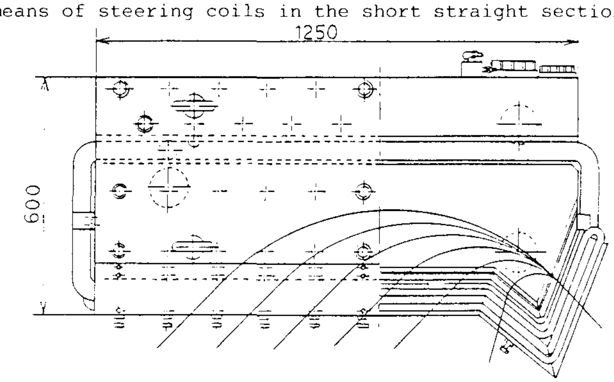

Fig. 2. Layout of the sector magnet EM4. EM1 has the same dimension in mirror symmetry.

The first recirculating system is quite different from those in the short straight sections. Since pole pieces of the sector magnets EM2 and EM3 are modulated at non-dispersive sides so that the lowest energy orbit passes well flat regions, the first turn beam is deflected 107°. In this system, the first turn beam accelerated in ACC1 is deflected 107°, -37°, 40°, -37° and 107°, then injected on the center line of ACC2. A large phase slip of beam bunch caused by a difference of velocity between the beam and the RF phase is compensated in this system by adjustment of the total orbit length. Horizontal and vertical beam envelopes in first order calculation are shown in Fig. 3 together with dispersion curve. Change of longitudinal emittance ellipse in the system is the same as in the other short straight sections.

Five Q-magnets in each short straight section are necessary for achromatic 180° bending system. The beam envelopes are designed to be symmetric about the third one, having waists at the center of the accelerating tubes without acceleration. Horizontal and vertical envelopes in the first section are shown in Fig. 4. The maximum field gradient of Q-magnets with aperture diameter 28 mm, outer diameter 104 mm and pole width 20 mm is 1100 G/cm, which is possibly an upper limit of field gradient realized by air cooling.

Whole envelopes from entrance to the first accelerating tube to exit of final tube are shown in Fig. 5, which was deduced using only first order beam transfer matrices. The beam envelopes grow by about 30 % at exit when second order matrices are involved. In Fig. 6 is shown corresponding behavior of longitudinal emittance ellipse, where we can see that the emittance of initial beam is matched with the DSM.

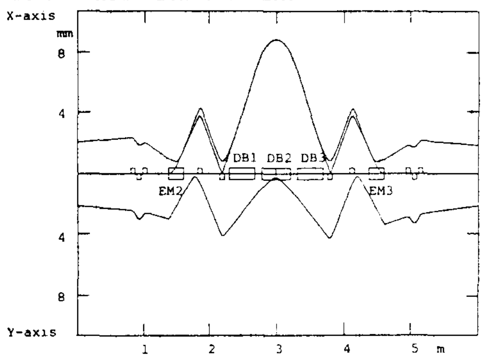

Fig. 3. Envelopes in the phase matching system.

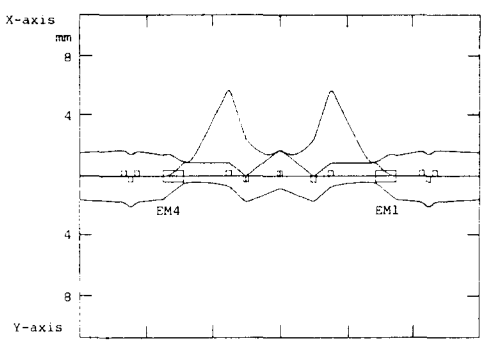

Fig. 4. Envelopes in the first short straight section.

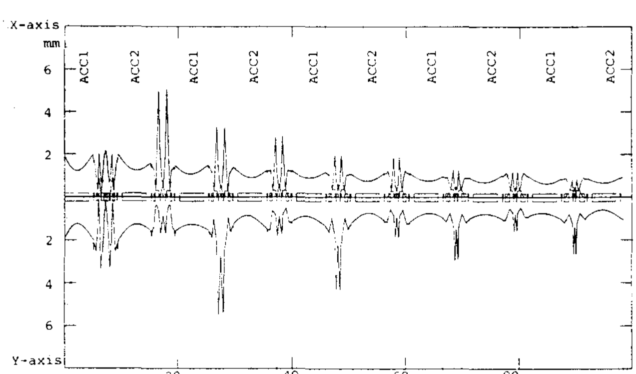

Fig. 5. First order calculation of envelopes from entrance to the first ACC1 to exit of the fifth ACC2.

Beam Test

Beam test of the injector and the first turn orbit in the DSM has been performed with 100 μs pulsed beam before all the recirculating systems are completed. Peak beam current out of the gun was restricted to less than 500 μA because of damage to the thermal cathode at vacuum breakdown.

The beam was proved to be accelerated to more than 4.55 MeV in the injector linac, which satisfies the energy required for injection to the DSM. A behavior of rough energy spectrum at the exit of the buncher was measured and compared with a computer simulation based on the electric field distribution obtained by a low power experiment. However agreement was fairly good, the electron beam has been shown not well bunched because of reduction of electric field in low β region compared with one expected from SUPERFISH calculation, so that less than 10 % of output beam current from the gun is expected to be acceptable in the DSM.

A large fluctuation of beam current in short time intervals (≦ 1 μs) was observed, which is considered as a result of instability of RF phase and frequency that might be caused by an RF amplifier.

In the beam test, the beam with peak current of 10 μA was injected into the DSM. Since both ACC1 and ACC2 had no magnetic shield, deflection of the beam in the tubes was compensated using steering coils wound along the outer wall of the tubes.

A profile of the beam accelerated through ACC1 and ACC2 was observed on the center of an output window which was located at the end of the vacuum duct for the first short straight section. The beam current was almost the same as which at injection point, which means that the beam was accelerated to 10 MeV without serious loss.

More than 60 dc power supplies used for beam handling, were controlled manually by observation of beam profiles on luminescent plates of beam profile monitors with TV cameras.

References

1. K. Hayakawa et al., IEEE Trans. Nucl. Sci. NS-30, No. 4, 3224(1983).
2. T. Tanaka et al., Proc. of the 1984 Linear Accelerator Conf., Seeheim, FRG, GSI-84-11.
3. M.A. Wilson et al., IEEE Trans. Nucl. Sci. NS-32, No. 5, 3089(1985).
4. K. Halbach et al., Proc. 1976 Proton Linac Conf., AECL-2600, 122(1976).
5. K.L. Brown et al., SLAC-91(1974).
6. J.S. Colonias, UCRL-18439(1968).

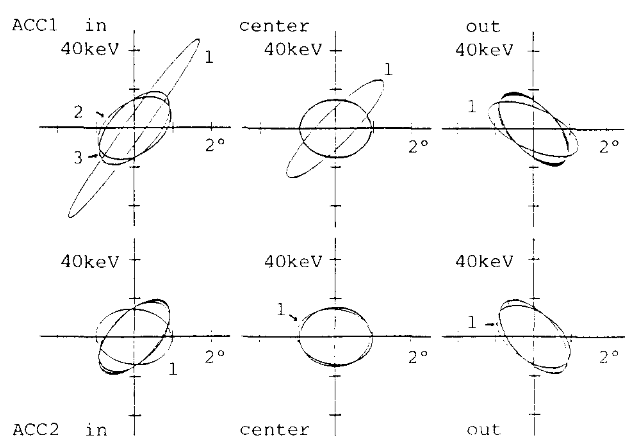

Fig. 6. Behavior of longitudinal beam ellipse during acceleration in the DSM when injected with matched condition. The number of recirculation is indicated.