ACCELERATOR PROJECT GEMINI
FOR INTENSE PULSED NEUTRON AND MESON SOURCE AT KEK

H. Sasaki and GEMINI Study Group[*]

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Abstract

A rapid-cycling synchrotron is designed for the intense pulsed neutron and meson source at KEK. This 800 MeV accelerator aims to deliver proton beams of 500 µA in time average. This paper describes conceptual design of the accelerator and also the present status of R & D for some technical problems.

Introduction

Five hundred MeV Booster Synchrotron at KEK, which is delivering 2 µA proton beam in time average, is used as a pulsed neutron and meson source of Booster Synchrotron Utilization Facility (BSF) as well as an injector for 12 GeV Proton Synchrotron in a time-shared mode. Since commissioning of BSF in 1980, a long-term future program of BSF has been discussed1). This is the construction of an intense pulsed neutron source (KENS-II program) and the extension of the present meson science experimental facility BOOM (Super-BOOM project). The most important part of this program is the construction of a high intensity proton accelerator. An accelerator system for KENS-II and Super-BOOM is named GEMINI, which is abbreviation of "a generator of meson-intense and neutron-intense beam". This is an 800 MeV rapid-cycling synchrotron aiming to deliver the proton beam of 500 µA in time average. Unlike the present meson factories or spallation neutron sources worldwide except those in BSF, GEMINI should deliver equally the pulsed proton beams to each of the meson and neutron experimental facility. In BSF, the unique features of the 70 nsec pulsed proton beam are effectively used for the time-of-flight technique in the neutron scattering experiments and for the studies on the relaxation phenomena of condensed matters with µSR. In GEMINI, it is also required that a single bunched beam is simultaneously supplied to each of the neutron and meson experimental facility. Particularly, some kinds of µSR experiment ask a single short bunched beam less than 30 nsec in bunch length even at the sacrifice of beam intensity.

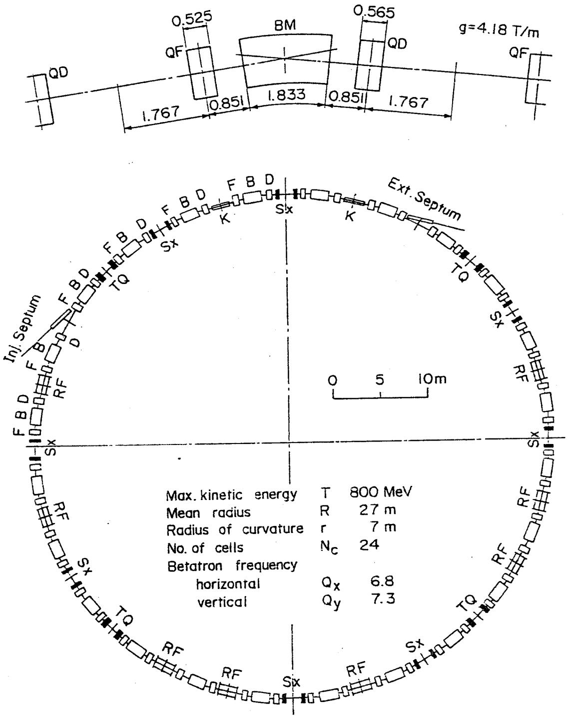


Fig. 1 GEMINI Layout

Table 1 A New Pulsed Neutron and Meson Source GEMINI

Maximum kinetic energy	800 MeV
Maximum intensity	6 x 10^{13} p/p
Repetition rate	50 Hz (100/3 Hz & 100 Hz)
Average beam current	500 µA
Injection energy	100 MeV
Injected H^- beam current	30 mA
Number of turns of injected beam	>240
Beam pulse width of injected beam	>330 µs
Magnet radius	7.00 m
Average radius	27.00 m
Number of period	24
Length of straight section	3.008 m
Structure	FBDO
Betatron frequency per revolution	
Horizontal	6.8
Vertical	7.3
Revolution frequency	0.757 - 1.489 MHz
Maximum beta-function	
Horizontal	12.4 m
Vertical	12.9 m
Momentum compaction factor	2.71 x 10^{-2}
Transition energy/rest energy	6.07
Beam emittance	
800 MeV	0.29 x 0.16 $(\mathrm{mm\ rad})^2$
100 MeV	0.97 x 0.52 $(\mathrm{mm\ rad})^2$
Number of bending magnets	24
Length of bending magnets	1.833 m
Length of quadrupole magnets	
Focussing magnet	0.525 m
Defocussing magnet	0.565 m
Bending magnet field	
800 MeV	0.697 T
100 MeV	0.212 T
Quadrupole magnet peak field gradient	4.18 T/m
Peak energy gain per turn	90.6 keV (60.4 keV)
Harmonic number	2
RF frequency	1.513 - 2.978 MHz
Maximum RF voltage	214 kV (166 kV)
RF bucket area	1.89 eV•sec
Number of RF stations	8
Incoherent space charge limit	7.2 x 10^{13} protons

Accelerator System

The parameters of GEMINI are listed in Table 1. The accelerator will consist of an H^- ion source, RFQ, 100 MeV Alvarez-type linac, and 800 MeV rapid-cycling synchrotron. A highly symmetric lattice with high tunes was chosen for the synchrotron lattice; 24 equal FBDO cells with a phase advance of about 90° per cell set the betatron tunes around 7. The layout of the accelerator is shown in Fig. 1.

Injector Linac2)

100 MeV linac with a 30 mA H^- ion beam is assumed as an injector to the synchrotron. The accelerating structure of this injector system is divided into three stages: 50 ∿ 100 keV H^- ion source, 1 MeV RFQ or APF and 100 MeV Alvarez linac. 1 MeV injection energy enables us to use klystron working around 400 MHz as RF

---

[*] T. Adachi, H. Baba, S. Inagaki, Y. Irie, N. Kaneko, T. Kawakubo, M. Kumada, S. Matsumoto, M. Miki, I. Sakai, H. Someya and Y. Yano.

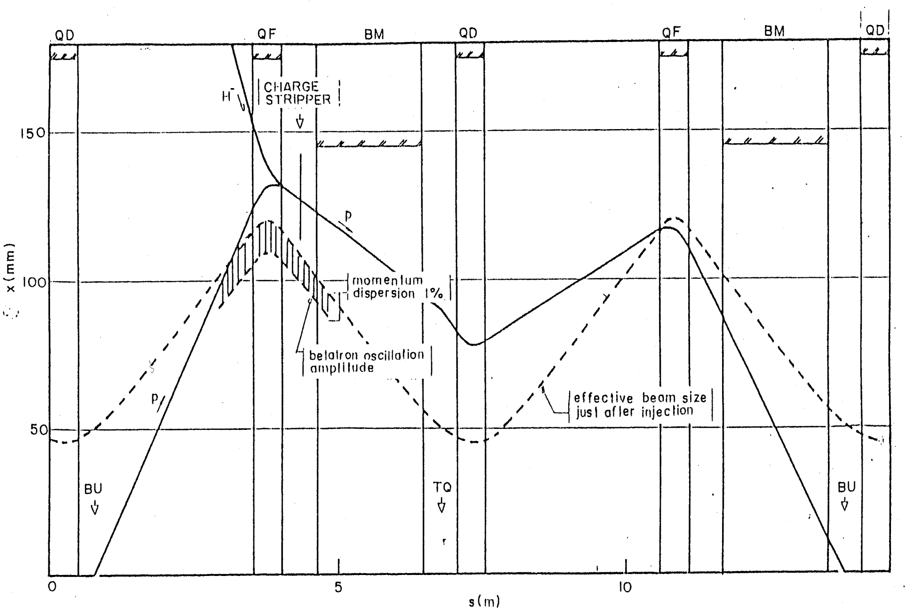


Fig. 2 Injection Optics

power source for the 100 MeV linac. This will simplify the power system of the linac. If the Alvarez linac is excited at 400 MHz, the diameter of cavity is reduced nearly to a half of the present proton linac at KEK. Table 2 shows accelerating energy by each cavity, cavity length, number of cells contained in a cavity and RF power for 6 partitions at the average accelerating voltage of 3.5 MV/m.

Table 2 Features of 100 MeV Injector Linac

Cavity Number	Energy (MeV)	Length (m)	Number of cells	Power (MW) Cavity	Beam	Total
1	18.37	7.267	81	0.852	0.521	1.373
2	35.57	7.138	41	0.835	0.516	1.351
3	52.68	7.305	33	0.870	0.513	1.383
4	69.93	7.483	29	0.911	0.517	1.428
5	85.38	7.180	25	0.898	0.464	1.362
6	100.39	7.458	25	0.929	0.450	1.379

Injection and Extraction

Beam injection will be carried out in horizontal plane. In order to store the number of protons of 6 x 10^{13} into the synchrotron with a 30 mA H^- ion beam, injection would occur at least over 240 turns requiring 330 μsec. For the purpose of filling the horizontal phase space, injection starts with a horizontal bump orbit, which coincides with the injection orbit of the H^- ion beam at the exit of a focussing quadrupole magnet as shown in Fig. 2. The density distribution of the beam after injection is regulated by choosing a proper decay waveform of the bump field.

Beam extraction is performed by the horizontal single-turn extraction. The emittance of the extracted beam is assumed to be twice of the expected one from adiabatic damping of the initial emittance. Figure 3 shows the extraction trajectory of beam. The deflection by the kicker magnet is 15 mrad for the first and second magnet. The septum magnet is divided into two parts, each of which deflects the beam by 150 and 225 mrad, respectively. These bends provide a separation of 80 cm between the central orbit and the central line of the extracted beam at the exit of the septum magnet. This distance is long enough for the extracted beam to clear the yoke of the quadrupole magnet following the septum magnet.

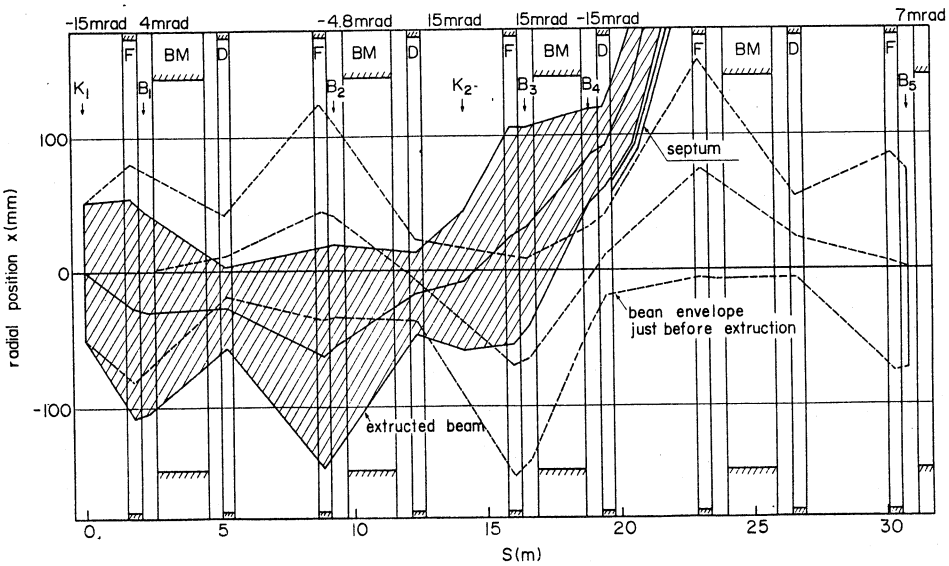
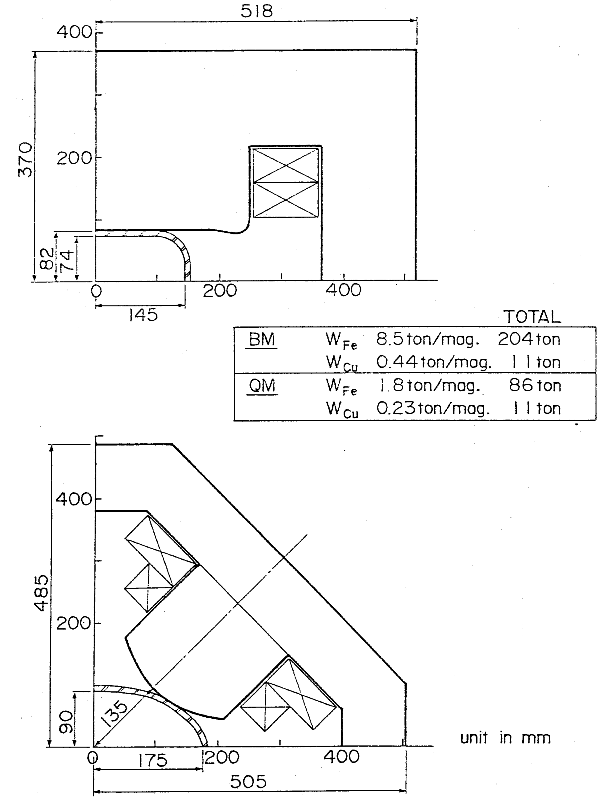


Fig. 3 Extraction Optics

Ring Magnets

The accelerator ring is made of 24 bending and 48 quadrupole magnets. The required semi-aperture of good-field region is 11.5 cm x 7.4 cm and 13.5 cm x 9.0 cm in the bending and quadrupole magnet respectively. For the vacuum chamber, it is necessary to add 3 and 4 cm in horizontal aperture of the bending and quadrupole magnet respectively to allow the room for injection and extraction of beam. The cross-section of the ring-magnet is shown in Fig. 4.

The ring magnet is excited with a repetition rate of 50 Hz. All of the bending and quadrupole magnets are divided into twelve groups. These are connected in series through resonant capacitors and forms a ring circuit. The dc bypass of the capacitors for the dc bias current is provided by installing chokes in parallel to the capacitors. In order to reduce the RF accelerating voltage, the magnet system would be excited by a dual-frequency system with resonant frequency of 100/3 and 100 Hz as proposed by M. Foss and W. Praeg at ANL[3]. This reduces the peak RF voltage of 214 kV to 166 kV.



			TOTAL
BM	W_{Fe}	8.5 ton/mag.	204 ton
	W_{Cu}	0.44 ton/mag.	11 ton
QM	W_{Fe}	1.8 ton/mag.	86 ton
	W_{Cu}	0.23 ton/mag.	11 ton

Fig. 4 Gap and Core Geometry of Ring Magnet

RF Acceleration

We assume a 100 MeV injected beam with an effective full momentum spread of 0.75 %. If the RF bucket area has to be twice of the injection beam emittance, the required peak RF voltage through the acceleration period is 166 kV in the 100/3 Hz operation of the guide field magnet. The RF voltage program and relevant parameters of RF bucket are shown in Fig. 5. The required RF voltage will be provided with eight RF stations, each of which is installed in a 3 m long straight section and consists of two reentrant ferrite-loaded cavities. A low impedance cathode-follower is proposed as a final-stage power amplifier in order to compensate for a large beam loading.

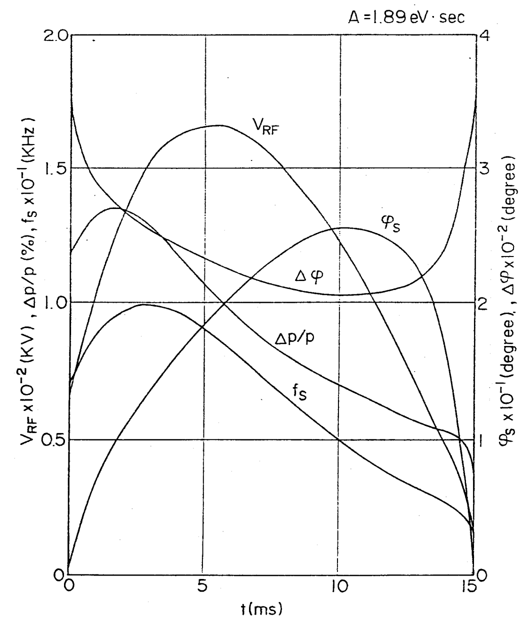


Fig. 5 RF Voltage Program and Relevant Parameters of RF Bucket

Vacuum Chamber

The vacuum chamber will be made from about 300 mm long sections of pure alumina, which are joined by metallizing the ends and brazing in vacuum. The lengths of vacuum chamber to be manufactured are within the limits of joining in this method, which enables us to attach directly metal flange at the end of the chamber.

Research and Development

R & D for some technical problems is in progress:

1) Prototype of the permanent quadrupole magnet for the linac drift tube. A few kinds of the permanent quadrupole magnet made of samarium cobalt were fabricated. The maximum field gradient of 16.1 and 12.8 kG/cm was realized with a segmented ring quadrupole and an ordinary quadrupole magnet of 6 mm in bore radius, respectively.

2) Beam chopper. In GEMINI using the H^- charge-exchange injection scheme, the most likely beam loss at around injection will result from the inefficiency of the beam trapping in the longitudinal phase space. A chopper synchronizing with the RF accelerating voltage will be introduced into the beam line following the preaccelerator. With a 20 % chopped beam, the inefficiency of the adiavatic trapping is estimated to be less than 1 %. Electronic test of such a chopper is under way.

3) Application of GTO thyristor to the dual frequency mode operation of the ring magnet[4]. The switching system of the resonant capacitor will be more simplified by replacing ordinary thyristor originally proposed at ANL with GTO thyristor. The test to confirm the switching behavior of the GTO thyristor is under way with a small scale resonant network.

4) Application of stranded cable to the exciting coil of the ring magnet. The power loss due to eddy current in the GEMINI magnet amounts to one third of the total a.c. power consumption of the magnet by using capper hollow conductor. In order to reduce the eddy-current power loss, aluminum stranded cable containing a stainless steel water-cooling pipe is under development.

5) A prototype of the bending magnet and a small scale model of the RF power amplifier system are under construction.

And also experiments such as the beam bunch shortening test will be carried out by practical use of the existing accelerator and experimental facilities.

References

1) T. Adachi (Ed.), Proc. of the Meeting on BSF Future Prospects, KEK Int. 82-6 (1982)
T. Adachi and Y. Masuda (Ed.), Proc. of the Meeting on BSF Future Prospects-II, KEK Int. 83-7

2) S. Inagaki et al., Proc. of 7th Meeting on Linear Acceleraters, KEK 82-14, 110 (1982)

3) M. Foss and W. Praeg, IEEE Trans. Nucl. Sci. NS-28, 2856 (1981)

4) H. Someya, et al., Proc. of 4th Symp. on Accelerator Science and Technology at RIKEN, Japan, 317 (1982)