

Superconducting rf linac driven FEL Project at JAERI

E. Minehara, R. Nagai, M. Sawamura, M. Sugimoto, J. Sasabe**,
N. Kikuzawa* M. Ohkubo, Y. Kawarasaki and Y. Suzuki

Free Electron Laser Laboratory, Department of Physics,
Tokai Research Establishment, Japan Atomic Energy Research
Institute

*Department of Nuclear Engineering, Kyushu University

**Hamamatsu Photonics Co., Research Center

Abstract

We have developed a far infra-red, and high average power FEL which incorporate a superconducting rf linac to realize the high quality acceleration and quasi-CW operation. An electron gun and a subharmonic bunching system for the FEL, which were completed last year, have been recently operated at their design values of voltage, current and other major performances. Superconducting accelerator modules, liquid-He refrigerators, and radio-frequency amplifiers are under fabrication now. A new accelerator vault as an extension to the old building are under construction now, and will be completed late March, 1992. All of the other accelerator components than the injector will be delivered by the mid of the 1992, and commissioning of the accelerator system is foreseen in 1992 Japanese fiscal year. A brief description and some progresses of the project are reported here.

Introduction

A superconducting rf-linac driven free electron laser(FEL) system at JAERI Tokai has been constructed to realize far infra-red, and high average power laser oscillation since 1988. A layout of the JAERI FEL system is shown in fig.1. The FEL system consists of an electron gun, a subharmonic buncher(SHB), a buncher, focusing lenses, 2 modules of a single-cell superconducting preaccelerator, 2 modules of a 5-cell superconducting main accelerator, a wedged-pole hybrid undulator, and an optical cavity.

All of the other accelerator components than the injector will be delivered by the mid of the 1992 Japanese fiscal year, and commissioning of the accelerator system is foreseen in the 1992.

An general description of the JAERI FEL Project ^{1,2)} have been reported these years. Therefore, we would like to report a brief description and some progresses of the project in the following.

Injector System

The injector system consists of the 250KeV thermionic electron gun with a grid pulser, the SHB, the buncher, and a beam transport line with focusing solenoid coils. The system including a streak camera and other beam diagnostic instruments are shown in fig.2.

We have chosen a rather higher voltage of 250KV for the electron gun than that of usual electron linacs in order to reduce growth of beam emittance by space charge effect in beam-transporting in the injector system. A conventional gridded thermionic cathode of EIMAC Y646B having 8mm diameter has been used to realize a low emittance of 10π mm mrad with a wehnelt electrode having a smaller aperture of 4 mm diameter.

A beam emission from the gun was measured by a fast Faraday cup and an amorphous current core monitor just around the exit of the gun and the first lens. A measured value of the pulse length is 4nsec or less, the gun voltage 200KV to 250KV, and the peak current 100mA.

The gun could produce 250KeV beam with about 4 nsec pulse length at a repetition rate of 10.4MHz during a macro pulse of 1 msec at the repetition rate of 10Hz. The electron beam should be compressed by the SHB and a 499.8 MHz buncher. The SHB is a quarter-wave cavity resonator, whose frequency is 83.3 MHz, and 1/6th of the main accelerating frequency 499.8 MHz. The buncher is a cavity with a re-entrant geometry of 499.8 MHz.

The beam was designed to be accelerated by pre-accelerators and main-accelerators up to 13.2MeV or higher energy with about 40 psec bunch length, and about 10A peak current. A timing of the grid pulser, SHB, buncher and superconducting accelerators was designed to be made by a master oscillator of the 10.4MHz and multiplied frequencies.

Just after the transportation through the SHB, and buncher, the 4 nsec pulse length of the electron beam should be compressed to several tens pico seconds at around the entrance of the first preaccelerator. A requirement for the compression is needed to

realize less energy spread than 0.5%, and the higher peak current. The bunched length was measured to be around 70 psec or less detecting Cerenkov radiations from energetic electrons in a sapphire glass plate, and using a streak camera made by Hamamatsu Photonics Co.

Superconducting Linear Accelerator Module

As shown in fig. 3, we have newly developed a multi-refrigerators system integrated into a superconducting linear accelerator module cryostat containing the cavities to realize the highly-efficient without any liquid coolant.

A 4K closed-cycle He gas refrigerator of 9.6W at 4.5K and 60Hz mounted just above a chimney of the module was adopted to cool down and to recondense cold vapour of liquid He around a heat exchanger in the liquid He vessel. A 20K/80K two-stage closed-cycle He gas refrigerator, which mounted in a vacuum vessel of the module like a piggy back, was adopted to cool down 40K and 80K heat shields and other major components of the cryostat.

A finite element method (FEM) calculation code (ANSYS Rev. 4.4A) has been used to evaluate temperature distribution of heat shields, and other major components of the cryostat. Thermal design for the cryostat is performed to optimize heat loads to the major components of the cryostat by utilizing the calculated and experimental results.

Major components in the cryostat are shown fig. 3. In the figure, we can see the 80K and 40K heat shields. Major components of heat inflow are located around beam tubes, outer conductor of the RF coupler and liquid He transport pipes. Thermal model to be solved here is mainly governed by a physical phenomenon of heat conduction. As there should be some contributions from two other physical phenomena of heat radiation and convection, we calculated to estimate the contributions independently in the same condition with the conduction.

The results of the calculation shows that the 5-cell accelerator modules cryostat can be cooled down satisfactorily by the multi-refrigerators system. The static heat load for the 80K shield without radiation is 39W, and the load for the 40K shield 10W. When the two heat shields thermally anchor each heat bridge between 4K and 300K stages, the static heat load to the liquid He vessel is calculated to be about 1 W. A half of the load comes from the RF coupler, because a thin copper layer of higher thermal conductivity can not be anchored by the heat shields.

Wedged-Pole Hybrid Undulator

We plan to use a wedged-pole hybrid undulator³⁾, manufactured by Spectra Technology Inc. Seattle, U.S.A., for the first experiment of the JAERI FEL system. In order to fit the undulator to the JAERI FEL system, the undulator was characterized by three-dimensional field calculation and two-dimensional field mapping. Major specifications of the undulator are summarized in table 1.

In order to characterize the undulator, a distribution of the multipoles⁴⁾ was derived from field distributions in a median plane of the undulator. A strip of the three-dimensional field distribution was obtained by using a conventional finite element method(FEM) calculation code ANSYS. An experimental distribution was obtained by field mapping with a commercially-available and three-dimensionally measuring equipment.

A shape of a half-periodic and quarter part of the undulator was reproduced by a mesh form in the calculation. Poles and permanent magnets of the undulator were made into wedged-shape which were designed to uniform, and to increase magnetic flux inside the poles. Edge shapes of the poles and magnets were slightly simplified, and misalignments and asymmetries of the undulator were not taken into account here.

Data of the two dimensional field map obtained from the measurement and the calculation were divided into a number of strips of the transversal field distribution. The multipole field components from dipole to dodecapole were derived from each strip by least square fitting to a following fifth order polynomial:

$$B_y(x) = \sum_{n=0}^5 B_n x^n \quad , \quad (1)$$

where B_n was coefficient of $2(n+1)$ -pole component, x transversal position, $B_y(x)$ the vertical component of the magnetic field as a function of the transversal position. A distribution of the multipoles along the undulator axis was obtained through a data reduction method mentioned above. Reduced data from the measured and calculated are shown in fig.4 and fig.5 respectively. The higher multipoles mixed in with the fundamental dipole were distributed in very similar fashion with the dipole. The multipoles of which n is odd were vanished completely in fig.5, because we assumed that the calculation was not taken into account of misalignments and asymmetries of the undulator.

As clearly shown in figs. 4 and 5, the calculational distributions of the multipoles quantitatively shows very good reproduction of the experimental distributions.

Accelerator Vault

A new accelerator vault for the JAERI FEL has been constructed this year as an extension to an old Van de Graaff accelerator building, which has been shut down for ten and several years, and the vault will be completed in March, 1992. A shielding wall of 1.0m - 1.5m thick normal concrete or the equivalent is required in order to keep less radiation level in the control room and offices neighboring the accelerator vault. The vault was designed to have the required shielding using normal concrete blocks, ceiling and wall.

Acknowledgement

We would like to thank Drs. N. Shikazono, H. Shirakata, H. Ohno and M. Ishii of JAERI for their continuous encouragements and interests on this work.

References

- 1) Y.Kawarasaki et. al., Proc. 10th Int. Free Electron Laser Conf., Jerusalem, Israel, 1988, Nucl.Instr. and Meth. A285(1989)338.
- 2) M.Ohkubo et. al., Proc. 11th Int. Free Electron Laser Conf., Nalpes, FL, U.S.A., 1989, Nucl.Instr. and Meth. A296(1990)270.
- 3) S. Sasaki, T. Takada, N. Matsui, S. Sasaki, and H. Ohno :
Proc. of Particle Accelerator Conference, San Francisco
- 4) E.Minehara, P. Billquist, P. Den. Hartog, and W. Kutschera :
Nucl. Instrum. Methods A252 (1986) 101-106

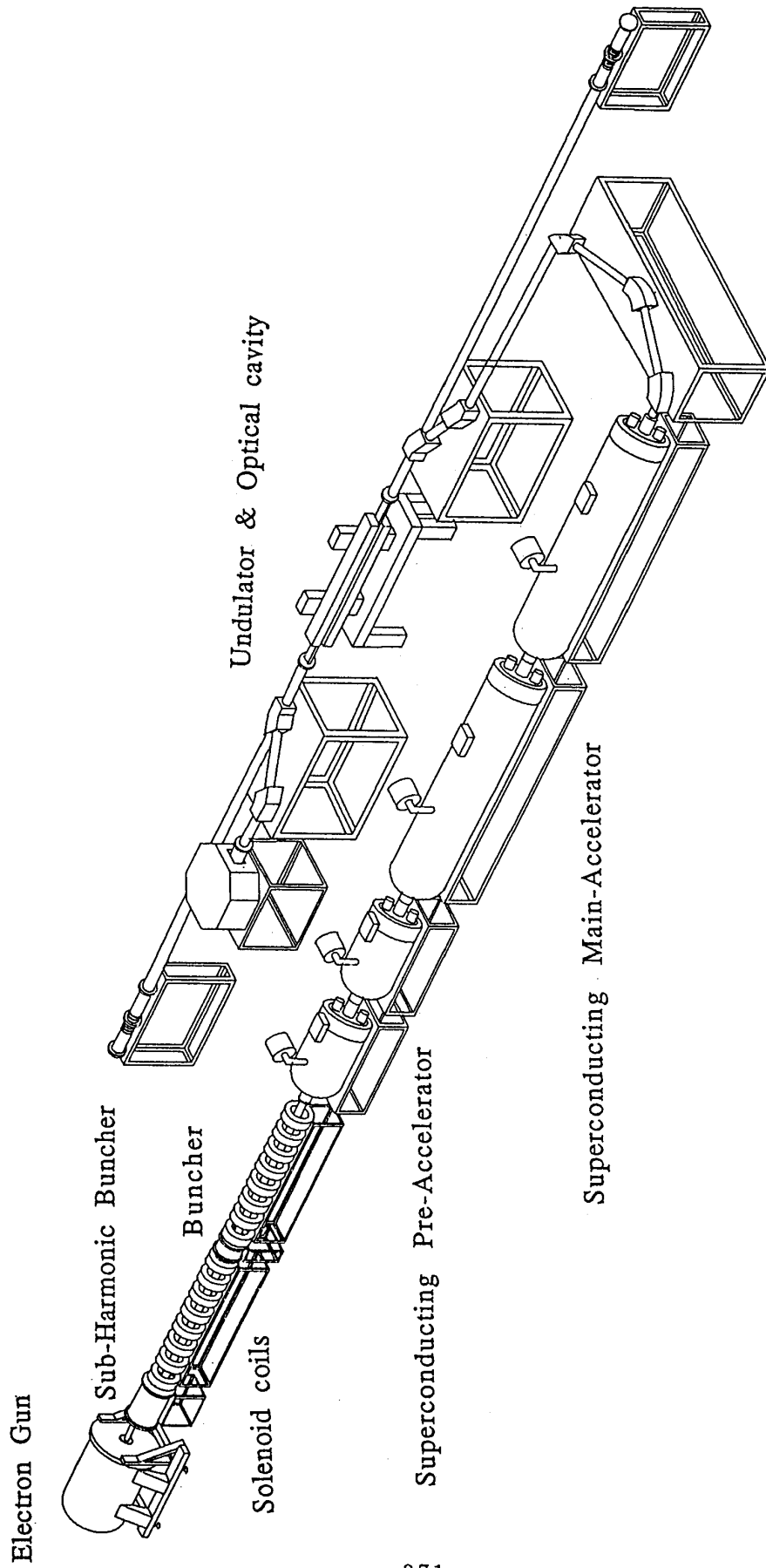
SCRF Abs 91

Table 1 Specifications of the wedged-pole hybrid undulator.

Magnet material,	Nd-Fe-B
Undulator period, λ_u (cm),	3.3
Pole gap range (cm),	1.35-30
Maximum peak field on-axis, B_{max} (kGauss),	5.9
Deflection parameter range, K,	≤ 1.8
Transverse rolloff at ± 1 cm (%),	≤ 0.09
Peak field error, $\Delta B/B$ (%),	0.4
Total steering error (Gauss-cm),	-11
Number of periods,	61.5
Pole width (mm),	62
Magnet width (mm),	78

Specifications of the wedged-pole hybrid undulator

Fig. 1, Layout of the JAERI FEL system



Layout of JAERI FEL

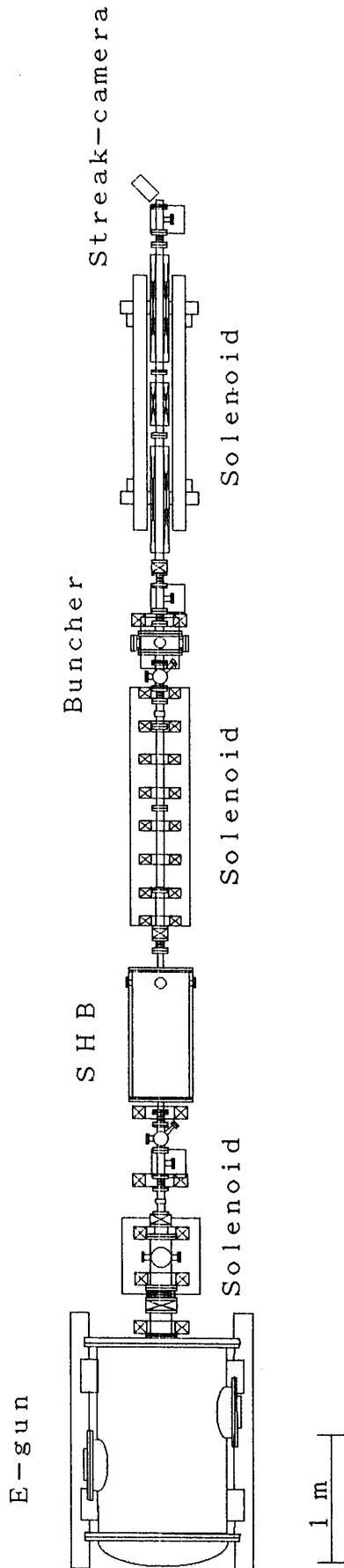
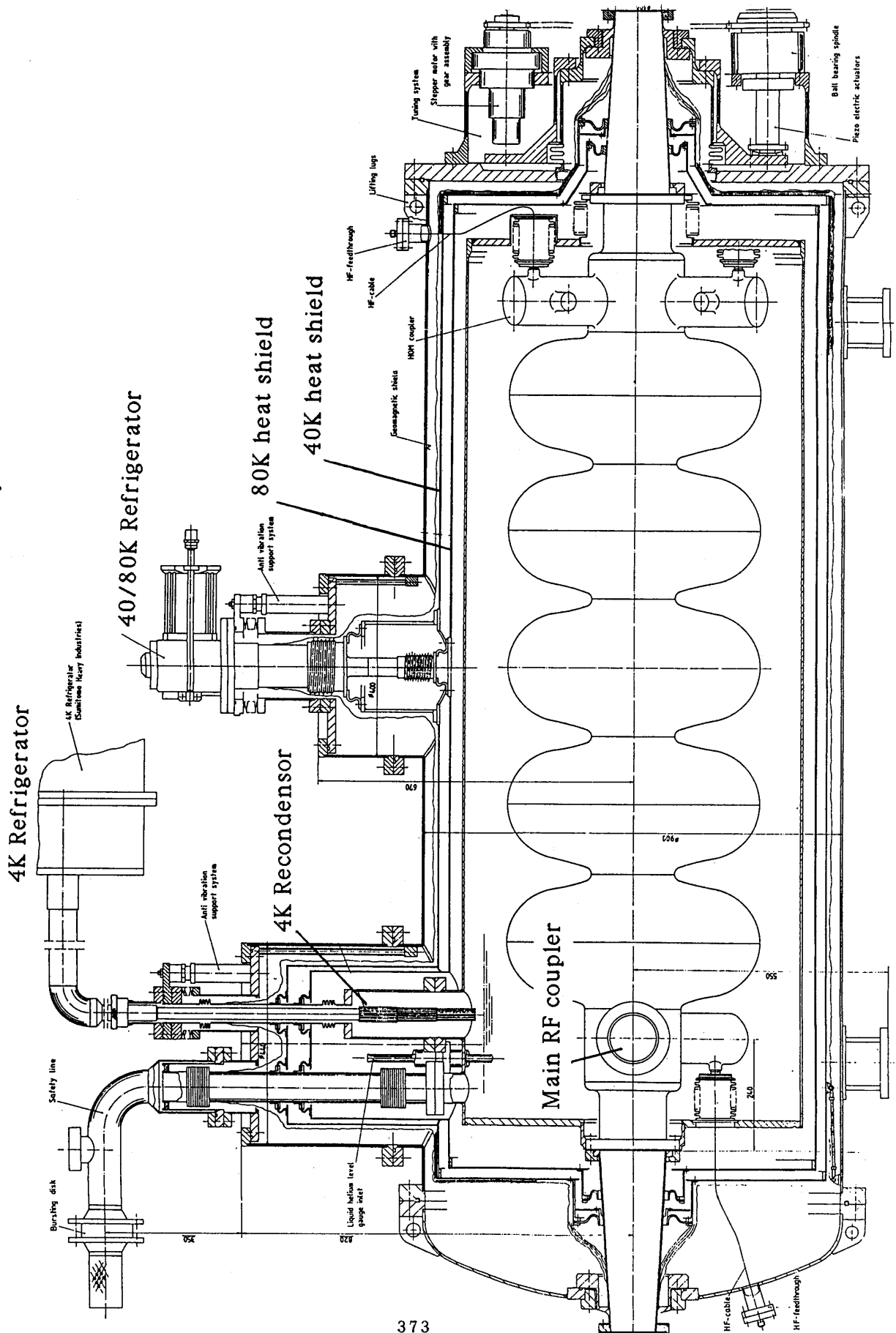
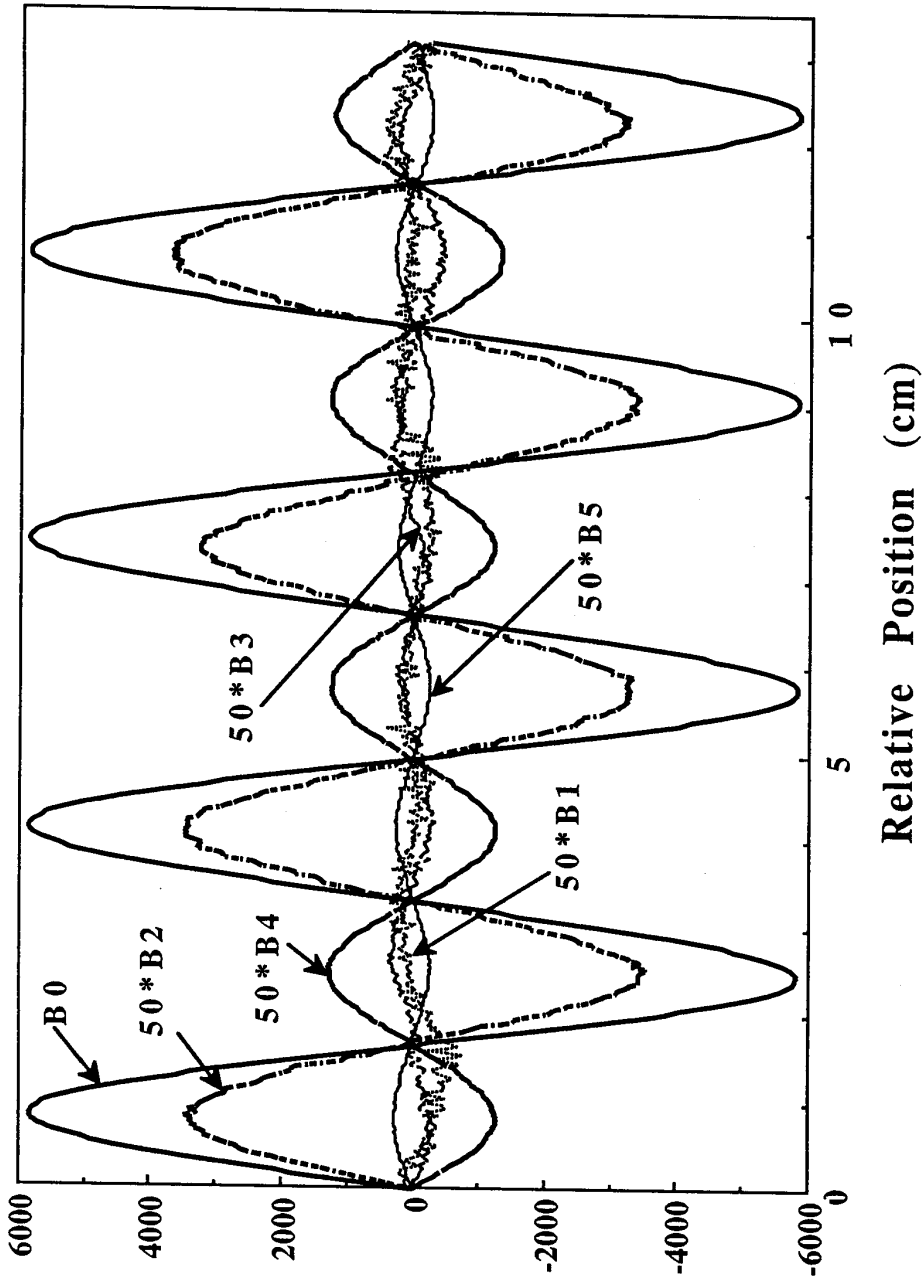


Fig. 2, Injector system including a streak camera and other beam diagnostic instruments.

Fig. 3, Multi-refrigerators system integrated into a superconducting linear accelerator module cryostat.



Multipole Components (Gauss/cmⁿ)



Longitudinal distribution of the multipoles obtained from the measured map

Fig.4, Longitudinal distribution of the multipoles obtained from the measured map. The higher multipoles were multiplied by fifty, to compare with others easily.

Multipole Components (Gauss/cmⁿ)

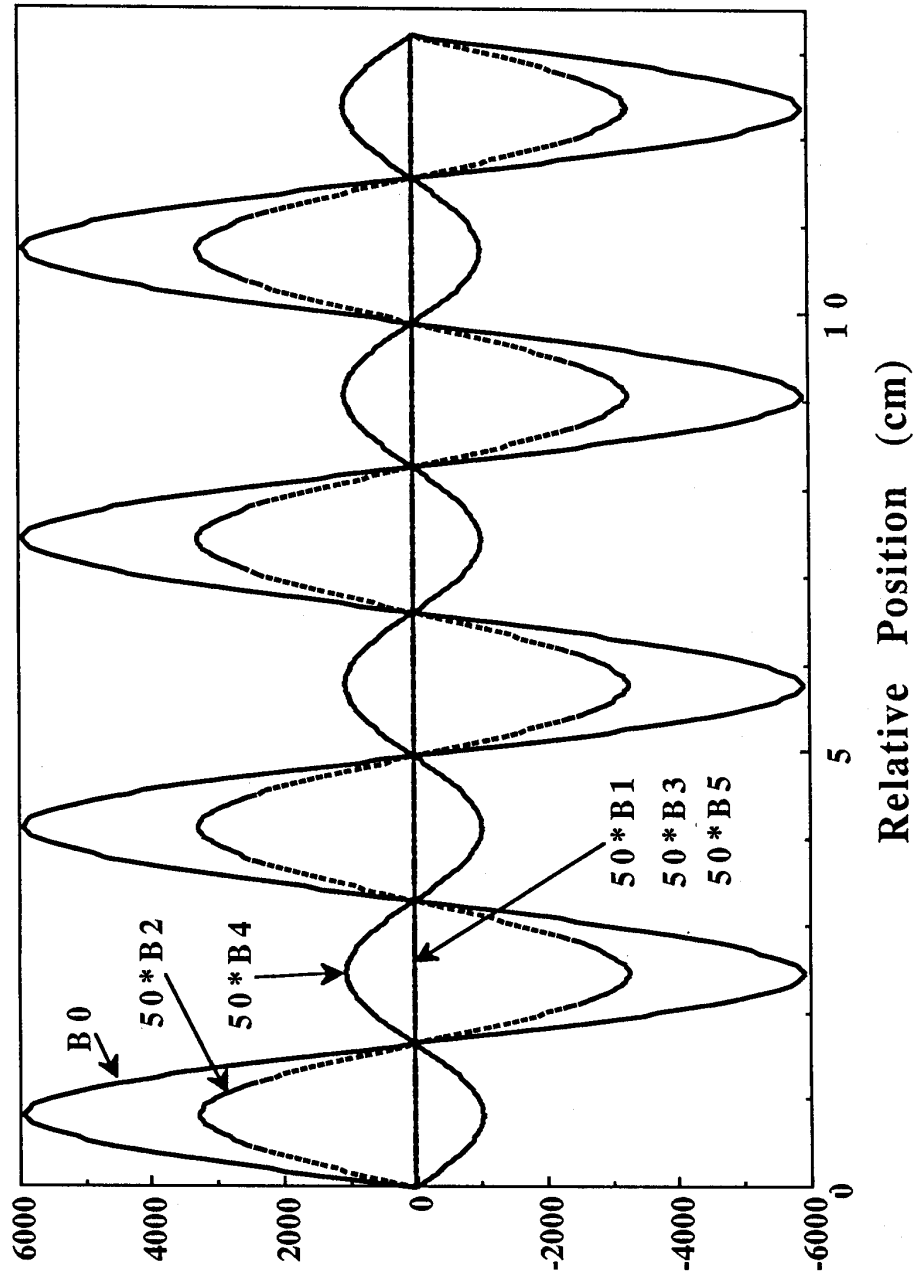


Fig.5, Longitudinal distribution of the multipoles obtained from the calculated map. The higher multipoles were multiplied by fifty, to compare with others easily.

Longitudinal distribution of the multipoles obtained from the calculated map