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PRESENT STATUS OF THE ACCELERATOR DEVELOPMENT AT THE ICR KYOTO UNIVERSITY

Makoto INOUE, Akira NODA, Yoshihisa IWASHITA, Hiromi OKAMOTO, Toshiyuki SHIRAI, Shigeru KAKIGI, Hiromu TONGUU, Hirokazu FUJITA, Hideki DEWA, Masanori IKEGAMI, Valeri KAPIN, Masaki KANDO, Takashi SUGIMURA and Hiroshi FUJISAWA*

Institute for Chemical Research, Kyoto University, Uji, Kyoto 611, Japan
*R&D Div., Nissin Electric Co., Ltd., Kuze Tonoshiro-cho575, Minami-ku, Kyoto 601, Japan

Abstract

The injection system of the 7MeV proton linac has been improved to transport the high intensity beam. A measurement device for the longitudinal emittance of the 7MeV proton beam has been developed. A 100MeV electron linac has newly assembled to study electron-photon beam physics. An electron storage ring will follow this linac. A heavy ion 4-rod RFQ linac was completed and has been moved to the cooperating company to perform acceleration test for industry. The cold model study of the improved DAW structure for the high energy linac was done and a power test model has been designed. A medical synchrotron design has been also studied. An untuned cavity for this synchrotron has been constructed and a new RF power feeding scheme has been tested. Theoretical studies of the space charge effect and an improved 4-rod RFQ structure are in progress. An accelerator-based reactor which consists of a proton linac and a subcritical assembly has been proposed as a pulsed neutron source.

1. Introduction

It may be necessary to use a large accelerator for high energy physics, nuclear physics, photon factory or neutron factory. Only at a national laboratory we can construct such large machine. While at universities accelerator physicists are now disappearing in this country because of the concentration of the budget into the national laboratory. But it is very important to study fundamental accelerator physics or beam physics at universities in order to develop advanced technology and educate younger generation. Our laboratory was a nuclear physics center with a cyclotron more than thirty years ago. But now it becomes a unique accelerator laboratory developing small accelerators and promoting accelerator physics or beam physics at the university.

2. Proton linear accelerator

Our 433MHz RFQ linac accelerated the first beam of 2MeV protons in 1991. Since January 1992 we have obtained 7MeV proton beam from a 433MHz Alvarez linac which follows the 2MeV RFQ linac. So far intensity of the beam has been limited by small aperture of the injection line. Recently we have replaced a bending magnet(a mixing magnet to-be) by a newly designed one which has a larger gap and an entrance angle against the sector focusing. We can now transport a wider envelope beam, which reduces space charge effect. Not only the high intensity beam transportation during the injection line but also beam matching to the RFQ acceptance is necessary to increase the accelerated beam intensity. For this purpose a permanent magnet symmetric lens(PMS) has been designed1). The injection line is shown in Fig.1. The designed beam envelope in this injection line is shown in Fig.2. To ensure the beam matching a measurement system of the emittance of the extracted beam from the ion source is now designed.

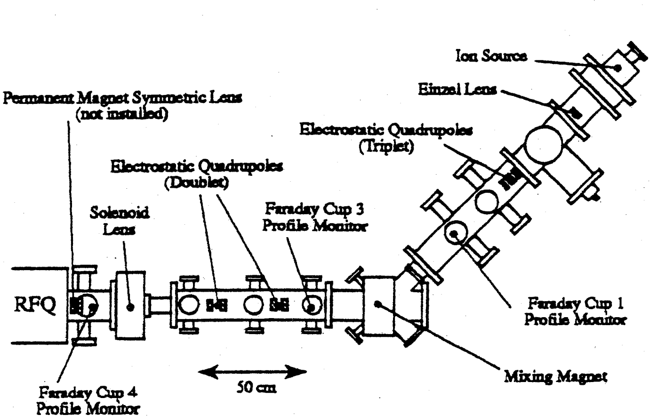


Fig. 1. The injection line of the proton linac

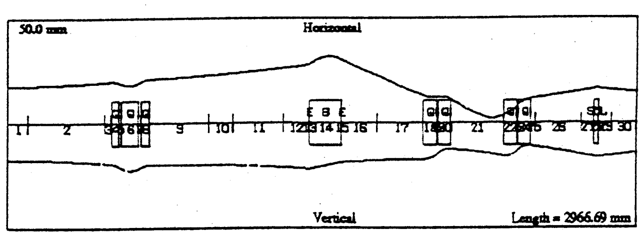


Fig. 2. The matched beam envelope between einzel lens and PMS section at current of 20mA (TRACE-3D calculation).

Measurement systems of properties of the 7MeV proton beam from the Alvarez linac have been constructed and installed in the down stream beam line. One of them is a double-slit emittance monitor2) and the other is a phase-energy distribution (longitudinal emittance) measuring system3).

The principle of the double-slit emittance monitor is not new but pulse beam detection is necessary in our case because the linac is operated in pulse mode with a repetition rate of 18-180Hz and pulse width of 50μsec. The typical measured rms emittance of the 7MeV proton beam is 4.8πmmmrad which varies depending on the RF power fed to the Alvarez linac2).

The schematic view of the newly developed system of the longitudinal emittance monitor is shown in Fig.3. It consists of a narrow gold target, an RF deflector and a position sensitive detector. A slit and a focusing system are also included. The phase of the accelerated particle corresponds to the position of the detected proton at the position sensitive detector. The energy of the accelerated particle is also obtained from the measured energy of the detected particle at the position sensitive detector.

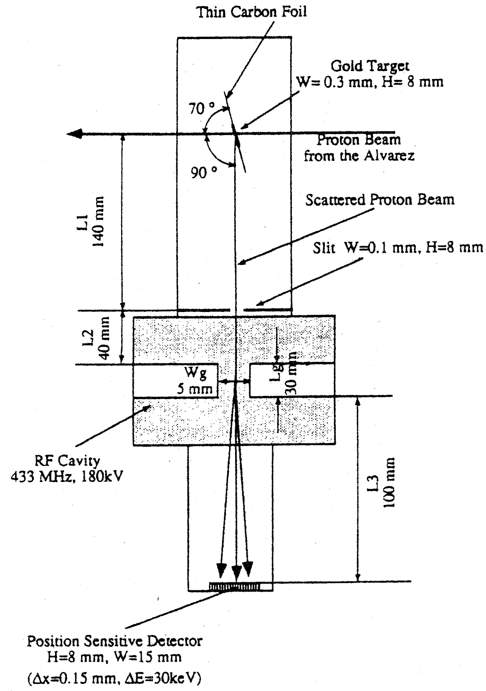


Fig. 3. Concept of the longitudinal emittance monitor

3. Electron linear accelerator and storage ring

On the occasion of the shut-down of the JAERI electron linac and the storage ring JSR some components have been kindly transferred to our laboratory. We have designed a 100MeV electron linac and our storage ring KSR for the study of the electron and photon beams using these transferred components and additional parts4)

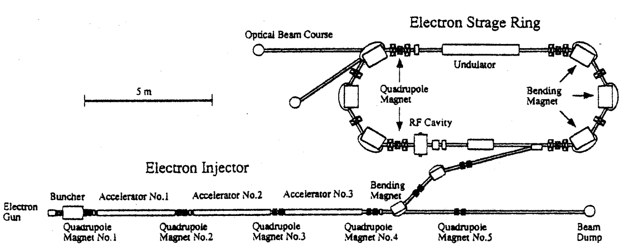


Fig. 4. Layout of the electron linac and the storage ring KSR

In Fig.4 the schematic layout of the accelerator is shown. At JAERI the linac had five accelerator tubes and it was operated with repetition up to 600Hz. But our laboratory area and electricity are limited so that the number of the accelerator tubes and repetition are reduced to three and 20Hz respectively. We changed the original triangular shape of the ring to a race-truck to have long straight sections, which requires rebuilt of the vacuum chamber. At the moment the electron linac has been completed but the storage ring KSR is not completed yet, where only the six bending magnets and focusing magnets are aligned. Main characteristics of the electron linac are listed in Table 1 and the designed values of the KSR are listed in Table 2. Only three of 3m accelerator tubes are used, while the first two of five accelerator tubes at JAERI were 2m. Therefore we have examined beam transport during acceleration in our case. The calculated beam envelope is shown in Fig.5. The first beam acceleration test is planned in September 1995.

Table 1. Characteristics of the electron linac

Output Electron Beam	
Energy	100 MeV
Beam Current	100 mA
Pulse width	1 μsec
Max. Repetition	20 Hz
Electron Gun (Pierce type)	
Cathode assembly	Y-796 (Eimac)
Extraction voltage	-100 kV DC
grid voltage (typ.)	100 V
Accelerating structure	
Mode	$2/3\pi$, Constant Gradient
Number of Cell	85
Bore Radius	11.74 - 13.4 mm
Length	3 m
Operating Frequency	2857 MHz
Shunt Impedance	53 MW/m
Maximum Electric Field	15 MV/m at 20 MW input
Klystron (ITT-8568)	
Cathode	250 kV, 250 A
Output RF Power	21 MW
Gain	53 dB

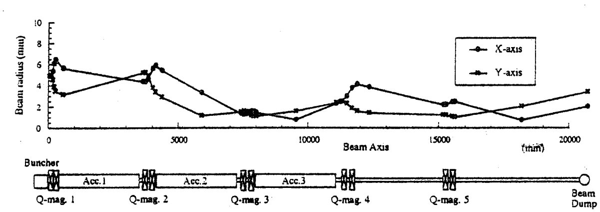


Fig. 5. Calculated beam radius (emittance of 100πmmmrad)

Table 2. Design parameters of the storage ring KSR

Maximum energy	300 MeV
Injection energy	100 MeV
Circumference	25.689 m
Lattice structure	Triple bend doubly achromatic lattice
Superperiodiciwy	2
Bending angle	60°
Radius of Curvature	0.835 m
n-value	0
Edge angle	0°
Length of long straight section	5.619 m
Harmonic number	10
RF frequency	116.7 MHz
Number of Betation Oscillations	
Horizontal	2.75
Vertical	0.75 (1.25)
Critical wave length from dipole	17 nm

4. Boron beam acceleration with the 4-rod cw RFQ linac

At the ICR Kyoto University the 4-rod cw RFQ linac was constructed and the first beam was obtained on December 25, 1992. At the University He, N and C ion beams were accelerated to test the operation of the system. After one year test the linac system was moved to Kuze factory of Nissin Electric Co., Ltd. to continue the acceleration test of the boron ion beam which would be used in the process of semiconductor industry. The characteristics of the 4-rod RFQ linac are listed in Table 3 and a schematic plan view is

Table 3. Characteristics of the 4-rod RFQ heavy ion linac

Injector :	
Ion source	Freeman type
Extraction voltage	50 kV max.
Mass analyzer	90° magnet with sextupole corrections
Focusing elements	four magnetic quadrupole lenses and one Einzel lens
Beam optical lengh	2.5 m, including a beam monitor
Size	1.5 (W)×1.5 (D)×1.8 (H)
RFQ :	
Type	fixed frequency "modified" 4-rod
Frequency	33.3 MHz (design)
Average bore radius	0.8 cm
Focusing strength	6.79
Inter-electrode voltage	54.9 kV
Charge to mass ratio	1/11 (design)
Injection energy	2.73 keV/u
Output energy	83.5 keV/u (w/o half-cell)
Length of electrode	222 cm (w/o half-cell)
Cavity inner diameter	60 cm
rf power	50 kW max.
Operation mode	cw
Transmission	≥80%

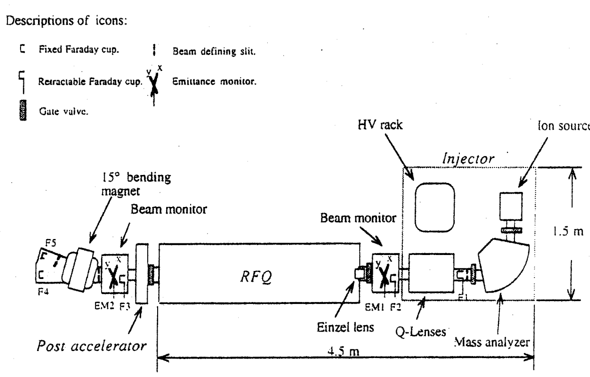


Fig. 6. Experimental setup of the 4-rod RFQ linac system

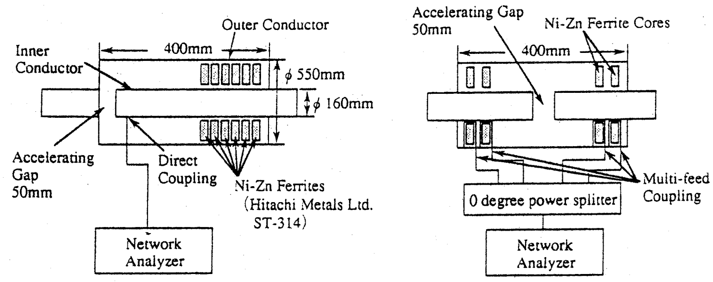
shown in Fig.6. We have obtained the singly charged boron beam intensity of 330μA with total beam transmission of 80% 5). The measured beam emittance was about 10πmmmrad at the accelerated beam energy of 0.92MeV.

5. DAW cavity

The disk-and-washer (DAW) structure of the linac has been studied in our laboratory. Recently a biperiodic L-support structure has been proved to have high quality without the mode overlapping problem. MAFIA and SUPERFISH calculations and cold model study have been made6). Then a power model is now under construction for S-band electron linac because the S-band RF power sources have become available as mentioned above.

6. Medical proton synchrotron

A compact 230MeV proton synchrotron with a combined function lattice has been designed for medical use. A proton linac like our existing 7MeV linac may be used as an injector. Slow beam extraction of diffusion-resonant scheme has been studied7). A ferrite-loaded untuned cavity with multiple RF power feeding has been designed and constructed8). The concept of the feeding is shown in Fig.7. According to the cold model test the reflection power from the cavity is reduced from 75% of the forward power in the direct coupling case to 20% in the multi-feed coupling case. It is also confirmed that the cavity voltage is increased by factor 1.5 for multiple coupling case comparing to the direct



(a) Direct coupling. (b) Multi-feed coupling.

Fig. 7. Setup of the direct and multi-feed coupling

coupling case8). The power model test is being carried out in cooperation with Hitachi Ltd..

7. Other studies

Space charge effect and halo formation in case of high intensity linac are investigated by analytical and simulation methods. A simulation code is developed at our laboratory9).

A normal mode analysis of transmission lines for TEM mode waves is applied to a 4-rod RFQ resonator10). Results of this analytical method are in good agreement with calculations by MAFIA code. A 2.5-D RF cavity code PISCES II is also developed11).

A pulsed neutron source which consists of a proton linac and a subcritical assembly is proposed for a future project of Kyoto University Research Reactor Institute12). The linac will accelerate a 300MeV-30mA proton beam and the power gain of the subcritical assembly will be 20. Characteristics of an example of the proposed pulsed reactor with a proton linac are listed in Table 4.

Table 4. A proposed pulsed reactor with a proton linac

Accelerator	
Ion source	multi-cusp field type
RFQ section	2 MeV, 433 MHz
DTL section	100 MeV, 433 MHz
DAW section	300 MeV, 1,300 MHz
Beam intensity	30 mA at peak
Pulse width	50 μsec
Repetition	60 Hz
Neutron yield	10^{18} n/sec at peak
Subcritical assembly	
Fuel	^{235}U
Peak power	180 MW
Average power	600 kW
Neutrons	10^{19} n/sec at peak

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