IMPROVEMENT AND APPLICATION OF THE BEIJING PROTON LINAC

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Introduction

The Beijing Proton Linac (BPL)[1,2] had been improved furthermore during the past two years. The modulation mode for RF final amplifier has been changed from anode voltage modulation by hard tube pulse modulator into grid RF voltage modulation. The previous minicomputer control system has been replaced with a microcomputer to make the shape of a new distributed control system which is easily operated and has a friendly man-machine interface. A plan of construction of a RFQ instead of the present Cockcroft-Walton type injector is in progress. Some basic and application researches with BPL were successfully completed and many interesting results have been obtained by many institutes in the fields of nuclear physics, radiation effect on high T_c supercondutors, isotope production and neutron therapy for cancer. A proposal to build a 250MeV proton synchrotron using BPL as the injector for proton therapy is being discussed. The improvements and some applications of BPL are described in this paper.

Main Performance Improvement

1. Modulation mode change of the RF power supply

The RF power supply of BPL is operated at a frequency of 201.25 MHz with a pulsed output of 5MW, pulse length of 300 to 500μs, repetition rate of 1,2,5,10 pps in option. The RF power is fed into the long cavity ($\sim$22m) by two symmetrical ways, and two TH116 triodes imported from France are used for the final amplifiers.

Originally the hard tube pulse modulator which consists of three bootstrap amplifiers in cascade was used. The output amplifier is made up by three ML-8618 tubes in parallel. This modulation mode can provide a fine RF waveform in the case of a high repetition rate and long pulse length. But the floating deck of modulator is very complicated and makes unreliability in operation. These ML-8618 tubes were imported from U.S.A and were not produced since 1990.

We changed the modulation mode from anode voltage modulation by hard tube modulator into grid RF voltage modulation, i.e. the anode voltage of the final amplifier tube TH116 utilizes a dc voltage. The output power of the final amplifier is controlled by the grid drive. So the machine was simplified, as seen in Fig.1.

In order to achieve this change the operational parameters of the tube have been changed and the protection system of the machine has been improved.

The operational experience during the last two years has shown that this change not only saves a part of operational outlay, but also improves the reliability of the machine, and the failure rate is significantly reduced.

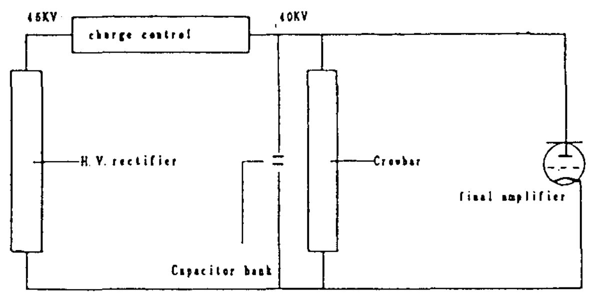

Fig.1 The modified 5 MW RF power supply

2. RF output performance improvement

The output of RF power and its top flatness can significantly affect the beam performance.

Within the limit of the maximum RF power from the supply, there are three ways to improve the efficiency and quality of the RF power to obtain the maximum pulse and average beam current:

1) forward compensation, which overcomes the drop of the field amplitude due to the beam loading, so that all particles in the 100μs pulse length can be accelerated with almost the same field amplitude.

2) minimizing the reflective power from the cavity during the beam pulse, i.e. in the high current operation, setting the coupler position such that the standing wave rate is minimized during the beam pulse.

3) Using the feedback loops of the amplitude and frequency to make the accelerating field stable and reliable during the long-period operation.

3. Improvement and replacement of the Control System

The previous BPL control system consists of two parts: the central platform and the local stations of several subsystems. The two parts connect with each other via CAMAC interface crate and interface system. It is a realtime multi-users 'minicomputer-CAMAC' system based on the host of PDP-11/34A. This series of system has been putting into service for near ten years. Some key hardware equipments have been deteriorated and outdated apparently.

As hardware is concerned, see Figs.2 and 3 , the change has been made as little as possible. It simply replaces the previous PDP11/34A minicomputer with a PC microcomputer and substitutes CCU-2-80B parallel interface system for the original KSI-2053 serial/parallel CAMAC interface system. Users can easily implement man-machine connection via the keyboard and color monitor.

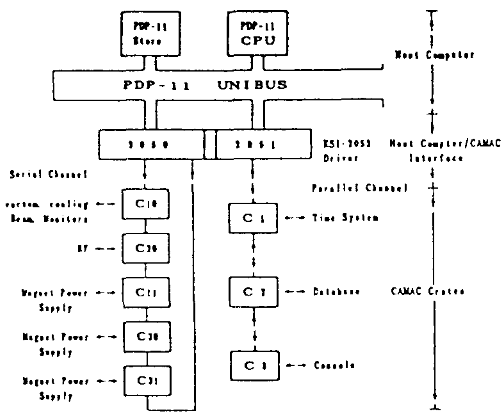

Fig.2 The original control system of BPL

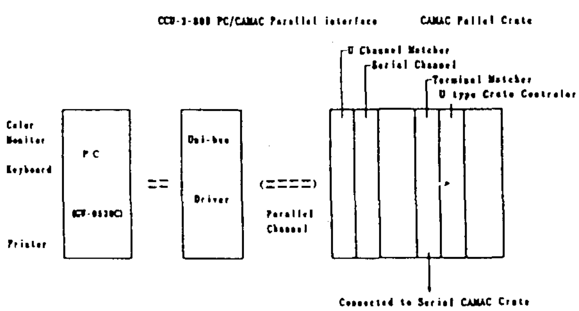

Fig.3 The new control system of BPL

As software is concerned, the system reconfigures the second generation control software which is more suitable for the need of the BPL adjustment and can be run on the PC. This software is a developed realtime control software and is run on the GW0530C. It preserves the whole control function of the previous system, including the realtime monitoring and the feed back control of hundreds of magnet power supplies and on-line modification of RF timing parameters, etc. From the point of utilization, the system set up the excellent user's interface via the plentiful choice menu driving, window supporting and help function. In addition, the system not only have the function of on-line maintenance of the general parameters, and data management such as realtime printing and restoring of the optimum running parameters, but also makes the off-line maintenance and sorting out of the whole accelerator database more convinent. The software is completed with C language. It adopts the pattern of modularization and has good programming. Furthermore, the foundation of the new system makes the shape of a distributed control system, which is a system controlled by several microcomputer and communicate through RS-232 port; it also gives good opportunity to expand functions of the whole system.

The performance of the new system is very stable and reliable now. It is highly appreciated by the operator because the system is easily operated and has a friendly man-machine interface.

4. BPL-RFQ system

In August 1993, the decision to construct an RFQ system as BPL's injector instead of the bulky Cockroft-Walton accelerator was made. Since then the design of beam dynamics, the design and manufacture of a cold model have been done. Recently, the cold model of 4-rod structure is being measured and tested. The mechanical design of RFQ structure, the construction of rf power supply, reconstructing the ion source and the other work are being gone on. The BPL-RFQ will be completed in the summer of 1996 by schedule.

The BPL-RFQ system is composed by three sections, as shown in Fig.4.

The 4-rod RFQ structure had been chosen for the BPL-RFQ, it has the advantage of easy manufacture and tuning, and other feature on feasibility of circular rods as electrodes giving very good mechanical as well as very good beam dynamic properties.

The basic parameters of the BPL-RFQ are listed in table 1.

Table 1. Basic Parameters of the BPL-RFQ

Input energy		40 KeV
Output energy		750 KeV
Input beam current		>100 mA
Output beam current		>60 mA
Total length of electrodes		~120 cm
Total number of cells		115
Number of modules		13
Radial frequency		201.25 MHz
Maximum surface field		24.9 MV/m
Inter-electrode voltage		130.2 KV
Characteristic radius		0.708 cm
Aperture radius		1.962—0.492 cm
Modulation parameter		1—1.824
Trans. focu. parameter		0.8—6.136
Input trans. emittance	ϵ_{xN}	0.138 πcm·mrad
	ϵ_{yN}	0.134 πcm·mrad
Output trans. emittance	ϵ_{xN}	0.258 πcm·mrad
	ϵ_{yN}	0.239 πcm·mrad

In the BPL-RFQ system, the first 6-quadrupoles of DTL will be used for the transverse beam match between RFQ and DTL. And the two solenoids will be used for the beam match between Ion Source and RFQ. The computer simulation for the beam motion from the exit of RFQ to the end of DTL had been done by PARMILA code. The simulation indicates that the 98% of beam can be accelerated to the end of DTL for the beam current of 100mA from RFQ.

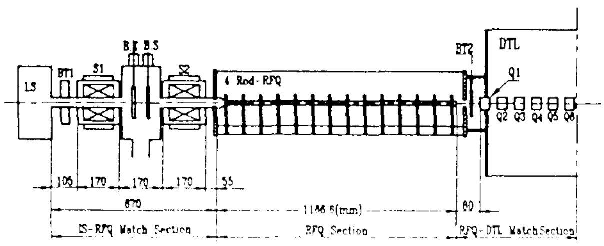

Fig.4 Scheme of the BPL-RFQ system

Applications

1. Nuclear experimental physics

A new delay channel has been discovered in β-delayed α decay ^{20}Na by the Institute of Modern Physics, Lanzhou, China[3]. In the experiment, the enriched Neon was bombarded with 35MeV protons of 3μA average intensity for 20hrs, several particle spectra were obtained at different collection conditions. A new peak at 0.695MeV in the spectra was observed, which was believed as a new decay channel in β-delayed α decay of ^{20}Na and was corresponding to the energy difference between the excited states of 5.785MeV of ^{20}Na and the ground state of 4.71MeV of ^{16}O. It has important implications in the study of astrophysics. In addition when the neon is bombarded with protons, there were strong evidences of ^{19}Na existence in the measurement of beta delayed proton decay. By the measured data, the new nuclide ^{19}Na was first found recently.

2. Radiation effect on high T_c superconductors

Some specimens of $YB_{a2}Cu_3O_{7-8}$ high T_c oxide superconductor are irradiated by 35MeV protons at temperature of 70K, the critical zero-resistance temperature is increased with the proton fluence within the range of 2.21×10^{13}—1.77×10^{14} p/cm^2. This experiment was made by Institute of Atomic Energy[4], one found that the critical zero-resistance temperature is increased from 91K to 97K at the fluence of 1.77×10^{14} p/cm^2 and the critical current at 91K is also enhanced by one order over the unirradiated value. The similar results are also obtained with the specimens of Bi(pb)-Sr-Ca-Cu-O.

3. Isotope production

Some kinds of short-lived radio-isotopes for medical treatment were produced with BPL by the Isotope Laboratory of IHEP. This laboratory was constructed in 1987 and located just by the BPL hall. The automatic controlled target system with water cooling works well. ^{201}Tl, ^{67}Ga and ^{11}C and ^{18}F have been successfully produced. The ^{201}Tl chloride injection produced by solvent extraction method was clinically tested with more than 100 examples, which indicated that the injection quality is very good for medical treatments, so that the production of this injection was officially approved in 1992. The injections are being sent to some hospitals in Beijing, Guangzhou, Shanghai and other cities.

4. Neutron therapy for cancer

The horizontal neutron beam with the average energy of 20MeV were produced by the 35MeV protons hitting on the ^{9}Be target, with a dose rate of 20—24 ncGy/min at a distance of 1.2m from the target in the forward direction.

The fast neutrons have some advantages in the radiotherapy. It is high-LET (Linear Energy Transfer) particles with the properties of high Radio-Biological Effectiveness (RBE) and low Oxygen Enhancement Ratio (OER), which are very important to cure for some kinds of cancers.

A neutron therapy laboratory at IHEP was constructed in 1988. By the collaboration with biologists and tumor experts, many researches in radio-physics and radio-biology by using neutron beams have been successfully made. After that the clinical treatment was started in November 1991. Up to June of this year, about 200 patients have been treated. The neutron therapy are very effective for some cancers, such as parotid, prostate, pancreas, osteoma, soft tissue, etc.

A proposal to develope the proton therapy for cancer is being discussed, since the proton has very important advantage of dose distribution in human-body, which is very helpful and effective for killing the deeply located cancer. The proposal is to construct a 250MeV proton synchrotron, using the present proton linac (BPL) as the injector. By the way, the neutron therapy will be improved furthermore , since one will get higher energy protons (say, higher than 60MeV) hitting on the ^{9}Be target and will get higher energy neutrons for more effective neutron therapy.

Reference

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