A Proposal of High Intensity Accelerator Complex for Meson Science in Kyoto University

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ABSTRACT

The construction of 800 MeV proton linac has been proposed for the "Research Institute for Meson Science" in Kyoto University. The planning of the upgraded version to the "Kaon Factory" by adding a rapid cycling synchrotron is in progress. The basic consideration of the plan and a reference design of the accelerator are presented.

INTRODUCTION

People, at Kyoto University, who are interested in the accelerator-based research in a broad range of science, organized a working group in order to make a proposal of the construction of a contemporary accelerator which can be used for various fields of science. In 1981, a proton linac of 800 MeV was proposed as a major facility of "Research Institute for Meson Science" in Kyoto University for medical applications, and for neutron/muon facilities.

Recently, among nuclear and particle physicists, it is claimed that national future plan of the accelerator, which will serve as the world first-class facility in nineties and next century, should be made as soon as possible. Under these circumstances, we are planning to propose an upgraded version of the accelerator of "Research Institute for Meson Science" in Kyoto University. The new version of the accelerator proposal consists of a proton linac of 800 MeV, a rapid-cycling synchrotron of 25 GeV and a stretcher ring. As options, we are thinking to construct a compressor ring of 800 MeV and an anti-proton accumulator ring.

Energy of the linac (800 MeV) is optimized for the production of secondary particles of intense slow neutrons, muons and pions, and also for an injector to the main synchrotron. The linac is designed to have a simple structure and it will be smaller and less expensive than the existing linac as LAMPF. It consists of a radio-frequency quadrupole (RFQ) linac of 2.5 MeV, a drift-tube linac (DTL) of 115 MeV and a coupled-cavity linac of 800 MeV. The H^+ and H^- beams will be accelerated simultaneously. The average beam intensities will be about 100 μA for both H^+ and H^-. The H^- beam from the linac will be used for the production of secondary particles like neutrons, muons and pions. Neutrons will be used for material science, pions for therapy and muons and pions for solid state and nuclear physics. The H^+ beam is also useful for the production of radio-isotopes.

The H^- beam will be injected into the main synchrotron. The compressor ring could be useful for the production of pulsed neutron and muon beams, and also for the injection of the linac beam to the main ring, when the short pulsed-beam from the main ring is necessary especially for the $\bar{p}$ accumulation and ν experiments. The beam intensity of the synchrotron will be 50 μA with the repetition rate of 30 Hz. In order to obtain the duty factor of 100%, the superconducting stretcher-ring will be installed in the tunnel of the main ring.

The accelerator complex will be able to provide the beams of protons, neutrons, neutrinos, muons, pions, kaons, anti-protons and hyperons, whose intensities will be higher than those from existing machines by almost 2 orders of magnitude. Therefore, the experiments using these beams are expected to open a way for various new fields of pure and applied science.

We will show a few examples of important experiments which can be made using the synchrotron.

Highlights of the elementary particle physics are meson rare decay searches and accurate measurements of neutrino reactions. Rare decay searches include various rare decay modes of charged and neutral kaons, pions and muons. The neutrino reactions include the neutrino-electron scattering and the neutrino oscillation. Hyperon β-decays can give valuable information on the weak current. We can expect the improvement of more than a factor of 10 in the sensitivity of all these experiments by the intense beams of high purity. At this sensitivity, the physics of energy scale of several hundred TeV can be studied through these rate decay searches. The high sensitivity study of rare decay seems to be only possible way to go beyond the energy region of future TeV × TeV collider and may open the new physics beyond the standard model. The neutrino-electron scattering has proved extremely valuable for the accurate tests of the standard electroweak theory. We believe that they can have enormous impact on the understanding of the elementary particles.

Hypernuclear spectroscopy, search for strange dibaryons, and hyperon-nucleon scattering experiments are important probes for studying the hadrons with strangeness quantum number. The high flux kaon will facilitate these experiments especially at low energy.

Intense kaon, pion and antiproton with good energy resolution make it possible to use these beams as new probe for the nuclear structure study. They may reveal new aspects of nuclear physics.

Concerning the physics of exotic atoms, search for Ξ^-, Σ^- and $\bar{p}$ atoms, test of QED by means of hyperfine structure of the muonium, and study of formation mechanism of exotic atoms are very important subjects. The muon catalyzed fusion is also worth notice.

A lot of exciting discoveries have been recently brought in from the Low Energy Anti-proton Ring (LEAR) at CERN. Much higher intensity anti-proton beam will provide more complete and precise understanding of the subjects opened by LEAR and may be able to open up a new application and new field of science like $\bar{p}$ therapy.

Continuous beams of high flux neutron, pion and muon available from the main ring should be valuable in the study of wide fields of materials science and chemistry.

The experimental research in such a broad range of science can be made using the proposed synchrotron, in addition to the neutron- and meson- physics, and the pion therapy with the linac, which are also very important and challenging.

ACCELERATOR COMPLEX

The accelerators for "Kaon Factory" have been proposed at LAMPF[1] and TRIUMF[2]. Several reference designs of the accelerators have been made in the energy range from 16 to 45 GeV and the intensity from 40 μA to 100 μA. The maximum proton energy and intensity of our first attempt of the reference design are 25 GeV and 50 μA, respectively, because of the following reasons:

i) High intensity anti-proton and kaon beams can be produced up to several GeV/c.
ii) The total cost should be reasonable.
iii) The construction should be possible within the today's technology of the accelerator and radiation handling.

One of the important design principles is that the accelerator should provide various kinds of beams for a broad range of science.

A shematic view of the first reference design of the accelerator complex is shown in Fig. 1. The linac provides the H^+ beam of 100 μA mainly for spallation neutron source, pion therapy and isotope production, and the H^- beam of 100 μA for the compressor ring and for the main ring. Since the repetition rate of the synchrotron is 30 Hz, the other H^- beam of 30 Hz will be compressed from 20 μsec macro-pulse to several hundreds nsec, especially for the epithermal neutron beam and pulsed muon beam. The compressor ring is also useful for the anti-proton accumulation and neutrino experiments. In this case, the compressed H^+ beam is transfered from the compressor to the main ring and accelerated and extracted as a pulsed beam of which length is comparable with the circumference of the anti-proton accumulator ring.

The stretcher ring which is located in the same tunnel as the synchrotron provieds a continuous beam at 25 GeV. In this case, the H^- beam is directly transfered from the linac to the main ring.

For the high intensity machine, it is of key importance to reduce the beam loss during the acceleration, injection and extraction. A pre-bunching at the injector to the linac to make the pulse proper time-structure will be necessary to avoid the loss during the rf bunching at the compressor and the main ring and also during the fast extraction.

This accelerator complex can provide several beams simultaneously, for example, 100 μA (20 μsec, 60 Hz) and 50 μA (∿0.4 μsec, 30 Hz) proton beams at 800 MeV, and also 25 μA (100% duty) and 25 μA (∿0.4 μsec, 15 Hz) beams at 25 GeV.

Linac

The 800 MeV proton linac to Los Alamos has proved quite successful for the study of intermediate energy nuclear physics and various kinds of applied science. Encouraged by this success many proton linac projects are being proposed. Among them a PIGMI project[3] is very attractive because of many technical inovations which allow the construction of smaller, less expensive, and more reliable proton linacs. We have made the present design of the linac based on a similar idea as the PIGMI project.

The linac consists of two ion sources, a RFQ linac structure, a drift-tube linac (DTL) structure, a disc and washer (DAW) linac structure, two 440 MHz rf system, eight 1320 MHz rf systems and a control system as shown in Fig. 2. Basic parameters of the accelerator are given in Table 1.

Both H^+ and H^- ions are simultaneously injected into the RFQ linac where the ions are bunched and accelerated up to 2.5 MeV. The DTL of 30 m long accelerates the beam from 2.5 MeV to 115 MeV. It contains 150 drift tubes and permanent-magnet Q lenses. The DAW linac accelerates the beam from 115 MeV to 800 MeV in 130 m. It contains 173 washers and permanent-magnet Q lenses.

The nominal pulse width of the beam is 20 μsec and the duty factor is 0.12% at the repetition rate of 60 Hz. To obtain the design value of the average beam current (100 μA), the peak current of both the H^+ and H^- beams should be 85 mA. Recent developments of high current H^- ion source showed that the above value is within reach[4].

After the acceleration, the H^+ and H^- beams are split by a magnet and transported to separate beam lines. A small portion of the H^- beam can be extracted at 250 MeV for the use of proton therapy. The H^- beam can be easily split by using a thin foil or wire. Total power consumption of the linac operation is estimated to be about1.5 MW and the total beam power is 160 kW.

Technical and theoretical studies about the machine and its components are in progress. Those are;

i) development of a cusp-type $H^\pm$ ion source
ii) construction of a split-type coaxial RFQ[5]
iii) three dimensional calculation of electro-magnetic field of DAW and DTL structure in collaboration with Los Alamos National Laboratory[6]
iv) fabrication of two types of permanent magnetic Q lenses made of strontium-ferrite[7].

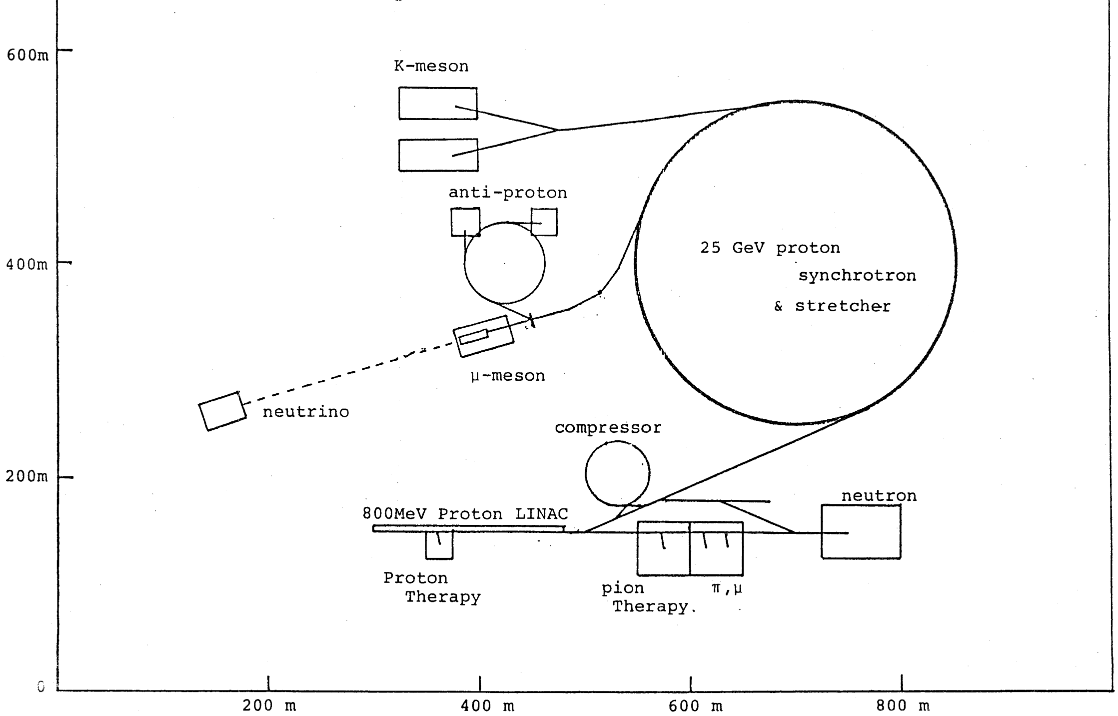
Synchrotron

A reference design for the synchrotron is of a 30 Hz rapid-cycling separated-function type. A lattice has a superperiodicity of 4 with dispersion-free straight sections. Each arc consists of 12 bending cells of FODO type with 60-degree phase shift per cell. Each straight section of the accelerator consists of 4 cells with two quadrupoles (D-F). The tune of each cell is 0.17 both in vertical and horizontal, resulting overall tune shift of 11.2 horizontal and 10.2 vertical. Matched beta-function is shown in Fig. 3 with the lattice structure of a half superperiod. Some of the parameters are listed in Table 2.

The RF system has to be tuneable from 40 to 48 MHz in which the harmonic number is designed to be 160. The number of rf cavities is 60 with 2m long each. Each cavity is required to provide the voltage of 250 kV.

A number of alternative designs are also now under

Fig.1 ACCELERATOR PLAN



consideration: a combined-type synchrotron may be interesting from the view point of compactness. There may also be substantial advantage for the rf system if a booster accelerator is adopted between the 800 MeV linac and the 25 GeV cynchrotron. Extensive studies of such alternative disigns are now under way, in addition to the feasibility study of the proposed rf system.

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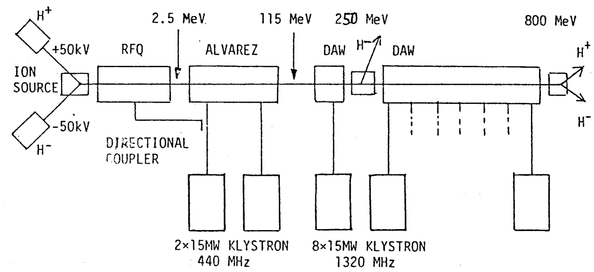

Fig.2 Constitution of the 800 MeV linac

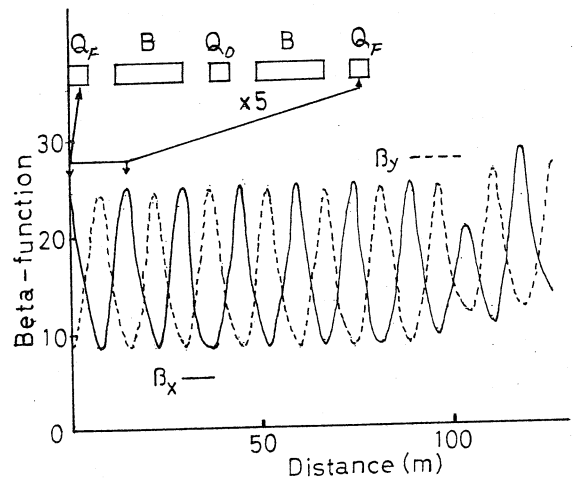

Fig. 3 Beta function and the lattice structure of a normal bending cell

Final energy	:	800 MeV
Peak beam current	:	85 mA(H^+), 85 mA(H^-)
Pulse	:	Length ; 20 μs. Reptition rate ; 60 Hz
RFQ	:	Cavity ; 30 cm diam. 2.5 m length, Frq ; 440 MHz, Energy ; 2.5 MeV
Alvarez	:	Cavity ; 40 cm diam. 30 m length, Drift tube ; 6 cm diam. 1cm bore diam. × 150, Focus ; PMQ 20 kG.cm × 150, Frq ; 440 MHz, Field strength ; 6 MV/m, Filling time ; 16 μsec.
DAM	:	Cavity ; 34 cm diam. 130 m length, Washer ; 173, Focus ; PMQ 5 kG/cm × 172, Field strength ; 8 MV/m, Filling time ; 4 μsec.

Table 1. Basic parameter of proton linac

E_{max}	25 GeV
Repetition Rate	30 Hz
Circumference(C)	1o11 m (R=160 m)
Superperiodicity	4
Normal bending cell	48
Non-bending cell	20
Lattice	FODO
Quadrupole field	8.1 KG max
Dipole field	16.0 KG, ρ=54.1 m
RF	40-48 MHz, h=160
RF cavities	60 x 250 kV , total 15 MV
γ_T	7.9 GeV
Nux, Nuy	11.2, 10.2
β_x^* , β_y^*	25.2, 8.45

Table 2. Parameters of a reference synchrotron