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Conceptual Design of the 800 MeV Multi-purpose Proton Accelerator

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A multi-purpose accelerator complex which accelerates protons up to 800 MeV is proposed. It consists of multi-step linear accelerators and two synchrotrons. The linac section contains a 433 MHz RFQ linac, a 433 MHz and a 1300 MHz Alvarez linacs and a 1300 MHz DAW linac. One of the synchrotrons is a weak current 250 MeV medical synchrotron and the other is a high current 800 MeV FFAG synchrotron. Main purposes of the accelerator are proton therapy, neutron and meson physics.

KEY WORDS: RFQ / DAW / Proton therapy / FFAG

Introduction

A meson factory of an 800 MeV proton linac was proposed about 10 years ago as a future project at the Kyoto University. The 7 MeV proton linac at ICR, Kyoto University was to be a prototype of the first step of the future linac. The 7 MeV linac has successfully accelerated proton beam. But the project is not realized yet because of financial difficulty. The medical group expects to start proton therapy right now rather than pion therapy in the future. We have studied proton therapy machines recently. Meanwhile users groups of the Kyoto University Research Reactor are now considering the next neutron source. The present reactor is old and will be replaced in 10 years. But the 2nd reactor is almost impossible to be constructed. Then a high intensity proton accelerator is one of the good candidates of the future neutron source. On the other hand energy problem becomes an important subject. An accelerator aided nuclear reactor, muon catalyzed fusion and nuclear waste incineration are examples of the future projects.

Thus we have considered a multi-purpose proton accelerator as the future project. But now, instead of the 800 MeV linac, a combination of a 350 MeV linac and 800 MeV FFAG synchrotron is studied to reduce the cost of the construction.

Main Concept

The total system should be constructed step by step. The first step is a proton therapy machine which consists of a 10 MeV linac as an injector and a 250 MeV small synchrotron. The medical synchrotron needs only small portion of the linac beam. Then the main beam of

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the 10 MeV linac is accelerated up to 50 MeV by the 2nd step linac which is 433 MHz Alvarez lianc (DTL). The 50 MeV proton beam is able to produce radio isotope for medical and chemical use. The 3rd step is a DTL operated with 1300 MHz which accelerates the beam up to 150 MeV. The 1300 MHz DTL is not constructed so far. But It will be possible to fabricate such a small size cavity and drift tube at an incident energy of 50 Mev. The shunt impedance of the DTL cavity decreases with frequency increace. This is shown in Fig. 1. The 150 MeV proton beam can be used as a neutron source. More intence neutron source is obtained by the 4th step which consists of a Disk And Washer (DAW) type cavity because it has higher shunt impedance than in case of the DTL at this energy as shown in Fig. 1. We obtain 350 MeV proton beam by this linac. The 5th step is the final step of the project which is an 800 MeV FFAG synchrotron. The FFAG synchrotron reduces the cost of the acceleration and pulse compression system.

The first injector

The first injector is a 10 MeV linac which consists of an RFQ and Alvarez cavities. The ion source is a multi-cusp field type H^- source. This linac system is operated at an RF of 433 MHz. At ICR, we have developed a prototype 433 MHz linac which accelerates protons up to 7 MeV. The general layout of the ICR linac is shown in Fig. 2.

Proton therapy synchrotron

The 10 MeV linac is used as an injector of the proton therapy synchrotron. The synchrotron accelerates protons up to 250 MeV at 10 nA intensity level. A plan view of the synchrotron ring is shown in Fig. 3.

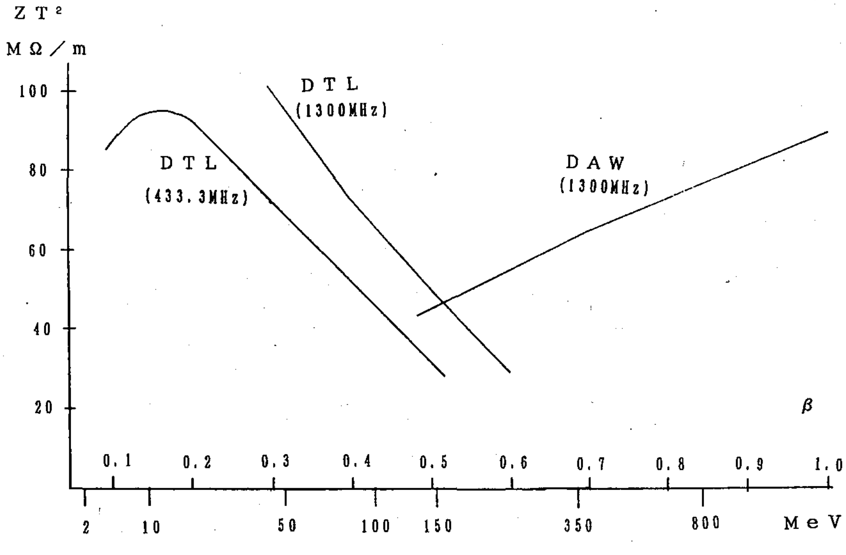

Fig. 1 Shunt impedance of 433.3 MHz DTL, 1.3 GHz DTL and 1.3 GHz DAW linac

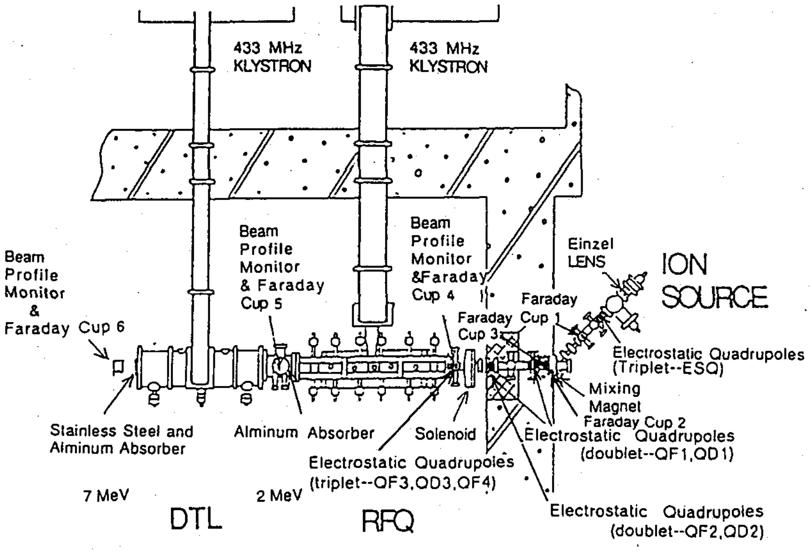

Fig. 2 Plan view of the ICR proton linac

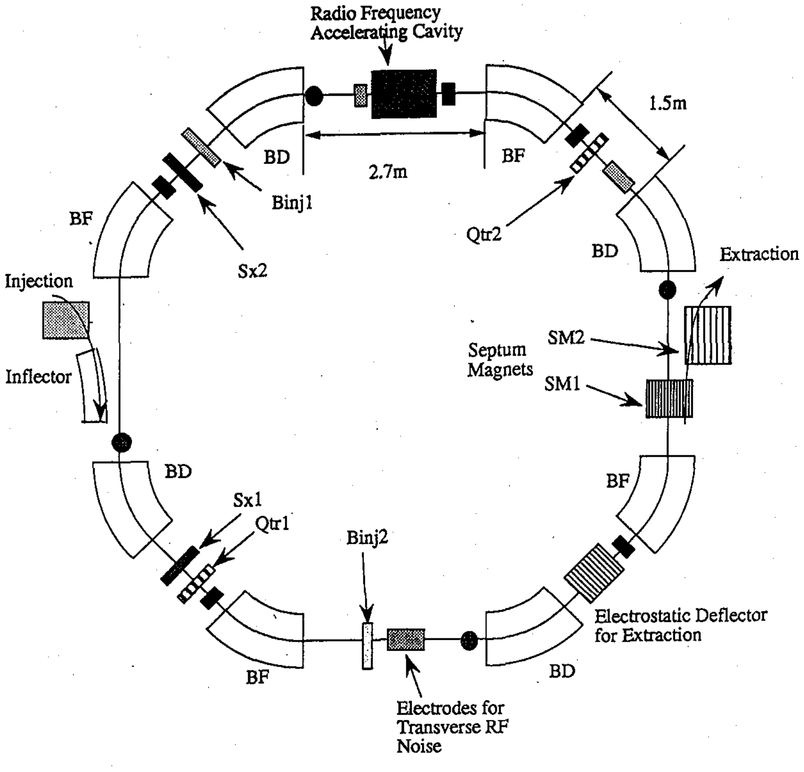

Fig. 3 Plan view of the medical synchrotron

The 1300 MHz DTL

The second step linac is the 433 MHz DTL which is an extended option of the first step DTL. Then at 50 MeV, the third step 1300 MHz DTL follows the 433 MHz linac. We have developed a short permanent quadrupole magnet for the drift tube at the energy of 2 MeV in case of the 433 MHz DTL. At 50 MeV, the length of the drift tube in the 1300 MHz cavity is enough to contain the permanent quadrupole magnet though a diameter of the magnet should be reduced. The cavity of the 1300 MHz DTL must be so small that the structure must be changed. A concept of the 1300 MHz cavity is shown in Fig. 4. The 1300 MHz DTL accelerates protons to 150 MeV.

The DAW linac

A 1300 MHz DAW linac connects to the 1300 MHz DTL at the energy of 150 MeV, where the shunt impedance of the 1300 MHz DTL cavity becomes lower than that of the DAW cavity. Using model tests and 3D calculations, the biperiodic T structure is a good structure for a washer suport in the DAW cavity[1]. It has a high shunt impedance under the good condition of resonance mode separation. A conceptual cross section of the DAW cavity is shown in Fig. 5. The DAW linac accelerates protons up to 350 MeV. This energy is sufficient for spallation neutron production.

The FFAG synchrotron

An FFAG synchrotron is chosen as the final step accelerator. The FFAG synchrotron has been often proposed to obtain high intensity beam, but not yet realized. At Los Alamos a stor-

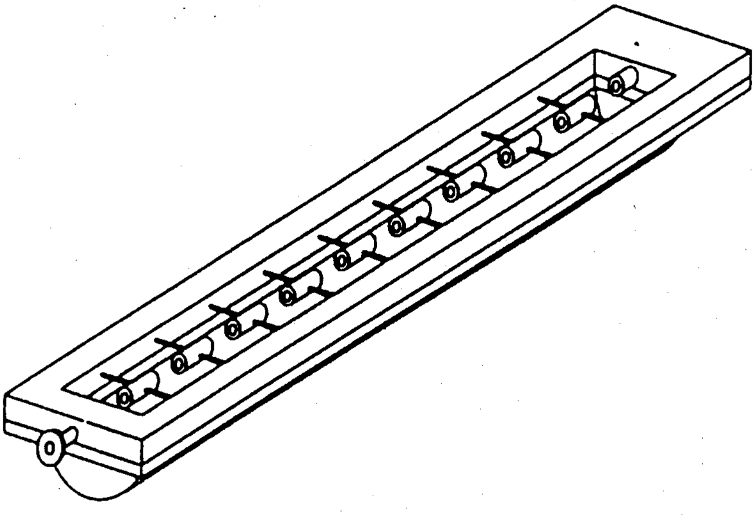

Fig. 4 Conceptual drawing of the 1300 MHz DTL cavity

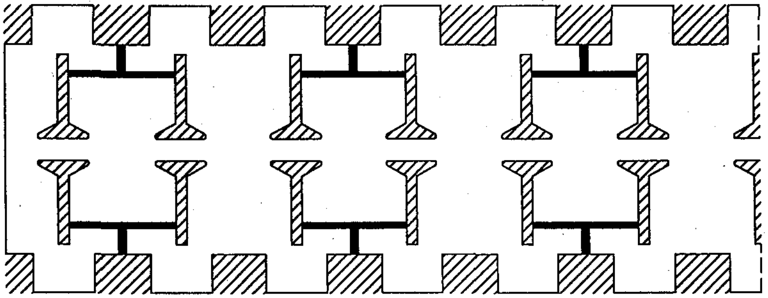

Fig. 5 Cross section of the DAW cavity with the biperiodic T support

age ring is attached to get pulsed beam which is necessary in case of a kind of neutron experiment because the pulse length of the linac is too large to make such an experiment. In case of a rapid cycling synchrotron, such a storage ring is not necessary. A fast extracted beam from the rapid cycling synchrotron has a short pulse structure but the repetition rate is usually fixed. In the FFAG ring, the time structure of the extracted beam may be flexibly changed. This is useful feature for multi-purpose machine.

A conceptual design of our FFAG ring is a scaling model based on the Mini-ASPUN project at Argonne National Laboratory[2]. But our design is simple for the acceleration scheme. At the Mini-ASPUN the injected beam at 50 MeV is captured and accelerated up to a stacking energy of 350 MeV on the second harmonic. Then four cycles are merged and accelerated from 350 MeV to 500 MeV on the first harmonic and finally the stacked bunch is extracted in one turn. In our case, the injection energy is 350 MeV. The injected beam is captured and accelerated from 350 MeV to 800 MeV on the first harmonic. Merging may be made at the injection radius to change the time structure of the extracted beam.

The average injection radius is 12.276 m and the average extraction radius is 12.987 m. This small increace on the ring radius makes the magnet small. In our scaling model the maximum field is 1.5T which is the same as Mini-ASPUN. The magnetic field of our FFAG is expressed as the following formula.

$$B\,(r,\,\theta)=\langle B\rangle\left(\frac{r}{r_0}\right)^k\left\{1+\sum_{n=1} f_n \cos n\,N\,(\theta-\tan\psi\,\ln\frac{r}{r_0})\right\}$$

where r is the radius measured from the machine center, ⟨B⟩ is the average field at the reference orbit r_0, f_n are the harmonic components of the azimuthly varing field, N is the number of identical sector magnets, ψ is the spiral angle, and k is the mean field index. The magnetic field on the magnet sector increases with average radius according to

$$B=1.5\left(\frac{r}{12.987}\right)^k\ \mathrm{T}$$

where $k=8$.

The spiral angle ψ for the sector magnet is 57° and nominal angular width is 5.625°. The magnet gap starts at 8.0 cm on the injection radius and reduces to 5.1 cm at the extraction radius. The weight of each sector magnet is 28 tons for iron and 1.35 tons for copper. The FFAG ring is shown in Fig. 6.

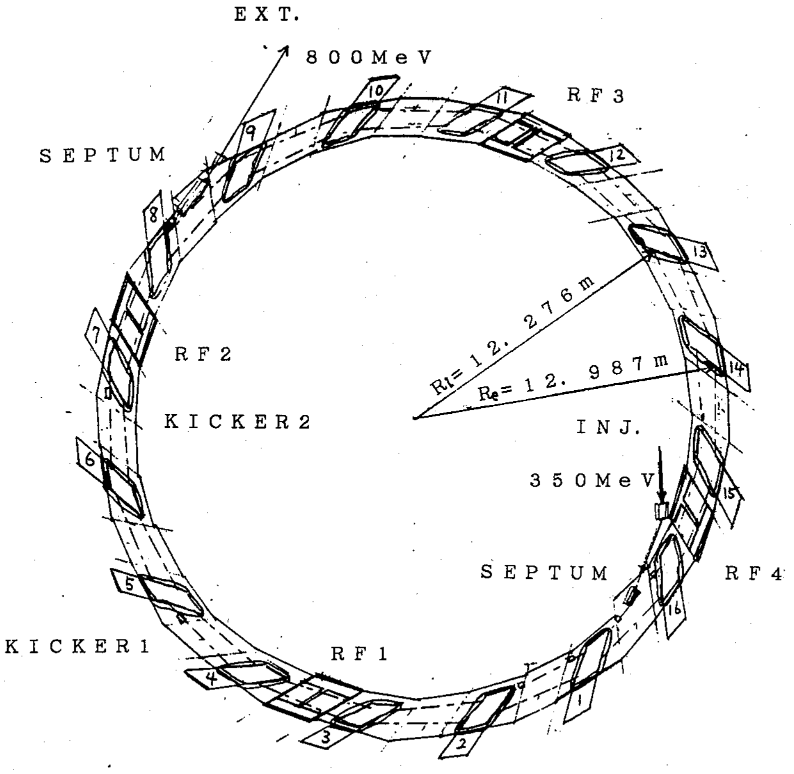

Fig. 6 Plan view of the FFAG ring

The extracted beam from the FFAG synchrotron is used for spallation neutron source, pion physics, pion therapy, muon science and so on. The conceptual view of the total facility is shown in Fig. 7.

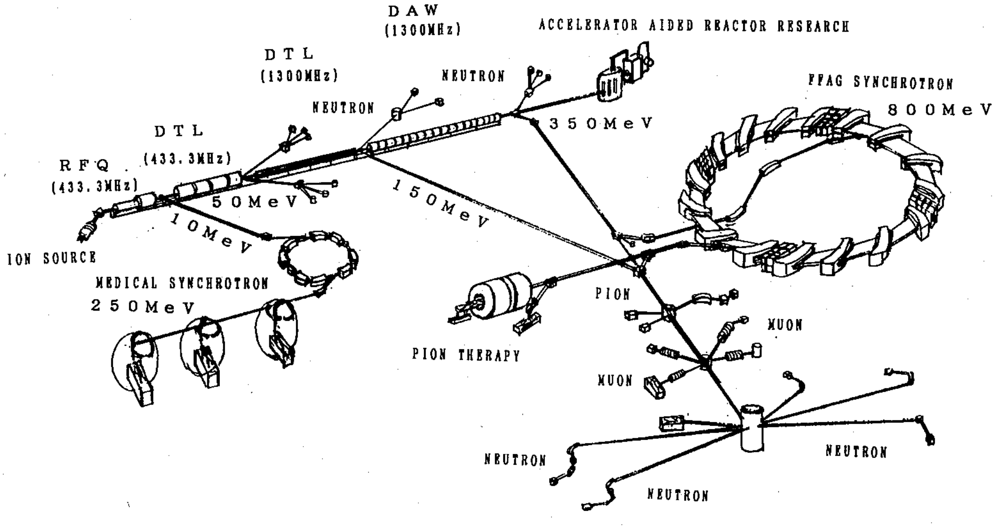

Fig. 7 Conceptual view of the total facility

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