THE TOHOKU PROPOSAL FOR A CW ELECTRON ACCELERATOR FACILITY

M. Sugawara
Laboratory of Nuclear Science, Tohoku University
Mikamine-1, Sendai, 982, Japan

ABSTRACT

The proposed electron accelerator system is composed of an electron linac of conventional type and a pulse stretcher ring which converts the pulse beam from the linac into a continuous one with slow beam extraction. The electron beam of 90 uA at 2.2 GeV with 90% duty factor is usable for various kind of experiments in nuclear physics. The outline of the system and the design arameters are described.

INTRODUCTION

These days it is widely admitted that the electron accelerator will be an important tool to explore the new frontier of nuclear physics, as it was in the past. The electron beam has been extensively used because of its unique characters. The electron behaves as a point charge without structure and interacts with a nucleus through well known electromagnetic force, which allows precise theoretical treatment. This clarity of electron interaction will be a fundamental advantage to study unknown properties of target materials.

To satisfy these requirements the accelerator should supply intense electron beams of about 100 µA with energy up to several GeV. The high duty factor will be inevitable for executing coincidence experiments between scattered electrons and emitted particles from excited nuclei, which results in unambiguous analysis fixing the energy and momentum transfer at a definite value.

Several projects of new accelerator which meet these requirements are already proposed at institutions over the world. There are two methods accessible to continuous electron beams. One is a microtron in which electrons are recirculated through the same accelerating structure many times and are accelerated up to high energy.

The first CW microtron is the one at University of Illinois with the maximum energy of 70 MeV which became operational in 1972 /1/ and the other one at University of Mainz has been operational since 1983 with maximum energy of 175 MeV /2/. However, it is pointed out that there is a possible limit to get high energies over 1 GeV with this method. Large bending magnets with very high accuracy are required to circulate electrons and the maximum beam current is restricted to a cirtain low value imposed by beam blow-up, because the total current inside the CW accelerating structure increases in proportion to the number of recirculations.

On the other hand, several laboratories studied and noticed that the technology exists for construction of a linac-stretcher system which could provide a 100 µA beam over several GeV at a cost relatively low /3/. In this combination, it is possible to use pulse beams as well as continuous ones for a variety of experiments. Moreover, the stretcher is used also as an ordinary storage ring, which could offer interesting usage for nuclear physics.

History of using high energy electrons and photons for nuclear physics at Tohoku university began in the 1950's. The 300 MeV electron linac came into operation in 1967, which has long been one of the powerful accelerators for nuclear physics. There are persistent requirments in here to maintain the present activity in the future by renewing the facility.

Consequently, our laboratory proposed 1.5 GeV linac-stretcher combination in 1979 after design studies for several years and began construction of a prototype of the stretcher ring. The aim of the prototype was to study technical problems inherent in the stretcher, such as high repetition rate of injections matched to the linac and beam extraction with high efficiency and high quality. Properties of extracted beam must be carefully studied. The time variation of beam intensity, for example, affects badly the coincidence experiments.

The prototype came in operation at the end of 1981. Since then, it has been tested from various aspects and proved that extension to high energy could be within existing technology, although there are still some properties we have to solve. At the moment the prototype machine is used for coincidence experiments as one of the CW machines in the world. The beam of about 1 µA is constantly obtained with 80% duty factor and an energy spread of 0.2% /4/.

OUTLINE OF THE PROPOSED FACILITY

The next accelerator comprises a conventional linac and a pulse stretcher as mentioned before. To answer the persistent request for increasing the maximum electron energy, the recirculation method was taken into account in the previous design. However, judging from the continuity of experiments till now we decided not to go too high energy at once in the first phase of construction. Therefore, the maximum energy are limited to the value possible with modification of accelerating structure design for high energy version. The recirculation system and the equipments needed to go higher energy is reserved for construction in the second phase.

Fig. 1 shows the general layout of accelerator housing and experimental halls. These experimental halls, the linac housing and the beam stretcher housing are underground in order to shield the radiation thoroughly. The linac housing is located at the south of the present 300 MeV linac, and the pulse stretcher housing and the experimental halls are in the east area.

The linac consists of 210 m long main accelerator, injector and energy compression system (ECS) which improves energy spread of the beam. At the end of the linac, every third or sixth beam pulse is deflected by a pulse magnet (PM1) toward the neutron diffraction hall. Most of the beam pulses are turned through 85 degrees toward the area for nuclear physics experiments. When a continuous beam is required, the pulse stretcher (STR) is excited to convert the pulse beam into the continuous one.

A beam sharing system is under design, which enables us to use the continuous beam as well as pulse beam in two experimental halls simultaneously. Beam transport system is so designed that vertically polarized electrons from the linac or the stretcher are transfered to the reaction target with spin parallel or untiparallel to the beam direction.

ELECTRON LINAC

The composition of the linac is simplified adopting long accelerating structures and being minimized the total number of devices in order to emphasize on easy control and maintenance and especially saving capital cost. Each klystron feeds rf power to its own accelerating structure.

To realize high energy beam, the rf power fed to each structure is increased up to 35 MW from a previous design value of 26 MW expecting appearance of 40 MW klystrons. Consequently the length of the accelerating structure is increased to 6 m in order to use rf power efficiently.

The accelerating structure is designed to produce a nearly constant axial electric field along its length. Each structure will start with a slightly different iris diameter and continue with continuously decreasing linear taper in this dimension. The aim is to make the amplification of the TM11 deflecting mode as incoherent and as low as possible.

High beam current and good energy resolution are essential for future accelerators. Transient beam loading is a major matter of concern in a pulsed linac, especially for ones using long accelerating structures with long filling time. This phenomenon is suppressed by staggered firing of klystrons. A simulating calculation shows an order of magnitude suppression of loading effect.

Efficient use of the facility imposes a careful design on the beam focusing and steering system along accelerating structures. The energy range of good focusing and steering should be as wide as possible to cover beam energies which may change with a large scale on a pulse-to-pulse base because pulse beams of different energies are shared to experimental halls by using pulse magnets.

A subharmonic buncher installed in the injection system modulates the electron beam at the same rf frequency of the pulse stretcher (476 MHz), when the stretcher is in operation with rf acceleration.

Energy spread of electron beams emerged from a conventional linac is normaly 1 - 2%. Recent experiments in nuclear physics require energy spread of about 0.1% or less than this. However it seems difficult to achieve it by only improving linac itself. Energy compression system is used to improve energy spread by an order of magnitude without loss of beam intensity. The debunching factor of the ECS is variable around 50° /% with respect to rf-phase of the linac operating at 2856 MHz. This system will be used also for shaping energy spread suitable to the stretcher.

The energy spectrum of electron beam injected into the pulse stretcher should be uniform in the range defined by the operating energy of the stretcher (3/0% at 1.0GeV and 0.3% at 0.5GeV), when the monochromatic beam extraction is adopted. The phase angle spread of the bunched beam are kept in a finite value in order to obtain designed energy spectrum by accelerating electrons not at the top but at the rising or descending phase of rf field.

The parameters of the linac are shown in Table 1.

PULSE STRETCHER

Pulsed beams out of the linac are injected in STR and continuous beams are extracted from STR during intervals of two successive pulses. Injection is achieved by a system of septa and kickers. To obtain continuous as well as uniform beams which are essential to perform coincidence experiments, the density of the stored beam in the ring has to be uniform adopting a suitable injection method and the extraction method has to be well studied.

In many cases, although not all, a single-turn injection is used and the beam is placed directly on the equilibrium orbit, which causes the stored beam size to be as small as possible and instabilities to be reduced. However two-turn injection should be used in case that the linac could not accelerate the beam with high peak current which usually occurs at the energy near to the highest end imposed by klystron. In this case betatron oscillation in the horizontal direction will be used for injection.

Failure of the beam injection in the correct orbit might cause harmful time structure with the period of integral multiple of beam revolution during a certain time after beam injection. This structure was found in the prototype. The lack of electrons on a part of circumference is inevitable because the kicker magnets fall to zero field in a finite time, which corresponds to about 10% loss of duty cycle.

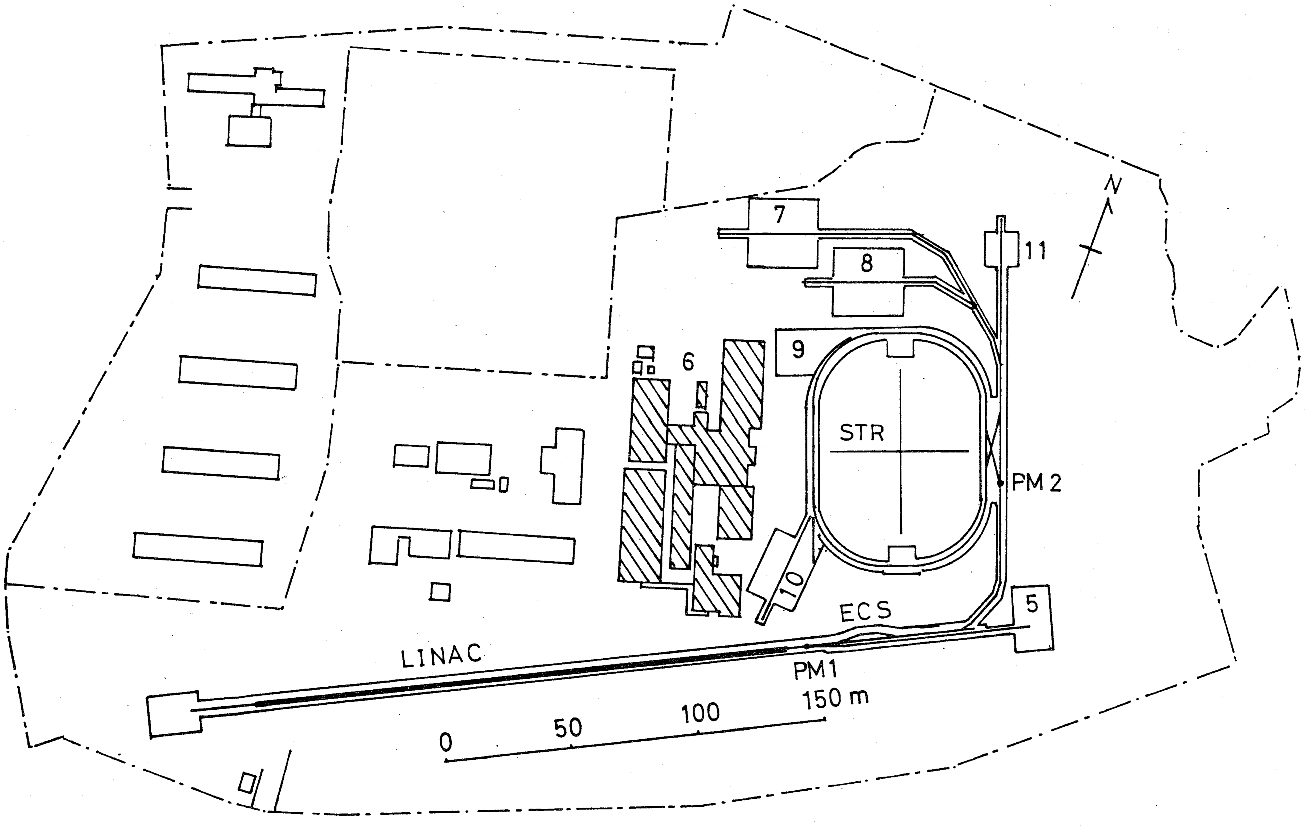

Fig. 1 Layout of CW electron accelerator facility.
ECS: energy compression system. PM: pulse magnets.
STR: pulse stretcher ring. 5: neutron difraction hall.
6: present linac facility. 7,8,9 and 10: experimental halls.

The third integer resonance is used in many cases for slow extraction because this belongs to weak resonance so that it is easy to control. In the case of the stretcher ring, high beam current should be hundled so that whole electrons injected must be extracted from the ring before next injection occurs. Otherwise, they would not only lose their intensity but also give serious damage to the ring. Complete extraction requires to keep the tune of the ring exactly at the third integer during a certain period of time at the end of extraction. To avoid this difficulty one use a hollow shape phase space of stored beam, In this case the tune does not need to be exactly the third integer, because no electron stays in the central region of the phase space. Formation of hollow shape is difficult with the one-turn injection.

These difficulty are rejected by using the half integer resonant extraction where the tune moves toward the half integer to decrease the area of stable region of the phase space. When the tune approaches near to the half integer across the certain value, all particle trajectories become unstable. Thus all electrons move outside from the central orbit oscillating resonantly and are extracted with high efficiency. Therefore it is needless to make the hollow shape. Thus the half integer resonant extraction is chosen in the proposed stretcher.

The stretcher does not need rf-acceleration essentially. However the operation energy higher than 1 GeV, rf-acceleration should be used to compensate energy loss due to synchrotron radiation. The energy loss during successive beam injection increases very rapidly with increasing electron energy and amounts to 3.0%, which is the maximum accetable energy width of the ring, at about 1.0 GeV. In this case electrons from the linac are bunched with 476 MHz (frequency of the rf system of the ring) by the subharmonic buncher. Then all electron bunches are injected into the same phase of the rf-bucket.

As shown in Fig. 1 STR consists of four quadrants and four straight sections. Electrons are extracted through two channels simultaneously at any rate of beam intensity. The important parameters of the ring are shown in Table 2.

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Table 1. Electron Linac Parameters

Accelerating structure	
Quasiconstant gradient,	$2\pi/3$ mode
No. of structures	32
(main acceleration	30)
(injector	1)
(energy conpression system	1)
Effective length	6.0 m
No. of cavities/structure	170
RF frequency	2856 MHz
Filling time	0.96 - 1.26 μs
Klystron	
No. of klystron	32
Peak power	40 MW
Average power	50 kW
(Typical Operation)	
Pulse repetition rate	250 pps
Klystron	
Peak power	40 MW
Average power	35 kW
RF pulse length	3.1 μs
Electron Beam	
Energy	2.2(2.7) GeV
Peak current	0.2(0.0) A
Pulse length	1.8 μs
Average current	90 μA
Energy spread	0.15%(with ECS)

Table 2. Pulse Stretcher Parameters

Circumference	272.081 m
Curved section	42.544m x 2
Long straight section	42.552m x 2
Short straight section	8.400m x 2
Mean Radius	43.303 m
No. of Bending Magnets	32
Bending radius	12.5 m
Bending angle	11.25°
Betatron Frequency	
Horizontal	7.5(7.48 at injection)
Vertical	7.38
RF system	
RF frequency	476 MHz
Harmonic number	432
Klystron	200kW x 1
(Typical Operation)	
Electron energy	2.2 (1.1) GeV
Injection	two-turn
Pulse length	1.8 μs
Peak current	0.2 A
Bunch (SHB)	476 MHz
Energy spread	0.1 (3.0) %
Repetition rate	250 pps
Stored Beam	
Circulating current	0.4 A
RF frequency	476 MHz(no use)
Beam loading	55 kW
Extraction	half integer resonance
Mode	achromatic (monochromatic)
Average current	90 μA
Duty factor	90 %
Energy spread	0.1 %