STRIPPING CARBON FOILS FOR H^- CHARGE-EXCHANGE INJECTION INTO THE KEK-PS BOOSTER

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A new type of the stripping carbon foil was developed for the H^- charge-exchange injection into the booster synchrotron of the KEK-PS. Stripping foils 20 and 30 $\mu g/cm^2$ thick were successfully used in routine operations at 20 and 40 MeV of the injection energies.

Introduction

The H^- charge-exchange injection into the booster synchrotron of the KEK-PS was successfully started with an injection energy of 20 MeV in 1985 [1], and the energy was raised, following the up-grade program, to 40 MeV [2] six months after in the same year. These energies are the lowest and the second lowest that have ever been used in the routine operation of the H^- charge-exchange injection into a synchrotron. At such low energies, one of the most serious problems is the preparation of the stripping foil. It should be as thin as 20 or 30 $\mu g/cm^2$ thick for a carbon foil and as large as 20 mm × 40 mm in area. Moreover, it should be mounted on a "U"-shaped frame so that the beam orbit is moved from the injection-orbit position to the acceleration-orbit one across the open end. These situations are very different from those of the stripping foil for heavy ions which has recently made remarkable progress [3].

It is very difficult to mount such a thin and large carbon foil on a "U"-shaped frame with one side completely open. To avoid this difficulty, other materials have been used for the foil at accelerator laboratories which adopted low-energy H^- charge-exchange injection into their synchrotron. In the Zero-Gradient Synchrotron of the Argonne National Laboratory, plastic (poly-paraxylene) foils 30 ∿ 40 $\mu g/cm^2$ thick have been used at 50 MeV.[4] Also at the Spallation Neutron Source of the Rutherford Appleton Laboratory, $A\ell_2O_3$ foils 50 - 60 $\mu g/cm^2$ thick have been used at 70 MeV.[5]

At KEK, a special "U"-shaped frame, which had a very thin tungsten wire (10 μm in diameter) extended at the open end, was devised to mount a carbon foil. With this frame and a newly-developed mounting method, a stripping foil as thin as 10 $\mu g/cm^2$ can be fabricated with comparative ease. Stripping foils about 20 $\mu g/cm^2$ thick were successfully used in the routine operation at 20 MeV, and those about 30 $\mu g/cm^2$ thick are now being used at 40 MeV. In the following sections, we describe about this type of the stripping foil.

KEK Stripping Foil

Thickness and Shape Requirements

The efficiency to strip an H^- ion to a proton by a carbon foil was calculated by M. Kobayashi [6] for 20 MeV and recently by S. Fukumoto et al. [7] for 20 and 40 MeV. These calculations indicated that, to obtain sufficiently high efficiency over than 95 %, the minimum necessary thickness of a carbon foil is about 20 $\mu g/cm^2$ for 20 MeV and about 30 $\mu g/cm^2$ for 40 MeV H^- ions, and that, the foil becomes thicker, the efficiency becomes higher. On the other hand, the energy loss and the multiple-scattering angle in the foil become larger with the foil thickness. So, in order to keep increases of the emittance and the momentum spread during the injection as little as possible, it is desirable to make the stripping foil as thin as possible. Thus if it is practical to fabricate and handle such a thin foil, a carbon foil about 20 $\mu g/cm^2$ thick is the best for the stripping foil to be used at 20 MeV, and also that about 30 $\mu g/cm^2$ thick is the best at 40 MeV.

The shape of the stripping foil and its frame was designed to fit with the injection method using a bump orbit and with the sizes of the injected H^- beam and the coasting proton beam. As is illustrated in Fig. 1, the stripping foil is set close to the acceleration orbit but not to scrape the beam in the acceleration. The H^- beam from the linac is guided to overlap with a bump orbit, namely the injection orbit, that is formed so as to penetrate the center of the stripping foil.

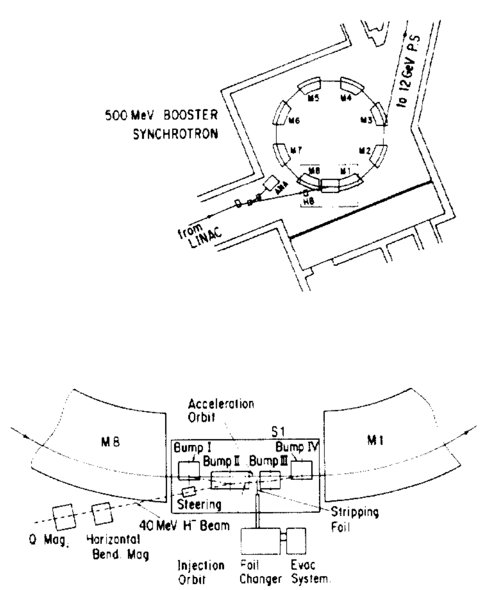

Fig. 1 The H^- injection system is installed in a straight section between two main magnets M8 and M1 of the 500 MeV booster synchrotron.

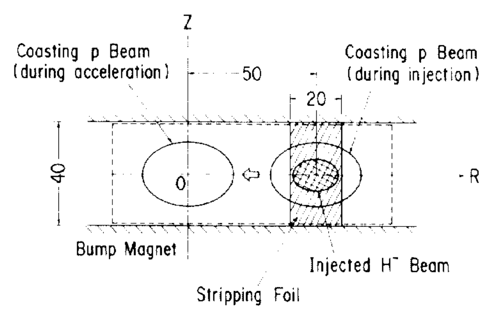

Fig. 2 Positional relations among the injected H^- beam, the stripping foil and the coasting proton beams. There should be no solid part of the frame that may obstruct the beam in the area enclosed by the dotted line.

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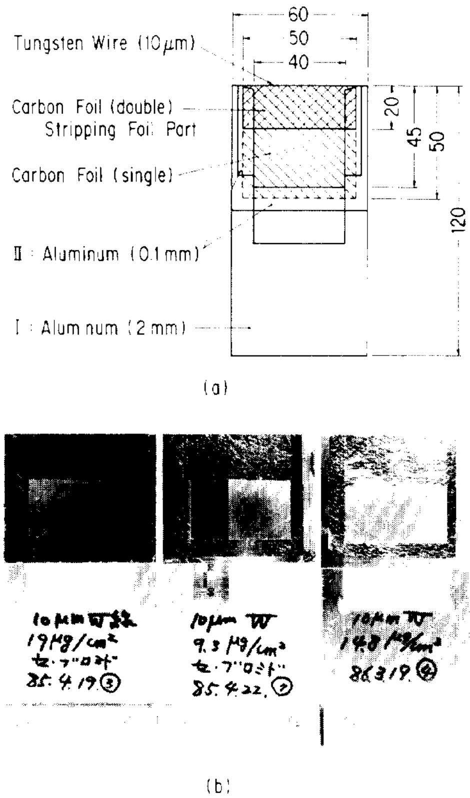

Fig. 3 (a) The design of the stripping carbon foil.
(b) Photographs of the stripping carbon foil. The thickness written on the frame means that of the material carbon foil.

The proton beam formed by passage through the foil is trapped and coasts on the injection orbit during the injection period. After the injection is finished, the injection orbit is turned off and the orbit of the coasting proton beam is rapidly moved to the normal accelerating orbit. Fig. 2 shows the movement of the beam orbit in the plane involving the stripping foil. Since the injected H^- beam is focussed on the foil to a spot about 20 mm or less wide in the horizontal direction, 20 mm is not only a necessary but also a sufficient horizontal width. The size of the coasting beam is enlarged by increases of the emittance and the momentum spread and probably by a small injection error remaining after the correction. Thus there should be no solid element that obstructs the beam in the area enclosed by the dotted line in Fig. 2. So the vertical length of the foil should be 40 mm or more. Moreover the solid part of the frame should be set out of the area.

Foil Design and Mounting Method

Fig. 3(a) shows the design of the stripping carbon foil. The frame consists of two aluminum parts and a tungsten wire 10 μm in diameter. The I part assures the overall strength of the frame and one side of it is connected to the foil magazine. The II part is attached to I putting both open ends together and a thin tungsten wire is extended on the open end of II. A material carbon foil [8], that has a shape of 70 mm × 50 mm, is mounted on the frame in the following manner. The foil is folded back at the tungsten wire with one side 50 mm long and this side is adhered to II on three sides. The short side is adhered not only to II on two sides but also to the other side of the foil to form a double layer 20 mm wide, as is shown in Fig. 3(a). This double layer part is used as the stripper at which the H^- beam is injected. Thus, when we mention the thickness of the stripping foil of this type, we mean the total thickness of the double layer. Actually, a material carbon foil is at first floated on water surface. Then it is carefully picked up on the frame.[9] It turned out to be easy to fabricate a stripping carbon foil thicker than about 10 μg/cm^2. The influence of the tungsten wire on the beam will be discussed in the third section.

Performance

Fig. 4 shows that, to obtain a high injection efficiency, it is effective to use such a thickness of the stripping foil as is expected from the calculations. As the pulse duration of the H^- beam becomes long, the injection efficiencies gradually decrease. This behaviour is probably caused by the increases of the emittance and the momentum spread resulting from the increase of the number by which the ions pass through the foil during the injection. However, the injection efficiencies are very high while the pulse duration is short, especially those obtained by a stripping foil 20 μg/cm^2 thick at 20 MeV and by a stripping foil 30 μg/cm^2 thick at 40 MeV are very close to 100 %. This fact ascertains that 20 and 30 μg/cm^2 are the sufficient thicknesses of the stripping foil used at the injection energies of 20 and 40 MeV respectively, and that appreciable beam losses are not caused by the 10 μm tungsten wire extended along the stripping

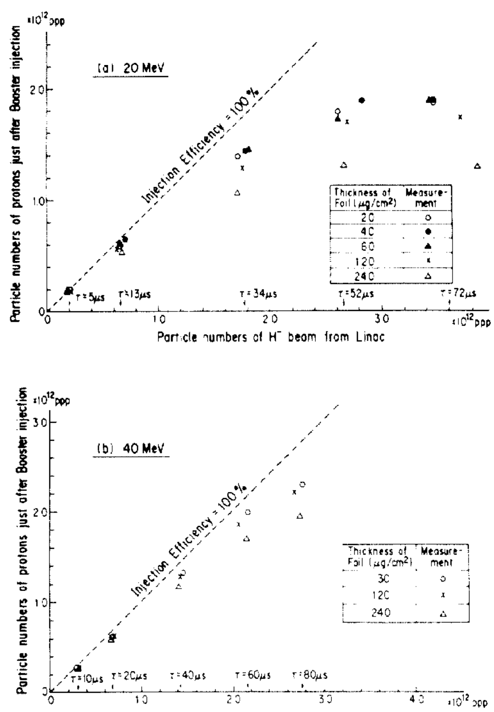

Fig. 4 Relationships between particle numbers of protons just after the injection and particle numbers of H^- beam from the linac at (a) 20 MeV and (b) 40 MeV. τ indicates the pulse duration of the injected H^- beam.[10]

foil.

During 2 months after the conversion, the injection energy was 20 MeV and stripping foils of about 20 μg/cm^2 thick were used in the routine operation of 900 hours. After the injection energy was increased to 40 MeV, stripping foils of about 30 μg/cm^2 have been used for over 4,000 hours so far. Throughout these period, the stripping foil was changed a few times except for changes for the machine study on the H$^-$ injection. However these changes were due to misoperations of the evacuation system and not due to damage by the beam irradiation. As a matter of fact one stripping foil has been used for over seven months so far and will be used more. Thus the life of this type stripping foil has been proved to be sufficiently long.

Handling and carrying of these stripping foils need some cares but are comparatively easy.

Discussion

As a tungsten wire is extended along the open side of the stripping foil, some fraction of protons in the captured beam hit the wire. There are two different manners by which the hit occurs. At first, during the injection, while the beam orbit is made stay at the centre of the foil, it occurs for a part of captured protons whose amplitudes of the betatron oscillation become larger than the width of the foil. Secondly, while the beam orbit is moved from the injection orbit to the acceleration orbit imediately after the injection, a part of the protons also hit the wire. Although the hitting probabilities of these cases depend on the operating conditions of the injection system, they are usually very small because the diameter ratio of the wire to the beam is about a few ten-thousandths and the average number for the captured proton to pass the foil position is at most 80. In a good condition, the overall hitting probability, involving the two cases, is expected to be at most 1 or 2 %[9].

Accompanying with the progress of the heavy-ion-acceleration technique, special carbon stripping foils for the heavy ion use have made a remarkable progress. One important feature of these foils is the high durability against the irradiation of high LET (Linear Energy Transfer) ions. However such a foil is more fragile than an ordinary carbon foil. It is more difficult to mount on a frame with one side open or nearly open to form a large-area stripping foil. If it is mounted, handling of such a stripping foil will be also very difficult. The stripping foil for the H$^-$ injection is not required such a high durability against the high LET as that for the heavy ion use. Thus an ordinary carbon foil is preferable to the special one for the heavy ion use as a stripping foil for the H$^-$ injection into a synchrotron.

An important application of this type stripping foil is the foil scraper which is used to scrape an unnecessary part from an H$^-$ beam. As the foil scraper changes the charge to plus, the unnecessary part is changed to a proton beam. So it is easily separated from the main part of the H$^-$ beam and conducted to a fixed beam dumper with a conventional beam-handling technique. The foil scraper is preferable to the ordinary scraper of metal sheet from some points of view such as the harmfull residual activity around the scraper, the space for installation and the simplicity of the control. Especially it will be very useful for a high energy H$^-$ beam. The advantage of a scraper with this type stripping foil is that the edge of the foil scraper is clearly defined by the wire.

Summary

A new type of the stripping carbon foil was developed for the H$^-$ charge-exchange injection into the booster synchrotron of the KEK-PS. A very thin carbon foil is mounted on a "U"-shaped frame with a thin tungsten wire 10 μm in diameter extended at the open end. The foil is folded back at the wire to form a double layer and this double layer is used as the stripper part. This type stripping foils 20 and 30 μg/cm^2 thick at the double layer were successfully used in routine operations at the injection energies 20 and 40 MeV respectively. Beam loss due to the 10 μm tungsten wire was ascertained to be negligible in the usual operation condition. The life of this type strippting foil was found to be longer than several months. Fabricating and handling of the foil needed some cares but were comparatively easy. Thus it was confirmed that this type stripping foil is very useful for the H$^-$ charge-exchange injection into a synchrotron. Moreover it is expected to be very useful for other practical application such as the foil scraper.

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