# A FAST-SPINNING STRIPPER MOD II FOR THE ZERO GRADIENT SYNCHROTRON (ZGS) BOOSTER*

Andrew J. Gorka
Argonne National Laboratory
Argonne, Illinois

## Summary

The use of $H^-$ negatively charged particles during injection into the ZGS booster requires the use of a stripping media to convert the particles to $H^+$ for acceleration in the normal manner. This process of stripping is accomplished with the use of thin plastic foils placed in and out of the acceleration orbit with the use of a unique and novel mechanism.

## Introduction

A scheme for increasing the circulating intensity of the ZGS utilizes negatively charged hydrogen ions for injection into a booster. This type of injection shows promise in order to attain the space charge limit intensity of the booster with subsequent injection of many such pulses at 200-500 MeV into the ZGS. [1] In the process of using these $H^-$ particles, it is necessary that they be stripped of the excess electrons to convert them to $H^+$ for acceleration in the booster. This stripping action must occur at a location where the injected beam is placed on the booster acceleration orbit. The stripper must be removed from this location to prevent beam losses due to multiple scattering.

Stripping has been done with the use of a gas as the stripping medium. The gas was pulsed through a collimating nozzle to produce a flat screen of suitable thickness across the beam orbit. The pulsing of the gas was controlled with a fast-acting solenoid valve. [2] Although this method of stripping accomplishes the removal of excess electrons, it is not very attractive when one considers multiple pulsing during rapid cycling injection rates of 30 Hz or so. One must consider the gas loading on the accelerator and its resultant gas scattering of the beam being accelerated.

In order to eliminate some of the disadvantages of the gas stripper, the use of thin foils was explored. Several factors had to be considered in choosing the material for use as a stripper. (1) The material must consist of a low Z atom type to minimize multiple scattering. (2) The material must not melt or decompose from heating due to energy loss. (3) The material must have ample tensile strength to support itself in large pieces, $1\frac{1}{2} \times 2$ in or larger. (4) The foil must maintain the tensile strength for a reasonable length of time, say an hour or better, so that even with remote means, the frequency of changing the foil does not become prohibitive. (5) The foil must be self-supporting, not be deposited on a backing, or require any framework on three sides.

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The following is a means of fulfilling the above requirements which I have proposed. The method involves the use of a polyparaxylene foil[3] of appropriate size and thickness attached to the edge of a rapidly rotating disc. This concept utilizes centrifugal force to extend the foil as a flat flag beyond the peripheral edge of the disc without the need for any supporting structures. The outward force or tension stretching the foil outward from the center is dependent upon the mass of the foil, the rotational frequency and the radius of the disc. In our application, we are considering a speed of 1800 rpm (30 Hz) to place the foil into the injection orbit for a precise interval once per acceleration cycle as indicated in Fig. 1. The injection period is in a range of 200-500 μs.

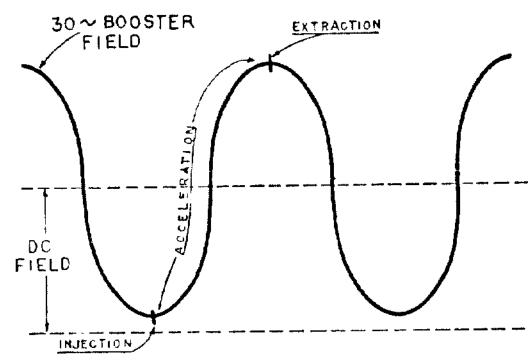


Fig. 1 Booster Operation

## Stripping Interval

The peripheral speed and the width of the foil plus the size of the beam determine the stripping interval based upon the following:

Disc radius = 18 in or 45.72 cm
Frequency of rotation = 30 Hz
Distance along periphery = $2\pi \times 18 = 113.1$ in = 287.3 cm
Linear velocity = $113.1 \times 30 = 3393$ in/s = 8618.2 cm/s
Time for 1-in travel = 1/3393 = .0002947 or 297 μs.

From the above, it is evident that if the beam were a point source and the foil were 1 in wide, a stripping time of 294 μs would be possible. Shorter time in beam path can be accomplished by keying the ion source after the leading edge of the foil has entered into the beam path. Longer injection periods can be handled by making the foil wider.

## Foil Parameters

The tensile strength of a 3500-Å thick foil was determined experimentally in the laboratory. A 1-in strip supported a load of 25 G. The tension on the lower edge of the foil while spinning is calculated as follows:

$$T = M\frac{V^2}{r}$$

$$V = 2\pi f r \text{ or } \omega r$$

$$T = M\omega^2 r$$

M = mass of foil in grams
r = radius of foil mass center = 18.5 in or 47 cm
t = 3500 Å or $3.5 \times 10^{-5}$ cm
D = density of polyparaxylene = 1.2
M = area x thickness x density
$M = 2.54^2 \times 3.5 \times 10^{-5} \times 1.2 = 27.0 \times 10^{-5}$ g
$T = 27 \times 10^{-5} \times (2\times30)^2 \times 47$
$= 27 \times 10^{-5} \times 3.553 \times 10^{-4} \times 47 = 450.8$ dyn or
$450.87/980 = 0.460$ g.

This is the pull experienced on the base edge of a 3500-Å foil 1 in x 1 in in size, mounted on a 36-in diameter disc whirling at a frequency of 30 Hz. This force diminishes to zero at the outer free edge of the foil. To prevent a slight curling or foldover at the leading edge, the foil is made in the shape of a trapezoid with the leading and trailing edge slanting toward the center ≈ 1/8 in/in of height. This assure a perfectly flat foil extending beyond the rim of the disc.

The size and shape of the beam tube in the booster are almost rectangular in cross section, ≈ 2 in in the horizontal direction and 3/4 in in height. Because of this shape, it is most reasonable to have the foil across the beam aperture in a vertical direction. In this case, the foil need be 2 in long and at least 1 in wide for a nominal 300-μs injection pulse.

## Foil Life

Experiments conducted with polyparaxylene foils intercepting a 50-MeV proton beam indicate a traversal of ≈ $5 \times 10^{18}$ particles through the foil before destruction occurred. Using this data, a foil should last ≈ 2 h when stripping a beam of $10^{12}$ particles, making 100 passes through the foil during each injection pulse, multipulsed 30 times/4-s period.

## Foil Changing

It is obvious the use of this foil on a continuous 24-h basis requires a means of quick changing to prevent prolonged downtime of the accelerator. In keeping with this requirement, the fast-spinning stripper includes a foil changing scheme to remove and reestablish a standing fresh foil while the disc is spinning.

Foils are secured to the disc in a fashion shown in Fig. 2. These foils are placed around the outer edge of the disc. The number of foils being placed on the disc is governed by the size of the foils. In our present design, 48 foils are attached to the disc.

The foils, when attached to the disc, are folded over a 2-mil nichrome wire running under the lower edge of the stored foil. The nichrome wire, when energized, will glow and thus melt the inner edge of the foil. As soon as this occurs, the centrifugal force puts the foil out beyond the edge of the disc and into the path of the injected beam.

The spent foils are removed from the rim of the disc with a solenoid plunger prior to the release of a new foil.

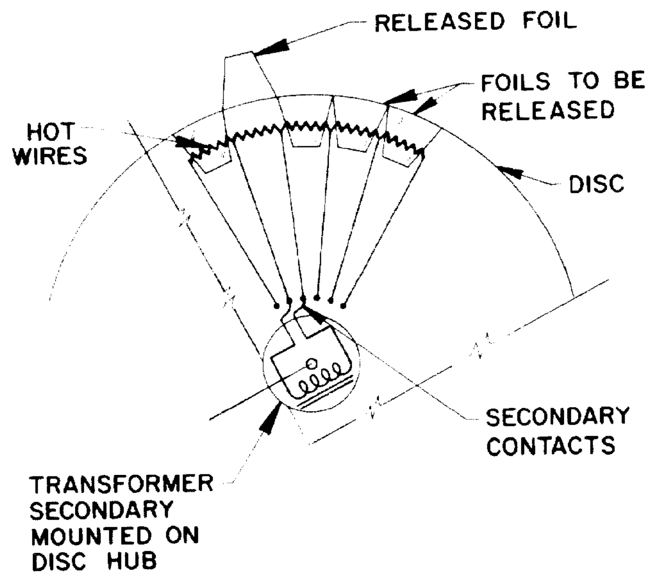


Fig. 2 Foil Changing Scheme

## Foil Selection and Release

The entire stripper assembly is an integral part of the booster installation and all internal mechanisms must operate in a vacuum in the region of $10^{-6}$ Torr. This constitutes an extremely hostile environment, especially for parts having mechanical contact while in motion. Bearings, slip rings, and brushes are short-lived and quite unreliable. To avoid problems of this nature, the foil selection and release are done with a device utilizing magnetic fields as the link between the moving machinery and the stationary parts. Selection is done with a dc tractive magnet effect and the release of the foil is done with ac transformer action.

## Transformer Action

The transfer of energy between a stationary body and a moving body is done with a transformer made in the shape of two annular rings, as shown in Fig. 3. Each transformer core is made up of 0.014-in silicon iron laminations stacked in a radial manner. This stacking makes the transformer phase insensitive when one core is rotating relative to the other. One of the annular cores is mounted to the vacuum vessel structure, the other is affixed to the rotating hub supporting the disc. The two cores are mounted parallel to one another with a space of 5/16 in between them. This device, when excited with an ac current, is a means of energizing the selected hot wire circuit with no mechanical contact.

## Tractive Magnet Effect

A magnetic circuit having a two-part core has another property that can be put to good use, especially in our application. The primary core with its winding constitutes an electromagnet core. The secondary core, disregarding the winding, can be considered an armature of a tractive magnet. A good sustained pull can be had when the primary is excited with a dc current. Although some pull is realized when this circuit is energized with ac, it is much stronger with dc excitation. The primary coil used in our design has a resistance of 60 Ω and an inductive reactance $X_L$ of 160 Ω. The pull, when energized with 0.8 A dc, is ≈ 2 lbs. AC excitation produces ≈ 2 oz with the same gap. This pulling force produces an axial movement.

## Axial Pull Converted to Rotational Motion

The selection of new foils on the spinning disc requires an incremental rotational motion as is noted in Fig. 2. The above described tractive force is harnessed to give rotational motion with a mechanical arrangement included on the hub structure shown in Fig. 4. The hub, in addition to providing a clamping means for the spinning disc, has a sleeve over the arbor. This arbor sleeve makes up the inner raceway for the linear bearing that surrounds it. The linear bearing can move axially as well as circumferentially on this sleeve. As parts are telescoped coaxially over one another, the linear bearing becomes a mounting for the transformer secondary core. A slanted pawl and a straight pawl are attached to the secondary core structure while a ratchet gear is mounted to the arbor sleeve part of the hub. As the primary coil is energized, the secondary core moves ≈ 1/4 in toward the primary core. This causes the slanted pawl to pull the secondary core rotationally one increment. A return spring placed between the arbor sleeve and the end of the linear bearing provides the return motion in the axial direction. The production of the rotational increments with axial motion is shown in Fig. 5.

The rotational motion is produced using a 96-tooth ratchet gear with an OD of 3.0 in. With a rake of 30° on the advancing pawl, the axial travel must be at least

$$\frac{3.0 \times \pi \times 2}{96} = 0.1963 \text{ in}$$

This distance plus at least 1/16 in is required for the deenergized gap, $G_1$. $G_2$ is required to keep the moving machinery from striking the static parts while the selection circuit is energized. Forty-eight foils are mounted on the disc, thus each foil selection requires two advance pulses. When this action is taken, the output of the secondary core matches up with the circuit conductors for the desired foil.

## Stripper Housing

The entire stripper assembly becomes an integral part of the booster installation. It must be housed in a vacuum-tight vessel that allows easy access to the foil disc for quick replacement, and it must contain all of the appurtenances needed to make the stripper

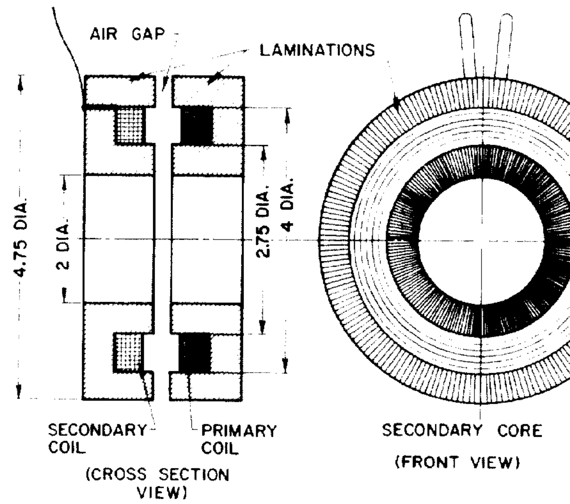


Fig. 3 Transformer Core Configuration and Arrangement

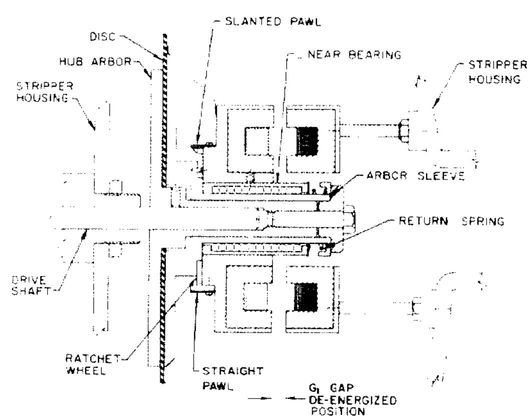


Fig. 4 Stripper Drive and Foil Changing Mechanism

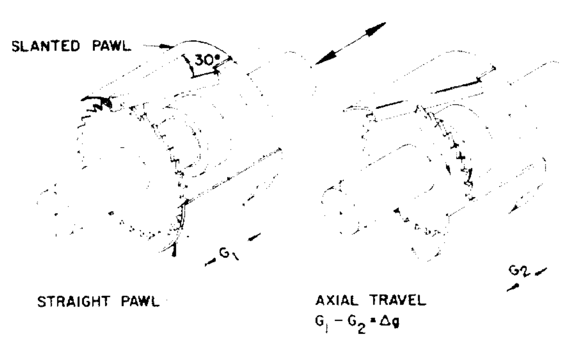


Fig. 5 Mechanical Arrangement of Pawls and Ratchet for the Conversion of Axial Movement to Rotational Incremental Stepping

operable. The stripper assembly takes the form shown in Fig. 5. The basic vacuum vessel is made of two aluminum dished tank heads. These tank heads are machined at the outer interface edges with a groove for an "O" ring gasket in one dish and a self-aligning flat surface in the other to serve as a vacuum-tight seal. An outer band with clamping sections is drawn around the matching edges of both heads to form a clam-shaped cavity. This band is a continuous strip going around the outer edge. It requires one bolt to secure it to make a vacuum-tight seal. The two heads have quick disconnect flanges which mate with the booster beam pipe. When replacing a disc with one having fresh foils, it is necessary to uncouple the beam line flanges and with the machine slide, move the cavity outward to remove the front cover of the stripper--a relatively simple operation.

## Disc Changing

Upon removal of one of the dished heads of the vacuum cavity, the entire disc is available. The disc is attached to the drive shaft with the transformer-magnet assembly described before. One bolt must be removed to remove the transformer core and the disc. Upon insertion, the disc is aligned with the transformer secondary connections and the bolt is secured.

## Drive Motor Arrangement

Two drive motors are attached in tandem to the drive shaft. One is a dc motor and the other an ac four-pole synchronous motor. The purpose of the dc motor is to bring the disc up to speed at a slow rate of acceleration so as not to tear the foils off with an abrupt change in velocity. Upon reaching the speed of $\approx$ 1800 rpm (about 1 or 2 min) with the dc motor, the synchronous motor is energized. This motor locks in step with the booster accelerator frequency to synchronize the speed and phase position of the foil with the booster field

The dc motor, upon reaching the desired speed, is left floating on the line to aid the synchronous motor should instabilities arise, such as mechanical friction variations or excessive hunting problems of the ac motor. Normally, the dc voltage is adjusted so that there is no drive power exchanged between the dc power supply and the motor. If the ac motor needs assistance in overcoming frictional drag, the dc motor can be adjusted to the desired level of drive power to offer this aid. The converse is also true--if the ac motor tends to lead a fraction of a degree, the dc motor power can be cut back to provide the required drag.

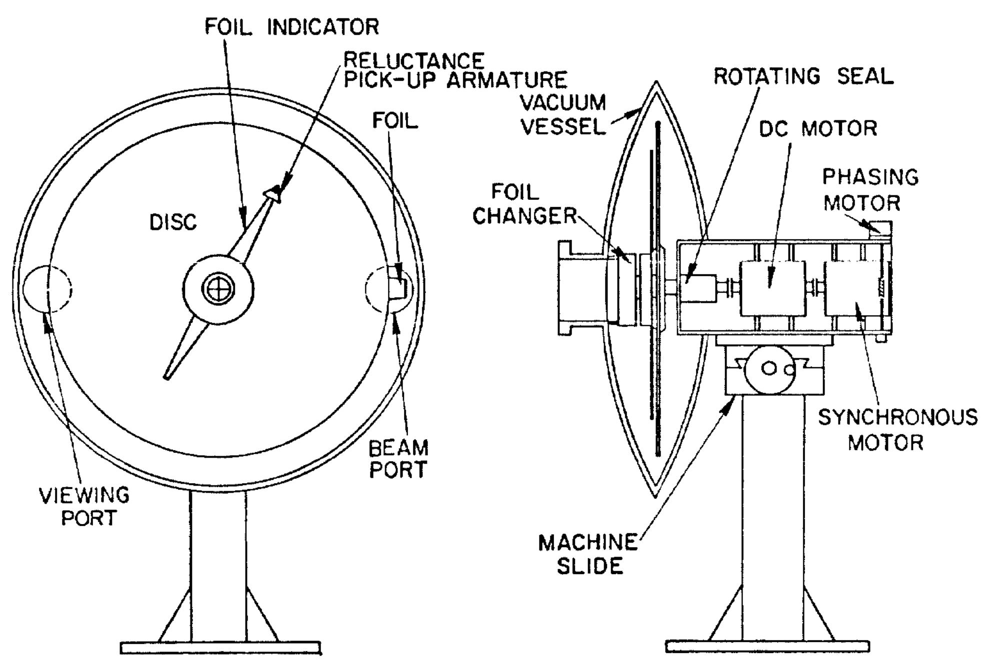


Fig. 6 Mechanical Arrangement of Fast-Spinning Stripper

### Foil Phase Adjustment

When spinning the foil, it is most important that it intercepts the beam orbit at precisely the right interval of the 30-cycle booster field. The adjustment of the foil position is accomplished by rotating the synchronous motor frame to the proper phase position. A third motor, a stepping motor plus a worm gear, is used to shift the motor stator into the proper angular position. Phase adjustments must be done after each change of the foil.

### Phase Positioning Resolution

To maintain a +10-μs accuracy in placing the foil across the beam, it is necessary to adjust the phase position of the foil to 0.1° during the 30-cycle rotation.

$$t = \frac{1}{f}$$

$$\frac{1}{30} = 0.033333 \text{ s}$$

$$\frac{0.03333}{3600} = 0.00000926 \text{ or } \pm 9.3\ \mu\text{s}$$

The adjustment of 0.1° requires phase adjustments in increments of better than one part in 3600. The drive used to make these adjustments is a low-speed geared dc motor coupled to a worm and worm gear drive. The motor plus the worm gear with a ratio of 80:1 will provide incremental movements in the order of one part in 8000.

### Phase Information Feedback

The stripper system is an open loop affair. It uses the power line frequency and the inherent phase locking characteristics of the synchronous motor to keep the stripper in step with the booster. In spite of this, two forms of foil position information are available to the operator. One is a TV monitor viewing a stroboscopic light flashed image of the phase displacement as well as the condition of the foil. It also indicates the position of the indexing mechanism. The indicator, a part of the indexing drive, is an arrow device extending to the rim of the disc. Figure 6 shows this equipment. In addition to being a visual indicator, the arrow contains a soft iron tip which generates a pulse as it passes a reluctance pickup. The pickup is in line with the beam opening port, thus it creates a pulse as the foil passes the beam position.

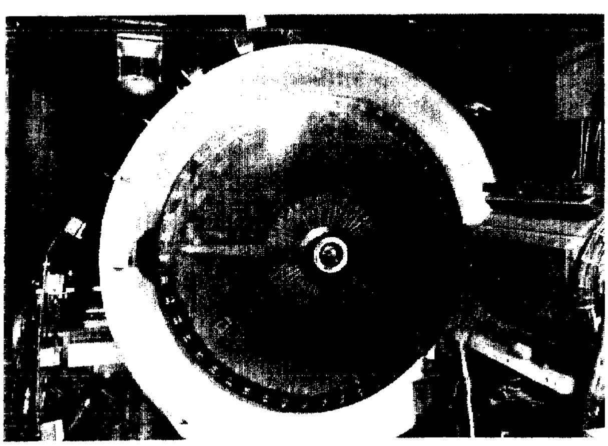

Fig. 7 Stripper with Front Part of Housing Removed

### Foil Production and Handling

The foils are made by a vapor deposition method, a proprietary method developed by the Union Carbide Corp. The foils are deposited on a substrate. We have found fresh slide glass quite suitable for this purpose. The thickness of the foil while undergoing deposition is controlled with the use of a monochromatic light and a talented operator. The thickness is further checked when the foils are removed from the deposition equipment with the use of an interferometer.

Once the foils are deposited on the glass slides, they can be stored for several weeks. The foil handling from this stage on is a hand operation. It is a technique that must be developed. It requires a person with a steady hand and an abundance of patience. Humidity seems to play an important role in the removal of the foil from the glass. If the foil is too dry, it tends to tear and break before it can be peeled off of the glass in one piece.

### Acknowledgements

I wish to acknowledge the fine mechanical design assistance of Roland Brewton. James Lewellen provided invaluable assistance with the electronics during the testing phase. Karl Meacham assisted in the construction and testing. His expertise in optics and foil handling and his knowledge of electrical and mechanical principles aided considerably in making the equipment a success. Kenneth Kellogg has done an outstanding job in improving the entire installation. His patience and determination have been responsible for the excellent improvements in the foil handling and preparation. He has also made considerable improvements in the electronics and foil changing equipment to enhance the reliability of the entire system. Vincent Patrizi assisted in the installation of the vacuum pumping system. Raymond Puccetti has contributed enormously in developing the foil production equipment and techniques. He and James Hrusosky produce and measure foils in a most professional manner.

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