Liquid Film Stripper for RIKEN RI Beam Factory

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Abstract

A charge stripper system using a thin oil film was developed for high intensity heavy ion beams of RIKEN RI beam factory. A stable free-standing film of silicone oil with fairly large area was made by a rather simple system. The design, performance, and preliminary results of low energy beam test are described.

1 INTRODUCTION

A charge stripper plays an essential part in heavy ion accelerators. Commonly used methods are foil stripping and gas stripping. Gas stripping has the advantages of causing less energy straggling and less multiple scattering, and being able to withstand intense heavy ion beams, but has the disadvantage of producing lower equilibrium charge states than foil stripping. Foil stripping has the advantage of producing higher equilibrium charge states but has the disadvantage that it breaks down with short lifetimes under bombardment by high-intensity heavy ion beams according to structural changes induced by radiation damage and possibly beam heating [1]. With higher intensity and high-mass beams of RIKEN RI beam factory (RIBF), the foil lifetime is expected to drop markedly to as low as one minute. Substantial progress has been made in developing carbon foil production techniques, which has lengthened the foil lifetime more than 10 times as compared with foils fabricated by conventional methods [2, 3]. Cramer *et al.* suggested a different approach to solving the stripper foil lifetime problem, which uses a thin free-standing oil film spun from the edge of a razor-sharp-edged rotating disc touching the surface of an oil reservoir [4]. Because the density of the oil film is roughly a half of that of a carbon foil, we can expect higher equilibrium charge states. Leemann *et al.* developed a liquid film stripper at the Lawrence Berkeley Laboratory SuperHILAC based on the same concept [5]. Another liquid film stripper system based on the same concept was developed for high intensity heavy ion beams of RIBF.

2 PRODUCTION OF LIQUID FILM

Figure 1 shows a conceptual diagram of the liquid film production apparatus. A disc with a diameter of 10 cm in a vacuum chamber is rotated by an AC servo motor which is placed outside of the vacuum chamber through a ferrofluid sealed rotary motion feedthrough. The lower edge of the disc is immersed in a reservoir of silicone oil. SH200 silicone oil with kinematic viscosity of 50 cSt was used as suggested in Refs. [4, 5]. The reservoir is suspended by slide rods so that the depth to which the disc is immersed in oil is adjustable over a range from zero to about 3 cm. A 'scraper' is mounted on a separate positioning mechanism so that it can be moved ± 2.5 cm in horizontal direction and ± 4 cm in vertical direction. The oil reservoir and the 'scraper' are also placed in the vacuum chamber.

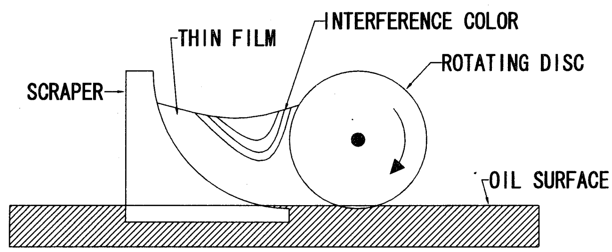

Figure 1: Conceptual diagram of liquid film charge stripper.

At first a disc such as those used in Refs. [4, 5] was adopted, and observed the three types of films described in Ref. [4]. When the disc was immersed very deeply in the oil and rotated at a very low frequency, a thick film of large area was produced. This film exhibited no distinguishable optical interference pattern. The next type of films showed strong interference colors and was of small area. The third type of films was observed to flicker in and out of existence, and showed a large area comparable to the first type of films.

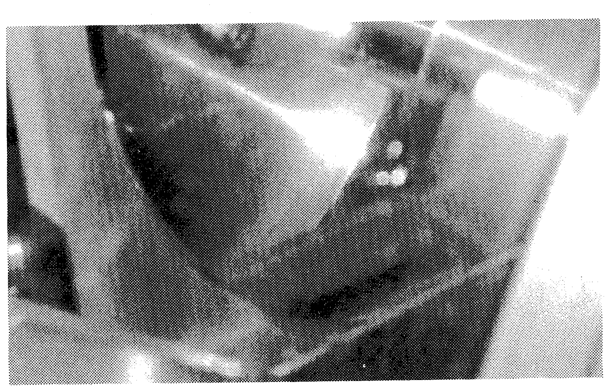

Figure 2: Photograph of liquid film.

Films with strong interference colors and a large area of more than 50 cm^2 were successfully produced by changing the shapes of the rotating disc and the 'scraper'. Figure 2 shows a photograph of the liquid film. A slightly slanting dim white line at the upper part of the photograph shows the upper edge of the liquid film. Higher rotating frequencies of the disc generally produced larger areas with the thinnest bands, as described in Ref. [5]. The 'scraper' seemed not to play an essential part in producing the liquid film, but play an important part in prevention from destructive turbulence of oil in the reservoir. The stability of the film became worse when the rotating frequency was increased. One possible source of this instability is disc vibration. The displacement in the normal direction against the disc was measured using an inductive displacement sensor, and found that it was as large as about 40 μm when the disc was rotated at 1800 rpm.

3 BEAM TEST

A low energy beam test of the liquid film stripper was performed by the Cockcroft-Walton injector of RIKEN heavy ion linac (RILAC). $^4He^+$ ions were accelerated to 500 keV and focused on a liquid film. $^4He^+$ ions undergo electron loss and capture processes while passing through the liquid film. $^4He^+$ and $^4He^{2+}$ ions which emerged from the stripper were separated by a parallel plate electrostatic deflector, and the currents were measured by a beam stopper which was divided into nine blocks.

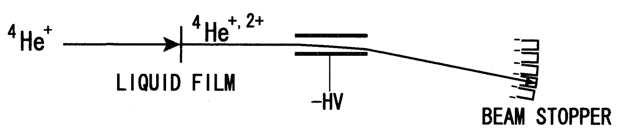

Figure 3: Schematic layout of experimental setup.

3.1 Experimental Procedure

Figure 3 shows a schematic layout of the experimental setup. $^4He^+$ ions at 500 keV were focused on the thinnest area of a liquid film by observing the fluorescent image of the beam on a quartz plate in front of the liquid film. The distribution of thickness of the liquid film was observed by an optical interference pattern of visible rays. The shape of the beam spot was nearly spherical, and the diameter was about 6 mm. A blue fluorescent image of the beam was also observed on the liquid film itself when a high intensity beam was bombarded. It is probable that a certain numbers of $^4He^+$ ions go without passing through the liquid film because the beam was focused nearly on the upper edge of the film. When beam intensity was increased, the upper edge of the film was broken like a waterfall into which a log was thrust. It increases the numbers of helium ions which go without passing through the liquid film. Some of the helium ions are likely to be charge exchanged by oil mist or other residual gases without passing through the liquid film. The energy of these helium ions is 500 keV as same as that of incident helium ions, while the energy of the helium ions which passed through the liquid film is somewhat lower than 500 keV because of the energy loss in the liquid film. Therefore, roughly speaking, $^4He^+$ and $^4He^{2+}$ ions with two energies go out of the stripper system.

The helium ions emerged from the stripper were injected into a parallel plate electrostatic deflector, and split according to the energy and the charge states. A beam stopper was placed behind the electrostatic deflector. The beam stopper was divided into nine blocks in each two degree, and the current of incident helium ions on each block was lead out separately. The currents were measured by varying the voltage of the deflector.

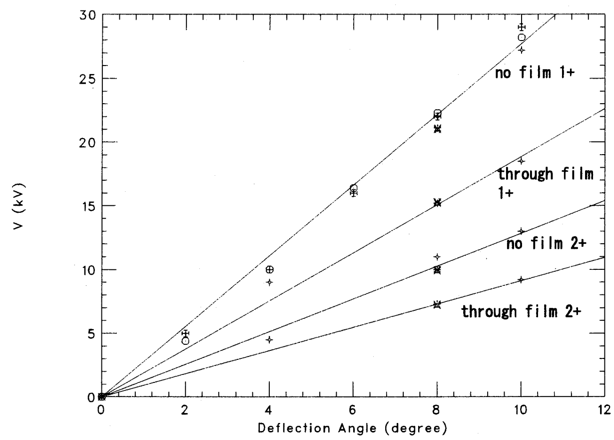

Figure 4: Sorted helium ions by electrostatic deflector according to their energy and charge states. The horizontal axis indicates the deflection angle, and the vertical axis indicates the voltage of the deflector.

3.2 Preliminary Result

Figure 4 shows the differences of the deflector voltages according to the energy and the charge states of the helium ions coming to each block of the beam stopper. The data points roughly form four lines. These lines are supposed to be corresponding to, from the upper line to the lower line, the $^4He^+$ ions which did not pass through the liquid film (first line), the $^4He^+$ ions which passed through the liquid film (second line), the $^4He^{2+}$ ions which did not pass through the liquid film (third line), and the $^4He^{2+}$ ions which passed through the liquid film (fourth line). Therefore one can estimate the thickness of the liquid film at the beam position from the difference between the first and second lines. The interpretation of the lines was checked by observing the data points of 80 μg/cm^2 carbon foil [6] lay closely on the second and fourth lines which had been fitted to the data points of the liquid film produced by 1600 rpm disc rotation.

The thickness of the liquid film varies as a function of the rotating frequency of the disc. Derived thicknesses are plotted on Fig. 5 as a function of the rotating frequency of the disc. When the disc is rotated at 1500-1800 rpm, the thickness of the liquid film at the thinnest area is suitable

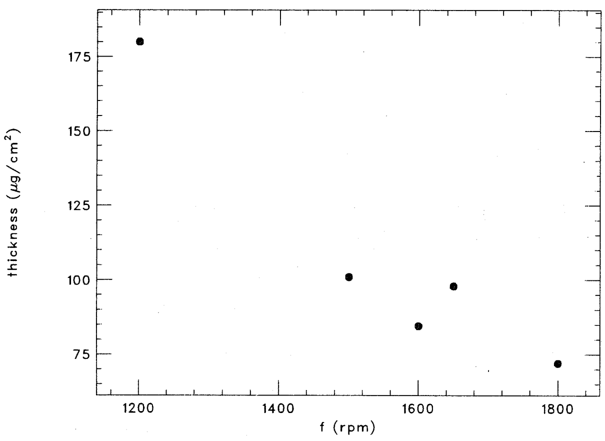

Figure 5: Thickness of the liquid film as a function of rotating frequency of the disc.

to be used as a charge stripper for the ions with energies of about 4-6 MeV/u [1].

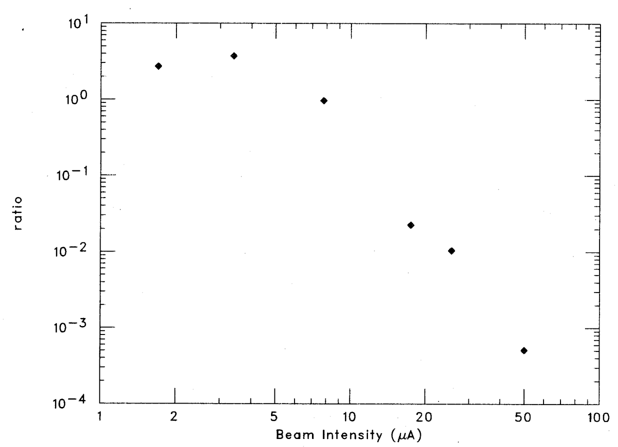

Figure 6: The current of $^{4}He^{2+}$ ions which passed through the liquid film divided by the current of $^{4}He^{+}$ ions which did not pass through the liquid film as a function of beam intensity. The disc was rotated at 1500 rpm.

Figure 6 shows ratios of the current of the $^{4}He^{2+}$ ions which passed through the liquid film to the current of the $^{4}He^{+}$ ions which did not pass through the liquid film in the case of 1500 rpm disc rotation. As beam intensity was increased, the upper edge of the film was broken. It drastically decreases the ratio as is seen in Fig. 6. The limit value of beam intensity is estimated to be about 10 μA, which corresponds to a power density of 8 W/cm^2. If a 5.85 MeV/u ^{136}Xe beam has the same beam spot size, this limit value corresponds to the beam current of 300 pnA. In the case of 0.9 MeV/u ^{238}U, the limit value corresponds to 200 pnA.

4 SUMMARY

A liquid film stripper using free-standing film of silicone oil was developed. A liquid film with fairly large area of more than 50 cm^2 was made. The thickness of the liquid film is suitable to be used as a stripper for the ions with energies of about 4-6 MeV/u when the disc is rotated at 1500-1800 rpm. Further modification should be made in order to be used for a high intensity heavy ion beam of RIBF. We are presently preparing a higher energy beam test at RILAC in order to measure the equilibrium charge state distribution and obtain more practical information about the durability against high intensity heavy ion beams.

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