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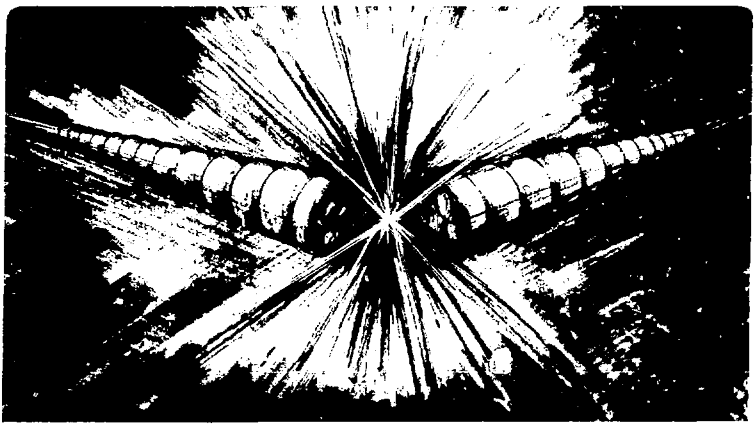

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A LIQUID-FILM STRIPPER FOR HIGH-INTENSITY HEAVY-ION BEAMS*

B. T. Leemann, P. Merrill, H. K. Syversrud, R. Wada, R. B. Yourd**

Introduction

Electron strippers are widely used in heavy ion acclerators such as tandem Van de Graaff generators and heavy ion linacs. Of the commonly used methods, gas stripping has the advantage to cause less energy straggling and less multiple scattering but has the disadvantage of producing lower average charge states than foil stripping. The choice between these two methods is based on the particular accelerator structure and on the ion velocity. The SuperHILAC at Lawrence Berkeley Laboratory, e.g., employs a fluorocarbon oil vapor stripper[1] at 113 keV/A for its high intensity injector "ABEL"[2], while after acceleration to 1.199 MeV/A a 35 μg/cm² carbon foil stripper is used. At present, the lifetime of these foils is about 1 hour for an ^{40}Ar beam of ~1 μA average particle current. With higher intensity high mass ($100 \leq A \leq 238$) beams available from "ABEL" injector the lifetime is expected to drop drastically and might be as low as one minute. In the past few years substantial progress has been made developing carbon foil deposition techniques that result in foil lifetime enhancement factors of up to 2 orders of magnitude as compared to foils made by standard carbon arc deposition[3,4]. A different approach to solve the stripper foil lifetime problem was suggested first by Cramer et al.[5], and uses a thin free standing oil film spun from the edge of a sharp-edged rotating disc touching the surface of an oil reservoir. Areas of about 10 cm² with areal densities down to 20 μg/cm² have been reported[6]. The work described here is based on the same concept, and produces a constantly regenerated, stable, free standing oil film of appropriate thickness for use at the SuperHILAC.

Experimental Setup

While Cramer's work[5,6] proved the basic feasibility to produce thin, free-standing liquid films, it appeared that vacuum compatibility, stability and reproducibility had to be improved for any practical application. Therefore, the experimental setup used in the present work and shown in figures 1 and 2 is placed in a vacuum chamber and all the SuperHILAC tests have been performed in vacuum.

The central piece is a 9 cm diameter disc made of tool steel with a hollow-ground, razor sharp edge. Care has been taken to make the drive mechanism of the disc vibration free to achieve film stability. The disc, supported by two roller bearings, is driven by a shaft, which is connected by a magnetic clutch to a variable speed (0-5000 RPM) motor outside of the vacuum chamber. A further essential improvement is achieved by the chosen design of the oil-disc contact: a fine stream of oil emerging from a 1.5 mm diameter nozzle mounted above the disc flows downward, tangentially touching the edge of the rotating disc. A movable scraper with a sharp, hollow-ground edge of concave shape defines the outside boundary of the film spun from the disc and collects any excess oil from the nozzle. Film instabilities caused by oil accumulation, formation and separation of oil droplets are minimized by this arrangement. A centrifugal pump provides the circulation of the oil from the reservoir to the nozzle, the position of which is fully adjustable with respect to the rotating disc. Large lucite ports on the chamber provide easy observation of the film and of the interference pattern produced by light reflected from it. Also, a ^{212}Po

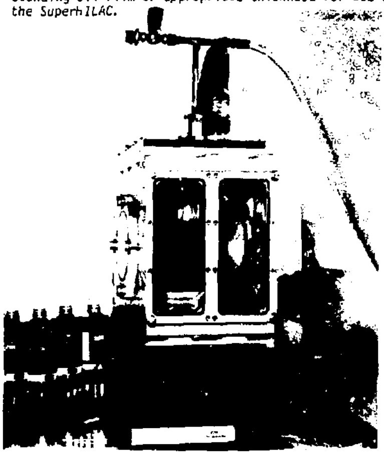

Fig. 1 Liquid film stripper test apparatus.

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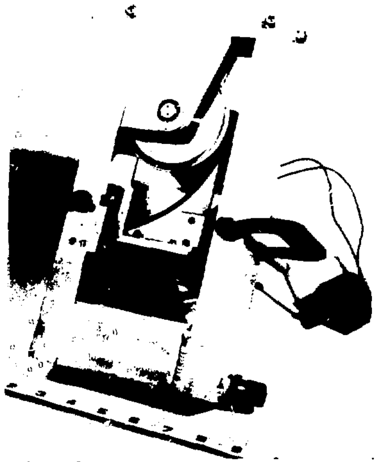

Fig. 2 Stripper rotating disc and scraper.

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source and a Si-surface-barrier detector mounted on either side of the film were used to determine the thickness of a particular area from α-particle dE/dx measurements.

Test Results

The circulation of oil in a vacuum introduces a new source of instabilities due to pressure modulations in the oil flow caused by the pump. After several early failures the use of a completely enclosed, vacuum tight centrifugal pump solved this problem. Three different types of oil have been tested for thin film production. Only marginal size films of a few cm^2 area could be achieved with diffusion pump oil DC 704. A small heater in the oil circuit was used to lower the viscosity of the fluorocarbon diffusion pump oil "Fomblin",[7] but still very small, unstable, thick films were obtained. The multipurpose oil DC 200 exhibited the most promising behavior. It is manufactured with viscosities ranging from 0.65 cs up to 100,000 cs. It was found that the 50 cs variety served best our purpose. In fact, the available film size seemed limited only by the position of the scraper, and the scraper was finally removed entirely. This allowed the film to span the entire area between the disc and its support frame, and it exceeded 100 cm^2 in total area for most measurements, with about 80 percent of it being in the range between 20 and 80 $\mu g/cm^2$. The motor speed was varied from 1500 to 4500 RPM with little effect on film stability. The higher speeds generally produced larger areas of the thinnest bands. When exposed to white light this film showed the characteristic interference pattern (figures 3 and 4) of a thin wedge, showing a sequence of colored bands caused by destructive interference of a particular wave length λ as given by equation (1)

$$d = m \frac{\lambda/2}{\sqrt{n^2 - \sin^2\alpha}}; \quad m = 0, 1, 2 \ldots \qquad (1)$$

where d = local film thickness
m = order of interference
n = index of refraction
α = angle of observaton

Table 1 lists the sequence of color bands observed *under 45° for DC 200 oil ($n = 1.4$) and 2000 RPM.* With increasing thickness the color appearance changes gradually since the conditon for destructive interference given by eq. (1) can be satisfied simultaneously by an increasing number of different wavelengths for different orders m. The fourth column shows the local areal density based on eq. (1) and a density of $\rho = 0.96$ g/cm^3. The fifth column lists the results of several energy loss measurements using 8.8 MeV α-particles from a ^{212}Po source. The overall accuracy of these measurements is estimated to be about 15 percent, mainly caused by source-detector alignment uncertainty. We found that there are a few very stringent requirements for a stable operation:

(i) The disc has to be absolutely true and the edge must be nick free.
(ii) Any excess oil on the disc has to be scraped off by some kind of a brush. Otherwise, on subsequent turns small drops are ejected from the disc, disturbing the incoming oil stream from the nozzle and eventually even destroying the entire film.
(iii) The oil stream from the nozzle must hit the disc edge with a substantial inward radial component as well as with a slight axial component.

Despite its excellent performance, it must be mentioned that the DC 200 oil has a high vapor pressure of about 3×10^{-2} torr at room temperature. In any stripper application this will require a differentially pumped system, unless a "stripped" version of DC 200 is available having the same properties except for a much lower vapor pressure.

Conclusions

We have demonstrated the feasibility of making stable liquid films in a reproducible way. Films of 30 cm^2 area with an areal density of 30 $\mu g/cm^2 \pm 20\%$ are easily obtained. In order to be used as an electron stripper, additional work is required to make it high vacuum compatible. We are presently preparing beam tests of this setup at the SuperHILAC in order to measure the equilibrium charge state distribution and to find the average charge state. Furthermore, we will determine the maximum intensity and duty cycle of a pulsed heavy ion beam the liquid films will sustain without damage. The outcome of these tests will ultimately demonstrate the feasibility of replacing existing carbon foils with a liquid film of this type as an electron stripper..

Table 1: Typical Sequence of Color Bands Found in DC 200 Thin Film Interference Pattern

Color Appearance	Destructive Interference For	Interference Order m	Thickness Based on Equation 1	Thickness Based on α-Energy Loss
dark	-----	m = 0	[$\mu g/cm^2$]	[$\mu g/cm^2$]
yellow-orange	violet-blue		16-18	
red-purple	green-yellow	m = 1	21-23	
blue	orange-red		24-28	28
yellow	violet-blue		32-36	
red-purple	green-yellow	m = 2	42-46	36
blue	orange-red		48-56	
green-yellow	violet-blue		48-54	
red	green	m = 3	63-69	
green	red		72-84	80
orange-red	blue-green	m = 4	72-88	88
green	red		96-112	

XBC 808-9110

Fig. 3 Liquid film interference pattern for f = 1600 rpm.

XBC 808-9112

Fig. 4 Liquid film interference pattern for f = 2400 rpm.

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