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PRODUCTION OF OPTICALLY THIN FREE-STANDING OIL FILMS FROM THE EDGE OF A ROTATING DISC *

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A method is described for forming thin free-standing oil films which are spun from the edge of a sharp-edged rotating disc. The films can be made thin enough to show strong optical interference colors when viewed in white light. The thinnest films have areal densities down to about 10–20 μg/cm^2. A stable roughly triangular film with an area of about 10 cm^2 and fairly uniform thickness can be readily produced. Much larger films having either greater thickness or less stability are also possible. Films have been produced both in air and in vacuum.

1. Introduction

The work described here was motivated by a desire to produce thin films which could be used as stripper foils in heavy ion accelerators. The research started with an investigation of oil bubbles formed when a disc with several holes in it was slowly rotated through a reservoir of oil. In the course of that work it was observed that when the disc was rotated at a higher speed, a free-standing oil film was spun off the edge of the disc. An investigation of this unexpected phenomenon was immediately begun.

This work has culminated in the development of a reproducible technique for producing free-standing optically thin films (a few wavelengths of light thick) which appear to have the stability, area, and thickness needed for stripper foils and other similar applications. However, the oil we have used to produce these films, as will be discussed below, is not suitable for high vacuum applications. A high vacuum substitute will have to be found before such films can be used in accelerators.

2. Description of technique

Fig. 1 shows a schematic diagram of the film production apparatus. A disc with a diameter of 9 cm is rapidly rotated by a vibration-free variable speed drive mechanism. The disc is made of tool steel and has been precision ground to a very sharp and uniform razor-like edge. The drive mechanism used to rotate the disc is a Dumore [1] precision grinder coupled to the disc through a vibration-suppressing coupler and support. The motor speed is varied electronically by a triac variable speed controller. Light reflected from an aluminized strip on the disc produces a repetitive signal in a phototransistor, permitting a direct measure of the rotation rate of the wheel using a digital frequency meter. It was determined that rotation rates in the range 2500–3500 rpm were optimum for thin film production.

The lower edge of the disc is immersed in a reservoir of oil. The reservoir is mounted on a motorized jack mechanism so that the depth to which the disc is immersed in the oil is continuously adjustable over

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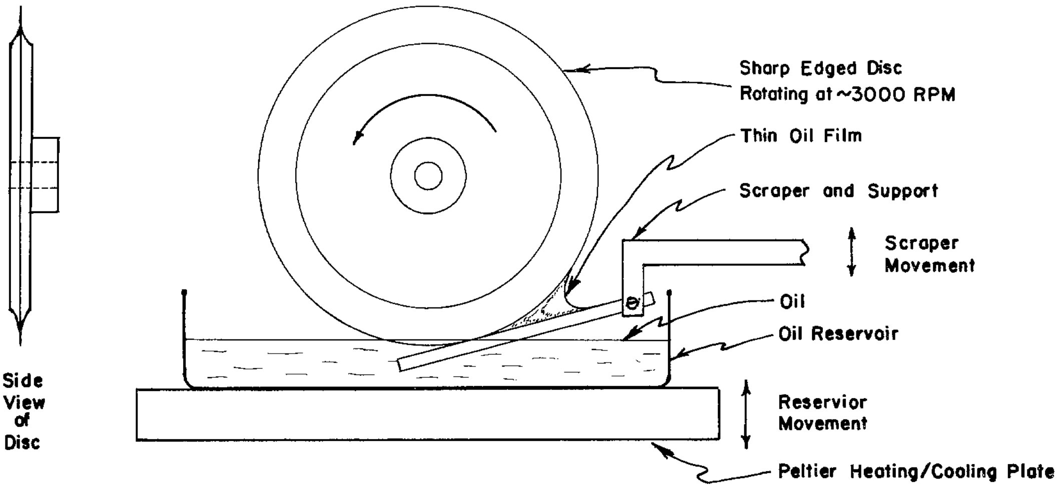

Fig. 1. Schematic diagram of apparatus for producing thin films. Rotating disc picks up oil from reservoir; shear between moving disc and scraper (or statatic reservoir) produces a thin triangular oil film. Scraper and reservoir are adjustable in height as indicated. A side view of the disc is also shown.

a range from zero to a few millimeters. A typical immersion depth for good film production was 0.2 mm. A thin aluminum "scraper" about 1.5 mm thick is mounted on a separate positioning mechanism so that it is raised to be tangent to and almost touching the rotating disc at a point within the oil-disc contact region. The function of the scraper is to increase the gradient of the shear forces in the liquid, to reduce the amount of oil picked at a given immersion depth, and to support the lower edge of the film which is generated and thereby increase film stability. Films could be produced with or without the scraper, but thinner and more stable films were obtained through its use. The presence of the scraper made the apparatus very sensitive to vibrations and to nonuniformities in the disc, and so a great deal of effort was devoted to making the disc as balanced and uniform as possible and to reducing vibration to an absolute minimum.

The oil reservoir was mounted on a Peltier cooling plate which permitted the temperature of the oil to be raised or lowered with respect to the ambient temperature by adjusting the electric current through the plate. Since the viscosity of the oils investigated is a fairly strong function of temperature, this permitted a determination of the optimum viscosity for good film production.

3. Film production

Successful film production was observed with three oils: DC-704 [2] diffusion pump oil (used in the early part of the investigation), Dow–Corning 550 Fluid [3], and Dow–Corning 200-50 Fluid [3]. The DC-704 fluid has a less than optimum viscosity at room temperature and required cooling to reach the 50 cS range which was found to be optimum. Further, it had a surface tension which was too high for optimum film production. The 550 fluid had a relatively high viscosity (115 cS) at room temperature and required heating. Its lower surface tension (about 24.5 dyn/cm) permitted better films than those observed with the DC-704 fluid. The 200-50 fluid had a viscosity (50 cS) chosen, on the basis of experience with DC-704, to be near-optimum, and it also had the lowest surface tension of the oils tested. It proved to be the best in producing thin stable films. Temperature variations of the 200-50 fluid produced no observable improvement in the quality of the films, confirming that its room temperature viscosity of 50 cS was indeed optimum.

Most of our investigations were conducted in air, but even better results were obtained when the apparatus was placed in vacuum. The turbulence produced by the entrained air apparently degrades film stability, for the stability of films is notably improved in the vacuum environment.

We observed the production of three distinct types of films with this apparatus. If the wheel was immersed very deep in the oil and no scraper was used a thick film of large area ($\approx$200 cm^2) could be produced when the wheel was rotated at rather low velocities. We will call these Type 1 films. These films exhibited no optical interference fringes, and appeared to have thicknesses of 0.1 mm or more. Type 2 films are the type shown in fig. 1. They showed strong interference colors, and could be produced with thicknesses down to about 10 μm/cm^2. Typically, these films had areas of about 10 cm^2. There was also another type of film which we will designate as Type 3 which was observed to flicker in and out of existence, showing a very large area comparable to that of the type 1 films. We were not able to produce this type of film in a stable form, but it was produced when the wheel was immersed somewhat more deeply than was the case for type 2 films and when the wheel was rotated somewhat more rapidly. Photographs of films of types 1 and 2 can be found in ref. 6.

Type 2 films, as described above, have been observed to remain essentially constant in area, position, and thickness for time periods on the order of 30 min. However, the present apparatus has not been optimized for long-term stability. In particular, the transport of oil from the reservoir to the "hood" surrounding the disc causes the oil level in the reservoir to change as a function of time, and for this reason a constant equilibrium oil depth has proved difficult to achieve. Further, external vibrations can greatly degrade the stability of the films produced.

4. Vacuum considerations

The Dow–Corning 200-50 fluid used in the work described here would not be suitable for accelerator applications because of its relatively high vapor pressure. In the vacuum tests described above, the apparatus when loaded with 200-50 fluid could not be pumped to a pressure below 10^{-4} Torr. Further, the vacuum tests terminated with the serious degradation of the diffusion pump of the vacuum chamber, and the latter required thorough cleaning to restore its performance. An attempt to "strip" the 200-50 fluid to a lower vapor pressure by pumping on the fluid for a period of several weeks while it was heated resulted in an increase in its viscosity but did not notably improve its vacuum performance. Therefore, it would appear that before the technique can be used for accelerator applications a low vapor pressure substitute for the 200-50 fluid must be found. We note, however, that the DC-704 diffusion pump oil, which has a very low vapor pressure and good vacuum characteristics, was used to produce somewhat thicker films. This can be taken as an indication that there is no fundamental conflict between the characteristics required for use in a high vacuum and the fluid properties needed for good film production.

5. Conclusion

The stripping of heavy ions plays an important role in virtually all heavy ion accelerators and represents the limiting factor in many designs. At present two types of stripping media are in common use: gas strippers which can handle large beams but degrade the local vacuum and yield stripped ions with rather low average charge, and solid foil strippers which can strip ions to rather high average charge but are destroyed in a relatively short time by intense beam and develop thickness variations due to differential radiation damage. Attempts to develop alternate media such as powder strippers [4] and droplet strippers [5] have proved unsuccessful.

The type 2 films produced by the technique described in the present paper may have important potential for providing an alternative stripping medium which offers interesting advantages over gas and solid foil strippers. Because the liquid film is being continuously renewed, it should be able to withstand large beam currents without destruction. It is not known whether a liquid will strip heavy ions to an average charge state as high as is the case with solid foils. Models accounting for the differences between solids and gasses in their stripping performance imply that such differences arise from differences in the time between collisions in the two media. Such times should be similar in liquids and solids, implying that these media should have similar stripping properties.

A possible problem with liquid stripping foils is the effect of ion bombardment on the oil of the film. Molecular decomposition, cracking, and perhaps polymerization may result, but the degree to which such effects would degrade the performance of a liquid stripper over a period of time is difficult to assess. Such processes may have serious negative effects on the oil viscosity, surface tension, or vapor pressure, and may require continual filtering, reprocessing, or renewal of the oil.

Another possible nuclear physics application of the technique might be the production of relatively thin high-current targets. The oils used in the present work are variants of poly-dimenthyl-solixine which has the chemical representation $(SiOC_2H_6)_n$. This type of oil would therefore be useable as a target of silicon, oxygen, carbon, or hydrogen. In neutron production applications, for example, it might be possible to use deuterated (or tritiated) oil. For other target materials, particularly solids, the oil might be used as a carrier for a colloidal suspension of a finely powdered target material which has been mixed with the oil. It would require some investigation to determine whether such a mixture would retain the necessary fluid properties needed for good film production and if the target material could be maintained in sufficient concentration to make the technique useful.

We would like to mention in closing that these investigations are no longer being actively pursued at our laboratory, but a group at the Lawrence Berkeley Laboratory SuperHILAC, under the direction of Dr. B.T. Leemann, is currently investigating the technique. They have been able to produce optically thin films as described above and have had some success in producing more stable films of type 3.

References

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