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THIN FOIL FABRICATION

Robert E. Reinovsky
Frank Kindel

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December 1979

Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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AFWL-TR-79-81

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (10) AFWL-TR-79-81	2. GOVT ACCESSION NO. AD-A106 483	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) THIN FOIL FABRICATION.		5. TYPE OF REPORT & PERIOD COVERED (9) Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Robert E. Reinovsky Captain, USAF Frank Kindel		8. CONTRACT OR GRANT NUMBER(s) (16) 8809 (17) 17
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Weapons Laboratory (NTYP) Kirtland Air Force Base, NM 87117		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62601F/88091709
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Weapons Laboratory (SUR) Kirtland Air Force Base, NM 87117		12. REPORT DATE (11) December 1979
		13. NUMBER OF PAGES 14 (12) 15
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION ST ENT (of abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY TES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Plasma Implosion Thin Foil Thin Cylinders Seamless Films		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method has been developed to produce seamless, freestanding plastic cylinders with dimensions up to 18 cm in diameter, 4 cm in height and with mass density from 15 µg/cm to 300 µg/cm (approximately 0.15 to 3 microns thick). The polyvinyl formal resin may be subsequently coated with a variety of materials by vapor deposition. The method employs standard thin foil fabrication techniques modified for use in cylindrical geometry and results in uniform reproducible cylinders.

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A

THIN FOIL FABRICATION

INTRODUCTION

The electromagnetic implosion of a hollow cylindrical plasma shell initially formed from a thin, solid, metal or plastic cylinder is a promising approach to the formation of a hot plasma of near solid density, for use as a radiation source (ref. 1). The success of this technique hinges on coupling energy initially stored in a large electrical store (such as a large capacitor bank) into kinetic energy of the moving plasma cylinder and then into internal energy of the pinched plasma column. Circuit model calculations for a plasma shell formed from a foil initially 7 cm in radius by 2 cm in height predict excellent efficiency (25-40%) of coupling energy from a 1 μsec, 1.1 MJ capacitive electrical store into kinetic energy of the imploding plasma - energy which subsequently heats the pinched plasma producing high radiation temperatures. The calculations assume a foil which is azimuthally and axially uniform for all times, but which may be composed of a variety of materials arranged radially in layers. The total mass density of the foil ranges from 10 to a few hundred micrograms/cm^2 with maximum coupling efficiency predicted for a mass density of 500 μgr/cm^2. Previously, the foils used in experiments were fabricated either commercially or in the laboratory in flat sheets which were wrapped around support rings which formed the electrodes of the discharge as shown in Fig. 1. This technique results in one or more seams where

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1. Baker, W.L., et al, "Electromagnetic Implosion Generation of Pulse High Energy Density Plasma," Journal of Applied Physics 49, pp 4694-4706.

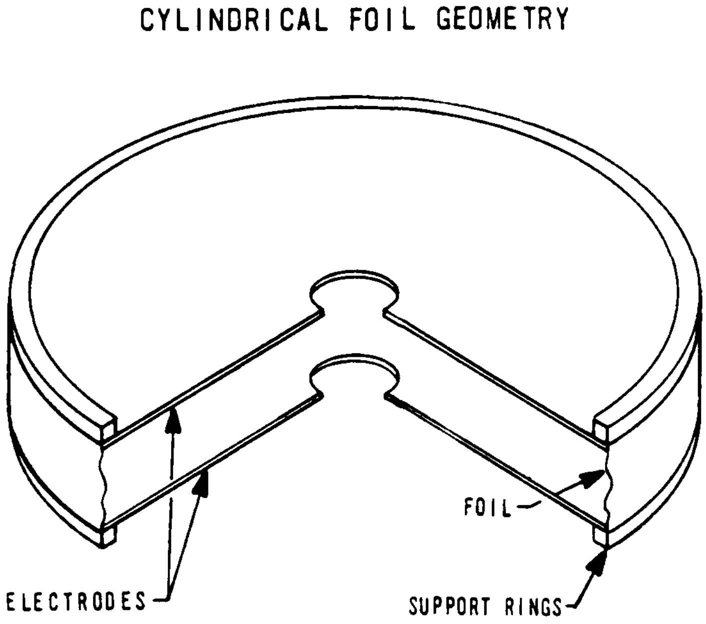

Figure 1. Cylindrical foil, support rings and electrode assembly.

the mass density either drops to zero (a butt seam) or doubles (a lapped seam) for some distance along the circumference. One anticipated effect of the local reductions or increases in sheath mass density is an attendant reduction or increase in the time required for this local region to arrive at the center as compared with the rest of the (assumed uniform) foil, and an attendant increase in the radiation pulse width. Evidence has also been observed indicating that the foil regions around the seams undergo the solid to plasma transition (initiation) in different ways depending on the structure of the seam. This observation underlines the concern that the seam region may further depart in behavior from that demonstrated by the rest of the foil.

This report examines a technique for fabrication of seamless cylindrical plastic films suitable for use in electromagnetic implosion experiments. The work described here utilized common techniques for the fabrication of very thin polyvinyl-formal films and details only those aspects of the process unique to the fabrication and mounting of cylindrical films.

FABRICATION TECHNIQUES

The seamless plastic film cylinders are fabricated using techniques similar to those described by R.J. Grader, et al, (ref. 2) and all precautions pointed out in that paper apply to the thin seamless cylinder fabrication. The polyvinyl-formal resin ($C_5H_7O_2$) is dissolved in a solvent mixture consisting of 20% (by volume) methylbenzoate, 48% toluene, and 32% ethanol as suggested by Grader. The film is formed by submerging a suitably sized cylindrical form into the solution and withdrawing it at a controlled, uniform speed. The solution is contained in a stainless steel tank and the form is suspended from a variable speed motor driven winch assembly (suitably vibration isolated from the tank) to permit accurate control of withdrawal speed. The solid film is formed on the surfaces of the cylinder as the solvent evaporates from the wet layer leaving the resin behind. For implosion loads only the film on the inside surface is subsequently used. The film on the outside is weighed and used as a guide for monitoring mass density.

The flat films described by Grader were made on float glass which was found to be the least expensive source of a suitable, smooth, impervious surface for film casting. Initial cylindrical films were cast on glass tubes with good results. But this technique limited

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2. Grader, R.J., et al, "Preparation of Large Plastic Film for Proportional Counter Windows," Rev Sci Instrum, 42, pp 465-467.

the radii of foil cylinders that could be fabricated to those of commercially available glass stock. Alternatively, expensive custom made glass tubes were required. To relieve this constraint, metal forms which could be machined to any desired radius and height and polished to a mirror surface were fabricated and tested. Aluminum cylinders performed well and were inexpensive to machine and polish, but, as expected, were subject to scratching and demonstrated very short useful life. In addition, aluminum showed a characteristic tendency to pit as a result of frequent cleaning and submersion in solvents. Stainless steel forms were adopted as the best compromise between ease and economy of fabrication and reasonable lifetime. The relatively large forms (up to 18 cm diameter and 10 cm high) were machined to allow approximately 0.020" diametrical clearance between the form and the mount to which the film was to be subsequently transferred, and polished to a mirror surface with graded abrasives, newspaper and machinists rouge. The forms were initially cleaned using acetone in an ultrasonic agitator to remove residual polishing materials. Careful soap and water washes were adequate between subsequent uses. Failure to thoroughly remove rouge or abrasive residue prior to initial use of the form resulted in complete failure of the film transfer process. The final preparation for casting the film was accomplished by dipping the form into a solution of a few grams of laboratory detergent in a liter of water and drying the form in a dust free, circulating air dryer such as a photo print dryer. The very thin soap film acts as a release agent in the transfer process, and was found to subsequently wash away easily.

The prepared forms were dipped into the resin solution using a motor driven winch similar to that described by Grader. Significant differences were noted between the mass density produced on flat glass plates and on cylindrical metal forms so new mass density vs speed calibrations were required. Further complications which change the foil mass for a given casting speed were observed, including: the temperature of the solution which affects its viscosity, the temperature of the form which affects the solvent evaporation rate, and the age of the solution which affects the relative solvent concentrations, resin settling, and impurity buildup. The time the form is allowed to soak in the solution between pullings was critical when multiple dippings were used to build up a required mass density. This effect is attributed to the redissolving of the film already cast. The difficulties were overcome by rigorously contolling solution temperature to within 1°F, by circulating and filtering the solution (also suggested by Grader) and by insuring that in multiple dip processes, the "soaking time" was carefully controlled. After casting, the films were thoroughly dried to remove residual solvent in a dust free circulating air cabinet prior to transfer to the support structure.

TRANSFER PROCESS

The casting of Formvar film on cylindrical forms represents a simple extension of standard plastic film fabrication techniques. For use in electromagnetic implosion experiments, it is necessary to transfer the film freestanding and intact to a support structure which consists of electrodes mounted in two parallel rings as shown in Figure 2. The transfer process consists of first inserting the electrode structure, with its removable spacing jig, carefully into the slightly oversize form. The film is loosened from the form and one edge transferred to the electrode. The electrode is then carefully removed in such a way as to pull the film out of the form.

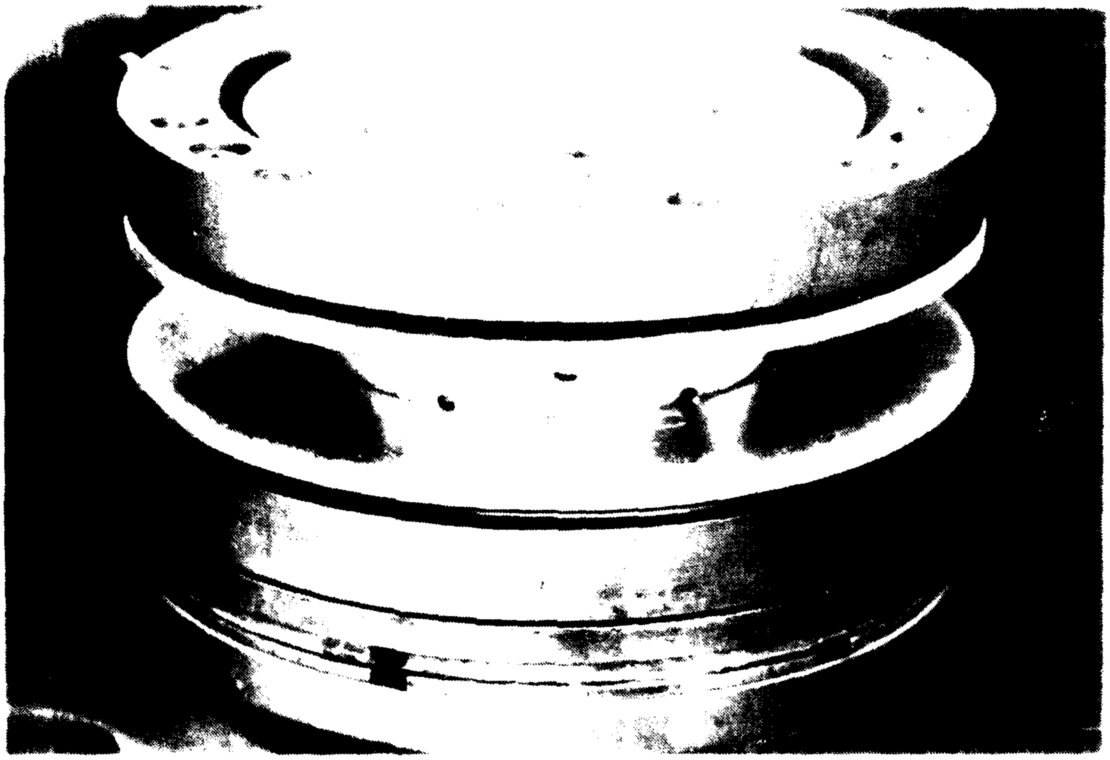

Figure 2. Full electrode assembly.

The apparatus shown in Figure 3 was designed to facilitate this transfer. The thoroughly dried form is placed in position on the jig and clamped in place. The precision column drive is raised and the electrode structure is mounted to the top of the column. The column is lowered,

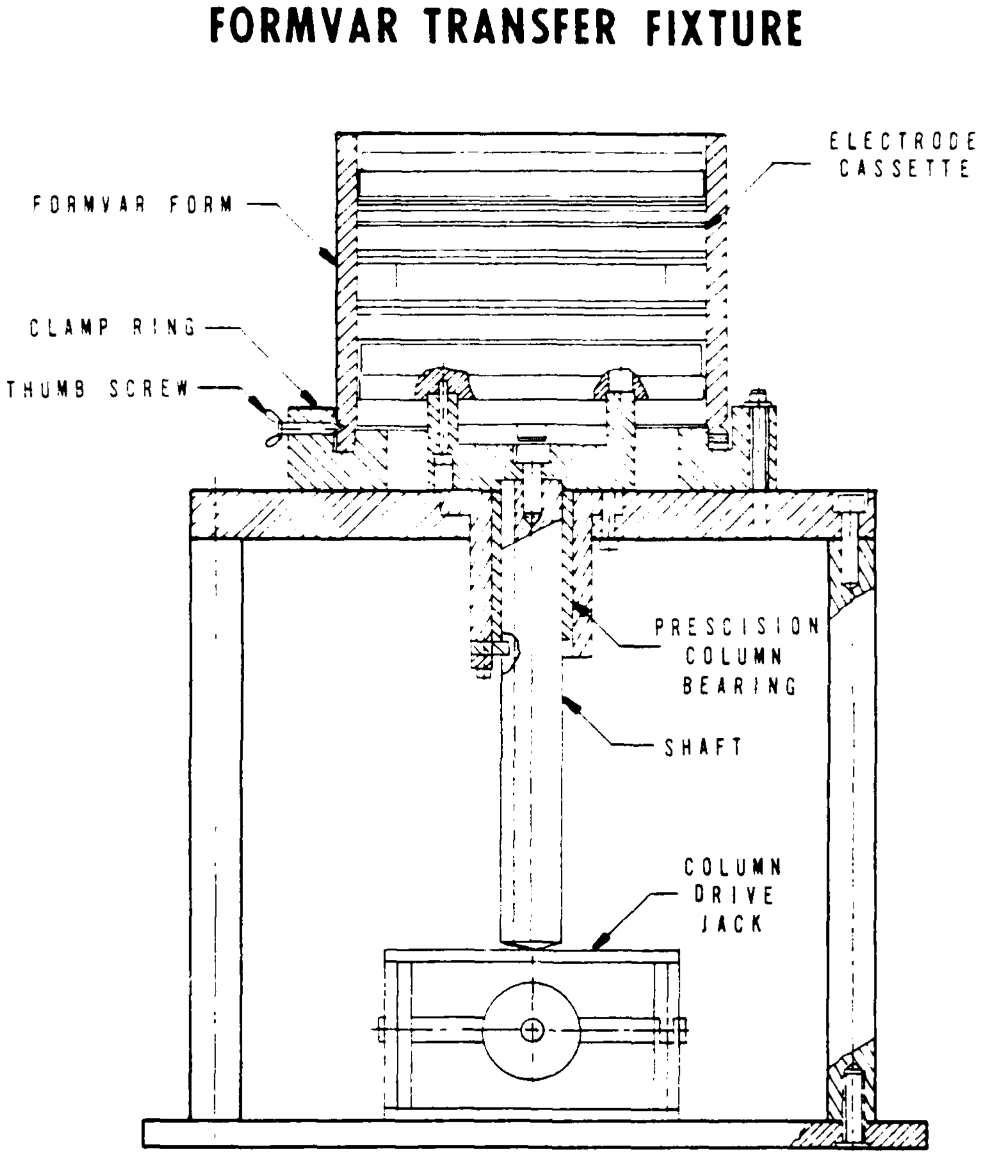
FORMVAR TRANSFER FIXTURE
ELECTRODE CASSETTE
FORMVAR FORM
CLAMP RING
THUMB SCREW
PRESCISION COLUMN BEARING
SHAFT
COLUMN DRIVE JACK

Figure 3. Transfer jig.

lowering the electrode precisely into the center of the form without scraping the film on the inner surface. Water is flowed into the tank and allowed to stand for about 15 minutes in order to dissolve the thin soap release layer, thereby freeing the film from the form. The water is [illegible] the [illegible] [illegible] [illegible] [illegible] completely [illegible] [illegible] attach [illegible] electrodes out of the form, [illegible] can then be inspected for imperfections. [illegible] readily [illegible] carefully [illegible] with water. Figure 4 shows [illegible] the electrode.

[illegible] 4. Seamless foil mounted [illegible].

RESULTS

Using this process, foils with mass density as low as 15 µg/cm have been transferred to electrodes 18 cm in diameter with 2 cm of unsupported height. Foils as heavy as 250 µg/cm have been fabricated and are easily transferred. Uniformity and reproducibility are readily judged by visually observing the color of reflected light. Mass density produced at a given withdrawal speed is dependent on temperature and solution concentration and, hence, requires constant surveillance. Table I is provided for reference, but under conditions of moderate environmental changes, mass density change by a factor of 2 have been encountered.

TABLE 1. THICKNESS VS SPEED

Specific gravity = 0.905
Temperature = 22°C

WITHDRAWAL SPEED cm/min	THICKNESS µgr/cm^2
5	25
10	35
15	44
20	51
25	56
30	59
35	61
40	63

Variations in mass density were evaluated for a variety of environmental conditions and film casting techniques using flat plate samples. The variation in the average mass of samples cast in nominally the same manner, but cast minutes or hours apart was about 2½% while the average deviation in mass from one part of a given film to another was less than 1%. This variation is within the accuracy of the weighing process. Thus, while film-to-film reproducibility is within a few percent, film uniformity is much better. The films cast on flat plates are typically 30% heavier than films cast simultaneously on glass tubes, while films cast on glass tubes and on stainless cylinders are within the generally observed 2½% sample to sample variation. Raising the solution temperatures by approximately 5°C (from 22.2°C to 27.5°C) resulted in a 21% decrease in the film mass density. Lowering the temperature by about 5°C (from 22.2°C to 17°C) resulted in a 7% increase in the film density. Thus, a temperature controlled (±1°C) tank system was used to contain the solution.

The rate at which the solvent evaporates constitutes an upper limit on the thickness of the film that can be cast in one operation. When excessively heavy films are attempted, the solution "runs" down the form before drying, thereby making the bottom of the film thicker than the top. To produce heavier films requires either a more viscous (or colder) solution or the use of multiple dippings. In general, the subsequent dippings do not add multiples of the initial weight. In one sample, subsequent dips added about 20% to the weight of the previous film when no soaking time was allowed, while adding only 5% per dip when the previous sample was soaked for a long time compared to the withdrawal time.

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