values of the radius ratio[6] λ and for Poisson's ratio equal to 0.3.

Comparison of the iterative solutions with the more accurate power-series solution demonstrates the rapid convergence of the approximate solutions. Indeed, the agreement between the stresses and deflection predicted by the second approximation is within 1% of the results given by the series solution. Thus, the second iteration is in essence an approximate closed form representation of the exact series solution.

References

[1] Goldberg, M. A., "A modified large deflection theory of plates," *Proceedings of the Fourth U. S. National Congress of Applied Mechanics* (American Society of Mechanical Engineers, New York, 1962), pp. 611–618.

[2] Goldberg, M. A. and Pifko, A. B., "Large deflection analysis of uniformly loaded annular membranes," AIAA J. **1**, 2111–2115 (1963).

[3] Way, S., "Bending of circular plates with large deflections," Trans. Am. Soc. Mech. Engrs. **56**, 627–636 (1934).

[4] Keller, H. B. and Reiss, E. L., "Non-linear bending of circular plates," Comm. Pure Appl. Math. IX, 633–659 (1956).

[5] Hencky, H., "Über den Spannungzustand in Kreisrunden Platten mit verschwindender Biegungssteifigkeit," Z. Math. Phys. **63**, 311–317 (1915).

[6] Pifko, A. B. and Goldberg, M. A., "Comments on an iteration procedure for the large deflection analysis of initially flat membranes," Grumman Research Dept., Publication RM-232 (June 1964).

Surface Effects in a Pulsed Plasma Accelerator

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Introduction

EXPERIMENTAL studies of several pulsed plasma accelerators on a thrust stand showed that a significant dropoff in impulse as well as changes in the plasma front velocity and plasma sheet structure could occur during a test that involves many thousands of consecutive discharges. The dropoff in impulse has been observed for varying electrode materials, insulator materials, energy per discharge levels, propellants, vacuum chambers and background pressures, polarity of the electrode assembly, initial surface preparation, and with pinch-type plasma accelerators as well as coaxial configurations (see Fig. 1).

The mechanisms responsible for observed changes that occur during continuous operation of the accelerator have been found to be related to the following surface effects: 1) outgassing of absorbed and adsorbed gas; 2) mass removal from the electrodes and insulator assembly due to the various erosion effects as well as the contribution of mass from loose particles, organic monolayers, and foreign matter such as trapped moisture, dust, etc.; 3) resistive changes due to thermal, chemical, and metallurgical changes at the electrode surface and deposition of ablated insulator material; and 4) viscous boundary-layer and current boundary-layer effects.

This note will present and discuss the techniques and some of the results of the experimental studies that have been carried out for evaluating items 1 and 2.

Studies Pertaining to Outgassing

Experiments carried out with the same initial electrode and insulator surface condition indicated that the magnitude of

Received March 23, 1964.

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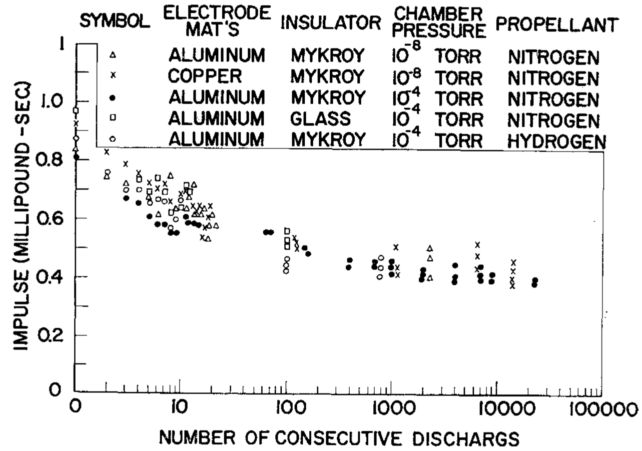

Fig. 1 Some representative impulse data.

the impulse of the first few discharges of a test series could be changed appreciably by methods that affect the level of outgassing prior to data taking. For example, it was found that the impulse measured after a device had been operated several hundred consecutive discharges could be raised roughly 10 to 40% by venting the vacuum chamber to atmospheric pressure for periods less than 1 hr. Similarly, it was found that heating the accelerator in the vacuum environment to a temperature of about 640°R prior to operation would lower the initial impulse by roughly 18%. Pressurizing the interelectrode spacing at 70 psi for a period of 16 hr prior to evacuation and operation raises the initial impulse levels by roughly 10%.

A device was installed on the thrust stand which permitted data to be obtained on the quantity of gas driven off by outgassing during pump-down and during operation of the accelerator and which also permitted the electrode-insulator assembly to be isolated from oil vapor contamination during the pump-down cycle. This device was a remotely controlled capping mechanism that sealed off the interelectrode spacing from the vacuum chamber. Figure 2 shows the accelerator on a thrust stand with the capping mechanism in the withdrawn position, thus permitting accelerator operation. Figure 3 shows the capping mechanism sealing the interelectrode assembly from the vacuum chamber. This technique permitted evaluation of only that gas which is evolved from the surfaces in contact with the electrical discharge. Unlike weighing procedures, the accelerator is not handled, and the measurement could be carried out in the vacuum environment at any particular moment of interest.

To determine the quantity of gas desorbed during pump-down, the interelectrode spacing is sealed by the remotely controlled cap immediately after the normal evacuation

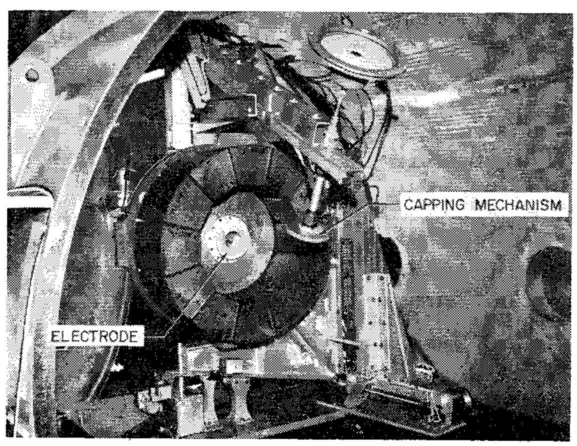

Fig. 2 Capping mechanism withdrawn.

cycle. The vacuum chamber is then vented to the atmosphere. The interelectrode spacing is then also very briefly vented to the atmosphere through a bellows-type valve. The outgassed interelectrode assembly subsequently absorbs some of the gas that is trapped in the interelectrode spacing, thereby lowering the pressure of the air trapped in the interelectrode spacing. Knowing this pressure drop and the total volume of the interelectrode assembly, one can determine the quantity of gas absorbed. Carrying out the same procedure after any desired number of discharges of the accelerator permits one to determine the additional amount of gas removed because of accelerator operation. Figure 4 shows the quantity of gas absorbed as a function of time after pump-down and after operating the accelerator for 50 and 3600 consecutive discharges. The amount of gas absorbed after accelerator operation is the difference between the pump-down curve and the curve obtained with the accelerator in operation. For the particular device tested, this amount could exceed 10^{-6} lb within a relatively short period of time. This is roughly an order of magnitude larger than the quantity of gas injected per discharge. From Fig. 4, one can see that an outgassed electrode can absorb air for as long as 80 hr. This amount usually depended on how "deeply" the assembly was outgassed and on the length of time the assembly was allowed to absorb air at atmospheric pressure.

This capping technique also permitted a check to be made on the effect of oil-vapor contamination. Using the water-break test,[1] it has been established that oil-vapor contamination exists. Since the water-break test is sensitive to a monolayer of organic contaminants, oil-vapor contamination to within a monolayer could not be ruled out. Since the impulse and its variation were substantially the same, independent of whether the interelectrode spacing was exposed to the vacuum chamber or sealed from it by the cap during pump-down, it can be deduced that oil-vapor contamination cannot account for the observed impulse dropoff. The available evidence points more strongly toward the effect of outgassing.

Erosion Studies

Since measurements have shown that large quantities of gas are rapidly absorbed by an accelerator after its removal from a vacuum environment, it was concluded that erosion studies based upon weight measurements of the accelerator components could not be considered reliable. The technique developed to determine erosion involved the use of two sets of the insulator-electrode assembly. These were weighed differentially against each other before accelerator operation. One of these sets was installed on the accelerator, whereas the other set was placed in the vacuum chamber. After accelerator operation and a cooling period in the vacuum chamber, both sets were removed and again weighed against each other. It has been observed that the new weight differential

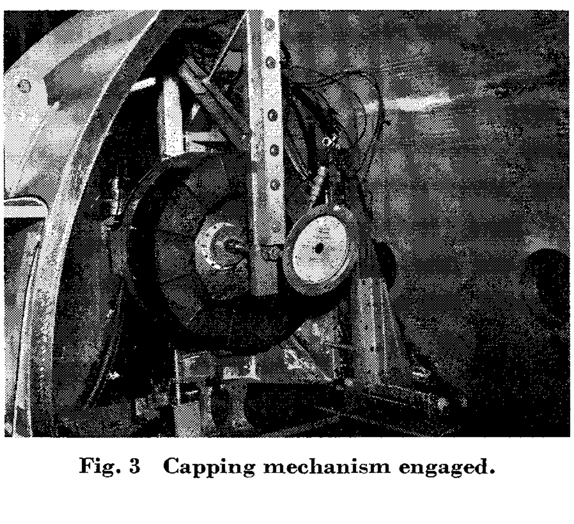

Fig. 3 Capping mechanism engaged.

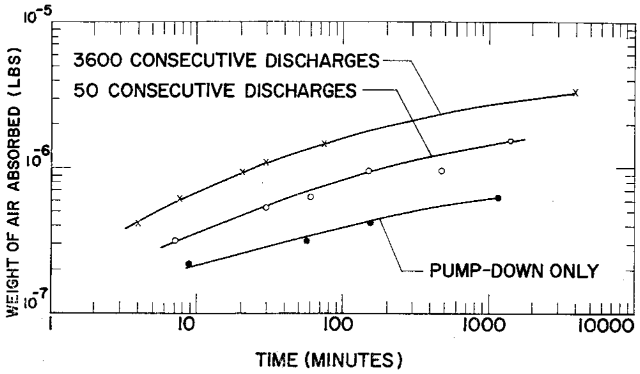

Fig. 4 Quantity of gas absorbed by electrode-insulator assembly.

remained constant within 0.0003 g for a period as long as 80 hr after removal from the vacuum chamber, even though both sets individually absorbed quantities of air several orders of magnitude larger than this constant weight difference. This constant difference in weight between the two assemblies was taken as the more reliable measure of the erosion.

A typical test carried out over 25,300 consecutive discharges provided the following data. The anode ablated the most. Its weight change was 0.022%, or the average total depth of erosion was 13.7×10^{-5} cm. The mykroy insulator was intermediate in ablation. Its weight change was 0.004%, or the average total depth of erosion was 5.65×10^{-5} cm. The inner electrode, the cathode, eroded the least. It underwent a 0.001% weight change. Its average depth of erosion was 1.13×10^{-5} cm. The average mass eroded per discharge was found to be of the order of 3.77×10^{-9} lb. This is roughly two orders of magnitude less than the total amount of neutral gas injected per discharge.

The contribution of surface effects to the discharge mechanism during prolonged periods of operation can appreciably affect the long-time performance of a pulsed plasma accelerator.

Reference

[1] Feder, D. O. and Koontz, D. E., "Detection removal and control of organic contaminants in the production of electron devices," *Symposium on Cleaning of Electronic Devices, Components and Materials*, American Society for Testing Materials Special Tech. Publ. 246, pp. 40–65 (1959).

A Flutter Design Parameter to Supplement the Regier Number

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Introduction

THOSE in the field of aeroelasticity realize the complexity of determining a solution for flutter and dynamic response. They have long strived for approximations and trends of the solution in terms of design parameters for use in design evaluation. One parameter that has been indicative of the trend of the flutter solution is the Regier number; this number is a nondimensionalized measure of the torsional

Received March 11, 1964. The efforts reported in this Technical Note were sponsored by the Air Force Office of Scientific Research Office of Aerospace Research under Contract AF 49(638)-1015.

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