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MATERIAL END-PLUGGING FOR THE SCYLLA IV-P LINEAR THETA PINCH

By

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Summary

Scylla IV-P is a 5-m linear theta pinch at the Los Alamos Scientific Laboratory primarily used to study end effects of linear theta-pinch plasmas. One method that may be used to reduce plasma end loss from linear theta pinches is to insert material end plugs. Two different assemblies that insert end plugs have been fabricated and installed on Scylla IV-P. The presence of the material end plugs have been found to increase the plasma confinement time by 20% to 30%; the plasma stability is increased (the m=1 wobble is suppressed), and the neutron production is not degraded. The design of the end plug insertion mechanisms are described in some detail and information is presented on end plug erosion. Material eroded from the end plug must be either removed by the vacuum system or it plates out on the vacuum system surfaces. A condensed gas end plug has been proposed to eliminate problems associated with ablated solid material; a third end plug assembly for this is being designed which inserts a cryostat coated with a condensed gas. A prototype of this cryogenically cooled end plug (cryo-plug) has been fabricated and tested. These data are presented and the insertion mechanism described.

Introduction

A linear Θ-pinch in an open-ended configuration has a confinement time limited by loss of plasma and energy out the open ends. One technique of reducing this plasma loss is to simply insert material plugs into the ends of the linear Θ-pinch. Malone and Morse[1] have analyzed the theoretical effect on plasma parameters by the use of end plugs made of Al, C, LiD, and Solid D_2. Plasma impinging on the end plug face ablates the plug material and drives a compressive wave back down the plasma column. Calculations indicate that ion temperatures will increase as the end plug Z is increased, but the end plug material must be relatively low Z to keep the plasma impurity radiation losses acceptable. The optimum plug material has yet to be determined.

End-Plug Experiments On Scylla IV-P

Scylla IV-P is a 5-m long, 11-cm-bore linear Θ-pinch at Los Alamos Scientific Laboratory (LASL). It is driven by a 2 MJ capacitor bank. Using a 1.1 MJ discharge, magnetic field rises to 50 kG in about 3.4μs. The discharge tube is initially pumped down to less than 10^{-6} Torr and then filled with 10-mTorr of D_2. Plasma parameters (without end plugs) are. $T_i \approx 1.5 - 2.0$ keV, $T_e \approx 400 - 600$ eV, $n \approx 1.6\times10^{16}$ cm^{-3}, and $\tau \approx 12.5\mu s$. The machine is fitted with 20-cm diam, 50-cm-long plasma expansion chambers on each end. The end plugs used were 5-cm-diam 3.8-cm-thick quartz discs which eliminate plasma flow out the ends of the Θ-pinch. Initial experimental results[2] are summarized in Figures 1 and 2. Streak photographs show that the plasma-column wobble instability is both suppressed and damped by the presence of end plugs, and that the plasma persists for 20-30% longer with end plugs. Figure 1 shows that the end plugs cause an increase in plasma energy density at the middle of the machine, and Figure 2 shows that the presence of end plugs have little effect on total neutron yield but do result in a more uniform neutron yield. Therefore, the use of end plugs does appear to increase the performance of a linear Θ-pinch.

End Plug Engineering

Several criteria must be met in the design of end plugs and their associated insertion mechanisms. The criteria for the Scylla IV-P end plugs and insertion mechanisms are:

1. The plug material must be low-Z (to reduce plasma radiation losses),

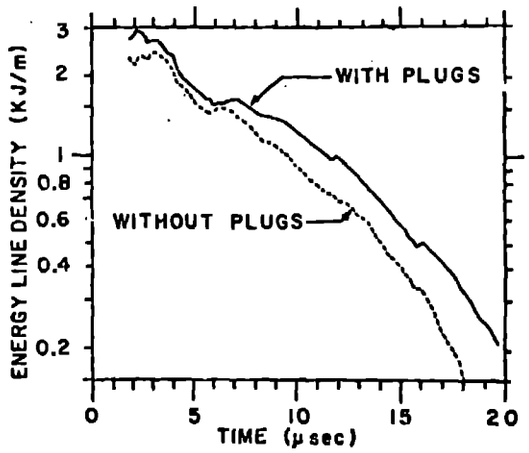

Figure 1. Plasma energy per unit length at the machine midplane. Data are averaged over 15 discharges.

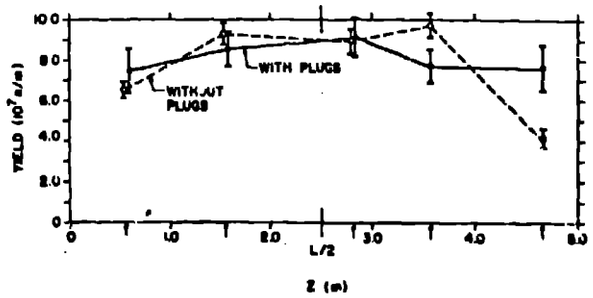

Figure 2. Total neutron yield along machine axis. Data are averaged over 23 discharges.

2. The plug material and holder must be nonmetallic (to prevent magnetic field perturbations),

3. The plug material which is eroded must not result in ablated metallic material (to prevent magnetic field perturbations on subsequent shots caused by metallic coats inside the machine),

4. The end plug must be accurately positioned in the pinch bore (for a reproducible experiment),

5. The end plug holder must be adequately rigid and shock resistant,

6. The end plug must be capable of being withdrawn for replacement without breaking machine vacuum,

7. The end plug must be easily replaceable,

8. The overall length of the insertion mechanism must be short enough to fit into the limited space available on the ends of Scylla IV-P, and

9. The cryogenically-cooled end plug (cryo-plug) must be able to condense various types of gases on its front surface.

Of these criteria number (2) and (8) became the most limiting on the engineering design. Quartz and boron nitride have been used as end plug materials in Scylla IV-P; the use of lithium deuteride and sapphire is contemplated for future experiments.

Figure 3 illustrates the approach used to meet these criteria. The valve is opened and an outer barrel holding the end plug is slid into place in the vacuum system. A differentially-pumped double Viton O-ring seal is the vacuum boundary on this outer barrel. A 1.27-cm-diam ball-nut and lead screw is used to move the end plug through the expansion chamber and into the discharge tube. The end plug is then positioned by moving the barrel. Figure 4 is a photograph of the first model of the end plug insertion mechanism which, while it worked, had certain drawbacks. To replace or closely examine the end plug, the entire assembly had to be removed from the machine. Assembly was difficult, and accessibility was limited. The differentially pumped sliding seal worked well, and the positioning mechanism worked adequately. The attachment of the quartz holder tube to the stainless steel tube moved by the lead screw produced many chipped quartz tubes because of the slide fit arrangement. Attachment of the end plug to the quartz holder by a slide fit was not sufficiently stable. Attention was paid to the minimization of virtual leaks, and the plug assembly could be pumped down by a roughing pump prior to opening the valve. Pumpdown has proved no problem, but the insertion mechanism was not compatible with a cryo-plug.

To rectify these drawbacks, the insertion mechanism and holder were redesigned as shown in Figure 5. Changes include: Macor (a Corning machinable glass-ceramic) inserts to allow the end plug to be screwed into the quartz holder; a Macor insert in the end of the quartz holder to allow it to be screwed into the stainless steel tube; the ball-nut/lead screw size was increased to 2.54-cm and a center hole was drilled to

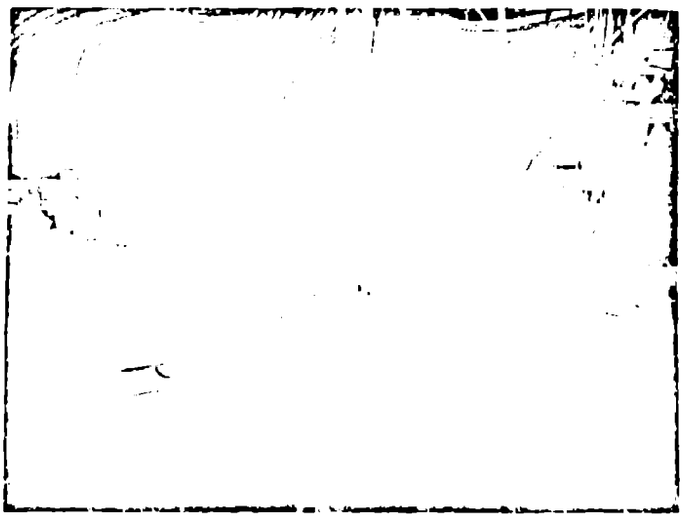

Figure 4. Model I end plug design.

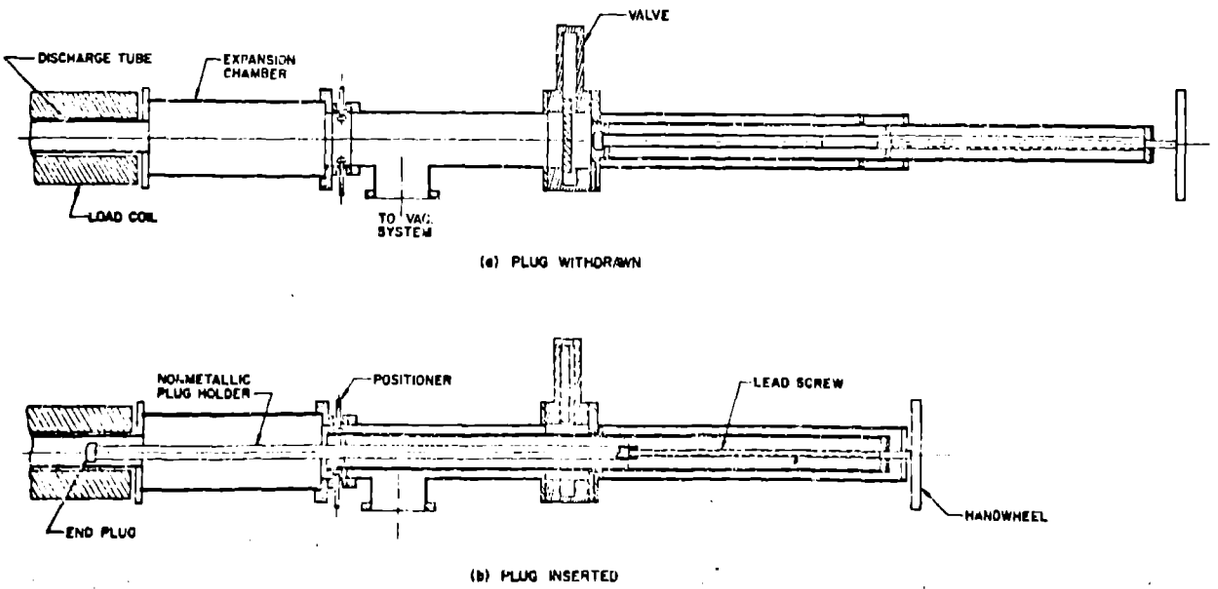

Figure 3. End plug insertion mechanism schematic.

allow probes to be brought up behind the face of the end plug; a chamber with a removable viewing window was added upstream of the valve to allow examination and quick replacement of end plugs; and nitrided steel bars instead of the large pipe were used for alignment of the barrel to improve accessibility. These improvements have greatly improved the ease of assembly and increased component accessibility.

It was initially feared that end plug erosion rates would be quite high based on energy deposition considerations. Erosion rates as high as 1-mm per shot were estimated; happily, actual end plug erosion rates have been quite low with some surface pitting noted. Figure 6 shows the erosion on the face of an end plug exposed to 29 plasma shots. The maximum erosion rate is less than 1 micron per shot; this indicates that erosion of end plug faces in present applications is not a problem, and the criteria of no metallic ablated material may be less restrictive than first thought.

Cryo-Plug Engineering

An insertion mechanism compatible with the cryo-plug is shown in Figure 7. It will utilize two telescoping mechanisms which allow the transfer of liquid helium following insertion of the plug. A schematic drawing of the cryogenic end plug is shown in Figure 8. The unit is constructed of quartz and pyrex; a full scale prototype unit has been designed, fabricated, and tested with various condensible gases. Since the condensed cryogen is not temperature shielded, it is exposed to 300°K thermal radiation. This heat load (estimated at 1 watt) and its resultant ΔT across the condensed cryogen and quartz substrate determine the maximum thickness of condensed solid at a maximum allowable vapor pressure of 10^{-6} Torr. Experiments were run with argon and neon using liquid helium at 4°K as the coolant. With argon, thicknesses in excess of 1.25 cm were routinely achieved; with neon, < 0.1 cm. Deuterium was not solidified; the ΔT across the quartz raised the condensing surface temperature to > 6°K which prevented meeting the vapor pressure design criteria of $\leq 10^{-6}$ Torr.

Figure 5. Model II end plug design.

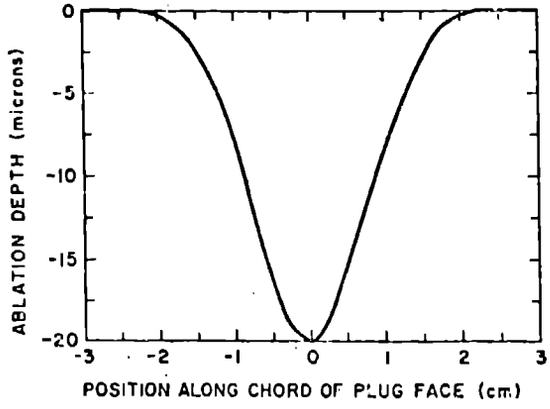

Figure 6. End plug face erosion profile. Plug exposed to 29 plasma discharges.

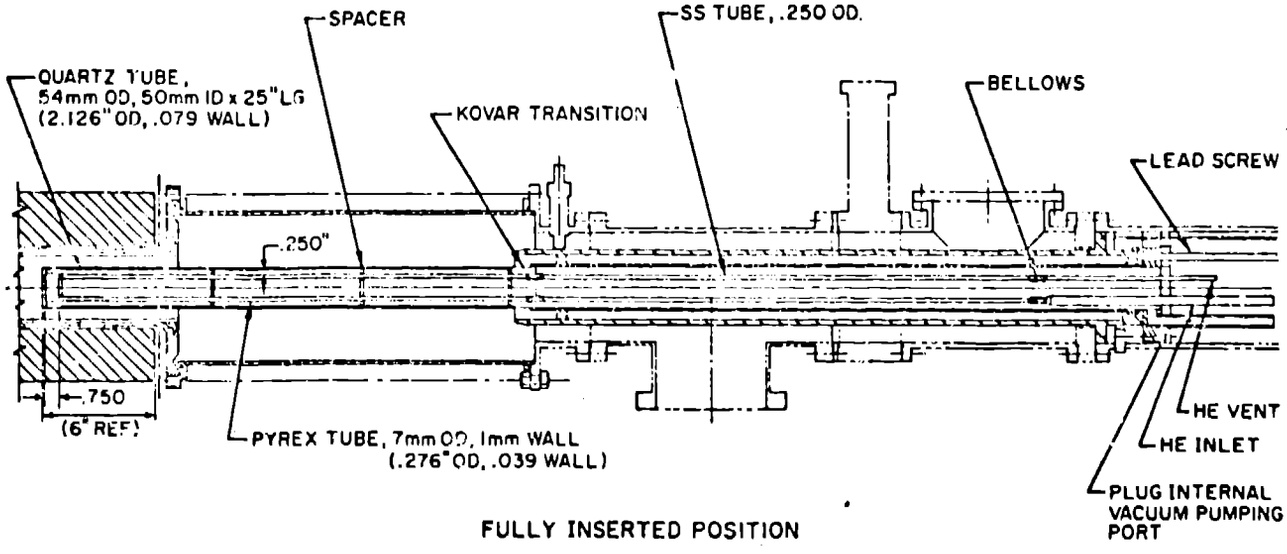

Figure 7. Cryo-plug insertion mechanism.

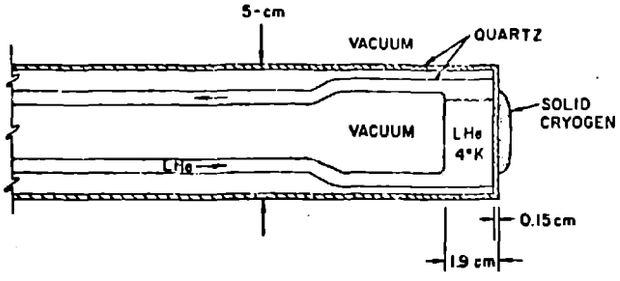

Figure 8. Cryo-plug schematic.

Conclusion

The use of end plugs on a linear θ-pinch has been successfully demonstrated from both physics and engineering standpoints. Low solid end plug erosion rates indicate that end plugs might be usable on a reactor. Since material and plugs are essentially passive, they lend themselves to combinations with other methods of end plugging.

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References

1. "Material End Plugging of Straight θ Pinch" by R. C. Malony and R. L. Morse, Phys. Rev. Lett. 39, 134 (1977).

2. "Solid-End Plug Experiment on a θ Pinch" by R. J. Commisso, C. A. Ekdahl, K. B. Fleese, K. F. McKenna, and W. E. Quinn, Phys. Rev. Lett. 39, 137 (1977).