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A DIVERTED PLASMA REVERSED FIELD PINCH.(U)
JUL 80 W M MANHEIMER
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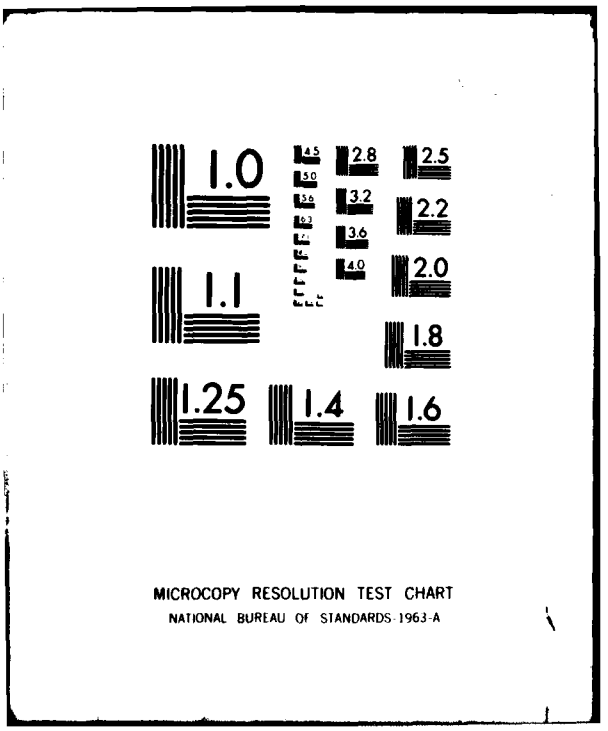
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This memo proposes a poloidal divertor as a method of reducing the strong plasma-wall interaction inherent in a reversed field pinch.

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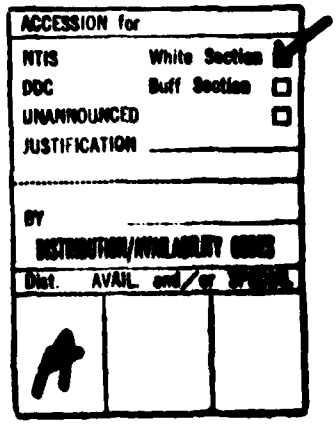

# A DIVERTED PLASMA REVERSED FIELD PINCH

This memo proposes the idea of using a poloidal divertor on a reverse field pinch, and is motivated by several recent experimental and theoretical works in this area. It has been shown that the natural, lowest energy state for a pinch to relax to is characterized by the force free state[1]

$$\underline{\nabla} \times \underline{B} = \mu \underline{B}. \tag{1}$$

For a cylindrically symmetric plasma, bounded by a perfect conductor of radius a, the solution is

$$B_z = B_o J_o(\mu r)$$

$$B_\theta = B_o J_1(\mu r). \tag{2}$$

The quantities $B_o$ and $\mu$ are determined by the axial flux, $\int\int d^2 r B_z(r)$, and the helicity $\int\int\int d^3 r \underline{B} \cdot \underline{A}$, which is equal to the stored Volt seconds times axial flux.

Clearly, for $\mu a > 2.54$, the first zero of $J_o$, or equivalently, $2I/aB_o c$ the pinch parameter greater than 1.27, the axial field reverses between the center and conducting wall. This field reversal has been observed on both Zeta[2] and $\eta\beta$II[3]. In fact in $\eta\beta$II stable operation was feasible only while this toroidal field reversal persisted. Because of magnetic diffusion, the reversal point gradually moves outward. Once the axial field null reaches the wall, $\eta\beta$II was observed to disrupt. Thus a reversed field configuration is not only the lowest energy state according to Taylor's theory, but this field reversal is apparently required for operation of such a device.

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Of course in the field reversed state strong axial and azimuthal currents exist right up to the plasma wall. Thus strong Ohmic heating of the plasma results here and the plasma struggles to achieve a high temperature right near the wall. Hence a strong wall-plasma interaction seems to be in the nature of a minimum energy state of a reversed field pinch. This is in sharp contrast to a tokamak, where the plasma current channels into the center of the discharge, away from the walls.

This strong wall plasma interaction in a reversed field pinch will, among other things, cool down the edge plasma, so this edge plasma is characterized by both strong heating and strong cooling. However the cooler the edge plasma, the shorter the resistive diffusion time in this region, and the more rapidly the field null is lost. Several schemes have been proposed to overcome this problem. In one,[4] negative toroidal flux is fed through a toroidal slit in the conducting chamber (that is a voltage is imposed across this slit). However the input energy flux through this slit, $\frac{cE_\theta B_z}{4\pi}$ is dissipated in the cool outer region near the field null, and does not really go to heating the plasma. This additional power input to maintain the field null not only decreases the energy confinement time, but it also increases the plasma wall interaction since more power is deposited in the outer region of the plasma.

Another scheme to circumvent this problem, proposed by Ohkawa,[5] is to impose the negative toroidal field in the outer region by using helical windings as in a stellarator. Then the plasma sets up the central current, but the field reversal is imposed externally and therefore cannot diffuse away. In addition a separatrix is imposed

by the helical perturbation so that the plasma has a natural boundary away from the wall. There are two potential problems with this scheme. First of all it is not clear how the plasma reacts to the helical windings. For instance if Eq. (1) is valid for the helically perturbed state, the plasma itself might try to set up strong currents in the region of the helical fields, but inside the separatrix. Another potential problem is that helically perturbed fields in toroidal geometry has no symmetry so the classical transport may be significantly enhanced, and flux surfaces can be more easily destroyed.

This memo then proposes an alternate scheme, which is simply to use a poloidal divertor inside the conducting shell. This might be simpler than setting up a separatrix with helical fields and also it does not destroy the toroidal symmetry. The divertor could be set up by simply imposing a vertical field so that flux surfaces in the poloidal plane are as shown in Fig. 1. It may be that the vacuum chamber would have to be re-designed so as to have a place for the diverted flux near the separatrix lines to go, above and below the plasma as is also indicated in Fig. 1. However if this could be done, the separatrix would serve as a vacuum boundary so that Eq. (1) would only apply inside this separatrix and there would be vacuum fields outside. Thus if the separatrix radius is denoted $r_s$, the toroidal and poloidal field might be as shown in Fig. (2).

It is not apparent what the density and temperature would be on the separatrix. However some information can be gleaned from reversed field theta pinch experiments.[6] There it has been shown that the

temperature is nearly uniform out to the separatrix and the density decays to perhaps 25% of its maximum value. Apparently there are large surface currents near the separatrix which partially confine the plasma. In any case, the reversed field theta pinch plasma does seem to be isolated, by the divertor, from the radial wall.

To summarize, this memo proposes that reversed field pinches could be run with a magnetic divertor. This divertor would allow the Taylor minimum energy state to exist right up to the plasma edge, but could substantially reduce the plasma wall interactions inherent in a state with high current density right at the plasma edge. The divertor could be set up with the vertical field coils which usually exist in toroidal configurations.

This work was supported by the U.S. Department of Energy.

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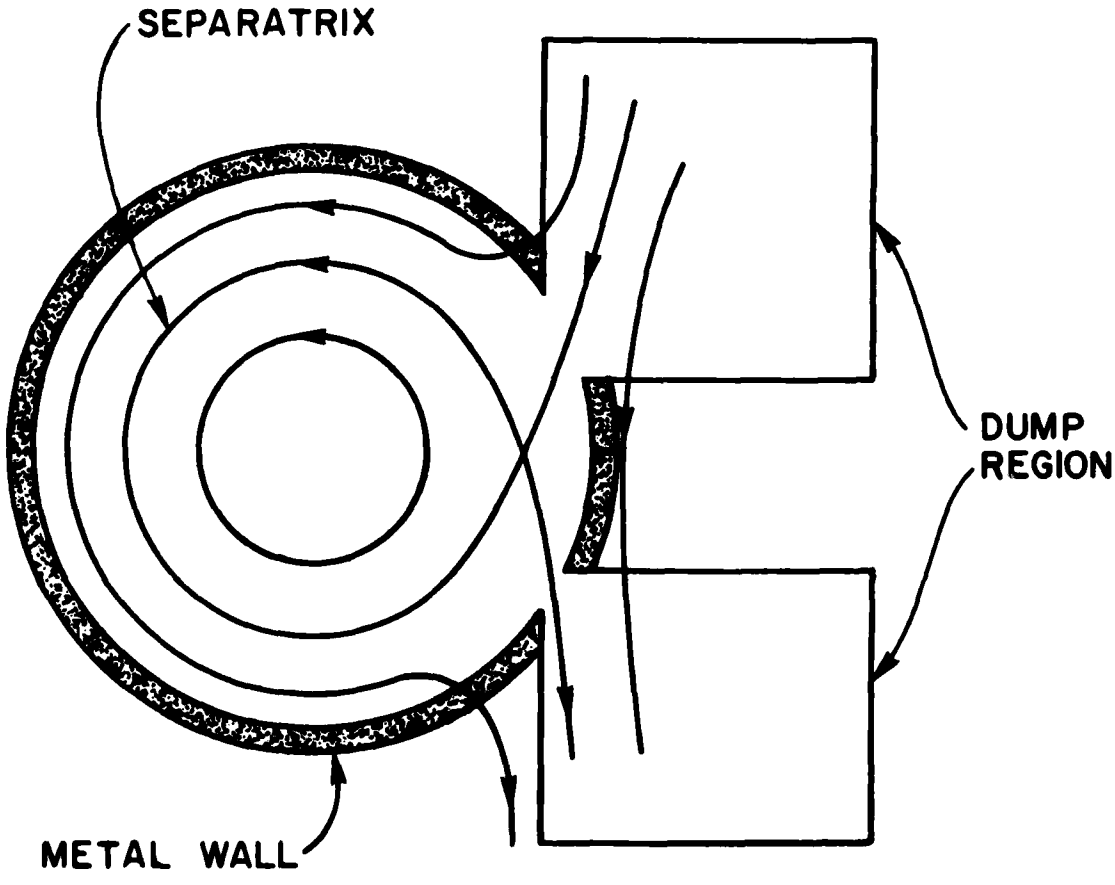


Fig. 1 - Schematic of a reversed field pinch plasma with a divertor

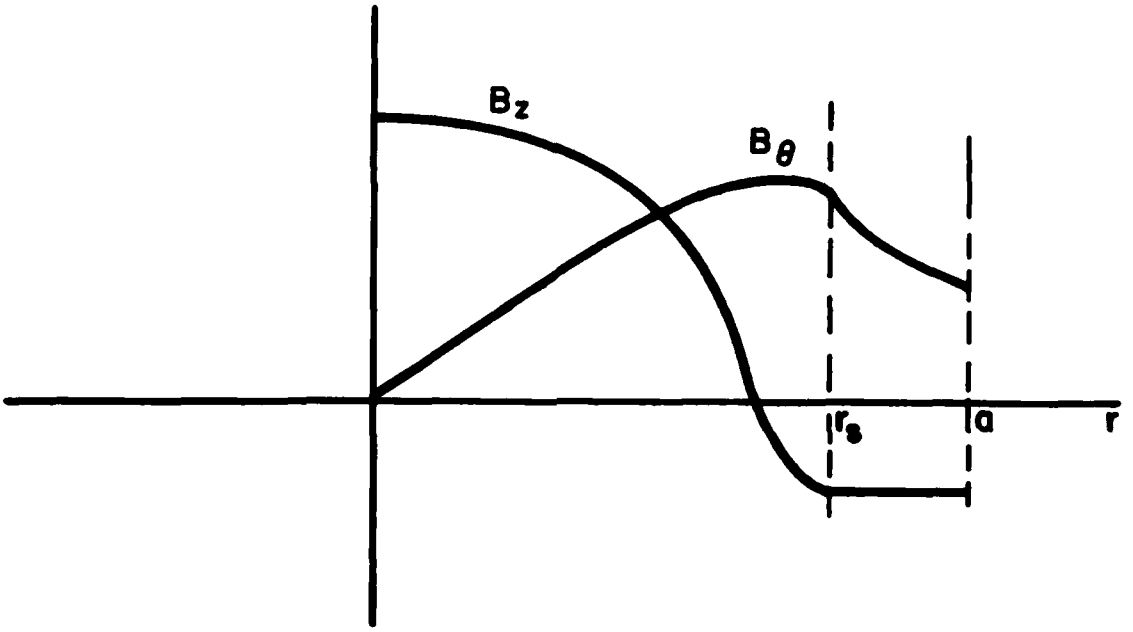


Fig. 2 - The radial profile axial and azimuthal magnetic fields, assuming low plasma pressure on the separatrix

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