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CONFINEMENT REQUIREMENTS FOR OHMIC-COMPRESSIVE IGNITION OF A SPHEROMAK PLASMA

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The Moving Plasmoid Reactor (MPR) is an attractive alternative magnetic fusion scheme in which Spheromak plasmoids are envisioned to be formed, compressed, burned, and expanded as the plasmoids translate through a series of linear reactor modules[1]. Although auxiliary heating of the plasmoids may be possible, the MPR scenario would be especially interesting if ohmic decay and compression alone were sufficient to heat the plasmoids to an ignition temperature. In the present work, we will study the transport conditions under which a Spheromak plasmoid could be expected to reach ignition via a combination of ohmic and compression heating.

Simple estimates of the effectiveness of ohmic heating in a Spheromak plasma can be obtained by writing the power balance in the form

$$\frac{W_M}{\tau_M} = \frac{\langle\beta\rangle W_M}{\tau_E} , \qquad (1)$$

in which W_M is the total plasmoid magnetic energy, $\langle\beta\rangle$ is a measure of the average local plasma beta, τ_M is the classical magnetic decay time, and τ_E is the plasma energy confinement time. Since the MHD-stable beta is limited to the 4-6% range[2], Equation (1) implies that for good plasma heating:

$$\tau_E \gtrsim \frac{1}{20} \tau_M . \qquad (2)$$

This criterion is somewhat more informative when expressed in terms of a "quality of confinement" parameter, Q_c, necessary for heating of the plasma:

$$\frac{\tau_E}{\tau_B} \equiv Q_c \gtrsim 3 \times 10^{-3} \frac{\langle\beta\rangle\, T_{(ev)}^{5/2}}{B_{(T)}\, z \ln\Lambda} , \qquad (3)$$

where τ_B is the Bohm time and Q_c is the minimum number of Bohm times required for power balance.

A parameter study of Q_c vs. T_e indicates that a typical reactor scale Spheromak plasma would be expected to heat rapidly (i.e., $Q_c \lesssim 1$) into the 100-500 eV range due to the classical ohmic decay of W_M. At some point just past this level, however, Q_c rises quickly into the 10-100 Bohm time range and it is conceivable that an ultimate temperature limit might be

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imposed by transport limitations. One possible method of increasing the plasma temperature beyond this point would be adiabatic plasma compression. It can be shown that, as the externally applied magnetic field B_e is raised, W_M increases proportional to $B_e^{1/2}$, T_e increases in proportion to B_e, and $n\tau_M$ increases as B_e^2. Our power balance during compression then becomes

$$\frac{W_{M_o}}{\tau_{M_o}} + \frac{(f_B^{1/2} - 1)\,\langle\beta\rangle W_{M_o}}{\tau_c} = \frac{\langle\beta\rangle W_{M_o}\, f_B^{1/2}}{\tau_E} , \qquad (4)$$

where the zero subscripts indicate values before compression, τ_c is the compression time, and the compression factor, $f_B \equiv B_e/B_{e_o}$. The quality of confinement parameter including compression becomes

$$Q_c \gtrsim Q_{c_o} \left\{ \frac{f_B^{1/2}}{1 + \frac{\tau_m}{\tau_c}\,(f_B^{1/2} - 1)\langle\beta\rangle} \right\} . \qquad (5)$$

Here we see, for example, that with an adiabatic compression of $f_B = 4$ and $\tau_c \sim .001\ \tau_M$, it would be possible to ignite the plasma under much poorer confinement conditions (i.e., $Q_c \sim 1/20\ Q_{c_o}$) than would be possible with ohmic heating alone. We are in the process of studying more detailed Q_c requirements for various compression-to-ignition scenarios by incorporating several possible plasma transport models into the framework of a 1 1/2-D Spheromak computational model.

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