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POWER CROWBAR IMPACTS ON PLASMA CHARACTERISTICS IN ZT-40

by

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ABSTRACT

Detailed analysis of the impact of I_ϕ and I_θ power crowbars on the ZT-40 plasma is presented for the operational period between shots 1620-3600. It is demonstrated that in both aided- and self-reversed modes the main effect of the I_ϕ power crowbar is to lengthen the time to 1/e of peak current, whereas the main effect of the I_θ power crowbar is to extend the reversal of B_ϕ at the wall, primarily in self-reversed operation. It is shown that this extension has the effect of also decreasing the current decay rate to the point where no distinction is seen between the two modes. A saturation is seen in the decay time ($\tau_{1/e} < 0.4$ ms) once the field reversal in either mode exceeds approximately 0.3 ms. Possible physical explanations of these effects are discussed.

Commencing at approximately shot 1920, the ZT-40 device at Los Alamos National Laboratory had a power crowbar available to help sustain the toroidal plasma current (I_ϕ). Commencing at approximately shot 2800, a power crowbar became available to help sustain the toroidal field (B_ϕ). A detailed study has been performed in an effort to quantify the major effects of these circuits on the ZT-40 plasma. Comparisons have been made to plasma discharges from the period of shots 1620-1919, during which no power crowbars were available.

Before presenting the new results, it is useful to review some of the major features observed in this plasma in earlier operations without the power crowbars. A sample plot of toroidal current, time rate of change of toroidal current ($\dot{I}_\phi$), and the toroidal field at the wall is shown in Fig. 1. The characteristics of these traces to be discussed are the time to 1/e of peak

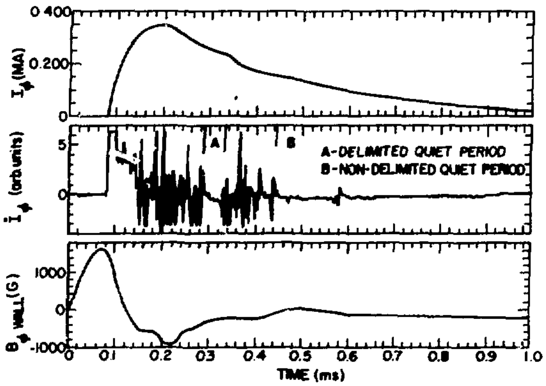

Fig. 1.

Typical current (I_ϕ), current decay ($\dot{I}_\phi$), and toroidal field (B_ϕ) at the wall traces for aided-reversal operations of ZT-40.

I_ϕ, the mean square deviation (on a fast time scale, $\lesssim$ 20 μs) of the decay ($\dot{I}_\phi$) from its mean, and the length of time the B_ϕ field at the wall remains below zero. Also seen on these traces are two distinct types of quiet periods in these discharges (labeled A and B in the figure). These quiet periods are the topic of a separate report.[1]

I. PRESSURE AND MAXIMUM CURRENT EFFECTS

Several trends that are a function of fill pressure have been noted in previous operations.[2] In nonfield-reversed and self-reversed operation, the decay times shortened abruptly to values < 200 μs as soon as the fill pressure dropped below 15 mtorr. In the aided-reversal mode such a transition was very much subdued, and in general the decay at a given fill pressure (and maximum current) was typically 0.05–0.1 ms longer than in the other modes. During the shots examined here, this transition in decay time was not as obvious due to masking by observation of many shots over a long period of time (previous analysis was done for many shots taken during the course of a pressure scan on a given day), but a generally upward trend which indicated the same physical effect did occur. The same 0.05- to 0.1-ms increase in $\tau_{1/e}$ between self-reversal and aided reversal was seen except during application of the I_θ power crowbar. No detailed presentation of data concerning pressure dependence will be made because the primary power crowbar effects are more clearly seen in other aspects of the plasma behavior.

Also observed in earlier work was a generally upward trend of $\tau_{1/e}$ with respect to the maximum current on a given type of shot. In the self-reversal mode for the present study, such a trend was not obvious except for the set of shots with the lowest, nonzero, I_ϕ power crowbar (I_ϕ-PCB) voltage. A plot of $\tau_{1/e}$ vs maximum current is shown in Fig. 2. As is shown on the plot, the lower the I_ϕ-PCB voltage, the more the decay time depends on peak current. At the highest power crowbar level, particularly in the case of aided reversal, the power crowbar externally holds the current up regardless of plasma effects. This current-sustaining capability is most pronounced at low peak current (highest possible ratio of $V_{I_\phi\text{-PCB}}/V_{I_\phi}$). This effect for the aided-reversal case is shown very clearly in Fig. 3. Below about 3 kV on the I_ϕ-PCB, the general plasma behavior approached the behavior without power crowbar application.

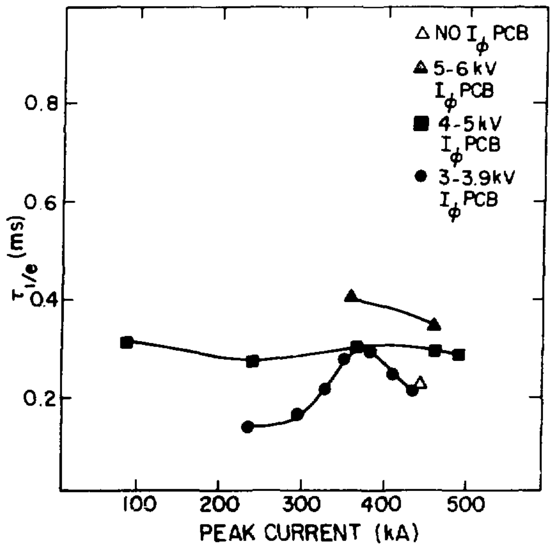

Fig. 2.
Time to 1/e of maximum I_ϕ vs maximum I_ϕ for a variety of I_ϕ-PCB voltages for self-reversed operation.

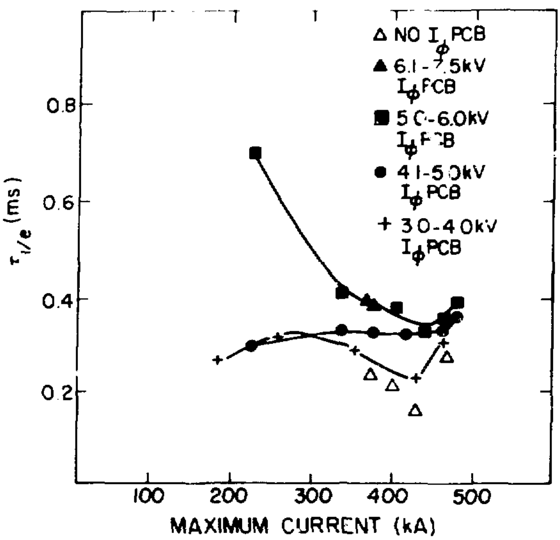

Fig. 3.
Time to 1/e of maximum I_ϕ vs maximum I_ϕ for a variety of I_ϕ-PCB voltages for aided-reversal operation.

II. I_ϕ-PCB VOLTAGE EFFECTS

Figures 4 and 5 are plots of the effects of I_ϕ-PCB voltage on the decay time for various peak currents and I_θ-PCB conditions, for self-reversal and aided reversal, respectively. These plots, as well as the remainder of the plots in the presentation, are all for fill pressure between 5-7 mtorr, and most following plots are for currents between 330-470 kA. The general behavior to be described seems to be relatively independent of fill pressure as long as it is not excessive (> 15 mtorr). As shown in both traces, a monotonic increase occurs in $\tau_{1/e}$ as the I_ϕ-PCB voltage is increased. The aided-reversal plots (Fig. 5) show the breakpoint at 3.0 kV I_ϕ-PCB most clearly. Above this voltage level the I_ϕ-PCB begins to be effective. Also clearly shown is the relative effectiveness of the I_ϕ-PCB at low current levels as mentioned above. An important point is that in the aided-reversal mode, no difference is seen between behavior with and without the I_θ power crowbar system in use. This is in direct contrast to the case for self-reversal (Fig. 4), where the decay time increased (at constant I_ϕ-PCB voltage) when the I_θ-PCB was utilized. This point will be examined below.

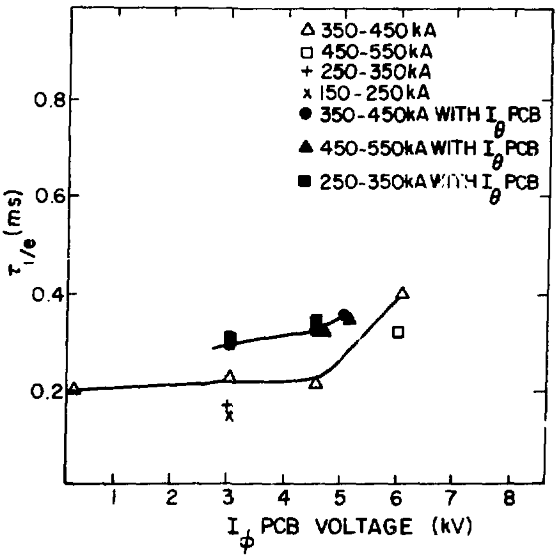

Fig. 4.
Time to 1/e of maximum current (I_ϕ) vs I_ϕ-PCB voltage, for various conditions, for self-reversed operation.

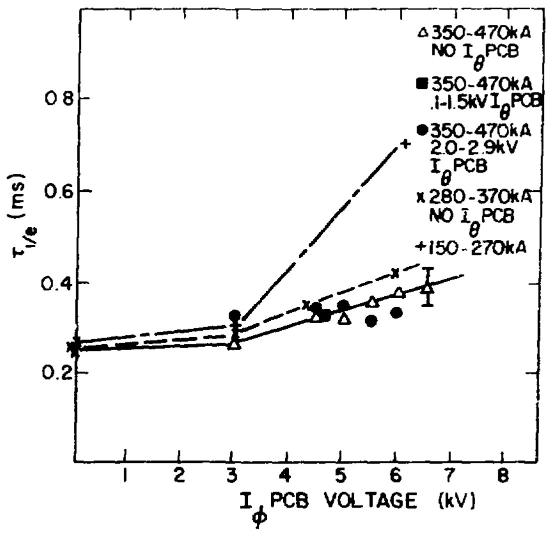

Fig. 5.
Time to 1/e of maximum current (I_ϕ) vs I_ϕ-PCB voltage, for various conditions, for aided-reversal operation.

III. I_θ-PCB EFFECTS

Figures 6 and 7 show the effect of the I_θ-PCB voltage on the length of B_ϕ reversal at the wall (τ_{rev}). The aided-reversal case has what appears to be an upward trend, which becomes pronounced only when the voltage exceeds 2 kV. The aided-reversal mode is created by delaying the crowbar on the I_θ circuits, which results in forcing $B_\phi < 0$ externally, so that the I_ϕ-PCB merely aids a process already started by the B_ϕ bank. In the self-reversal case (Fig. 7) the I_θ-PCB is much more effective because the field tends to lose its reversal near the wall rapidly when the plasma itself controls the reversal. In either mode the reversal extends indefinitely when a large enough I_θ-PCB voltage is applied, enabling the circuit to perform its design function. At the higher voltages, however, the reversal is not held constant but actually tends to increase. Other considerations indicate that the best operating regime (at least in terms of fluctuations)[2] is with the field near zero and not varying appreciably with time so application of very high levels of I_θ-PCB may not be the best operational procedure.

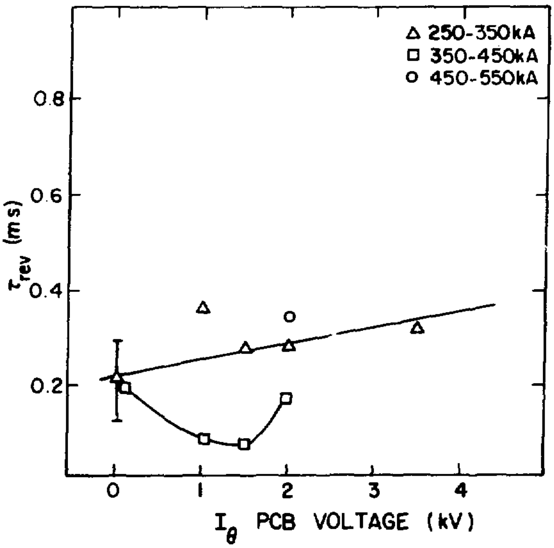

Fig. 6.
Length of field reversal at the wall (B_ϕ) vs I_θ-PCB voltage for aided-reversal operation.

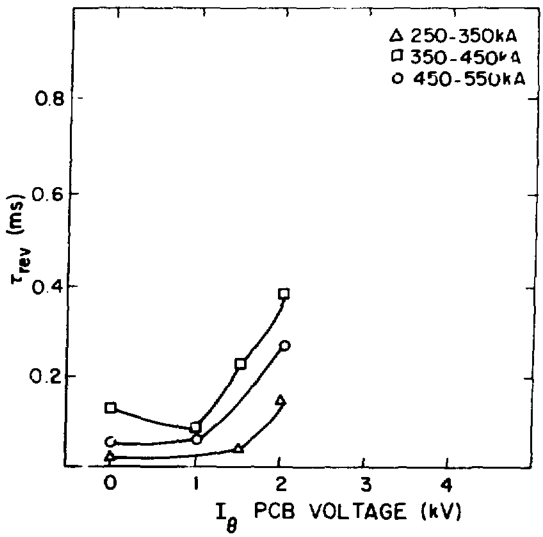

Fig. 7.
Length of field reversal at the wall (B_ϕ) vs I_θ-PCB voltage for self-reversed operation.

IV. OVERVIEW

At first glance the effects of the power crowbars appear to fall into two distinct categories: (1) the I_ϕ-PCB is capable of aiding $\tau_{1/e}$ and (2) the I_θ-PCB is capable of aiding τ_{rev}. This is exactly what would be expected from a superficial examination disregarding the plasma. The contribution of the I_ϕ-PCB to the current decay seems much the same in both of the modes examined, although the breakpoint may be slightly higher in the self-reversed case. The I_θ-PCB is very effective in the self-reversal mode in lengthening the reversal time but is less effective for the aided-reversal case.

An interactive scenario of these two responses emerges when one compares the characteristic plasma quantities $\tau_{1/e}$ and τ_{rev}. Figure 8 is a plot of $\tau_{1/e}$ vs τ_{rev} for both the aided- and self-reversal cases. Within the statistics of the two curves, there is no difference. The implication of the curves is that the decay time (and presumably the resistivity of the plasma) in the two modes is dependent (up to a point) only on how effectively one can hold the reversal at the wall, not on the formation technique. In particular, once the plasma is allowed to respond up to its current-limited capacity by holding the reversal in the self-reversed case, the performance becomes identical to

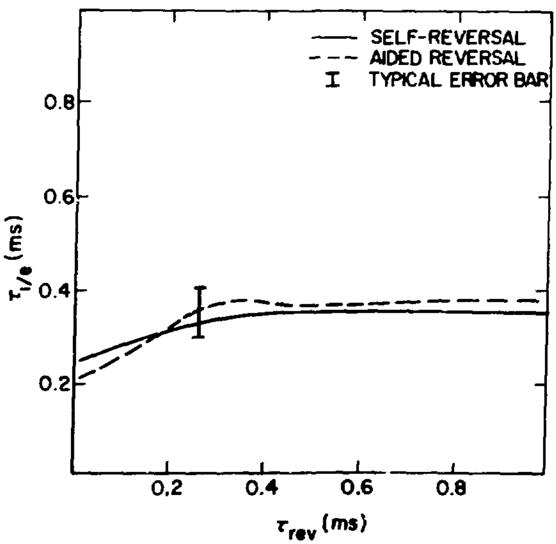

Fig. 8.
Time to 1/e of maximum current vs length of reversal for self- and aided-reversal modes.

the aided-reversal case, which has appeared to be a better mode of operation in previous discharges. The implication is that the self-reversed case, without I_θ-PCB, was losing its reversal (and thus getting into thermal contact with the wall) too early in the discharge to reach the lowest possible resistivity level (highest T_e level) at a given peak current. The aided-reversal case reached its current-limited capacity because it didn't lose its reversal as early. Consequently, prior to application of the I_θ-PCB, aided-reversal appeared to be a longer-lived mode of operation.

The second important point that emerges from this comparison is that $\tau_{1/e}$ at a given current level (in this case 330-470 kA) does not increase indefinitely, but rather saturates at ~ 0.4 ms once the reversal is held long enough to get to that point. Because $\tau_{1/e}$ does not continue to increase, a second plasma energy loss mechanism common to both modes over and above what was presumably a thermal-conduction energy loss mechanism that was eliminated from self-reversed operation by the I_θ power crowbar is indicated. The fact that it is a plasma loss mechanism is indicated by the presence of a positive feedplate voltage (and consequent radially inward Poynting vector) late in time coincident with a decay in current. If the phenomenon were simply an external circuit limit, the positive voltage would compensate for it and hold up I_ϕ indefinitely. Indeed, this was the case for very low peak current and high I_ϕ-PCB voltage. The implication is that if one can isolate and eliminate this second energy loss, the plasma current and consequent heating should be indefinitely sustained until the next loss mechanism (if it exists) becomes effective. Examination of fluctuation and current decay correlations[1] indicate that one possible source of plasma energy loss may be anomalous transport due to large-scale fluctuations, but the mystery is by no means solved.

REFERENCES

1. R. G. Watt, "Plasma Current Fluctuations and Decay Rate Behavior in the ZT-40 Device," Los Alamos National Laboratory report LA-8896-MS (July 1981).

2. D. A. Baker, C. J. Buchenauer, L. C. Burkhardt, J. N. Downing, K. B. Freese, R. F. Gribble, A. Haberstich, R. B. Howell, A. R. Jacobson, K. A. Klare, G. Miller, J. A. Phillips, K. S. Thomas, R. G. Watt, P. G. Weber, "Four Feed-Plate Operation of ZT-40 With Passive Crowbars," Los Alamos National Laboratory report LA-8752-MS, to be published.