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Computing plasma focus pinch current from total current measurement

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The total current I_{total} waveform in a plasma focus discharge is the most commonly measured quantity, contrasting with the difficult measurement of I_{pinch}. However, yield laws should be scaled to focus pinch current I_{pinch} rather than the peak I_{total}. This paper describes how I_{pinch} may be computed from the I_{total} trace by fitting a computed current trace to the measured current trace using the Lee model. The method is applied to an experiment in which both the I_{total} trace and the plasma sheath current trace were measured. The result shows good agreement between the values of computed and measured I_{pinch}. *© 2008 American Institute of Physics*. [DOI: 10.1063/1.2899632]

The total current I_{total} waveform in a plasma focus discharge is easily measured using a Rogowski coil. The peak value I_{peak} of this trace is commonly taken as a measure of the drive efficacy and is often used to scale the yield performance of the plasma focus.[1,2] This is despite the fact that yields[3–5] should more consistently be scaled to focus pinch current I_{pinch}, since it is I_{pinch} which directly powers the emission processes. The reason many researchers use I_{peak} instead of I_{pinch} for scaling is simply that while I_{peak} is easily measured, I_{pinch}, which is the value of the plasma sheath current I_p at time of pinch, is very difficult to measure even in large devices where it is possible to place magnetic probes near the pinch.[3–5] This measurement is also inaccurate and perturbs the pinch. In a small device, there is no space for such a measurement. A simpler method was tried to compute the I_p waveform using measured waveforms of I_{total} and tube voltage.[6,7] This was achieved only up to the start of the radial phase thereby missing the crucial I_{pinch}. To date, I_{pinch} is still one of the least measured and often misunderstood quantities. In this connection, an attempt was made[8] to compute the time of pinch. However, in that work, I_{pinch} was assumed to be I_{total} at pinch time.

The relationship between I_{pinch} and I_{peak} is not simple and has only been recently elaborated.[9] It primarily depends on the value of the static inductance L_0 compared to the dynamic inductances of the plasma focus. As L_0 is reduced, the ratio $I_{\text{pinch}}/I_{\text{peak}}$ drops. Thus, yield laws scaled to I_{peak} will not consistently apply when comparing two devices with all parameters equal but differing significantly in L_0. Better consistency is achieved when yield laws are scaled to I_{pinch}.

In this paper, we propose a numerical method to consistently deduce I_{pinch} from any measured trace of I_{total}. This method will improve the formulation and interpretation of focus scaling laws. Specifically, we define I_{pinch} as the value of I_p at the start of the quiescent (or pinch) phase of the plasma focus radial dynamics. We now discuss the distinction between I_{total} and the plasma sheath current I_p.

A measured trace of I_{total} is commonly obtained with a Rogowski coil wrapped around the plasma focus flange[10] through which is fed I_{total} discharged from the capacitor bank between the coaxial electrodes across the back wall. A part of I_{total}, being the plasma sheath current I_p, lifts off the back-wall insulator and drives a shock wave axially down the coaxial space. At the end of the anode, the plasma sheath turns from axial into radial motion. The previously axially moving I_p becomes a radial inward moving cylindrical sheath, driving a radially collapsing cylindrical shock front. When this shock front arrives on axis, because the plasma is collisional, a reflected shock (RS) moves radially outwards[11] until it meets the incoming driving current sheath. The increased pressure of the RS region then rapidly slows down the sheath. This is the start of the pinch phase. All the dynamics dominating the axial and radial phases is determined by I_p. A proportion of the current, the difference between I_{total} and I_p, does not take part in the dynamics. This leakage current stays at the back wall,[4–7,12] but parts of it may be diffusely distributed.

We define for the axial phase f_c as I_p/I_{total} and distinguish it from f_{cr} for the radial phase. Likewise, it had been shown that only a fraction of the mass[6,12] encountered by the axial sheath is swept up. This fraction we call f_m, distinguishing the radial phase fraction as f_{mr}. The rest of the mass either leaks through the sheath or is swept outwards due to the canting of the sheath.

The exact time profile of the I_{total} trace is governed by the bank, tube, the operational parameters, and by the mass and current fractions and variation of these fractions through the axial and radial phases. Although we may expect these fractions to vary, for simplicity, we average these model parameters as f_m, f_c and f_{mr} and f_{cr}.

The Lee model couples the electrical circuit with plasma focus dynamics, thermodynamics, and radiations enabling realistic simulation of all gross focus properties. The basic model was described in 1984 (Ref. 13) and used to assist projects.[6,7,10,11,14–16] An improved five-phase code crucially incorporating small disturbance speed,[17] and radiation coupling with dynamics, assisted further projects,[8,18–23] and was published in the internet in 2000 (Ref. 24) and 2005.[25] Plasma self-absorption was included[24] in 2007. It has been used in machines including UNU/ICTP PFF,[10,11,15,16,21] NX2,[18–20] and NX1,[18] and has been adapted to the Filippov-type DENA.[8,22,23] Neutron yield Y_n using a beam-target mechanism,[1] is included in the present version RADPFV5.13, (Ref. 26) resulting in realistic Y_n scaling[27] with I_{pinch}. Since

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