Computing plasma focus pinch current from total current measurement

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The total current $I_{\text{total}}$ waveform in a plasma focus discharge is the most commonly measured quantity, contrasting with the difficult measurement of $I_{\text{pinch}}$. However, yield laws should more consistently be scaled to focus pinch current $I_{\text{pinch}}$ rather than the peak $I_{\text{peak}}$. This paper describes how $I_{\text{pinch}}$ may be computed from the $I_{\text{total}}$ 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 $I_{\text{total}}$ trace and the plasma sheath current trace were measured. The result shows good agreement between the values of computed and measured $I_{\text{pinch}}$. © 2008 American Institute of Physics. [DOI: 10.1063/1.2889632]

The total current $I_{\text{total}}$ waveform in a plasma focus discharge is easily measured using a Rogowski coil. The peak value $I_{\text{peak}}$ 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.¹² This is despite the fact that yields³–⁵ should more consistently be scaled to focus pinch current $I_{\text{pinch}}$, since it is $I_{\text{pinch}}$ which directly powers the emission processes. The reason many researchers use $I_{\text{peak}}$ instead of $I_{\text{pinch}}$ for scaling is simply that while $I_{\text{peak}}$ is easily measured, $I_{\text{pinch}}$, 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 $I_{\text{p}}$ waveform using measured waveforms of $I_{\text{total}}$ and tube voltage.⁶,⁷ This was achieved only up to the start of the radial phase thereby missing the crucial $I_{\text{pinch}}$. To date, $I_{\text{pinch}}$ is still one of the least measured and often misunderstood quantities. In this connection, an attempt was made⁸ to compute the time of pinch. However, in that work, $I_{\text{pinch}}$ was assumed to be $I_{\text{total}}$ at pinch time.

The relationship between $I_{\text{pinch}}$ and $I_{\text{peak}}$ 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 $I_{\text{peak}}$ 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 $I_{\text{pinch}}$.

In this paper, we propose a numerical method to consistently deduce $I_{\text{pinch}}$ from any measured trace of $I_{\text{total}}$. This method will improve the formulation and interpretation of focus scaling laws. Specifically, we define $I_{\text{pinch}}$ 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 $I_{\text{total}}$ and the plasma sheath current $I_p$.

A measured trace of $I_{\text{total}}$ is commonly obtained with a Rogowski coil wrapped around the plasma focus flange¹⁰ through which is fed $I_{\text{total}}$ discharged from the capacitor bank between the coaxial electrodes across the back wall. A part of $I_{\text{total}}$, 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 outwards¹¹ 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 $I_{\text{total}}$ 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 $I_p/I_{\text{total}}$ and distinguish it from $f_c$, for the radial phase. Likewise, it had been shown that only a fraction of the mass⁶,¹² encountered by the axial sheath is swept up. This fraction we call $f_m$, distinguishing the radial phase fraction as $f_m$. The rest of the mass either leaks through the sheath or is swept outwards due to the cantoing of the sheath. The exact time profile of the $I_{\text{total}}$ 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.⁴,⁷,¹⁰,¹¹,¹⁴–¹⁶ An improved five-phase code crucially incorporating small disturbance speed,⁶,¹² 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 included²⁶ in 2007. It has been used in machines including UNU/ICTP PPF,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 RAPPP5.13, (Ref. 26) resulting in realistic $Y_n$ scaling²⁷ with $I_{\text{pinch}}$. Since

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