Use of triple Langmuir probes in the study of expanding shocks from a dense plasma focus

M. Martínez-Fuentes[1], F. Castillo-Mejía[1], J.J.E. Herrera-Velázquez[1],
M. Nieto-Pérez[2], G. Ramos-López[2]
[1]*Instituto de Ciencias Nucleares,Universidad Nacional Autónoma de México*
Mexico City, Mexico
[2]*Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada*
Instituto Politécnico Nacional
Santiago de Querétaro, México

Dense plasma focus devices have been and will continue to be extensively studied, in their first three stages, namely, the breakdown, rundown, and focusing of the plasma column. However, one of its features has been neglected; namely, the expansion of its discharge along the vacuum chamber, after the compression of the plasma column, which is akin to those in plasma guns. This work is motivated by the possibility of using this stage as a source of energetic plasma, which might simulate the effect of high density plasmas colliding on wall facing materials. For this purpose, it is necessary to be able to determine the dynamics of the discharge, for which measurements of density, temperature and speed are needed. We show preliminary results obtained using a triple Langmuir probe (TLP). The present work is done along the axis of the FN-II dense plasma focus, which is a 4.8 kJ device.

In the triple probe a third electrode is added in close proximity to a double probe, and is used in order to measure the floating potential independently. They offer an advantage over single and double Langmuir probes, allowing simultaneous measurement of plasma parameters without the need for voltage sweeps that can be limiting in pulsed plasma environments, specially if the discharges are not reproducible from shot to shot [1-4]. In voltage mode operation there is an external potential applied only between two probes while the third one is floating (Fig. 1).Temperature T_e and density n_e are obtained from

$$\frac{1}{2}=\frac{1-exp\left[\frac{-eV_{13}}{kT_e}\right]}{1-exp\left[\frac{-eV_{12}}{kT_e}\right]} \quad , \tag{1}$$

$$n_e=\frac{J_i}{exp\left[\frac{-1}{2}\right]e\sqrt{\frac{kT_e}{m_i}}} \quad , \tag{2}$$

where J_i is the ion current density, given by

$$J_i = \frac{1}{A_P} \frac{I_{13}}{\exp\left[-\frac{e(V_{12} - V_{13})}{kT_e}\right] - 1} \quad , \qquad (3)$$

where A_P is the parallel area of the cylindrical probe, and I_{13} is the current between probes 1 and 3, measured over the resistance *r*.

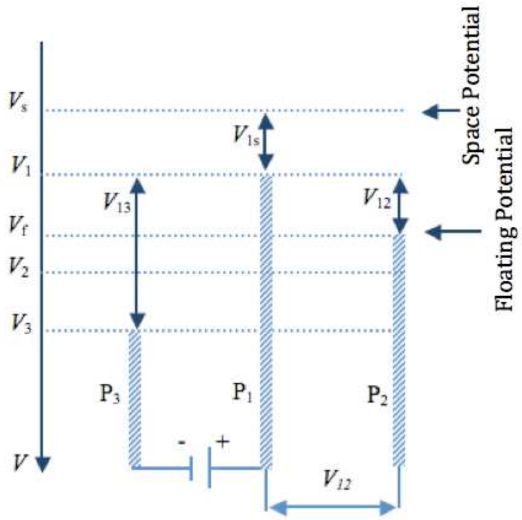

Figure 1a. Diagram of voltage-mode triple Langmuir probe.

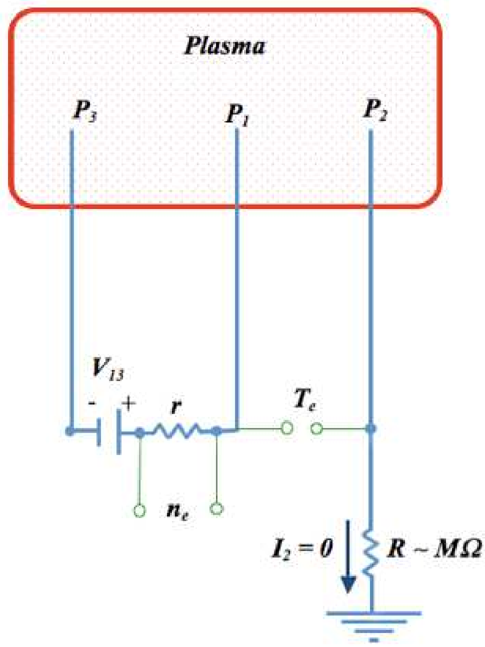

Figure 1b. Electric circuit for a triple Langmuir probe operating in voltage-mode.

The device in which this work was done is the Fuego Nuevo-II dense plasma focus, which operates at the Instituto de Ciencias Nucleares, UNAM, and has been described in Ref. 5. A voltage-mode TLP was placed inside the vacuum chamber, along the axis of the plasma focus, at three different distances from the inner electrode (Δx = 16 cm, 21 cm, 26 cm) (Fig. 2). The device was operated with pure deuterium at ~ 2.6 Torr, and the data were collected with Tektronix TDS3034 oscilloscopes. Figs. 3 and 4 show the behaviour of the signals of $\boldsymbol{V_{12}}$ (as defined in Fig.1) and the potential measured in the resistance ***r***, respectively, when ***r*** was varied with values of 1MΩ, 100 kΩ, 10 kΩ, 1kΩ, 100 Ω, 10 Ω and 1 Ω (always with $\boldsymbol{V_{13} = 100\ V}$). The purpose of varying the value of ***r*** is to find out how electromagnetic noise may be reduced. Although it decreases, it is possible to see in the curves that there are two peaks after the pinch that do not vanish with the different values of ***r***. These are encased in Figs. 3 and 4 in blue boxes. We interpret them as a sign of the discharge front passing across the TLP. Fig. 5 shows that there is a phase difference (Δt) between the three curves (at the start of the first peak of the discharge that passes across the TLP), this allows the determination of the value of the average velocity (between curves) of the expansion: $\Delta v_{16\ cm\ -21\ cm}$ = ***5.7×10⁵ m/s*** ± ***3.6×10⁵ m/s,*** $\Delta v_{21\ cm\ -26\ cm}$ = ***5.3×10⁵ m/s*** ± ***3.5×10⁵ m/s.*** Using the Voltage-Mode operation allows the measurement of the electron temperature and the density of electrons in the zone when the discharge passes across the TLP (Fig. 6).

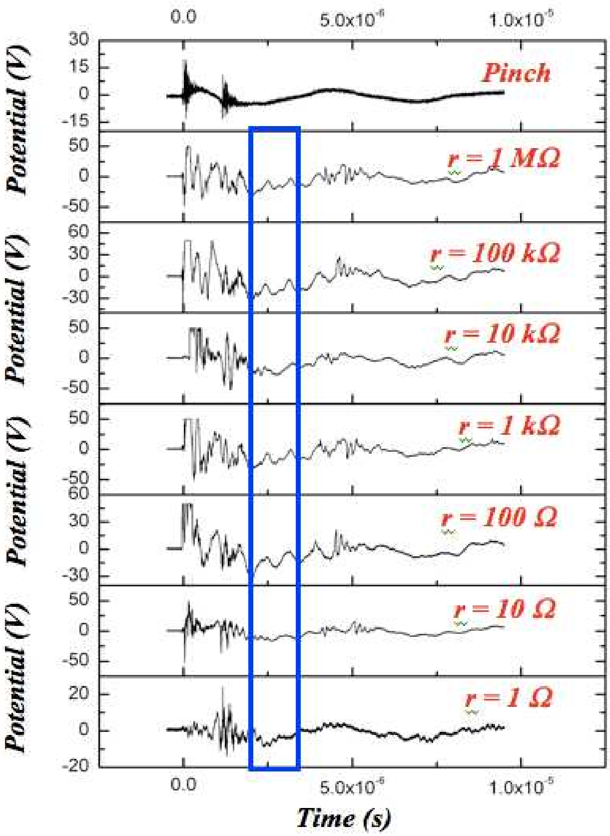

Figure 3. Signal of V_{12} for different values of *r*. The first curve is the signal of the Rogowski coil which measure the derivative of the current. The two peaks mentioned in the text are encased in the blue box.

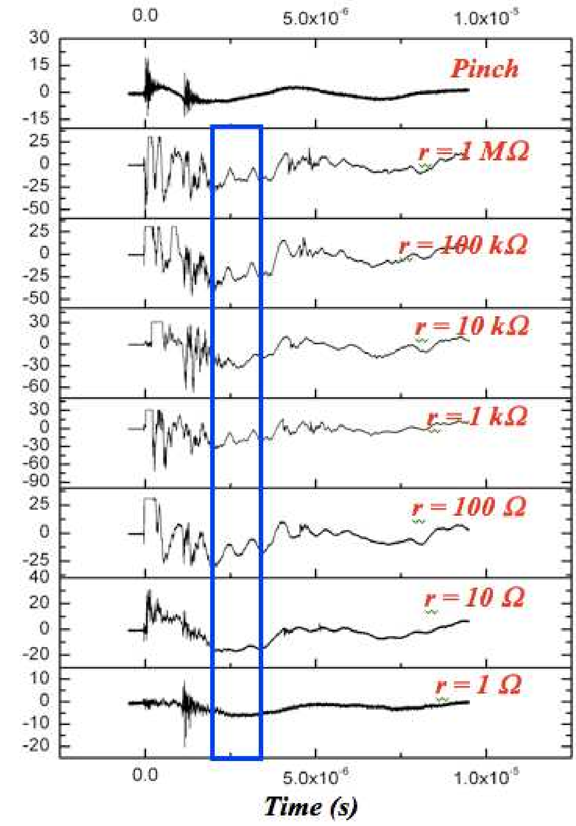

Figure 4. Signal of the potential measured in the resistance *r*, when *r* has different values. The first curve is the signal of the Rogowski coil. The two peaks mentioned in the text are encased in the blue box.

Although it has not been reported in the literature to our knowledge, there are at least two groups (The PACO team at Tandil, Argentina, and the CCHEN group at Santiago, Chile) that have recently followed the evolution of the discharge at this phase with Schlieren photography, and have found the formation of a plasma dome, which evolves like a shock wave, out of which a bubble emerges on the axial direction. This was also reported in pictures in the early days of plasma focus research by Bernard et al. [10], although no attention was paid to the bubble, since the interest was focused in the neutron production. It is probably produced by a plasma jet, which emerges from the focus region, although it is preceded by an ion beam, as has been established in previous studies by Lepone et al. [11]. Since the speed of this bubble is larger than that of the dome, which roughly has the same speed as the plasma sheath before the pinch, this may help to explain the high speed reported in this paper.

On the other hand, it is important to notice that the speeds obtained using two different distances are consistent.

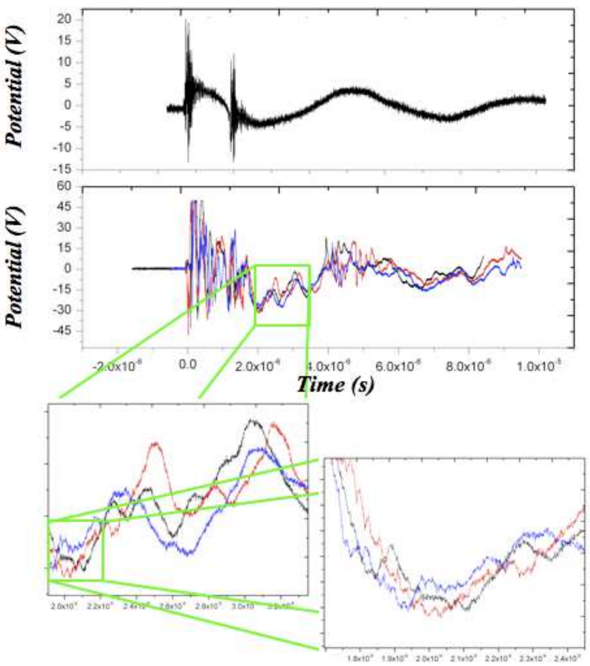

Figure 5. The upper signal comes from the Rogowski coil. Signals below show probe signals at different distances (Δx = 26 cm, 21 cm, 16 cm). The red square is the zone where the discharge passes across the TLP. The blue line is at Δx = 16 cm, the red line is at Δx = 21 cm, and the black line is at Δx = 26 cm. (Right) Zoom in the zone where discharge passes across the TLP.

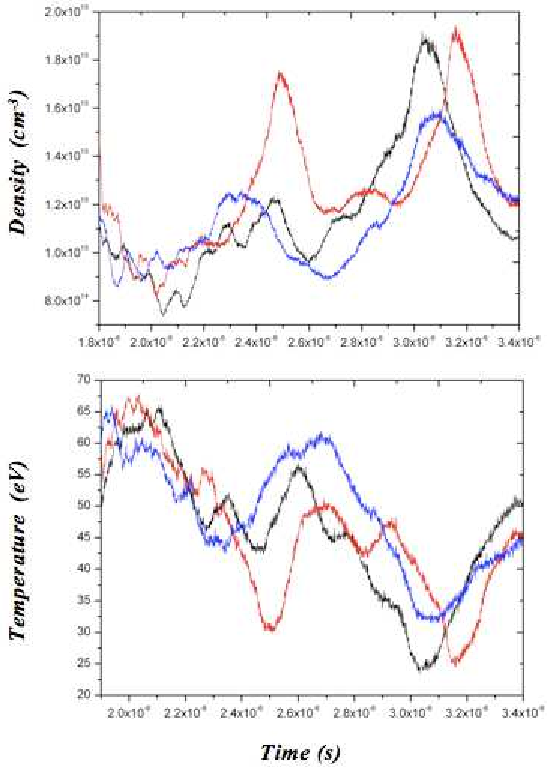

Figure 6. (Left) Curves of electron density and (Right) electron temperature. Both curves were calculated in the zone when the discharge passes across the TLP (green square, see Fig. 5).

Acknowledgments

This work was partially supported by PAPIIT-DGAPA-UNAM IN120409. M.A.M.F. acknowledges the financial support by the Programa de Apoyo a los Estudios de Posgrado (PAEP) of the Coordinación de Estudios de Posgrado (CEP), Mexico.

References

[1] S. Chen, T. Sekiguchi, *J. Appl. Phys*. **36**, 2363 (1965).

[2] N.A. Gatsonis, L.T. Byrne, J.C. Zwahlen, E.J. Pencil, H. Kamhawi, IEEE *Transactions on Plasma Science* **32,** 2118 (2004).

[3] W. Lohete-Holtgreven, *Plasma Diagnostics*, (American Vacuum Society Classics, American Institute of Physics, 1995).

[4] N.A. Gatsonis, J.C., Zwahlen, A. Wheelock, E.J. Pencil, H. Kamhawi, *J. Propulsion Power* **20,** 243 (2004).

[5] F. Castillo, J.J.E. Herrera, J. Rangel, A. Alfaro, M.A. Maza, V. Sakaguchi, G. Espinosa, J. I. Golzarri, *Brazilian J. Phys.* **37,** 3 (2002)