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A Simple Measurement of Line Density

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A SIMPLE MEASUREMENT OF LINE DENSITY

by

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ABSTRACT

Energy line density, $E_L = \int (F/2)nk(T_e + T_i)dA$, has proved to be one of the easiest (and most critical) measurements made on the Scylla IV-P, 5-m linear theta pinch. A quantitative evaluation of end-stopping techniques is made available by extracting the line energy containment time, τ_{E_L} , from the time history of E_L . To model $E_L(t)$ properly and, hence, determine the details of energy loss mechanisms (streaming and thermal conduction) requires separate measurements of n and T . A simple measurement of line density, $n_L = \int ndA$, is proposed, in which a single laser beam is passed repeatedly through the plasma column along different chords. A discussion is presented of the measurement accuracy as a function of the number of passes.

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At present, energy line density is calculated from two directly measured quantities: $\Delta\phi$, the excluded flux and B_0 , the vacuum magnetic field; that is,

$$E_L = \frac{F}{2} \frac{B_0}{4\pi} \Delta\phi,$$

where F is the number of degrees of freedom. In terms of plasma parameters, E_L is given above as

$$E_L = \frac{F}{2} \int nkT dA.$$

Assuming T is constant over the plasma radius yields

$$\begin{aligned} E_L &= \frac{F}{2} kT \int ndA \\ &= \frac{F}{2} n_L kT. \end{aligned}$$

A separate measurement of either n_L or T determines the relative contribution of particle loss and thermal loss to τ_{E_L} .

Through neutron production and Thomson scattering measurements, T_i and T_e can be inferred. It is desirable, however, to measure n_L independently, as well. Present side-on interferometric techniques¹ give the integrated chord density, n_{ch} ,

$$n_{ch} = \int_{r=0} n(r,s) ds,$$

where s is a path along the line of sight and r is the transverse position of the chord. To some degree, n_{ch} is a desirable measurement by itself. In the low β approximation, $a/r_\phi = (2/\beta)^{1/2}$ (Ref. 2). With this approximation, a Gaussian profile and $a/r_\phi \approx 1.75 \pm 15\%$ for $0.8 > \beta_A > 0.5$, one may write the approximate expression

$$E_L \approx \frac{F}{2} [(2\pi/B_0)kT \int_{r=0}^a n_{ch} ds]^2,$$

where a is the mean plasma radius and r_ϕ is the excluded flux radius $r_\phi = (\Delta\phi/\pi B_0)^{1/2}$. Alternatively, side-on holographic interferometry gives n_{ch} for all chords, that is, $n_{ch}(r)$.³ Numerical integration of the fringe-shift profile results in n_L . However, only one exposure typically is available during the plasma discharge. A simplified data reduction method is also preferred.

We propose the use of multiple passes through the plasma of a single coherent beam, as illustrated in Fig. 1, which gives an effective measurement

$$\begin{aligned} n_L &= \int n(r,s) dr ds \\ &\approx \sum_j \Delta r_j \int n(r_j,s) ds. \end{aligned} \quad (1)$$

Fig. 1.

Multipass interferometric system for determination of the line density, $n_L = \int n dA$.

The result is a single, time-dependent signal, capable of simple recording and independent of plasma shape assumptions. The limitations of this technique are (1) plasma distortions smaller than Δr and (2) degradation of beam quality caused by multiple passes through the discharge tube. At least 10 passes, spaced over 2 cm, are believed technically possible. This may require a more elaborate window system than that shown in Fig. 1 (for example, a polished tube section or flat windows). Furthermore, a quadrature interferometric system would simplify interpretation of the interferometric signal.⁴

A minimum, required number of passes can be estimated by comparing n_L , calculated from Eq. (1), to the exact n_L for a Gaussian profile. In Fig. 2, the calculated n_L is plotted as a function of the number of passes. The passes are equally divided across a discharge tube with a diameter equal to $10a$. The exact n_L is $\pi n_A a^2$. Figure 2 shows that an odd number of passes overestimates n_L and an even number of passes underestimates n_L for fewer than 7 passes. The symmetry of the passes (odd or even) with respect to the plasma axis would change as the plasma column moved. Thus, the even and odd curves in Fig. 2 represent bounds of error for varying positions of the plasma column.

Fig. 2.

Line density n_L , as calculated from multiple passes, vs number of passes for a Gaussian density profile.

Convergence to the exact n_z occurs at ~ 7 passes. Faster convergence would be expected if the passes were divided over a length smaller than the "tube diameter" of 10a. Convergence near 7 passes is an indication of the sampling width becoming comparable to the plasma width. To measure n_z accurately for plasma columns with radial distortions $< a$, it is advisable to use the maximum number of passes technically possible. This analysis shows that a minimum of 7 passes is a reasonable requirement.

REFERENCES

1. F. C. Jahoda and G. A. Sawyer, *Optical Refractivity of Plasmas, Methods of Experimental Physics*, R. H. Lovberg and H. R. Griem, Eds. (Academic Press, Inc., New York, 1971), Vol. 9, Part B, pp. 48.
2. Carl Ekdahl, Los Alamos Scientific Laboratory, unpublished data, March 1977.
3. R. Kristal, "Pulsed HF Laser Holography Interferometry," *Appl. Opt.* 14, 628 (1975).
4. C. J. Buchenauer and A. R. Jacobson, "Quadrature Interferometer for Plasma Density Measurements," *Rev. Sci. Instrum.* 48, 769 (1977).