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RESTORATION OF TWO-DIMENSIONAL RADIATION FOR AN OPTICALLY THICK PLASMA

V.V. Pickalov and N.G. Preobrazhensky.


Abstract. A concept of local diagnostics for an optically thick plasma without axial symmetry is proposed. It is possible to reduce the problem in two-dimensional case to the system of one-dimensional problems by decomposition in polar and cartesian coordinates.

Recently [1] the authors proposed an algorithm of data conversion to the local emissivities for an optically thick plasma of arbitrary configuration. Simulation procedure proved the reasonable accuracy for optical densities from 0 till 10 and the level of experimental errors 5-10% [2]. By decomposition technique in polar coordinates one can reduce the two-dimensional integral equation for local emissivities $E(r,\theta)$ to the system of linear integral equations [2]:

$$
\tilde{I}(p_i,\xi) = \int_0^{\pi} \frac{E_i(\theta + \xi)}{\sin \theta + \xi} d\theta \times 
$$

$$
\times \exp\left[-\int_0^{\pi} \frac{k_i(\theta + \xi)}{\sin \theta + \xi} d\theta\right] d\theta .
$$

$E_i(\xi,\theta) \in [0,2\pi]$, $p \in [-R, R]$, $i = 1, 2, \ldots$, $k_i(\theta)$ is the absorption coefficient for i-ring, $\tilde{E}(p_i,\xi)$ is the intensity of escaped radiation for i-ring and angle $\xi$.

The system (1) can be solved successfully with due regard for smoothness of solution as a priori assumption. If some additional information about solution is available the mathematical formulation of the problem can be efficiently simplified. E.g. the possibility of factorization in local coefficients:

$$
k(x, y) = k_1(x)k_2(y), \quad \xi(x, y) = \xi_1(x)\xi_2(y)
$$

permits the retrieval of $\xi(x, y)$ by means of decomposition in cartesian coordinates. In this case only two orthogonal directions are sufficient for observation and the problem comes to the system of two integral equations:

$$
\tilde{I}_1(x) = \int_{-\infty}^{+\infty} \xi_1(x) \exp[-k_1(x)] \xi_2(y) dy dx,
$$

$$
\tilde{I}_2(y) = \int_{-\infty}^{+\infty} \xi_2(x) \exp[-k_2(y)] \xi_1(x) dx dy .
$$

Another kind of a priori information related to the form of isolines for basic plasma parameters can be prominent. In the special and the most popular axisymmetrical case (isolines are concentric circles) the problem of local diagnostics is described by one-dimensional Abel or Freeman-Katz [3] equations. In the more general case of isolines which are convex closed curves without self-intersections $\Psi(x, y, b) = 0$ one can find the spatial distribution of emissivities solving the Volterra I-st kind integral equation

$$
\tilde{I}(\xi) = \exp(-\int_{-\infty}^{+\infty} k dt) \int_{-\infty}^{+\infty} \xi(t) \exp[-k(t)] dt .
$$
The "fan-shaped" measurement scheme (Fig.1a) is supposed here and the differential \( dS \) along the line of sight \( DL \) for two-place function \( x = x(t) \) is given by

\[
\int_{t_0}^{t_1} \exp \left( \frac{t}{k} \right) \, dx = \exp \left( \frac{t}{k} \right) x \end{equation}

The case of side-on recording is easily obtained from (3); as to the special case \( f^- = f^+ \) taking place for the system of shifted ellipses one comes to the generalized Freeman-Katz equation

\[
I(x) = 2 \exp \left( -\frac{t}{k} \right) \left( \frac{d^2}{dx^2} + \frac{2}{b} \right) \left( \frac{d^2}{dt^2} + \frac{2}{b} \right) \, d\xi = 0. \tag{4}
\]

Geometrical arrangement of observation for a plasma with the known isolines is sketched in Fig.1a. The result of restoration for the model function \( \xi(x, y) = x \) is shown in Fig.1b \((x \times x \times \times)\) and is related to the system of shifted ellipses

\[
\frac{(x - \xi (1 - b))^2}{a^2} + \frac{y^2}{b^2} = 1. \tag{5}
\]

\( a = 1.1, \quad b = 1, \quad \xi = 0.4, \quad \phi = \varphi = 0. \tag{6}\)

Also in Fig.1b are plotted the "experimental" function \( I(x) \) with the noise level 5% \((0000)\) and the coefficient of random error amplification \( \gamma^2 = \frac{\delta I}{\delta ^2} \) \((-----)\) in the method of regularization when the equation (3) is solved \((k=0)\).

Fig.2 corresponds to the results of simulation in the problem of asymmetrical plasma field diagnostics for the lack of information about isolines. Modified "onion peeling" strategy [4] was used for eq. (1), maximum optical density being \( \tau = 1 \) and the initial noise level 1%.

Our results and theory show reasonable accuracy for retrieval of rather complicated plasma fields as in laser explosion of targets, high temperature, tokamak or stellarator plasma etc.

**REFERENCES**