X-ray Imaging for Plasma Position Control in the Ignitor Experiment

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Abstract

In burning plasma environments, traditional magnetic measurements may be expected to fail because of the high neutron and gamma radiation background. Light extraction and detection will also be more difficult than in present day tokamaks. In general, it will not be possible to keep detectors in the proximity and in direct view of the plasma. In this work we propose a diagnostic system for plasma position control using a multilayer mirror (MLM) as the dispersing element for the soft X-ray radiation emitted from the plasma outer region, and a Gas Electron Multiplier (GEM) detector. In the proposed layout, the radiation of the lower and upper region of the plasma is diffracted by cylindrical MLMs at shallow Bragg angles, and is collected by 2D detectors placed outside the machine horizontal port. GEM detectors are suitable for radiation in the 0.2-8 KeV range, and they are characterized by a very high counting rate. This system should measure the plasma position and detect any plasma movement with sufficient time resolution to be used for real-time feedback control of the vertical plasma position.

The use of a curved diffracting element serves the double function of selecting the radiation spectral range and of focusing it on a detector that can be located outside the plasma chamber, not in direct view of the plasma.

The port geometry determines, in the toroidal plane, the maximum Bragg angle for the radiation to be channelled out of the port: \( d_B \geq 12.2^\circ \).

Assuming a distance between the MLM and the detector of approximately 2 m, for \( \theta \leq 35^\circ \), the radius of curvature 2R of the MLM and the interplanar spacing 2d need to be:

\[
2R = \frac{\lambda}{2d} \left( \frac{\sin \theta}{\cos \theta} \right) \approx 10 \text{ m},
\]

\[
2d = \frac{\lambda}{2R} \left( \frac{\sin \theta}{\cos \theta} \right) \approx 165 \text{ Å}.
\]

Clearly, this kind of spacing requires the use of multilayer mirrors rather than natural crystals. MLM can be made of different materials, for example a combination of NiC, for which the reflectivity can be very good, of the order of 10% in the range of interest [1].

With cylindrical mirrors, in order to obtain some spatial resolution of the observed plasma is necessary to introduce a slit along the line-of-sight (spherical mirrors are not suitable, but toroidal ones may be a possibility). Since we want to keep the dimension of the detector within the limit of what is commercially available, the slit will need to be placed between the MLM and the detector to get a reduction of the source. With the following arrangement about 15 cm of plasma can be imaged on a 10 cm wide detector.

A detector suitable for this application is a GEM (Gas Electron Multiplier) [2], since it can be made with a large surface area (10x10 cm), it operates at high counting rates (\( \approx 1 \text{ MHz/pixel} \)), its spatial resolution in the two directions, x and y, can be adjusted as needed, its intrinsic energy discrimination can provide a primary means of background rejection.

The throughput of the instrument can be calculated as:

\[
L = \frac{2R}{\pi} \frac{1}{d_{\text{eff}}} \sin \theta \approx 4 \times 10^{-11} \text{ sr m}^{-2}.
\]

This should provide a sufficiently fast signal (<1 ms) for the control system (see paper R1.00010).

[1] P. Gornstein, Private Communication