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Plasma Position Control Strategies for Ignitor*

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The ignition experiment Ignitor will produce, in high performance discharges, a neutron flux at the first wall that is comparable to that expected in future power producing reactors. The electromagnetic diagnostics are expected to suffer an appreciable, although temporary, degradation that can cause the measurement of some fundamental plasma parameters, such as current and position, to become problematic. The Ignitor project [1] is addressing the issue with an R&D program aimed at the development of electromagnetic diagnostics with higher damage threshold. At the same time, supplementary methods for plasma position measurements are explored to provide an appropriate degree of redundancy. One of these is based on the diffraction and detection of soft X-ray radiation emitted near the top or bottom of the plasma column, where the distance of the LCMS from the wall is only few millimeters. For the purpose of real-time plasma control, the system needs to be sufficiently fast (>1 kHz) and possibly provide an output signal to the control system without additional inputs from other diagnostics. The conceptual study described here is essentially an adaptation of the space resolving, curved crystal spectrometer in use on the FTU machine for ion temperature profile diagnostics from Doppler broadening measurements of highly ionized impurity lines [2]. Initially the main goal is to assess the possibility of monitoring the vertical position of the plasma column, since VDE's are the main concern for the integrity of elongated machines and to develop a strategy for interfacing this different type of signal into the control system.

The Ignitor Plasma Control System

The vertical position and shape controller for Ignitor [3] has been designed on the basis of the CREATE_L linearized plasma response model [4], which assumes an axisymmetric system and describes the electromagnetic interaction of the plasma with the surrounding structures by a small number of global parameters (i.e., β_{pol}, l_i, I_p). In particular, the vertical stabilization system has been designed assuming that the vertical plasma centroid position can be estimated by a suitable linear combination of the available magnetic measurements. A possible partial failure

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of these magnetic diagnostics has already been taken into account, showing a good resilience to such events. However, in case of severe failures, it will be necessary to resort to a completely different (i.e. non-magnetic) measurement of the vertical position, as the Soft X-ray spectrometer described in the following section. To take this new diagnostic into account, we make the following assumption: the vertical position measurement provided by the spectrometer can be obtained from the real position of the centroid after application of a sample-and-hold (holding time t_H) and a quantizer (quantization level z_Q). Also a gaussian multiplicative noise with mean 1 and standard deviation 5% has been considered. Here, t_H can be an estimation of the time needed to get a measurement and z_Q of the minimum vertical position variation that can be detected.

Fig. 1 shows the simulated time behaviour of the vertical position after an initial displacement of 5 mm along the unstable eigenmode, due to a perturbation. The reference flat-top 11 MA configuration has been considered. Here, we assume t_H=1 ms and z_Q =2.5mm; evidently, with such parameters the system can be stabilized. A sensitivity analysis shows that with the same quantization level, the system can tolerate measurement times up to 2.5 ms, while larger values of z_Q would require a faster measurement system.

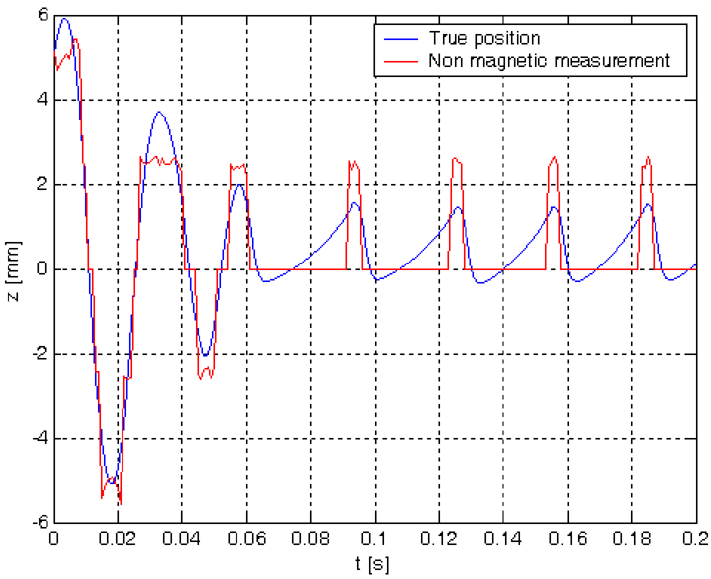
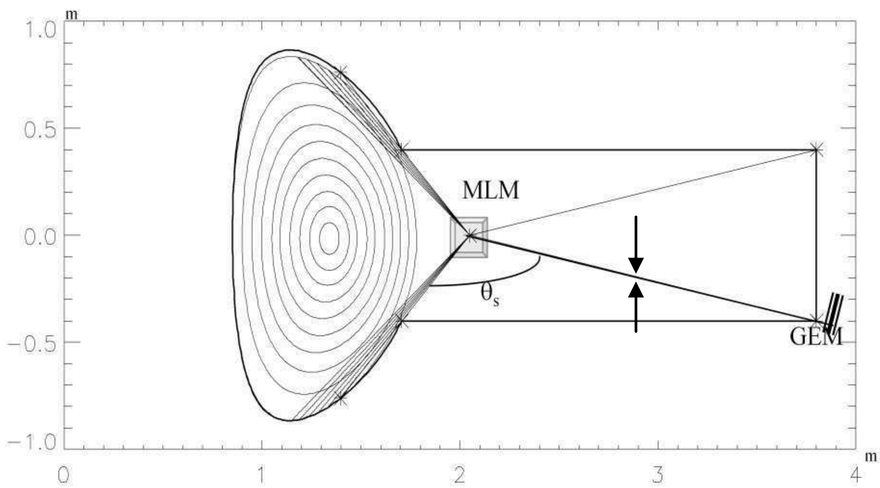


Fig. 1. Time behavior of the vertical position

A Soft X-ray Spectrometer for Plasma Position Control

The geometry of the Ignitor plasma chamber allows most of the central section of the plasma to be viewed from the horizontal ports, but it allows only a relatively narrow image in the toroidal direction. In the absence of tangential views, and with the objective of fast, direct measurements not requiring additional inputs from other diagnostics nor signal inversions, the most effective solution is to monitor the plasma edge region, where gradients in the X-ray emission are more prominent. With further constraints imposed by the considerable length of the horizontal port, it was impossible to find a space-resolving configuration that could look at both the top and bottom of the plasma with a single, double-curvature diffracting element. On the contrary, a cylindrical diffracting element placed inside the horizontal port can focus a spectrally resolved profile on a space resolving detector, as in the conventional Johann mounting. In this arrangement [5], the diffracting element is placed inside the horizontal port, while the detector is outside the vessel and removed from the direct view of the plasma, where the front-end electronics can be more easily protected. In order to provide spatial resolution, it is also necessary to use a slit parallel to the diffracting plane. For our study we position the slit 1/3 of the way between the diffracting element and the detector, and assume that this is as high as needed to image about 20 cm of plasma. The diagnostics would include two diffracting elements, one pointing to the upper part of the vacuum vessel, the other to the bottom, but the possibility of relying on the signal from only one view is also taken into consideration. A schematic side view of the layout is shown in Fig. 2. A crucial component of the system is the detector. Despite tremendous progress in solid state detectors technology, extremely fast read-outs are still more readily achievable with Gas Electron Multiplier devices. In particular, the new GEM detectors, developed at CERN and already tested on fusion devices [6] provide an optimal combination of design flexibility, high counting rates (>1 MHz) and low sensitivity to background radiation.



$\lambda \sim 40.555$ Å
$\theta_B \sim 12°$
$2d \sim 221$Å
$2R \sim 10$ m
$D_{CD} \sim 2$ m
$R_i \sim 10\%$
$L_c = 25$ mm
$h_{slit} = 1$ mm
Δx(plasma) ~ 20 cm

Fig. 2. Schematic cross section of the plasma and instrument lay-out

We have simulated the plasma conditions at ignition with parametric expressions for the magnetic equilibrium, plasma temperature and density profiles, and common assumptions of impurity concentrations and distributions. The X-ray radiation emitted by the core plasma is, in general, a combination of continuous bremsstrahlung and line radiation, while the emission from the plasma edge would be, in the case of Ignitor, mostly line radiation from Molybdenum. We have selected the electric dipole transition of Mo^{+14} at 50.444 Å, an isolated line well localized at the plasma edge, which has a reasonable transmission through Be windows. For this wavelength, diffraction can only be obtained by means of Multilayer Mirrors

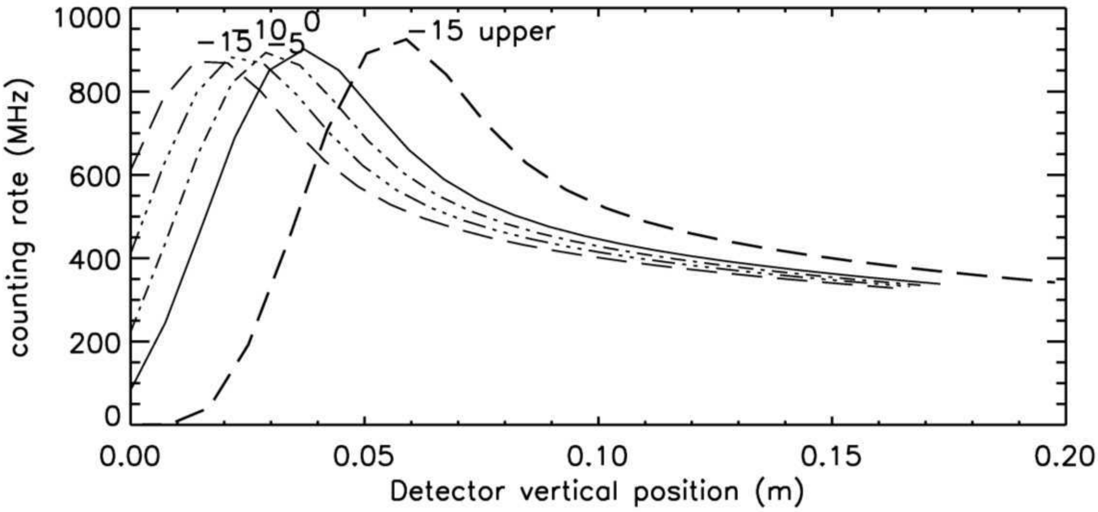


Fig. 3. Simulated signal of the Mo^{+14} line on the detector for different downshifted positions of the plasma column, as observed from the lower view, and one upper view

(MLM), given the shallow Bragg angles allowed by the port dimensions. One advantage of these materials is that they provide much higher reflectivity relative to natural crystals, of the order of 10%, thus ensuring the overall high throughput required for real-time measurements.

The line and the total emission were both estimated with the plasma in its reference position and with the plasma column vertically shifted downward in steps of 5 mm, with no changes of global plasma parameters. The corresponding signals on the detector are shown in Fig. 3. If a simultaneous measurement of the radiation emitted by the upper part of the plasma is considered, the sensitivity of this method can be assessed at few mm. The huge counting rate (probably somewhat overestimated) can certainly meet the requirements set by the control system. Other events could induce similar variations, for example a broadening of the temperature profile. Nevertheless, top-bottom asymmetries and time dependent variation of signals between adjacent channels can provide the necessary clues to distinguish between plasma movements and changes of plasma parameters.

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