Plasma Position Diagnostics for the Ignition Experiment Ignitor*

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Introduction

The ignition experiment Ignitor [1] will produce, in its high performance plasma regimes, a neutron flux at the first wall comparable to that expected in power generating reactors (10^{15} n/cm^2/s). As a consequence, traditional magnetic diagnostics may fail due to a considerable, although reversible, degradation of the coil inorganic insulators. The measurements of some fundamental plasma parameters, such as current and position, by means of electromagnetic diagnostics can thus be problematic. Light extraction and detection will also be more difficult than in present day experiments, since, in general, it will not be possible to place detectors in the proximity and in direct view of the plasma. The Ignitor project is addressing these problems with an R&D program aimed at the development of effective and affordable devices for electromagnetic diagnostics with higher damage threshold, in collaboration with SALENTEC and Università di Lecce. Prototype diagnostic coils of different shapes have been manufactured. At the same time, an alternative plasma position control method is being explored, based on the diffraction and detection of soft X-ray radiation emitted near the top or the bottom of the plasma column, where the distance of the Last Closed Magnetic Surface from the wall is only few millimeters. The underlying principles and general layout of this new diagnostics, which is essentially an adaptation of the 2-dimensional high resolution crystal spectrometer installed on FTU for ion temperature profile measurements, are described.

Electromagnetic diagnostics

The design of the full set of electromagnetic diagnostics for the Ignitor experiment and their integration with the plasma chamber has been completed. All the in-vessel pick-up coils for B_p and B_T fluctuation measurements, saddle coils (for magnetic flux), Rogowsky's (for plasma current), and diamagnetic loops (for stored energy) will be attached to the vacuum chamber behind the Molybdenum first wall tiles. Burning plasma experiments pose demanding conditions on the insulation materials used for magnetic measurements: high neutron and γ radiation fluxes increase the conductivity, and can cause electromotive forces and thermoelectrical sensitivity; good insulation has to be maintained at the kV level, while the vacuum vessel can reach temperatures up to 470 K during baking operations; electromechanical stresses caused by disruption events have to be sustained. In the special case of the Ignitor experiment, the coil design is challenged also by space requirements, with thin conductors (200μm) bent to small curvature radii (<6 mm) and reduced overall sizes. Commercially available pre-insulated ceramic wires (e.g. Ceramawire Ni) are not able to meet all these requirements; nonetheless, they provide a good starting material. We have aimed at improving the insulation quality by submerging the coil in a bath of magnesium oxide compound at elevated refractoriness, chemically inert, and neutron radiation resistant. Two prototype coils have been manufactured, of different design. In one case, the pre-insulated nickel coil is completely encased in a plastic alumina container (Fig. 1), which can be cast in any shape, also curved ones. A suspension based on Magnesium Oxide (MgO > 87.8%) and inorganic bindings is poured into the container, where the coil is placed; the suspension is kept drying for 24 hours in air at room temperature, and a sintering procedure is carried out at 1100°C in inert atmosphere of N_2 or Ar (treatment in air cause an increased brittleness of the Ni wire due to oxidation). The cover is sealed on the alumina container by means of glazes with high vacuum tightness. To guarantee an optimal sealing, the glaze is also baked at 1100°C. For the second prototype, the Ni wire was initially wound on one of the NSTX original rectangular Macor support, which proved unsuitable to sustain the subsequent high temperature treatments. A new support in alumina has been produced. After impregnation with the liquid magnesia suspension, a thick layer of Mg oxide/fiber was applied, and baked at 1100 °C (Fig. 2). This material can then be machined and finally a vitreous coating is applied for vacuum tightness.

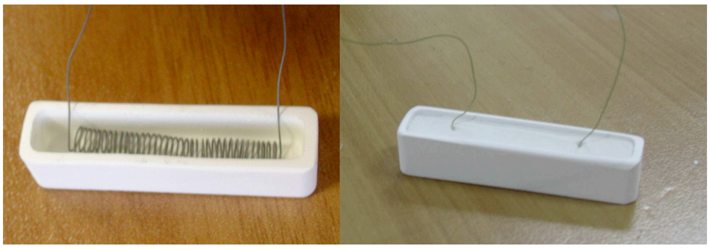

Fig. 1 - Cylindrical coil fully encased in a sintered alumina container.

Fig. 2 – Rectangular coil prototype (NSTX design): initial winding, MgO wrapping, and detail of the 2D reinforcing material in Alumina Nextel 610.

X-ray diagnostics for plasma position control

The control of the plasma position is crucial in Ignitor as for every elongated configuration. The capability of the Poloidal Field Coils system to provide an effective vertical stabilization of the plasma column has been investigated using the CREATE_L response model [2], also taking into account the possible failure of the relevant electromagnetic diagnostics. An additional means for monitoring the (vertical) position of the plasma column may be provided by the detection of the soft X-ray radiation emitted at the edge. This is a combination of continuous bremsstrahlung and line radiation that, in the case of Ignitor, is emitted mostly from Molybdenum. The Ignitor geometry allows the lower or upper sections of the plasma to be viewed from the horizontal ports. For the purpose of plasma position 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. A cylindrical Multilayer Mirror (MLM) placed at a suitable location inside the port can selectively diffract the radiation and focus it on a space resolving Gas Electron Multiplier (GEM) detector outside the vessel, not in direct view of the plasma, where the front-end electronics can be properly protected. The high counting rates allowed by GEMs allow the possibility to detect any plasma movement with sufficient time resolution to be used for real-time feedback control of the vertical plasma position. For radiation wavelengths of 20-50 Å thin Beryllium windows can still be used to separate the machine high vacuum from the rough vacuum in the detection arm attached to the external part of the port. The cylindrical Johann mounting is self-focussing in the (meridian) diffraction plane. In order to obtain a space resolved image of the plasma in the poloidal direction, a horizontal slit needs to be located between the MLM and the detector. The use of spherical mirrors is prevented, in the case of Ignitor, by the specific port geometry, but toric ones could be considered in successive optimization of the system design. In this first step we have defined the essential optical parameters of the spectrometer. Two possible types of measurement are considered: the first adopts two symmetrical spectrometers, looking at the upper and lower regions of the plasma, respectively. The shift in vertical position is then deduced as a difference between the two signal intensities at each time. The second method relies on the time evolution of the signal from a single system pointed either to the top or the bottom. This will require a more sophisticated algorithm to distinguish signal changes associated with position shifts from variations of the background plasma parameters, but it offers the advantage of a simpler construction. The X-ray emission for Ignitor plasmas at ignition, both in the nominal extended limiter configuration and for a shifted plasma limited at the bottom of the first wall, but otherwise same plasma parameters, have been simulated and line brightness profiles of the radiation impinging on the MLM are shown in Fig. 4. The variation in brightness for the electric dipole transition of Mo^{14+} at 50.444 Å appears to be as large as a factor of two, thanks to the very high sensitivity of the line emission to the temperature profile along the line-of-sight. The full optical path to the detector remains to be completed in order to estimate the spectrometer throughput, nevertheless these first results indicate that X-ray measurements may provide a complementary method for plasma position control, and possibly replace the electromagnetic diagnostics in case of radiation-induced failure of the latter.

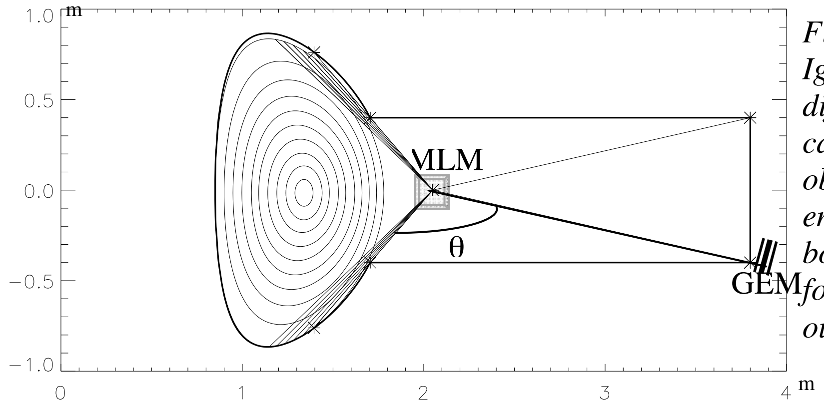

Fig. 3 – Cross section of the Ignitor horizontal ports. A diffracting element (MLM) can be placed in C to observe the radiation emitted at the top (and/or bottom of the machine and focus it onto detectors outside the vacuum vessel.

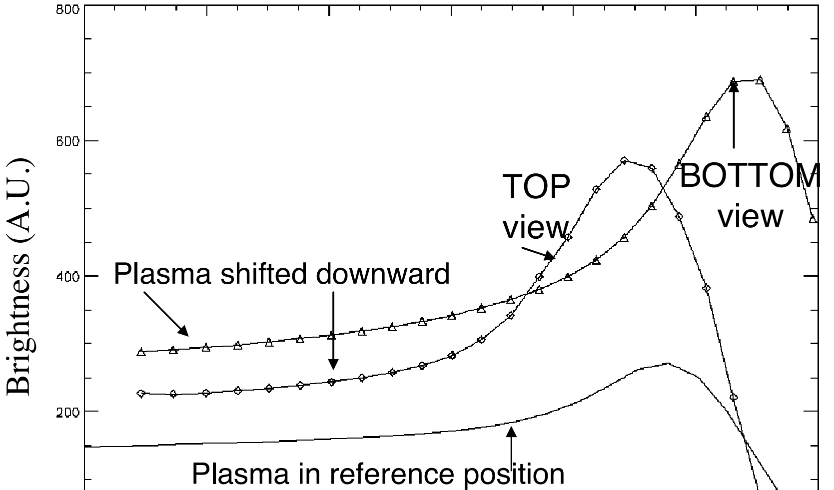

Fig. 4 – Brightness profiles for the Mo^{14+} dipole line at 50.444 Å, for the reference plasma position (solid line), and for the plasma column shifted to the bottom. The triangles refer to the lower view, the diamonds to the upper one.

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