Influence of the stray magnetic field on the neutral particle diagnostic performance

W. Schneider[1], M.R. Turnyanskiy[2], V.I. Afanasyev[3], F.V. Chernyshev[3], T. Richert[1]

[1]*Max-Planck-Institut für Plasmaphysik, EURATOM Association, Teilinstitut Greifswald, Wendelsteinstraße 1, D-17491 Greifswald, Germany*
[2]*CCFE / EURATOM Fusion Association, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, U.K.*
[3]*Ioffe Physical-Technical Institute of the Russian Academy of Sciences, 26 Politekhnicheskaya, St. Petersburg, 194021, Russia*

Introduction

A Compact Neutral Particle Analyser (CNPA)[1] has been deployed on the MAST tokamak and is later foreseen to be installed on the W7-X stellarator as a part of a multi-analyser neutral particle diagnostics to study ion heating and the energy distributions of the fast ions. In addition, the final W7-X NPA diagnostic set-up will include 2 ACORD-24 analysers. The residual magnetic field at NPA locations on both machines is expected to be in the range of 10-20 mT for typical discharge conditions. The presence of such stray magnetic fields can potentially distort the measurements and result in significant errors in the derived ions temperatures and energy distributions of fast ions. Thus, the influence of the residual magnetic field on NPA operation was studied and methods against this influence were considered.

Experimental

The planned experimental set-up of NPA diagnostics with its mechanical support structure at W7-X is shown in Fig. 1, consisting of two ACORD-24 analyser in the energy range from 0.3-100 keV for H and D atoms and one compact analyser CNPA in the energy range from 0.7-80 keV. The sight lines of these analyser can be directed from plasma core to the edge plasma. Active NPA measurements will be enabled at the crossing points of the diagnostic neutral beam with a local resolution of about 5 cm. The system can be moved between pulses which enhances the accuracy of ion temperature profile measurements. Fig. 2 shows the distribution of the stray magnetic field of W7-X at the height of analyser location, where the stray magnetic field reaches values up to about 10 mT. The experimental set-up of the NPA-diagnostics on MAST has been described in [2] - [3]. At MAST, the stray magnetic fields exhibit values up to 30 mT under special discharge conditions (Fig. 4).

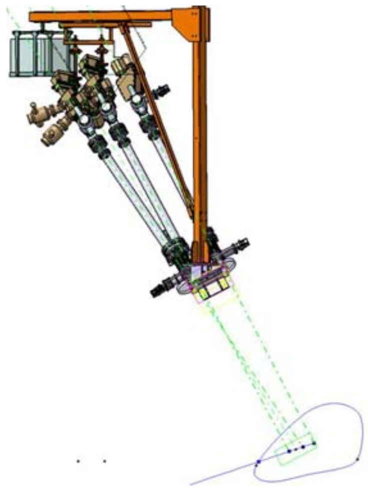

Figure 1: Set-up of the NPA analyser array at the W7-X stellarator

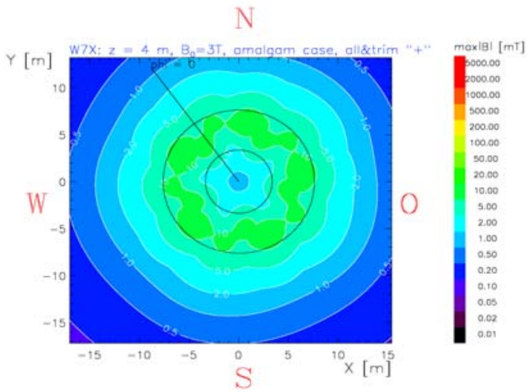

Figure 2: Magnetic stray field contour of W7-X for the plane z=4 m

Though first CX-NPA and CX-RS measurements on MAST have shown a relative good agreement of determined ion temperatures, the stray magnetic fields of MAST and the expected stray fields of W7-X must be considered for evaluation of NPA measurements [3] - [6]. The tolerable stray magnetic field for an undisturbed NPA operation amounts to 5 mT for the CNPA and only 2 mT for ACORD-type analyser. The results of measurements with unshielded analyser at the presence of higher stray fields can result in increasing errors for T_i determination.

Results

As a part of the studies in order to detect the influence of the residual magnetic field on NPA operation the poloidal, toroidal and vertical components of the stray magnetic field have been monitored during a MAST standard discharge using a fast Hall probe with time resolution of 1 kHz (Fig. 3). The main contributions of stray magnetic field were found during this discharge in vertical and radial directions, which have been caused by the poloidal coils P4 and P5. The toroidal contribution (B_z) was found to be lower than 3.5 mT.

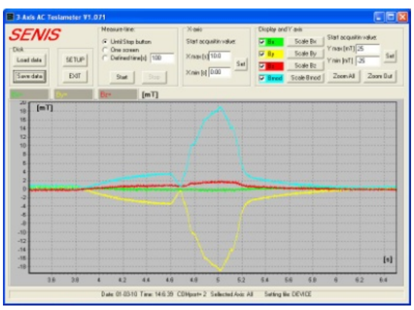

Figure 3: Temporal behaviour of Hall signals during MAST #24014 standard plasma discharge

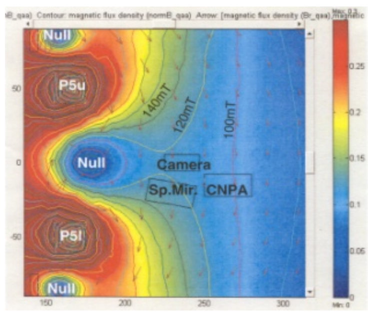

Figure 4: Contour of the magnetic flux density of MAST around CNPA location

In order to ensure reliable NPA measurements in the presence of higher stray magnetic fields the trajectories of H- and D-ions in the CNPA were modelled und the necessary shielding thickness of soft steel was calculated.

The following table shows the results of calculations for the 3 assumed outer stray fields of 30, 45 and 50 mT, respectively. The red areas represent an insufficient shielding, which means that the deviations of trajectories are much higher then the permissible ones. For outer stray magnetic fields up to 30 mT a shielding thickness of 6 mm soft steel can be considered as sufficient. The proposed shielding structure for a CNPA is shown in Fig. 5.

B_{stray} (mT) / Shielding thickness	$B_Y = 30$	**$B_Y = 45$**	$B_Y = 50$	$B_Z = 30$	**$B_Y = 45$**	$B_Z = 50$
5 mm	$D_Z = 2.2$		$D_Z = 5.7$	$D_L = 3.5$		$D_L = 11.5$
6 mm	**$D_Z < 2$**			**$D_L < 3$**		
10 mm	$D_Z = 0.2$	**$D_Z < 2$**	$D_Z = 2.5$	$D_L = 0.95$	**$D_L < 3$**	$D_L = 3.5$

The influence of an outer stray magnetic field on an ACORD 24 analyser has been tested in a Helmholtz coil set-up with W7-A coils. Because of an insufficient shielding of the turbo pumps of the ACORD analyser, the outer magnetic field could only shortly increased to about 15 mT. The necessary changes of parameter sets for analyser voltage and magnet current with and without the outer magnetic field have shown, that the shift of trajectories of studied K+ ions, emitted form a thermal source of alkali ions located behind the entrance of the analyser, is greater than 6 mm in direction parallel to the detector rows. This shows clear, that an ACORD-24 analyser will not operate without disorders at the presence of stray magnetic fields up to 15 mT. This yields increasing errors regarding T_i-determination.

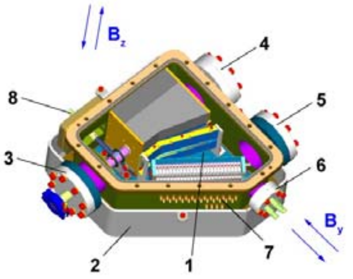

Figure 5: Proposed magnetic shielding of CNPA (1 – CNPA; 2 – magnetic shielding ; 3,4,5,6 – CNPA flanges; 7,8 – cable feedthroughs)

Figure 6: Helmholtz coil set-up with W7-A coils for testing an ACORD-24 analyser in an outer magnetic field

Summary and outlook

Stray magnetic fields greater than 5 - 10 mT cannot be neglected during NPA-measurements with unshielded analyser. After MAST upgrading and during its later deployment on W7-X the CNPA should operate with an additional magnetic shielding using ARMCO material (soft steel) with a thickness of about 6 mm. The ACORD-24 analyser, which are more sensitive against stray magnetic fields cannot sufficiently be shielded because of their shapes and the needs of two turbo pumps for differential pumping in order to realise the N_2-stripping. In any way, the shielding of ACORD-type analyser would be more complicated compared to the CNPA. Because of these reasons the CNPA is foreseen for a reliable measurement of ion temperature of the core plasma, whereas the results of ACORD analysers should be fitted to the CNPA result in order to get ion temperature profiles. The NPA arrangement is adjustable in such a way, that the sight line of one ACORD-24 can be directed to the same point of impact with the diagnostic beam as the sight line of the CNPA. In future, an exchange of ACORD analyser toward CNPA is foreseen for the NPA diagnostics at W7-X.

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