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S. Baeumel, A. Werner, R. Semler, S. Mukherjee, D.S. Darrow, F.E. Cecil, L. Pedrick, H. Altmann, V. Kiptily, J. Gafert, and JET-EFDA Contributors

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S. Baeumel[1], A. Werner[1], R. Semler[1], S. Mukherjee[1], D.S. Darrow[2], F.E. Cecil[3], L. Pedrick[4], H. Altmann[4], V. Kiptily[4], J. Gafert[4], and JET-EFDA Contributors[*]

[1]*Max-Planck-Institut fuer Plasmaphysik EURATOM-Association, Wendelsteinstr.1, 17491 Greifswald, GER*
[2]*Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ, USA*
[3]*Colorado School of Mines, 1500 Illinois St., Golden, CO 80401, USA*
[4]*UKAEA/Euratom Fusion Association, Culham Science Center, OXON, UK*
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ABSTRACT
Good confinement of alpha particles in a large magnetic fusion device is a precondition for building a magnetic fusion reactor. The direct measurement of alpha particle losses is of particular interest. Appropriate diagnostics are now being prepared for the JET tokamak: a scintillator probe and a set of Faraday cups. Both systems are capable of measuring fast ions and ICRH tail ions. The design of the lost alpha particle scintillator probe is in the scope of this paper. It will allow the detection of particles with a gyroradius between 20 and 140mm (15% resolution) and a pitch angle between 30 to 86^{o} (5% resolution). As scintillating material P56 will be used. The light emitted by the scintillator caused by charged particles that pass the collimator and hit the scintillator will be detected via a set of optical lenses and a coherent image fiber bundle with a CCD camera and a photo multiplier array. In the following the present design of the scintillator probe with emphasis on the performance of the system, structural resistance against plasma disruptions and the requirements on the heat protection against plasma and neutral beam induced thermal loads will be described.

1. INTRODUCTION
The motivation for alpha particle experiments is to make an initial assessment of the prospects for sustained alpha particle heating of an ignited or burning plasma. Ignition in a DT plasma requires that a substantial fraction of 3.5MeV alpha particles created in the fusion reaction $D+T \rightarrow n(14.1MeV)+\alpha(3.5MeV)$ should remain confined sufficiently long to thermalize within the plasma. Assuming a classical thermalisation this normally means a large number of alpha particle transits around the machine (huge trajectory lengths). An overview on results and upcoming possibilities of these measurements can be found for example in [1–3]. The two new fast ion diagnostics - the scintillator probe and the Faraday cup array - now being prepared for installation at JET for future experimental campaigns will extend the measurement capabilities of the formerly installed fast ion diagnostic Kα 1 [4–6] and replace it. The scintillator probe diagnostic (see Fig. 1) is based on the design of similar diagnostics installed in the past for example at TFTR and W7-AS [7–9] and will be described in the following.

The basic principle of this type of diagnostic is illustrated in Fig. 2. Charged particles in the magnetic field B that can pass the collimator will hit the scintillator plate. The collimator is chosen such, that charged particles with certain gyro radii (particle energy) and pitch angles can hit the scintillator plate. The light emitted from the scintillator plate will be transmitted via optical lenses and a coherent image fibre bundle. Finally the image will be detected by a CCD camera and by a photomultiplier array.

2. DIAGNOSTIC SET-UP
In the following the set-up of the lost alpha particle scintillator probe will be described. The envisaged performance, the design of the collimator set-up, the poloidal and radial positioning will also be addressed as its consequences - i.e. the necessary protection of the diagnostic against electromagnetic forces and the heat load deposited on the diagnostic.

2.1. ENVISAGED PERFORMANCE

The sensitivity of the system will range from 20 to 140mm in gyro radius and 30 to 86^{o} in pitch angle. The resolution which the diagnostic aims at is a pitch angle resolution of 5% and a gyroradius resolution of 15%.Besides the pitch angle and the energy information, the current flowing through the scintillator plate which is caused by the particles hitting the plate will be measured with an ADC. The dynamic range of this measurement will be 10pA/cm^2 to 1μA/cm^2.

2.1. COLLIMATOR SET-UP

The actual design of the probe head starts with deriving the boundary surfaces of the probe head that allows the transmission of ions with velocities almost perpendicular to the field lines. A Monte-Carlo simulation code that has been used for the design of the fast escaping ion probe of the Wendelstein 7-AS stellarator (EfipDesign [9]) was modified for the JET tokamak. With this code boundary shapes can be defined, the shape and position of the scintillator can be derived and the expected resolution and sensitivity of the system can be calculated. The latter depends on the combination of the entrance collimator and the scintillator alignment relative to it. After several iterations an optimum collimator set-up has been found, which allowes the realization of the desired resolution mentioned above.

2.3. TOROIDAL AND RADIAL POSITIONING

From the physics point of view a lost alpha particle diagnostic should to be placed as close as possible to the plasma edge. Therefore, the integration of that kind of diagnostic into any limiting structure (e.g. CFC limiter tile) would be most favourable. As a sideeffect constraints about any kind of loads would nearly vanish. However, since it was not possible to integrate this diagnostic into a limiter tile at JET another position had to be found. This process of finding an appropriate position for a lost alpha particle diagnostic is basically a search for the right balance between high ion fluxes and low heat loads. The suitable toroidal position for the scintillator probe was the lower limiter guide tube of octant 4 since this port is close to a poloidal limiter and in near the midplane.

In order to find the optimum radial position of the diagnostic simulations of particle trajectories were performed. These simulations make the dependence of the ion fluxes on the limiting structures in the close vicinity of the diagnostic quite obvious (see Fig.4). Figure 4(a) shows the model of octant 4 with the scintillator probe, limiting structures in this octant, a poloidal limiter and a sample trajectory. In Figs.4 (b),(c) and (d) the trajectory length of particles passing the entrance aperture of the scintillator probe is plotted on a logarithmic scale as a function of energy and pitch angle for Pulse No:52732. Without any limiting structure particles with large trajectory lengths will be collected by the scintillator probe (Fig.4(b)). The effect of structures within the vacuum vessel that are very close to the plasma edge on the particles that will be collected by the scintillator probe can be seen in Fig.4(c).

Some particles hit these structures and won't contribute to the signal detected by the scintillator probe diagnostic. If these structures are moved radially backwards towards the vessel wall for 10mm almost all particles that were blocked before are visible for the diagnostic again (Fig.4(d)). These simulations were performed for several other types of discharges, especially those envisaged for future campaigns (high field/high plasma current). As a result of these simulations together with constraints about a safe operation it was found, that the front face of the scintillator probe has to be 5mm behind the nearby poloidal limiter. This position meets the requirements for a safe operation and allows sufficient lost alpha signal for many different scenarios.

The chosen toroidal and radial position of the lost alpha particle scintillator probe has two major drawbacks: huge electromagnetic forces due to halo- and eddy-currents and high heat loads due to the closeness of the neutral beam injector. These two constraints will be discussed in the following.

2.3.1. Electromagnetic forces

Since the diagnostic has to be positioned close to the front face of the poloidal limiter, it will protrude quite far into the vessel. Therefore, the amount of Eddy- and Halo-currents collected by the large area offered by the probe assembly will lead to enormous forces onto the tube due to the ExB interaction of these currents with the strong magnetic background coming from the toroidal field coils. First estimates of the electromagnetic forces revealed extremely large loads in the order of 30 tons onto the periscope. A more detailed analysis of a disruption by using the model shown in (Fig.5(a)) confirmed the magnitude of these forces. A gap between the limiter guide tube and the tube of the scintillator probe of 3mm (in diameter) resulted in a maximum displacement of the probe tip of about 7mm (Fig.5(b)). The acceleration of the probe along this short gap is high enough to cause von Mises stresses of 2.5GPa in the lower limiter guide tube (Fig.5(c)) and 214MPa at the probe (Fig.5(d)). These simulations make obvious, that the gap between the scintillator probe and the limiter guide tube has to be as small as possible in order to allow a safe operation of the system.

2.3.2. Heat load

Since the probe is located near one of the neutral beam injector lines (see Fig.6) that deposits heat load on the side of the diagnostic a heat protecting concept had to be found. The heat load coming from the neutral beam injector can add up to a maximum heat load of 13.2MW/m^2 on the scintillator probe. The convective heat load coming from the plasma is of about the same order of magnitude. A rather sophisticated shape of a heat protection cup made of CFC material was found, taking into account the needs of the collimator set-up chosen before. In Figure 7 simualtions of the temperature distribution on the cup with maximum heat load coming from the neutral beam injectors and the plasma is shown. The peak temperature after a 10s discharge is 748^{o}C. At the beginning of the next shot the temperature of the probe does not reach the initial value by passive cooling. This leads to temperature ratcheting. Since the temperature of the scintillator (P56) should be limited to about 400^{o}C it was decided to install an active water cooling system in order to protect the diagnostic.

2.4. DETECTION SYSTEM

The scintillator light will be transmitted via a set of lenses and a coherent image fibre bundle attached to the end of the scintillator probe tube to a beam splitter in the diagnostic hall about 77m away from the diagnostic. This light will be detected by a CCD camera (ANDOR EMCCD) and a photo multiplier tube array (Hamamatsu). The current flowing through the scintillator plate and caused by particles hitting the scintillator plate will be measured in an ADC of the Farday cup system.

SUMMARY

A scintillator probe diagnostic is being built for lost alpha particle measurements at JET. Besides lost alpha particles it will also be able to measure other fusion products and ICRH tail ions. This diagnostic will allow the detection of particles with a gyroradius between 20 to 140mm and a pitch angle between 30 to 86^o. The pitch angle resolution will be 5% and a the gyroradius resolution 15%. Due to its radial and poloidal position it needs a tight fitting support, a heat protection cup and an active water cooling system.

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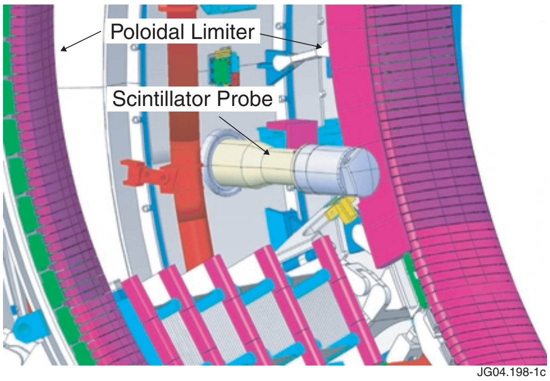

Figure 1: Schematic view of the scintillator probe installed in JET. The probe is located in octant 4 close to the poloidal limiter.

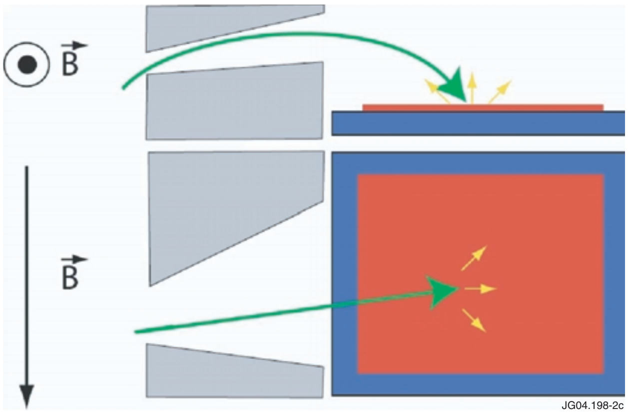

Figure 2: Basic principle of scintillator probe measurements. Charged Particles that can pass the collimator set-up in the magnetic field B will hit the scintillator plate. This will consequently lead to a emission of light with a certain wavelength, which finally is detected and gives information on the energy and pitch angle of the particle.

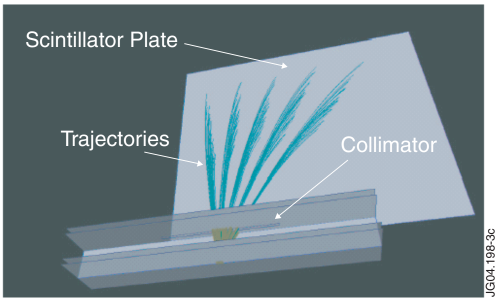

Figure 3: Collimator set-up. The basic limiting structures and the scintillator plate together with particle trajectories for different energies and pitch angles are shown.

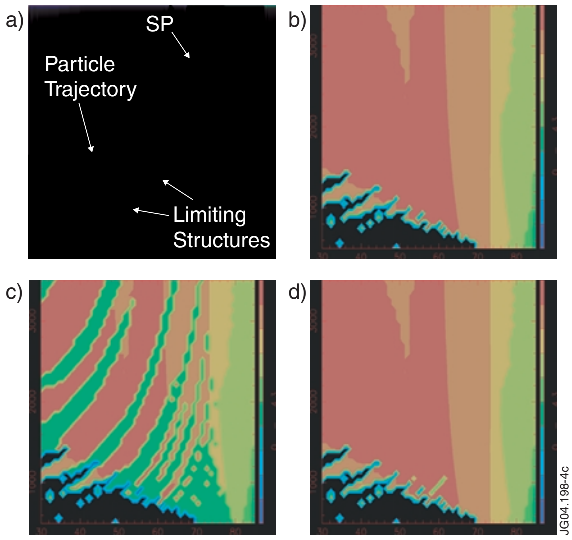

Figure 4: a) Pulse No: 52732. Model for limiting structures within the vacuum vessel. b) Particle trajectory length without limiting structures. c) Particle trajectory length with limiting structures. d) Particle trajectory length with limiting structures pulled 10mm radially backwards.)

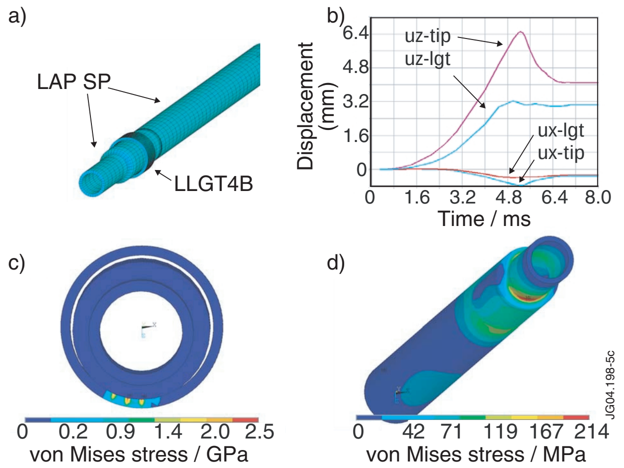

Figure 5: Simulation of electromagnetic forces onto the probe during a disruption. a) Model of the probe tube together with the contact ring of the vessel in the lower limiter guide tube. b) Displacement of the probe tip and a point near the limiter guide tube in x- and z-direction. c)Von Mises stress at the contact ring. d) Maximum von Mises stress at the tube.

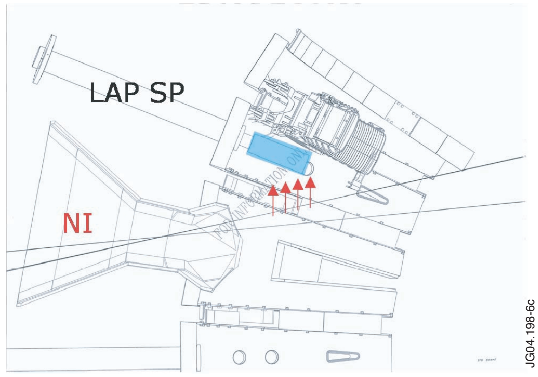

Figure 6: Top view of the midplane crossection of octant 4. The scintillator probe (LAP SP) is located near the neutral beam injector line in octant 4 (NI), which deposits up to 13.2MW/m^2 heat load.

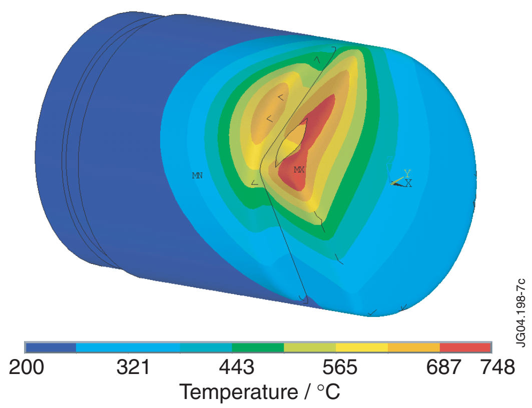

Figure 7: Temperature distribution on the heat protection cup. The maximum temperature after one discharge reaches 748^{o}C.