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ABSTRACT

In a future magnetic fusion reactor alpha particles will be utlilized for plasma heating. In order to achieve a high efficiency of this process the aim has to be a good confinement of alpha particles. Therefore, direct measurement of alpha particle losses is of particular interest. Two diagnostics are being prepared for the JET Tokamak that are targeting on exactly this subject: a scintillator probe and a set of Faraday cups [1]. These systems are capable of measuring ICRH tail Ions and charged fusion products. The scintillator probe aims to allow the detection of particles with a pitch angle between 30° to 86° (5% resolution) and a gyroradius between 20 and 140mm (15% resolution). The Faraday cup array will detect the current of fast ions at multiple poloidal locations, with a dynamic range of 1 nA/cm^2 to 100 A/cm^2 at a temporal resolution of 1ms. For 3.5MeVparticles the energy binning of the foil detector will be 15 -50% of the full energy depending on the geometry of the individual collector. The experience in operating both diagnostics in a high temperature and high radiation environment will give valuable information in preparation for the design of similar diagnostics for future fusion devices. This paper covers the design and engineering of both diagnostics together with their envisaged performance.

INTRODUCTION

The driving force behind 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 (about one second) to thermalize within the plasma. Assuming a classical thermalisation this normally means a large number of alpha particle transits around the machine. An overview on results and upcoming possibilities of these measurements can be found for example in [2–4]. The scintillator probe diagnostic (see Figure 1) is based on the design of similar diagnostics installed in the past for example at TFTR and W7-AS [8–10]. The Faraday Cup system is based on the concept of thin Faraday foil experiments (see Figure 4), similar to the Kα 1 system[5–7] employed during the first JET DT experiments.

1. SCINTILLATOR PROBE

1.1. PRINCIPLE

The underlying principle of scintillator measurements is the emission of light by a scintillating material (here: P56, Y_2O_3 : Eu) after particles hit this material. A selection criteria for the particles that hit the scintillator is introduced by using a set of collimators within the magnetic field of JET. By the external magnetic field and the collimator set-up the particles get discriminated with respect to their energy resp. gyro radius and their pitch angle. An optical arrangement within the scintillator probe is used to transfer the light emitted by the scintillator towards a coherent fiber bundle, a CCD camera and a photomultiplier array.

1.2. PERFORMANCE

Located in the lower limiter guide tube of octant 4B and about 28cm below the midplane the tip of the scintillator probe is only five millimeters behind the front face of the nearest poloidal limiter. The set-up of the diagnostic within the vacuum vessel is shown in Figure 1. Simulations of particle trajectories have shown, that this exposed position will allow the scintillator probe to detect fusion products with trajectory lengths of more than 100m. For example 3.5MeV α-particles with a gyro radius of about 77 mm at a toroidal magnetic field of 3.5T will be detectable with the chosen arrangement. The diagnostic will have a sensitivity of 20 to 140mm in gyro radius and 30 to 86° in pitch angle. The resolution of the developed collimator set-up is a pitch angle resolution of 5% and a gyroradius resolution of 15%. Together with this information the total current caused by particles hitting the scintillator plate (acts in principle like a Faraday foil collector) will also be recorded. The dynamic range of this measurement will be 10 pA/cm^2 to $1\mu A/cm^2$. Figure 2 gives an indication of the performance of the system by showing the -counts versus different radial positions for plasma parameters taken from different shots of the JET DT campaign. The expectation of a decrease of the signal level with an increase of the radial position along the major radius is confirmed by these calculations. For the development of the diagnostic vignetting effects caused by other in-vessel installations near the plasma edge within the two nearby poloidal limiters were also well-investigated.

1.3. DESIGN DETAILS

At the development of this diagnostic a lot of effort was invested in concerns about the high heat flux and the high structural loads onto the probe due to it’s exposed location near the plasma. Additionally the high heat fluxes from the plasma together with a heat load of about $13MW/m^2$ by the nearby neutral beam injector made a sophisticated design of the heat protection cup necessary. This process was alos accompanied by finite element calculations. Therefore CFC material from Carbone Lorraine was chosen in order to give the protection shield the necessary heat resistance and strength. Although the scintillator may withstand temperatures up to 1000°C, an active watercooling system was also integrated into the design of the diagnostic in order to prevent glowing. Finite element calculations were also necessary to determine the impact of Halo- and Eddycurrents, which interact with the background magnetic field of JET and finally cause huge stresses at the support of the scintillator probe. It was shown, that a gap of three millimeters between the tube and the support of the tube results in stresses of about 2.5GPa acting onto the tube. Even in the case of no clearance a load of about five tons will act onto the tube. Figure 3 shows the final design of the support as chosen by the operator. A set of spring washers will be used in two of four positions along the circular circumference of the scintillator probe. These Inconel 718 spring washers will ensure a permanent preload onto the tube and therefore reduce any additional loads coming from the jxB forces mentioned above. The spring washer concept prevents the scintillator probe of being able to accelerate. The pads which touch the housing tube are made of Al-Bronze in order to avoid cold welds.

2. FARADAY COLLECTORS

The fifteen Faraday foil collectors will be located in octant 7 on different radial and poloidal positions close to the plamsa. The Faraday cups are spread over a poloidal section between z=0 and 80cm below the midplane. Radially the detectors are equally spaced on three locations between 25 and 85 mm behind the adjacent poloidal limiter. Figure 5 shows the integration of the Faraday cup array into the JET fusion experiment. Due to the closeness of the system to the plasma edge it was also necessary - similar to the scintillator probe system - to install CFC tiles. In the case of the Faraday cups the protection tiles have the shape of a mushroom. Each detector consists of at least four 75mm x 25mm Ni foils (2.5µm thin) which are seperated by phlogophite mica electrical insulating foils (also 2.5µm thin). The set-up of the Faraday cup array is shown in Figure 5. Each of the five different poloidal positions can be identified by the CFC tile that is located in front of the detectors.

2.1. BASIC PRINCIPLE

The basic principle of Faraday foil collectors is the penetration of charged particles through a stack of conducting foils, which are seperated by insulating foils (see Fig.4). Depending on the particle energy they can pass a certain number of foils before they are stopped in one foil and cause a current signal. The detection of the temporal evolution of the current signals of all foils in the radially and poloidally distributed detectors results in a map of particle energies at different locations near the plasma.

2.2. ENVISAGED PERFORMANCE

The current signal of each conducting layer will be transmitted via superscreened cables from within the torus towards the ADCs located in the diagnostics hall. They will allow the detection of signal levels of about 0.5nA and result in a temporal resolution of about 1ms. The energy resolution at which the system aims is between 15 to 50% depending on the exact geometry of the foil and aperture. In order to quantify the performance of the array simulations with former JET experimental data were performed. The result is indicated in Figure 6, where the signal current is plotted versus the poloidal position of the detector (in degrees) for different types of shots. These simulations show a decrease of the signal current with increasing poloidal position. In most of the considered shot scenarii the system will provide information on the current caused by fast ions hitting the detectors.

2.3. DESIGN DETAILS

A detailed picture of the set-up of a single detector was already shown in Figure 4. Besides the Ni and mica foils also the front plate is shown there. Due to the heat load of the ICRH tail ions and the charged fusion products that hit the different layers of each detector, this front plate consists of an array of 3mm diameter circular holes. Therefore, the temperature of the foils will be less than about 900°K.

Besides the reinforcement of the existing support for the Faraday cup array, a lot of effort was made in the design of the cable conduit, which is flexible during installation, but becomes rigidwhenpluggedinthefeedthroughlocatedatthevesselwall.

Another constraint coming from the existing surrounding of the location within the JET vessel was the choice of the direction of the entrance apertures of each detector. Close to the position of the Faraday cup array a Beryllium evaporator is located. This together with the possibility of dust accumulation could cause a screening of the entrance aperture and finally disturb the measurement. Consequently the normal to the aperture plane was tilted away from the vertical in both, the radially outward and toroidally counterclockwise directions.

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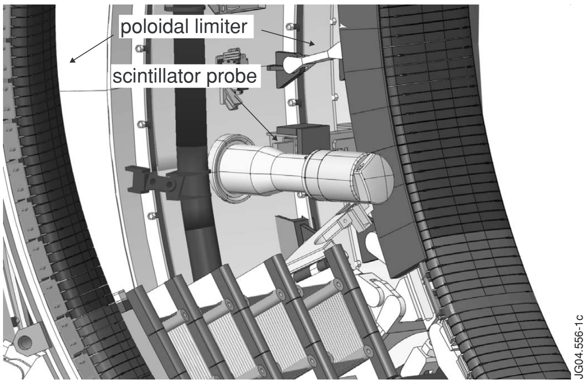

Figure 1: CAD view of the scintillator probe installed in JET. The probe is located in octant 4 close to a poloidal limiter.

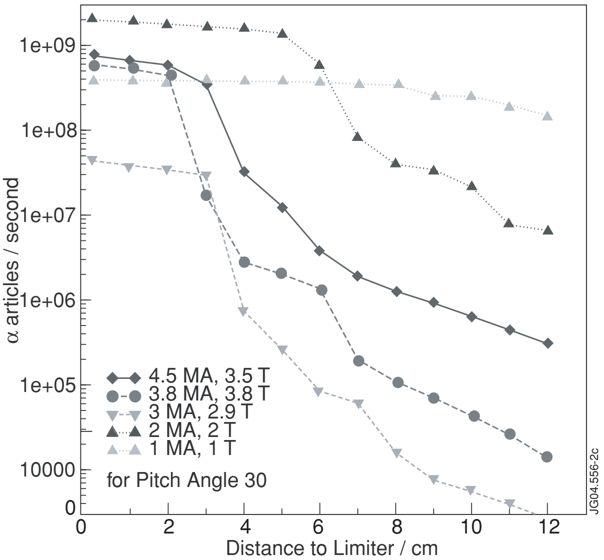

Figure 2: Simulated performance of the scintillator probe diagnostic. The expected α counts are shown for different radial positions and types of shots.

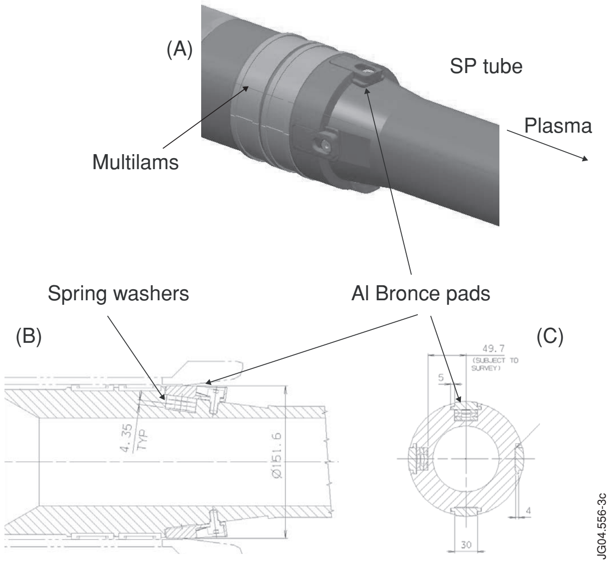

Figure 3: Support structure of the scintillator probe. (A) schematic view of the support structure near the end of the JET housing tube. (B) Cross section in radial direction showing two of the spring washer arrangements together with the Al-Bronze pads. (C) Circular cross section indicating the position of the four supports that are used to ensure 0mm clearance between the lower limiter guidetube and the diagnostic tube.

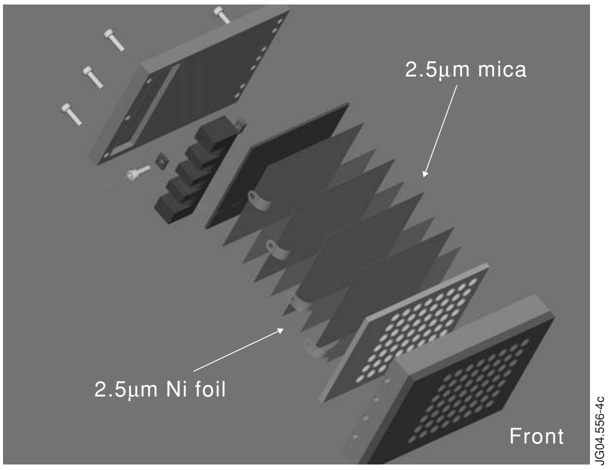

Figure 4: Detailed view of the set-up of a single Faraday cup.

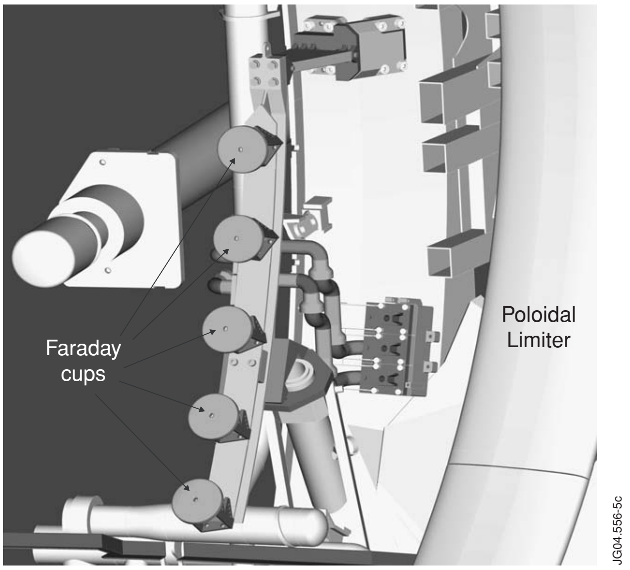

Figure 5: Schematic view of the arrangement of the Faraday cup array. The system is also placed in octant 7 close to a poloidal limiter.

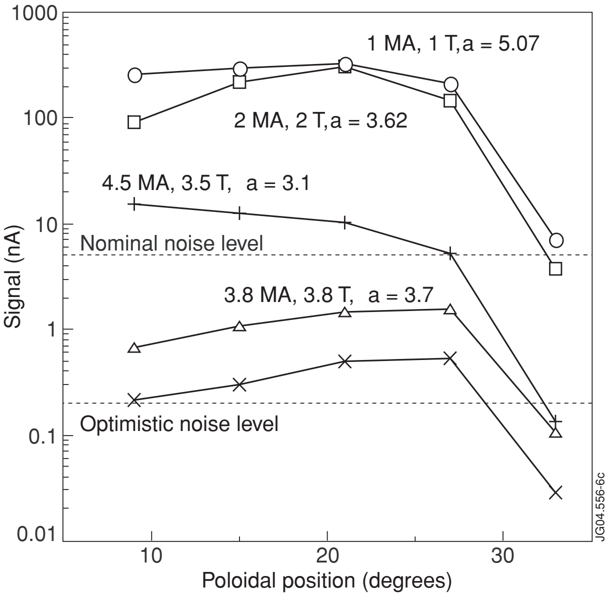

Figure 6: Diagram of the simulated performance of the Faraday Foil Collector array. The graph indicates the current signal versus the poloidal angle for different shot scenarii. The nominal noise level together with the optimistic noise level derived from experiments on former fusion devices is also shown.