Feasibility study and physics performance of a fast-ion loss diagnostics for the JT-60SA tokamak

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INTRODUCTION

A good fast-ion confinement is essential for a self-maintained burning plasma. However, several transport mechanisms, such as Magnetohydrodynamic (MHD) instabilities [1] and externally applied magnetic perturbations [2,3] can lead to a significant and premature fast-ion loss and redistribution. Fast-ion losses are undesirable, not only because they imply plasma energy and momentum reduction, but also because they can damage the plasma facing components within the machine [4]. Furthermore, in the case of JT-60SA, where the plasma current will be driven by fast-ions injected by the 500 keV Negative Neutral Beam Injector (N-NBI), their losses will imply a deficit in the current drive.

Scintillator based Fast-Ion Loss Detectors (FILD) are used to study fast-ion losses in almost all major fusion devices [1,5,6]. In particular, JT-60SA will operate in scenarios with a large fraction of fast-ion pressure and a FILD detector will be used to assess the direct wave-particle interaction of fast-ions with MHD instabilities such as Alfven eigenmodes, fishbones, neoclassical tearing modes (NTMs), resistive wall modes (RWM), etc. Also, edge 3D field effects on fast-ions, like edge localized modes (ELMs), error field correction coils (EFCC) and resistive wall modes correction coils (RWMCC), will be analyzed using this diagnostic.

In this work, the conceptual design of the JT-60SA FILD is described. Also, a feasibility study dealing with important aspects, such as the expected signal and the thermo-mechanical behavior of the detector during the tokamak operation, is presented.

THE JT-60SA FILD CONCEPTUAL DESIGN

The JT-60SA FILD will be located in sector 15, slightly below the midplane, as shown in Fig.1. FILD works as a magnetic spectrometer, using the magnetic field within the machine to collimate and disperse the escaping ions onto a scintillator plate, located into the probe head. The velocity-space of the particles hitting the scintillator can be determined by imaging the light pattern emitted. To that end, an optical relay will be used to transmit the light to two different acquisition systems: a high spatial resolution camera and a fast camera/detector providing the high temporal resolution needed to resolve high frequencies associated to MHD instabilities.

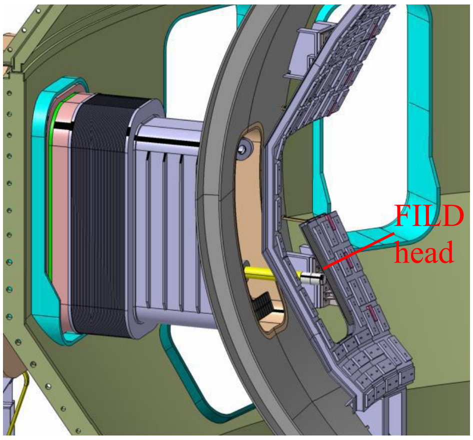

Fig.1. Overview of the JT-60SA FILD, located at the sector 15.

The diagnostic will be mounted on a reciprocating arm, so its radial position can be adjusted. The optimal radial position will be determined by a proper balance between signal and thermal load.

SIGNAL ESTIMATION

Preliminary simulations using the Monte-Carlo full orbit code ASCOT [7] have been performed to estimate the fast-ion losses. For that, the power deposited by fast ions on the probe head has been evaluated for different radial positions of the detector, as can be observed in Fig.2. The results show that significant fast-ions losses are expected at the FILD head, even without overcoming the radial position of the stabilizing plate (limiter).

The simulations have been performed for scenario #2 using a realistic 3D wall and including all the NBIs as fast-ions source. Also, resonant magnetic perturbations (RMP) have been included using a standard error field correction coils (EFCC) configuration (n=3 perturbation, with upper and lower coils shifted 120º, energized with a maximum current of 30 kA). The inclusion of this external perturbation allows enhancing the losses, thereby mimicking the behaviour of the MHD perturbations.

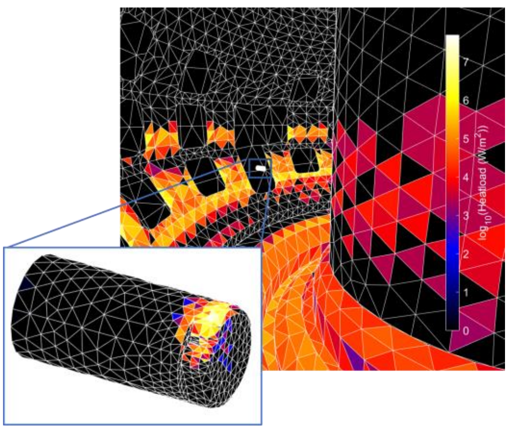
Fig.2. Power deposited by fast-ions in the JT-60SA wall and FILD head (detail).

Furthermore, the synthetic signal of the detector, shown in Fig.3, has been estimated using the FILDSIM code [8]. This code allows

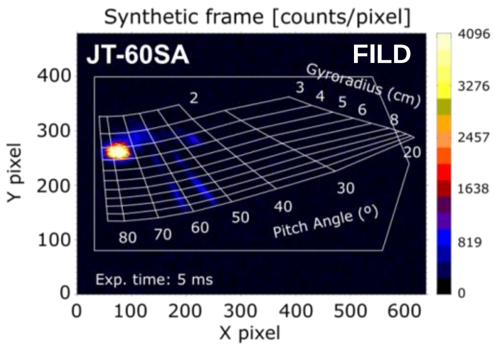

Fig.3. Synthetic signal of the JT-60SA FILD.

optimizing the probe head geometry (collimator, scintillator and graphite protection) by obtaining the strike map in the scintillator plate and estimating the spatial resolution both in pitch angle and gyroradius (which is equivalent to the particle´s energy).

The probe head geometry has been optimized to provide the maximum resolution for escaping deuterium ions injected by the N-NBI but also allowing to detect losses of ions produced by the 85 keV positive NBIs.

PRELIMINARY THERMO-MECHANICAL ASSESSMENT

The structural integrity of the JT-60SA FILD has been assessed to determine the impact of disruptions on the detector and the thermal behavior of the probe head when exposed to the plasma heat load.

During disruptions, the JT-60SA plasma current decays from 6 MA to 0 MA within 4 ms. The associated time-variation of the vertical magnetic field (dB_z/dt) will induce rectangular Eddy current loops in the probe head support, as shown schematically in Fig.4. This current loop, in combination with the toroidal magnetic field (B_t) will lead to torsional forces (X-torque) on the support. This torque depends on the induced current (magnitude and loop area) and on the toroidal field, and might become significant. Simulations results, also represented in Fig.4, show that for the estimated torque (7 kN·m for 8 kA induced current and $B_t = 2.3$ T), the maximum equivalent stress (Von Mises) induced in the support is 90 MPa, 3 times below the allowed stainless-steel elastic limit.

The probe head thermal behavior has been analyzed via transient thermal simulations for a 41 MW injection power scenario. In this case, at the stabilizing plate level, the head will be subject to 0.3 MW/m^2 heat flux (considering radiation from the plasma core, edge and SOL). The results from this study (see Fig.5) show that FILD can measure for more than 20s without reaching non-operational temperatures.

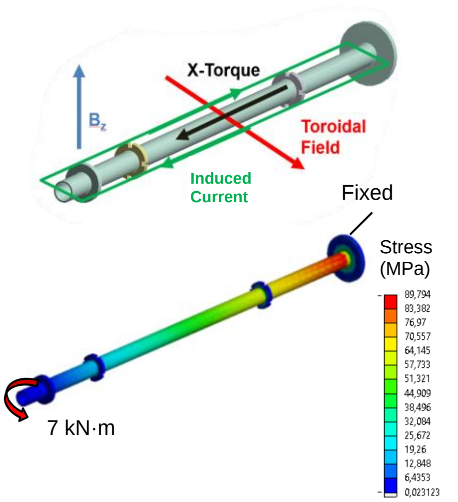

Fig.4. Response of the FILD head support against plasma disruptions

CONCLUSIONS AND FUTURE WORK

A feasibility study has been performed for the FILD diagnostic for JT-60SA, considering the expected signal and the thermo-mechanical behavior of the detector. Preliminary fast-ions simulations show good signal level expected at FILD without overcoming the stabilizing plate radial position. The system will withstand forces derived from disruptions and, in measurement position, FILD will resist the thermal load for several seconds, allowing for different operation cycles.

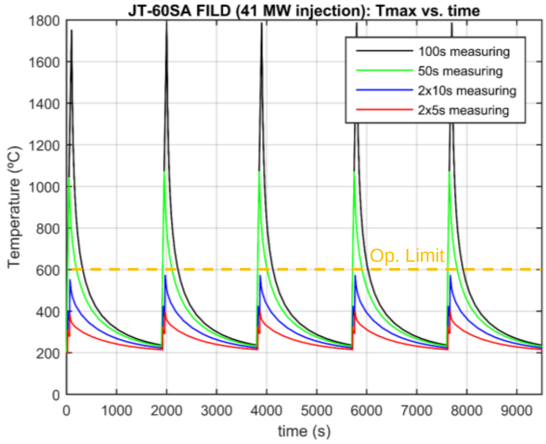

Fig.5. FILD head maximum temperature for different operation cycles.

Further studies will focus on refining the structural analysis while considering the port plug geometry, Halo current effects and load combinations. The thermal analysis will also be refined to include the heat load from fast-ions impacts and additional fast-ions simulations will be performed to estimate the expected signal for other scenarios with different combinations of heating methods and external magnetic perturbations.

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