Final design of the JT-60SA fast-ion loss detector

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Understanding and mitigating MHD instabilities driven by energetic particles is critical for advancing tokamak performance in future fusion reactors. JT-60SA provides a unique platform for exploring these phenomena under DEMO-relevant conditions, leveraging its 500 keV super-Alfvénic Negative Neutral Beam Injection (N-NBI) for off-axis current drive and heating. The fast-ion loss detector (FILD) presented here plays a key role in this effort, offering high-resolution measurements in both time and velocity space, enabling detailed characterization of fast-ion transport and confinement losses.
Fast-ion fluxes at the probe head are modeled using full-orbit ASCOT code simulations, considering various probe insertions, axisymmetric fields, toroidal field ripple, and configurations of the error field correction coils. The collimator and probe head geometry have been optimized using the FILDSIM code to maximize signal-to-noise ratio and velocity-space resolution for both 500 keV N-NBI and conventional 85 keV NBIs.
The probe head operates dynamically, moving 70 cm during the plasma discharge between a position exposed to fast-ion fluxes and a retracted location inside its port plug. This motion is enabled by an in-vessel worm gear linked to an ex-vessel servo motor unit enclosed in a Faraday cage. The scintillator temperature is reduced by a passive heat exchanger that combines copper and vespel to maintain electrical insulation against halo currents during its operation. An optical relay system, spanning ~4 m, transmits scintillator light to an ex-vessel charge couple device (CCD) camera and a 4x4 fiber bundle. The direct visualization of the scintillator by the camera enables optimal velocity-space tomographic reconstructions. The fibers transfer the light to the radiation-free basement, where a set of PMTs provide super Alfvénic (~2 MHz) time resolution. Prototype performance for optical relay, CCD and PMT signal conditioning, and data acquisition has been simulated and validated against electronic models.
Acceptance tests under ultra-high vacuum conditions are scheduled to ensure the readiness of the detector for delivery to QST, marking a crucial step toward integrating this high-performance diagnostic into JT-60SA and unlocking its full potential for fast-ion experiments.