Determination of Runaway Electron Distribution Parameters from Synchrotron Radiation Measurements

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• Runaway Electron (RE) beams, forming after disruptions, are one of the main concerns for ITER operations since their impact onto the plasma facing components may cause damages.

• Synchrotron radiation emitted by RE is a powerful tool to infer information on their dynamics.

• A portable Runaway Electron Imaging and Spectroscopy (REIS) system has been developed by ENEA and used in FTU, AUG, TCV and COMPASS.

• An upgrade of the original system (REIS-Extended) now covers the wavelength range 0.4-5 µm.

• Comparison between experimental and simulated synchrotron images and spectra (simulation by means of SOFT: Synchrotron-detecting Orbit Following Toolkit) leads to the estimates of RE parameters:
  – pitch angle
  – maximum energy
  – radial density profile
  – number
Synchrotron Emission from RE

**SPECTRA**

**ITER**

\[ B_t = 5.3 \, \text{T} \]

**FTU**

\[ B_t = 5.6 \, \text{T} \]

**IMAGES**

RE synchrotron emission (FTU #43654, t=370 ms)
REIS Components

2 fibers for FW & BW view

Trifurcated fiber for the 3 spectrometers (FW view)

VIS range spectrometers (FW & BW views)
400-800 nm

2 wide-angle objective lenses coupled to the 2 fibers, one for **forward (FW) view** and one for **backward (BW) view**, and with a CCD camera

Fast JAI CCD camera (120 frames per second)

NIR range spectrometer
900-2500 nm

MIR range spectrometer
1400-5000 nm
REIS Set-Up

FTU midplane cross section. CCD camera and spectrometers field of view (FOV) are shaded, respectively, in gray and brown.

Fibers length: 19 m

Calibration performed considering all the components combined in the system using blackbody sources

Protective BK7 glass window 8 mm

CaF2 wide angle lenses

Outer Casing

Camera control unit

CaF2 wide angle lenses

Outer Casing

Protective BK7 glass window 8 mm

Camera control unit
Analysis Method

SPECTRA SIMULATIONS
- Fixed pitch
- Mono-energetic
- Flat radial distribution (r/a=0-0.99)

Loop on pitch angle and energy

Comparison between simulation and data (least squared minimization)

Information on energy and number of RE

IMAGES SIMULATIONS
- Exponential pitch
- Mono-energetic (selected from spectra)
- Flat radial distribution (r/a=0-0.99)

Loop on pitch angle

Comparison between simulation and data (least squared minimization)

Information on pitch angle and radial profile

- Simulation using SOFT software developed by Chalmers University
- Method applied for each time of the acquisition.
- Monoenergetic distribution function found to be slightly better than exponential distribution.
SPECTRA: experimental (red) vs SOFT reconstruction (black)

FTU #43651
RE Number

RE number as determined by best match of SOFT simulated spectra to experimental spectra

Estimated RE Current fraction of total Current
IMAGES: experimental (left) vs SOFT reconstruction (right)

FTU #43651

540 ms

580 ms

660 ms

700 ms

740 ms

780 ms

**BEST** Pitch Angles = [0.3, 0.25, 0.25, 0.25, 0.3, 0.3]
Images are more sensitive to pitch angle than Spectra

Showing pitch angles determined from Images (see previous slide) for 3 FTU RE discharges
In plasma current ramp-up time interval no REIS data are available (low RE synchrotron emission) **simulation using Test Particle Model has been performed** → based on experimental measurements (density and loop voltage) → good match with experimental data

‘BEST’ corresponds to values obtained using pitch angle derived from Images
Radial profiles are derived comparing simulated images and experimental ones.

An algorithm determines the radial profile maximizing the similarity between the two images.
Synchrotron Emission from RE in TCV
SPECTRA and ENERGY from RE in TCV

Spectra #72062

Energy results

#72062 @1667.5 ms
Energy: 18.75 MeV
Pitch: 0.3
Future installation on WEST (2022)

Spectra from REIS + images from WEST fast visible camera
Outcomes and Prospects

- REIS-E successfully calibrated, tested, and installed so far on FTU, COMPASS and TCV
- Demonstrated the potential of combining spectra and images for RE dynamics reconstruction with determination of time evolution of RE parameters
- Work results contained in “Overview of the FTU results”, OV/P-2 (IAEA 2020).

Future applications:
- Planned installation on WEST in March 2022
- Future use of the diagnostic for DTT device
- Planned development: real-time version

Thanks for your attention