SXR tomographic imaging in MST

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Abstract

We present SXR tomographic images of multiple magnetic islands in the core of the MST RFP plasma.

The tomographic diagnostic is comprised of four multi-channel cameras viewing the plasma at different poloidal angles.

The islands appear as a result of pulsed parallel current drive (PPCD). With the application of PPCD, all tearing mode amplitudes can be reduced, and the overlap of the associated islands decreases to such an extent that magnetic flux surfaces are at least partly restored, and multiple, discrete islands can form. In some PPCD plasmas, however, the mode resonant nearest the magnetic axis remains relatively large, resulting in a single island in the plasma core.

The presence of multiple or single helical islands indicated by tomographic imaging is confirmed with numerical modeling. The correlation of these structures with transport and magnetic self-organization will be presented.

In addition, preliminary measurements with “multicolor” SXR tomography (where the four cameras are used with filters of different thickness) will be shown.
1. High-resolution soft x-ray tomography

A high-resolution soft x-ray tomography has been recently installed in MST

- total of 74 lines of sight
- 4 fans
- frequency resolution up to 100kHz (central chords).
- Be thickness about 15µm (cutoff about 1keV)
- Si thickness of 35 µm (cutoff about 7keV)

2. Magnetic chaos reduction in the RFP

The reversed-field pinch (RFP) is sustained in time by dynamo mechanisms (MHD, Hall, ...) relying on the excitation of a broad spectrum of tearing modes. In the standard multi-helical (MH) regime these induce magnetic chaos by island overlapping and severely limit the plasma confinement.

Several methods are being studied to reduce the impact of magnetic chaos in the RFP. Among them, two promising regimes are the pulsed parallel current drive (PPCD) and the quasi-single helicity (QSH) regimes.

The inductive modification of the magnetic profiles produced by PPCD strongly reduces the dynamo mode amplitudes and greatly improves the plasma confinement ($B_{SXR0} \propto n_e T_{e0}^2$ in these plasmas).
PPCD plasmas can have either a multi-helical MHD spectrum, with all modes of similar amplitude, or a quasi-single helicity spectrum, dominated by a single mode.

The core topology is sensitive to the detailed shape of the mode spectrum and in both cases reflects a strong magnetic chaos reduction.

Soft x-ray tomography and numerical modelling with the ORBIT and the MSTFit codes show that single or multiple helical flux surfaces can be present in the plasma core during PPCD.
Spontaneous quasi-single helicity states are observed in standard plasmas. **Helical magnetic flux surfaces** form in the plasma core during these periods.

*Time evolution of the soft x-ray emissivity and the Poincaré sections of the magnetic field lines (ORBIT) during a QSH state with a growing (1,6) mode.*
5. “Multicolor” tomography

- Each photocamera with different Be foils, with possible thickness of 15, 80, 140, 254 and 478 µm
- SXR brightness measured in different energy ranges
- 254 and 478 µm should be enough to reduce the contribute of the aluminum lines (@ 2 keV) in the SXR measurements

Filter transmission
6.1 Double-foil technique

- Starting from the reconstructed SXR emissivity distributions \( \varepsilon_1 \) and \( \varepsilon_2 \) obtained with two different Be foils, for example 140 and 478, or 254 and 478 \( \mu \text{m} \), the ratio \( R \) can be calculated:
  \[
  R = \frac{\varepsilon_1}{\varepsilon_2} = R(T_e)
  \]
  which is a function of the electron temperature \( T_e \):

  ![Graph showing the relationship between R and Te](image)

  Using the emissivity instead of the measured brightness (as in the usual double-foil method) there is no need to know the temperature and density profiles.

- Thus the temperature can be calculated using the expression:
  \[
  T_e = \exp\left( \sum c_i \ln R \right)
  \]
  where the coefficients \( c_i \) are the results of the interpolation of the curve \( R(T_e) \).
6.2 SXR model

- With the multicolor measurements, it is difficult to obtain the emissivity \( \varepsilon \) with a tomographic inversion of the data.
- In this case, \( \varepsilon \) can be evaluated using a SXR model to simulate the measurements (brightness).
- The line integrated signal measured by a photodiode can be described as follow:

\[
X = k \int_L d\mathbf{r} \int_0^\infty dE \left( \frac{n_e^2(r)}{\sqrt{T_e(r)}} e^{-\frac{E}{T_e(r)}} A_{Si}(E) T_{Be}(E, t) \right)
\]

where \( A_{Si} \) is response of the photodiode and \( T_{Be} \) is the transmission of the beryllium foil. In the model the density and temperature profile should be defined; a profile of the type \( 1-r^\alpha \) has been used.

- By varying the parameters of the model the brightness profiles can be simulated, and the corresponding SXR emissivity can be calculated.
7.1 Example of “multicolor” measurements

550kA PPCD
QSH \( m=1, n=6 \)
7.2 Example of “multicolor” measurements

550kA PPCD
QSH $m=1, n=6$
8. Conclusions and future work

The **pulsed parallel current drive** produces a global magnetic chaos reduction in the RFP with a consequent confinement improvement.

**Single or multiple helical flux surfaces** have been imaged in PPCD plasmas and represent a direct evidence of chaos healing.

**Spontaneous quasi-single helicity** states have been studied in standard conditions but, due to a residual level of secondary modes, the plasma confinement is only locally improved. Nevertheless such helical states represent a promising path towards the realization of a RFP with favorable confinement properties.

The **multicolor tomography** and the double-foil technique allows for spatially resolved measurements of the electron temperature $T_e$. During QSH states the observed SXR structures can be associated with a local increase of $T_e$.

The next step will be the **double-foil tomography**, with two beryllium foils in two couples of SXR probes, to obtain better reconstruction of the temperature.
9. References

**QSH**

**SXR tomography and results**

**SXR diagnostic**
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