Progress of J-TEXT on RMP and Disruption Physics

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10th US-PRC Magnetic Fusion Confinement Workshop, LLNL, March 23-26, 2021
Outline

I. J-TEXT overview

II. RMP and disruption mitigation

III. Runaway electron control

IV. Summary and future work
China Magnetic Fusion Road Map

- **ITER**: (2030’s start operation)
  - Phase II: DEMO validation, Q=10, CW, 1GW, >50dpa
  - Phase I: Q=1-5, steady-state, TBR>1, >200MW, <10dpa

- **CFETR**: (2025)
  - Phase II: Q=5, 3000s, 350MW, steady-state burning plasma
  - Phase I: Q=10, 400s, 500MW, Hybrid burning plasma

- **EAST**: Advance PFC, steady-state advanced operation

- **HL-2M**: Advanced divertor, high power H&CD, diagnostics

- **J-TEXT**: Disruption mitigation, basic plasma

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10th US-PRC Magnetic Fusion Confinement Workshop, LLNL, March 23-26, 2021
Recent J-TEXT system upgrade

- 30+ diagnostic systems, including first polarimeter for tokamak in China
- First high frequency DRMP system and dual SPI system in China
- ECRH system and midplane divertor

Toroidal arrangement: flux loops, 2D Mirrov Pick-up coils

---Blue developing---
ECRH on J-TEXT reaches $T_e$ above 1.5keV

ECRH system parameters on J-TEXT: 105GHz/500kW/1s
Enhanced J-TEXT plasma performance ($T_e > 1.5$keV)
To conduct localized heating and ECCD experiments on J-TEXT
J-TEXT high-field-side divertor configuration

- Successful discharges in HFS single-null and double-null divertor configurations
- Extended operation space of J-TEXT

Major US collaborators: UT Austin
A new 256-channel ECEI system has been developed on J-TEXT tokamak.

It is the **first full-function digital control** ECEI system which can remotely set and control the diagnostic.

**Major US collaborators:** UC Davis

Publications:
Dual SPI system installed on J-TEXT

<table>
<thead>
<tr>
<th></th>
<th>Ar</th>
<th>Ne</th>
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</thead>
<tbody>
<tr>
<td>Port</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Propellant gas</td>
<td>Ar</td>
<td>He</td>
</tr>
<tr>
<td>Pellet diameter (mm)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pellet length (mm)</td>
<td>2-8</td>
<td>2-8</td>
</tr>
<tr>
<td>quantity</td>
<td>$1 - 4 \times 10^{21}$</td>
<td>$1.7 - 6.7 \times 10^{21}$</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>130-300</td>
<td>150-350</td>
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- SPI disruption mitigation: Collaboration with GA in the frame of ITPA MHD task force
Ensuring the success of ITER

- TBM effects
- ELM control
- Disruption mitigation
- Runaway electron control
- Non-activated operation
- Hydrogenic inventory control
- Scenario demonstration discharges
- Neoclassical tearing modes
- Divertor heat transport
- Startup and rampdown

J-TEXT focuses on key ITER physics areas:

- MHD instability control
- Disruption avoidance
- RE suppression & dissipation
Neural network developed for disruption prediction

Hybrid neural network for density limit disruptions prediction and avoidance

DRMP TM control avoids disruption onset

Rotating RMP unlocks TM and drives island rotation
Jin H, PPCF 2015, Wang N, NF 2019

Rotating RMP accelerates rotation and avoids disruption
Ding Y H, IAEA FEC 2018
DRMP regime optimized for disruption control

Higher frequency rotating RMP more effective on suppressing LM amplitude

Nonlinear RMP effects on q profile allow disruption avoidance

Li D, NF 2020
Effects of 2/2 RMP on sawteeth

- Mitigation of sawteeth by 2/2 RMP in region with $q_a < 2.8$ and $n_e < 2 \times 10^{19} \text{m}^{-3}$ in J-TEXT ($I_{\text{RMP}} = 4 \text{kA}$)
- Core rotation driven in co-$I_p$ direction
- Reduction of sawteeth is highly related with trigger of 2/2 island

New scheme for sawteeth control using RMPs with $m/n = 1$ but $m, n > 1$
Novel schemes developed for RE control

Ensure the success of ITER
- TBM effects
- ELM control
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Runaway electron current control schemes

◆ Schemes-I:
RE suppression via
RMP/SMBI/MGI/ETC

◆ Schemes-II:
RE dissipation via
MGI and SPI

Disruption mitigation:
RMP and electrode
biasing control LM and
avoid disruption onset
3 RE control regimes found on J-TEXT:
1. Partial suppression
2. Enhanced RE
3. Full suppression by (a) Mode locking; (b) RMP penetration
Full RE suppression achieved via RMP mode locking & penetration

Partial RE suppression – Enhanced RE regimes

Full RE suppression due to mode locking

Full RE suppression due to RMP penetration

Jiang, Z. H., et. al., Nuclear Fusion 56(2016) 092012.

NIMROD simulation show RE loss enhancement in presence of islands

- Major US collaborators: NIMROD team (US)
Schemes-I: RE suppression (SMBI)

- Developed novel RE suppression scheme based on SMBI induced magnetic perturbations.
- Combined MGI+SMBI scheme enhances magnetic perturbations during disruption and enable RE suppression.

Nucl. Fusion 60, 066004 (2020)
Minor disruptions triggered by supersonic molecular beam injection (SMBI) on J-TEXT tokamak

- The core plasma temperature decreases to less than tens of eVs after a relatively long period of multistage thermal collapse.

- Different MHD modes appear as impurity cold front propagates toward the $q = 2$ surface.

**Major US collaborators:**

NIMROD team (US)
Schemes-I: RE suppression (ETC-Energy Transfer Coil)

Novel ETC system provides a new scheme for disruption mitigation

\[ E_m = \frac{1}{2} L I_p^2 \]

ITER ~ 500MJ

ETC can effectively reduce loop voltage during disruption, thus enable RE suppression.

\[ I_p (kA) \]
\[ I_{MET} (kA) \]
\[ V_{loop} (V) \]
Schemes-II: RE dissipation (MGI) -ITPA

ITPA WG11: Control of Locked Modes
ITPA MDC-19 Error Field Correction for ITER

- Dissipation rate ~ 26MA/s, highest so far in world;
- Dissipation rate saturation found and confirmed on DIII-D
SPI adopted as top option for disruption mitigation on ITER

Dual SPI system installed on J-TEXT, and successfully applied to disruption mitigation experiments.

MGI penetration reaches \( q=2 \) surface, SPI penetration reaches \( q=1 \) surface and enhances mitigation efficiency

SPI dissipation of RE current
Radiation asymmetry reduced by dual SPIs

- In single SPI, there is a strong radiation asymmetry. The radiation in Port 13, which is closed to the injection port, is much stronger than that in Port 5 and 6.
- The localized thermal radiation is reduced by dual SPIs.

The thermal radiation in TQ phase, (a) single Ne SPI; (b) dual SPIs
Schemes-II: RE dissipation (E field reversal – soft landing)

- Active RE current control extends plateau duration to 30-80ms.
- Electric field reversal dissipates RE current (-4MA/s), leads to soft-landing.

Reference shot


Critical electric fields for zero RE current growth rate, where measured value 6 times of theory prediction.
Summary and future work

J-TEXT has made major progresses on

- RMP-aided disruption mitigation
- Runaway electron current suppression and dissipation

Future work continues ITER-relevant physics on:

- 3D configuration optimization for disruption and thermal transport control
- Novel divertor design study for fusion reactor
## 2021-23 J-TEXT-US MFC collaboration plan

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<thead>
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<th>J-TEXT</th>
<th>PRC &gt; US</th>
<th>US &gt; PRC</th>
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<tbody>
<tr>
<td>UT-Austin</td>
<td>High-field side diverter operation and control</td>
<td>Study impurity transport in presence of RMP; ECE upgrade and CECE development</td>
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<tr>
<td>UC-Davis</td>
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<td>High resolution visualization diagnostic; Smart feedback control development for diagnostics; Joint experiment for plasma disruption avoidance</td>
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<td>General Atomics</td>
<td>Study of dual SPI on radiation and electron density asymmetry during fast shutdown</td>
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<td>UC-San Diego</td>
<td>Mean field model of the L→H transition in a stochastic magnetic field</td>
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<tr>
<td>UW-Madison</td>
<td>MHD theory and simulation for: tokamak plasmas in Q &gt; 5 and B &gt; 10T regimes; FRC and stellarator plasmas</td>
<td>Disruption physics collaboration</td>
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This table outlines the collaborative research plans between J-TEXT and the United States for the period 2021-2023.