Progress on the ITER DMS design and integration

T.C. Luce, et al.,
ITER Organization

Design and Performance of Shattered Pellet Injection Systems for JET and KSTAR Disruption Mitigation Research in Support of ITER

L. R. Baylor, et al.,
Oak Ridge National Laboratory

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization
Outline

- Introduction and ITER DMS Concept
- ITER DMS Overall Configuration
- ITER DMS Design Status
- ITER DMS Port Integration
- Progress on Engineering Studies and Design Specifications
- Conclusions
Mitigation of Disruptions in ITER

- Disruptions can cause large thermal and mechanical loads in absence of mitigation

**Disruption Mitigation Concept**

- Convert thermal and magnetic energy into radiation
- Runaway electron avoidance by increase of plasma density and resistivity
 ITER DMS Solution: Shattered Pellet Injection

- Conversion of plasma free energy (up to 800 MJ) into radiation with increased plasma density requires delivery of substantial mass to the plasma within a few milliseconds
  - Gas injection is slow with significant dispersion in the direction of mass flow
  - Solid projectile injection is fast but can go through plasma without the desired interaction and impact PFCs
  - Shattered Pellet Injection (SPI): speed and density of solid, but shattering before injection yields pieces absorbed in plasma
ITER DMS Project Timeline

2018: Proposal to ITER Council of DMS design solution using Shattered Pellet Injection (SPI) in 3 equatorial ports and 3 upper ports

**Phase I:** Installation of captive components and completion of DMS final design by 2022

**Phase II:** Manufacturing, installation, and commissioning in time for PFPO-1 (end 2028)

*DMS Project Phase-I Tasks*

- Design and install infrastructure for necessary services (gas, vacuum, cryogenic)
- Completion of DMS Design including Design Specification and Engineering Studies
- Integration of DMS in ITER Ports
ITER DMS configuration

**Equatorial Ports** (24 Injectors)
- Main injectors to mitigate the thermal and current quench and runaway electron impact
- Pellets with H and H/Ne mixtures
- $d = 28.5 \text{ mm}, L = 57 \text{ mm} \, (\sim 10^{24} \text{ atoms})$

**Upper Ports** (3 Injectors)
- Post-thermal quench injection
- Aiming at 100% reliability of electromagnetic load mitigation
- Strong shattering for maximum assimilation in cold post-TQ plasma
Overall DMS Design

**DMS in equatorial EP02**

- **Port Plug** houses flight tube and shatter chamber
- **Interspace** houses pellet formation, launch and diagnostic hardware
- **Port Cell** houses services

## Services
- **Connection & Disconnection**
- **Cryogenic Distribution System**
- **Gas Handling System**
- **Vacuum & Exhaust System**

**Key Elements:**
- Gas Handling System
- Cryostat
- Port Cell Support Structure
- Interspace Support Structure
- Port Plug

**Key Features:**
- **Shattered Pellet Injector (1, 6 or 12 per Port Cell)**
- **Flight Tube**
- **Shatter Chamber**
- **Propellant Suppression**
- **Launch Unit**
- **Optical Diagnostic**
- **Coldhead**
- **Bio-Shield**
- **Torus Vacuum**
- **Atmosphere**
- **Plasma Radiation**
DMS Design Challenges

- **Technological design challenges**
  - Robust and reproducible pellet generation and acceleration process
  - Monitoring of pellet integrity and its trajectory with minimum interaction between the pellet and the flight tube
  - Optimised shard distribution

- **Mechanical implementation challenges**
  - Integration of complex SPI systems into an environment with advanced design maturity
  - Integration of required services in limited space
  - Design enabling maintenance in congested, activated, and potentially contaminated environment
DMS Component Design Details

Shatter Chamber

- Subject to plasma radiation and neutron heating \( \rightarrow \) high temperatures (up to 600º C)
- Optimum shatter angles still not fixed \( \rightarrow \) flexible design to accommodate range without modification of interfaces

Propellant suppression system

- SPI propellant should not reach plasma before SPI shards (decreased mitigation efficiency)
- Propellant gas recovery system cannot be implemented in ITER due to space restrictions
- Propellant suppression system design being optimized to minimize the amount of gas entering the plasma before SPI shards
Overall DMS Port Integration

**Integration in modular design ports (in-port)**

- Standardization of components and interfaces allows faster adaptation of previous designs

**Integration in modular design ports (ex-port)**

- Common solutions allow efficient maintenance
- Integration follows other ports applying the same concept for faster development

*Colored parts in green, blue and purple correspond to diagnostic systems*
Diagnostic Integration: X-Ray Spectrometer

Original 55.E5 X-Ray Spectrometer:
- Poloidal spatial coverage and toroidal spectral dispersion

Introduction of Highly Oriented Pyrolytic Graphite (HOPG) reflectors:
- Discrete lines of sight, rather than imaging, and spectral dispersion in vertical direction
- (+) Dispersion crystals and detectors can be placed behind bioshield
- (-) Limits bandwidth and signal throughput
Engineering studies are necessary to develop SPI technology and adapt to the ITER requirements

- To bring the technology to the level needed for investment protection in ITER
- To prototype and improve components that can be used in the ITER environment

Design Specifications are refined or determined through experiments and modelling

- Operational requirements
- Optimization of pellet mass and mixture
- Optimization of shattering
DMS Engineering Studies - I

- Fast propellant valve development
- First 28.5 mm pellet formation and shattering
- Pellet flight path assessment
- Shear strength for dislodging pellets

**Experimental set up**

Shear strength depends on pellet material and decreases with increasing temperature

**Shear strength**

US IPO ITER DMS support

Oak Ridge National Lab (see paper by T. Gebhart this conference)
Fundamental Studies
Optimisation of pellet formation and release process through modelling and experimental validation

Modelling of pellet formation

Test bench

CEA-Grenoble/DSBT
Optical Pellet Diagnostic
System to diagnose pellet integrity, volume, and velocity orientation as well as pellet flight line alignment

- Environment with limited space availability
- Relay optics must be compatible with radiation environment

*(Fusion Instruments, Hungary)*
Support Laboratory
Main facility for integrated testing of components:
Shattering unit, pellet launching unit, optical pellet diagnostic, cold head

Operational in Q3/2021

First Task:
Development and testing of shattering units to deliver the required fragment sizes

(Centre for Energy Research, Hungary)
DMS Design Specification - Modelling

- Theory and modelling programme providing physics-based extrapolation from experimental results to ITER
  (see papers by E. Nardon, C. Kim and A. Matsuyama, this conference)

- 3D MHD simulations with JOREK, M3D-C1, NIMROD
- Simulations of generation and mitigation of runaway electrons
- Simplified modelling for ITER DMS parameter studies
- Shattering process in support of engineering studies

Example: JOREK SPI simulations for ITER: reduction of radiation asymmetry

(courtesy of D. Hu, Beihang University)
DMS Design Specification - Experiments

Key questions addressed:

- Can the density be raised efficiently by superimposing multiple pellets?
- Can the required radiation levels be reached with sufficient symmetry to avoid first wall melting?
- What is the optimum fragment size for maximum mitigation efficiency?
- How much mass must be delivered in ITER?

SPI data from 5 tokamaks by end of 2021:

ASDEX, DIII-D, JET, J-TEXT, KSTAR
(see papers by D. Shiraki, S. Jachmich, U. Sheikh, Z. Chen and J-H. Kim, this conference)

These experiments have complementary physical characteristics and SPI capabilities to define as completely as possible the ITER design specifications
Conclusions

- Design and integration of DMS into ITER tokamak and ancillary systems has progressed since 2018 IAEA FEC:
  - Configuration for ITER DMS ports established
  - Installation of networks to supply vacuum, gases and cryogenic services starting in 2021
  - Integration of DMS into ports underway; re-design of diagnostics sharing ports with DMS underway
  - Technology studies launched for the reliable formation, injection and shattering of pellets
  - Improved specification of the design basis through experiments in tokamaks and model validation

- Main ITER DMS project milestones set in 2018 have achieved coordinated effort across IO departments and extensive support from ITER Members institutes

- DMS project is on route to deliver a fully functional DMS system for operation in PFPO-1