Remote Handling – impact on DEMO design and availability

Martin Mittwollen
Remote Handling - Impact on DEMO design and availability

- Remote Handling
- Availability
- Components
- Downtime

Impact on DEMO design

- using the example of maintenance of blanket Multi Module Segments (MMS)
Superordinate goal: DEMO to reach 30% overall availability

Availability is primarily impacted by:

a) Operational availability
   - Pulse length / dwell time – ratio
   - Unexpected failures

b) Down-Time for maintenance
   - Remote Handling Equipment design
   - Machine / Component design
   - Process design (logistics)

Need for sophisticated remote maintenance concepts
   - Well-engineered Remote Handling Equipment
   - Comprehensive DEMO-Design
   - Optimized Plant layout

- Pulse length investigated by plasma specialists et al.
- Maintenance system designed by Remote Handling specialists
- Collaboration and Coordination necessary from start (esp. with other WP)
Reminder: iter blanket maintenance

- **Maintenance frequency**: 1 full replacement after 10 years, 6 components/year (lower part), 3 components/year (others)

- **Maintenance duration**
  - 1 module: 6 weeks
  - 1 toroidal array: 3 months (max 36 modules)
  - All modules: ~2 years

- 440 blanket modules
  - 30 types | 4.5 tons | RH Class 1

- Extremely long maintenance phase estimated – scores of individual operations necessary
- **BUT**: iter is a dedicated experimental machine – to get „familiar“ with a really big tokamak
- Remote handling introduced quite late – complicated operations resulted (e.g. cask transport)

Isabel Ribeiro (IST), SOFT 2010
DEM0 development (I): remote handling => dedicated design driver (wisely)

Vessel concept / Blanket (MMS) attachment concepts until 2012

- Blanket modules are combined to blanket multi-module-segments (MMS)
- Thermal expansion of the MMS is meant to be compensated by flexible bars called Bending Bars
- EM-loads are calculated but there is no technical design solution
- Attachment of MMS to vacuum vessel w.r.t. RH-accessibility is unsolved

- Initially pure functional design – driven by plasma specialists et al.
- Few requirements were indicated – e.g. thermal expansion, withstand EM-loads, etc.
- Remote Handling (RH) feasibility lowly considered – but to be involved early
DEM0 development (II): requirements identification

2012-2013: Classification (trial)

- Items to be removed
- Ports

- Upper port
- Equatorial port

- Blanket modules (IB [32] and OB [48])
- Equatorial port plugs (Heating System, control diagnostics)
- Port cover (16x)
- Shielding elements
- Cooling (2x) and breeder pipes (2x) per blanket segment
- Port cover (16x)
- Shear keys (LTS)

2012-2013: Radiation hardness assessment

- Radiation hardness of RH components

2012-2013: Cooling of blanket decay heat production

- Passive cooling:
  - cannot fail
  - cheapest
  - capacity limited by design
  - cooling of the building!

- Decentral cooling unit:
  - capacity much higher
  - Less handling as central cooling
  - Cask needs cooling device
  - cooling of the building!

- Central cooling unit:
  - unlimited capacity
  - high reliability
  - Connecting / disconnecting!
  - no cooling of the building!

- Collecting data and information (classification, size, shape, weight, radiation, heat, space, ...)
- Mostly assumptions, only few requirements
- Checking RH feasibility of “scientific” DEMO-design => DEMO baseline CAD design
Translating data and information into concept options for feasible maintenance system
“Wild” pre-conceptual studies => to discuss and converge
First DEMO baseline CAD design – RH feasible

- Blanket MMS shall fit through port opening!
- Pin supports at top of blanket segments
- Lower supports changed from bending bars to pre-loaded spring system
- Blanket Attachment options discussed
  - w.r.t. radiation, accessibility etc.
  - e.g. springs at top (lower radiation)
- Servicing-
- Preload- end-effector
- In-Vessel Mover (IVM) introduced + different end-effectors
Characteristics of this first design solution

Complete in-vessel-maintenance can be executed => RH feasibility proven

But:
- Still several design options to be discussed and converged
- Partly long-winded procedures, e.g. Divertor & MMS replacement:
  1) divertor cassettes to be removed at first
  2) Then IVM to be inserted
  3) Unfixing lower MMS-end
  4) Taking over MMS-load on IVM (support structure shall carry load)
  5) IVM moves lower ends of MMS radially, circularly, vertically

→ complicated kinematics of extraction/insertion
→ Failure-prone, time consuming
→ Improvement necessary

Ancillary RHE: Multi-Purpose Deployer (MPD)
- sophisticated helper for multi purpose use in vessel
- not involved in normal maintenance
- ready for fast access to in-vessel components in case of failure
- no extraction of whole segments => downtime short, impact on availability low

- Maintainability of DEMO in-vessel components shown as feasible
- Kinematics of extraction / insertion partly complicated & time consuming
- Operational availability was not the major goal of this phase => but intended for future work
DEM0 development (III)
In-vessel RMS: Latest Design & Characteristics

Cask strategy:
- Vertical maintenance strategy
- New structure: interface casks, tool casks, transport casks
- Critical contamination control contact (at vessel casing) to be operated only once per maintenance phase
- Transport/tool casks more frequently changed but better accessible in case of failure => availability increases

Blanket segmentation:
- Predetermined sequence of replacement
- OB center-MMS extractable without impacting other MMS
- Segment dogleg geometry avoiding neutron streaming

Blanket MMS attachment significantly improved
- Pins at bottom, clamping at top of segment
- Neutron shield plug at top (new) used as structural member
- Now MMS manageable in parallel with Divertor cassettes (no chronological dependency)

- DEMO-design in terms of Remote Handling significantly improved
- New Blanket MMS attachment releases MMS replacement from Divertor work chronological
- Availability increased by simplified design and separation of functions
Blanket MMS Attachment System

- Clamping elements at the top of the blanket MMS … structural integrated in upper port neutron shielding plug
- Radiation protection of elastic components by shield plug
- Fixation at the bottom by the means of pins ➔ Geometry proportions fixed
- No longer need for In-Vessel mover (& end-effectors)
- Independent maintenance of blanket and divertor

MMS Pipe Layout

- Separation of port closure plate from pipes
- Minimise pipe removal in the event of blanket failure
- Reduction of stress in pipes produced by thermal effects and flow induced vibrations (compensated by pipe-bellows)
- Reduction of MMS maintenance duration

- MMS attachment improved w.r.t. replacement procedure, radiation
- New pipe layout providing faster maintenance / less impact of unexpected blanket failure
- Availability increased by simplified design and separation of function
DEMO design evolution in terms of Remote Handling

(I): “physical design”
- Few requirements from physics
- Coarse design assumption
- Rest unsolved

(II): RH baseline design provides maintainability
- Physics translated into design
- Requirements met
- Pre-concepts for Remote Handling Equipment
- RH feasibility shown

(III): adult concept design (still evolving)
- Viable solutions

- Cask concept
- Contamination control
- Pipe layout
- Blanket MMS attachment
- Independent from Divertor work

- RH feasible maintenance process concept – now ongoing deep engineering
- Parallelising of Divertor/Blanket maintenance - lowers downtime, increases availability
- Reduced number of actions (e.g. w/o IVM) - accelerates maintenance, increases availability
demotech in terms of availability

(I): “physical design”
- Plasma shut down
- Plasma down
- Preparing for maintenance
- Ready for maintenance
- Maintenance process
- Maintenance finished
- Preparing for operation
- Ready for operation
- Plasma operation

(II): RH baseline design provides maintainability
- Ports opening
- Ports open
- Divertor cassettes extraction
- Div. cassettes extracted
- IVM insertion
- IVM inserted
- MMS extraction
- MMS extracted
- “Vice versa for insertion”

(III): adult concept design (still evolving)
- Ports opening
- Ports open
- Divertor cassettes extraction
- Div. cassettes extracted
- IVM insertion
- IVM inserted
- MMS extraction
- MMS extracted
- “Vice versa for insertion”

- All parts inserted
- Ports closing

- Technical realization
- Improvement

- Parallelising lowers downtime & avoids dependencies of serial process chain
- Reduced number of actions lowers failure probability & increases availability

- maintenance process structured described with “event driven process chain” (EPC)

- RH baseline design provides maintainability

- Adult concept design (still evolving)

- IVM insertion
- All parts inserted
- Ports closing
Remote Handling - Impact on DEMO design and availability

Every element and every process can fail!

- Very big number of RH elements in connection in series
- Very big number of maintenance processes in connection in series
- => Ambitious goal to reach 30% overall availability

Technical Reliability (goal: 70%) decreases dramatically with no. of elements in series (see diagram)

- 80% of reliability - with only 10 elements in series
- Unacceptable 45%! with e.g. 40 elements (which is assumed decently) (68% for individual reliability of 99%)

There are:

- scores of functional elements (connection clamps, pipes, compensators, plugs, drives, guides, bearings, gaskets, etc.)
- Lots of RH tools on duty (in sequence)
  (also consisting of high number of components)

Reliability could be increased by (only referred to technical reliability!):

- Higher individual reliability => done by e.g. radiation hardness assessment
- Functional parallel placed elements (Redundancy) => done by e.g. multi purpose deployer
- Reduction of functional elements => done by simplified design / shortened processes

Big numbers of elements / processes in series impact availability significantly

- Shortening of the dependency-chain reduces risk of failure => availability increased
- Simplified design is more robust, failure probability decreased
Remote Handling - Impact on DEMO design and availability

Remote Handling as well as DEMO design and availability do not stop at the vessel casing!

➤ A view beyond in-vessel’s “own nose” is mandatory!

e.g.: For each upper port (all upper ports) (with 16 TF coils => 16 ports)

• 96 (1536) docking/undocking operations
• 60 (960) cask transports from/to the Active Maintenance Facility (AMF)

take place during maintenance period (192 days)
(tool casks may stay aside port, transport from/to AMF only once)

➤ Transportation (not only) has to be solved sophisticatedly

⇒ by technical means (casks, contamination control, cranes, tools)
⇒ by logistics (process design, layout, sequencing, parallelising)

➤ Transportation means and routes through reactor hall shall be capable for “heavy traffic” during maintenance

➤ Active Maintenance Facility shall be capable for sending / receiving big numbers of casks in short time during maintenance

➤ well-structured maintenance plan needed!

➤ Optimum in-vessel maintenance process may cause ex-vessel throughput problems
➤ Especially layout of reactor hall / AMF has to be checked in terms of cask throughput
➤ Maintenance phase has to be optimized in structure / sequence / logistics
“Everybody knows his personal dependencies” => Error-prone phenomenological description

Structured description with EPC => basis for streamlining

On-instinct-description of maintenance processes may be defective and incomplete
Processes should be described structured as basis for optimization
Selection of dedicated RM Equipment should be supported by analytical assessment
Remote Handling - Impact on ex-vessel design and availability

Optimization Process:
- Simulate different scenarios
- Integrate failure strategies
- Identify bottlenecks
- Propose design changes (needs brains!)

Optimization Process:
- Simulation
- Configuration
- Results

Optimization Potentials:
- E.g. Transportation Times:
  - One entrance/exit: 100%
  - Two entrances/exits: 40%
- Saving: Several Weeks!

Optimization Consequences:
- Big impact on layout
- Interfaces with other buildings (generator hall / auxiliary rooms / AMF)
- Adaptation / development of RHE (additional, other)

➢ Process modelling to start simulation
➢ Simulation results to be examined for optimization potentials (no automatism! – brains needed!)
➢ Consideration of impacts on other systems mandatory – all in all still improvement possible?
Remote Handling - Impact on DEMO design and availability

Summary & Conclusion

- Remote Handling interacts with DEMO design – coaction improves availability
- Activities beyond in-vessel have to be embedded – getting a comprehensive solution
- Working at all knots may cause more effort – but ensures reliable maintenance process
Thank you very much for your attention