Complex Cryogenic lines installation
Features, challenges and status

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OUTLINE

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2- ITER Cryogenic System

3- Cryogenic Complex Cryolines – Design and Features

4 – Installation / Testing strategy

5 – Installation Challenges, Constraints and difficulties

6- Prospective & Conclusion
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Main Goal: Achieve $Q > 10 \sim 500$ MW thermal energy

**The ITER Tokamak**

Vacuum Vessel: $\sim 8 \,000 \,t$
TF Coils: $\sim 18 \times 360 \,t$
Central solenoid: $\sim 1 \,000 \,t$
+=...
Total $\sim 23 \,000 \,t$

$R=6.2 \,m, \,a=2.0 \,m,$
$I_p=15 \,MA, \,B_T=5.3 \,T,$
23,000 tonnes

3.5 times the weight of the Eiffel Tower!
• Major plasma radius; 6.2m
• Plasma volume 840m³
• Plasma current 15MA
• Fusion power; 500MW

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Due to plasma pulsed operation (plasma initiation, ramp-up, flat top/burn, ramp-down, dwell,) repeated every 1800s:
Important variable heat loads are deposited on the magnet system which is transferred after to the cryogenic system.
Other variable heat loads on cryopumps and current leads.

ITER variable heat loads
(overall heat loads)
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ITER Cryogenic system

A joint procurement by Europe, the ITER Organization and the Indian Domestic Agency
Complex Cryolines in B50s

- 4 Cryolines: 3 CLs CTCB to LHe CBs + 1 CL CTCB to LHe tank CB
- 4 to 7 process pipes in single vacuum jacket
- DN500 to DN700
- 15 spools with L, E and S shapes

Complex Cryolines in Tokamak

- 2 Cryolines: 1 CL for magnet & 1 CL for CP connected to 5 ACBs + 2 CLs for TSCVB
- 10 Cryolines to feed clients (Feeders & CVBs)
- 4 to 6 process pipes in single vacuum jacket
- DN500 to DN1000
- > 150 spools with different shapes

Complex Cryolines in Cryo-Bridge

- 2 Cryolines: 1 CL for magnet & 1 CL for CP
- 4 to 5 process pipes in single vacuum jacket
- PP up to DN250 (10’’)
- OVJ → DN800 to DN1000
- Total length of 130 m per CL
- 32 spools with L and E shapes

In total ~ 1.5 km of complex Cryolines
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COMPLEX CRYOLINES – Design MAIN FEATURES

- Roughness of vacuum facing surface < 50 micro meter (except welds)

- Process pipes with different temperature level of 4K, 50K, 80K accommodated together (with MLI) under single vacuum jacket with tight heat load budget due to space constraints

- Designed for Heat load ranges from 1.5 W/m for 4 K lines and 4.5 W/m for 80 K lines (thermo-mechanical optimized design for vacuum barriers and sliding spacers)

- Aluminum thermal shield design considering thermal and mechanical roles:
  - Thermal role to reach the performance Cryolines system
  - And mechanical role to allow displacement during cold contraction and ensure mechanical resistance during severe events i.e. Seismic
• Complex design of external supports considering, lines routing, very limited space and mechanical loads generated by Cryolines during namely pressure test (End loads due to the presence of bellows) → Example of iterative calculation to reach the final design.
• Designed to sustain very stringent mechanical load cases on the top of construction code requirements

  - PP $\rightarrow$ NO at NO
  - ACP event $\rightarrow$ Up to 140°C on OVI
  - LIV event $\rightarrow$ minimum temperature -50 °C

• Designed to meet mechanical requirements (loads and displacements) at the interface with civil works and equipment (Magnet feeders and cold boxes)
COMPLEX CRYOLINES – Design MAIN FEATURES

- Designed to decouple displacements between crossed areas by Cryolines in particular between B52/Cyo-Bridge and Cryo-Bridge/Tokamak (up to 150 mm per direction)

- Designed considering safety confinement requirements leading to development of dedicated technical solutions. This is first of kind in cryogenic design systems (iterative integrated calculation has been performed to meet requirements)

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• Nearly **200 spools** Complex Cryolines manufactured ranging from 5 to more than **10 m** of length, weight ranging from 1 ton to almost **10 tons** and size from **DN 500** to **DN 1000**

• Some manufacturing requirements more **stringent than** codes and standards (e.g. tungsten inclusion in welds is not allowed)

• Art of integrating many process pipes, internal supports, MLI, bellows/hoses, thermal shield and vacuum jacket in single spool

• Specific sequence of a spool assembly..

• High level of level of **cleanliness** (e.g. grinding not allowed), **protection** of insulation during welding, **humidity control** for storage of MLI etc...
The shape of segments is derived by the following factors:

- The outcomes of global flexibility analysis in particular the presence of internal (fixed points and vacuum barrier) and external supports
- The feasibility of installation activities:
  - Space available to perform handling, transport and welding
  - Space available for leak testing on interconnections
However, some more complex shapes of spools have been resulted in particular the following:
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Installation activities started on Q4 2019

The contract is structured in 3 main phases:

- Mechanical Installation phase
- Warm Tests phase
- Cold Tests phase

Each phase is composed of “Work Packages” identified by level in Tokamak building and by area in the plant buildings.
Installation Contract is executed considering the same requirements applied for manufacturing:

- **Welders qualification**: A additional qualification program for process pipes welding has been put in place to authorize every welder per DN and per thickness.

- **Process pipes NDT requirements**: 100% VT, 100% RT and 100% LT

- **Level of cleanliness onsite**: The level of cleanliness has been tracked and checked all along the installation activities.

- **Follow-up of manufacturer installation documents**: Installation works performed considering as inputs mainly installation guidelines, drawings (handling/lifting areas) and procedures (MLI wrapping etc.)
Cryoline spools inside the tokamak are installed in float mode due to the absence of interface equipment (mainly Feeders & ACBs).

The following approach has been implemented:

1. Survey of embedded plates to determine the as-built coordinates.
2. External support extra-length cut determined based on as-built coordinate in z direction of plates and as built dimensions of the spool.
3. 3D modeling using laser tracker considering spool as-built dimensions and results from point 1) & 2).
4. Then, the required process pipe extra-length cut is determined with the objective to meet the theoretical coordinates of spool on both side within +/- 5 mm.

Golden rule: The objective is to meet the theoretical coordinates at the interface equipment within +/- 5 mm.
**Phase 1: Handling and Lifting Operations**

- Handling/lifting drawings
- Context 3D model (Installation area congestion)
- Coactivity as per sequence and site coordination

**Lifting Lugs welded on EPs**

**Dedicated Crane**

**Lifting Plan/Procedures Development**

- Spool weight/shape
- Area accessibility
- As-built drawings

**B2 Activities**

**B50 Main Cryolines**

**Cryocharts B13**

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Phase 1: Handling and lifting operations in photos (B50s)
Phase 1: Handling and lifting operations in photos (Tokamak B2/B2M level)
Phase 1: Handling and lifting operations in photos (Cryolines spools crossing the Cryo-Bridge opening)
Phase 1: Lifting operations in photos (Cryolines spools lifting/insertion inside Cryo-shafts)
Phase 1: Handling and lifting operations in photos (Main Cryolines spools along the west wall in L3)
COMPLEX CRYOLINES – Installation & Testing strategy

- Process pipes welding
- Process pipes MLI wrapping
- Thermal shield assembly & MLI wrapping
- Outer Vacuum Jacket (OVJ) Closure

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Installation Challenges, Constraints and difficulties

- **High level of co-activity management**: Up to 5 contractors in the same area (systems + civil works contractors)

- **Installation sequence**: Detailed installation sequence has been established considering the in-context 3D model.
安装挑战、限制和困难

- 过程管道焊接操作的复杂性由于薄厚度（2 mm）。
- 焊接缺陷的数量随着主液氦线的DN增大而增加。
- 焊接缺陷的数量在B52接口处与液氦CB和CTCB的交互比预期的要多。
- 中间氦泄漏测试由于内部固定点/真空屏障的缺失而不可行。**这导致了长时间的待机期**。
- 焊缝的放射照相在夜间进行（瓶颈风险）。

免责声明：此处表达的观点和意见不一定反映ITER组织的观点。
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Installation activities of ITER complex Cryolines has been completed successfully as per design and project requirements.

No major in-field changes have been detected.

Start of Cryodistribution system Commissioning in TOKAMAK Building
Particular warm thanks to:

- The cryogenic project team colleagues
- Our industrial partners Alat and ENDEL-ORYS-CRYO DIFFUSION consortium
Thanks for Your Attention

Questions?