Japan Contribution to the HL-LHC

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KEK
Engagement to the HiLumi-LHC Design Study
High Luminosity LHC Project

Participation from KEK

A visiting scientist from KEK to CERN

Another contribution to the LIU: PSB RF and PS damper
Possible Contribution to the HL-LHC (Plan)

• In-kind contribution
  – 6 full-scale D1 beam separation magnets assembled in cryostats for the new insertion region.
    • 4 for HL-LHC machine, 2 for spares.
    • All cold masses to be evaluated at warm and cold.
    • Only 1 or 2 full cryostats to be evaluated at cold.

• Accelerator Technology R&D
  – Study on beam related performance limitation
  – Beam diagnostics

• Japanese industry engagement
  – As realized in the present LHC (cold compressor, superconductors, non-magnetic steel, cable insulation, etc.)
  – Items and scale depending on the funding
New D1 in IR (ATLAS, CMS)

- Short distance btw D1 and D2.
- A large aperture of 150 mm.
Latest Design Parameters of D1

- **Coil ID:** 150 mm
- **Integrated field:** 35 T m (26 Tm at present LHC)
  - 5.59 T at 12 kA, \( L_{\text{coil}} = 6.3 \) m, \( E = 2.1 \) MJ
- **\( T_{\text{op}} \):** 1.9 K by HeII cooling
- **Op. point (2D coil):** 75 %
- **Coil layout:** 1 layer of 15.1 mm cable
  - Better cooling. Saving space for iron yoke.
- **Conductor:** Nb-Ti LHC MB outer cable (by CERN)
- **Structure:** Collared yoke structure by keying
  - RHIC dipole, LHC MQXA, J-PARC SCFM
  - Enhancing iron material for stray field issue
- **Field quality:** \(< 10^{-4}\) at \( R_{\text{ref}} = 50 \) mm
- **Cold mass OD:** 550 +10 x 2 = 570 mm
- **Cryostat OD:** 914 mm, same as MB cryostat
- **Radiation, energy deposition:** 20 MGy, \( \sim 2 \) mW/cm\(^3\)

◆ Stress management
◆ High saturation, stray field, flux return cryostat
◆ Radiation resistance, cooling capability
2m-long D1 Model Magnet

Single-layer coil, 4-split spacer collars, collared yoke by keying

- Notches and $\phi$ 34 mm holes for iron saturation effects
- $\phi$ 60 mm HX hole
- 4 split stainless steel spacer collars: NSSC-130S
- Brass shoes
- Shell: SUS304L
- Same outer-interface for J-PARC SCFM jigs
- Collaring keys
- Horizontal split iron yoke: low-carbon steel (EFE by JFE steel)
- Radiation resistant GFRP (S2 glass + BT resin) wedges
- NbTi SC cable (LHC MB outer) + Apical insulation
Development of Radiation Resistant GFRP

- Target: 50 MGy or higher (< 20MGy expected in the D1)
- Irradiated in vacuum at RT, evaluated at RT.

- Ordinary G10 (Epoxy) already showed significant degradation even at 10 MGy.
- New GFRPs (CE&Epoxy, BT, and BMI) show good radiation resistance up to 100 MGy.

**GFRP (S2 glass & BT resin) will be adopted for the new D1**
Design Tools

Parameters, specification given by CERN (beam, radiation, cooling analysis)

- EM Design
  - ROXIE, OPERA (for benchmarking in 2D and 3D)

- Structural Analysis
  - ANSYS

- Quench Analysis
  - Original code in KEK
Design Tools

• Engineering
  – Preparatory work: bridge between ROXIE output (.catia, .cnc) and CAD/CAM modeling
    • MS Excel w/ Visual Basic for Applications
  – 3D CAD/CAM: coils
    • NX7.5 (SIEMENS) for modeling
    • Solid Edge for drawings
  – 2D CAD: drawings for tooling and jig
    • OneSpace Designer (CoCreate)
In-kind contribution: D1 magnet w/ cryostat

It should be something like...

- D1 (MBXF) for the HL-LHC (Plan)
  - Cold mass in cryostat will be delivered by KEK with industry
  - Possible supplies from CERN
    - NbTi SC cables with insulation.
    - Insulated cold bore-tube with tungsten shield
    - Hell internal HX
  - Accessories from Japan
    - Vacuum and pressure vessels
    - Pipe, fitting, ferrule, welding
    - Signal wire
    - Alignment target, special feature, etc...

MQXA in cryostats

Compatibility with Japanese safety regulation

Compatibility with CERN’s and/or European regulation

In accordance with CERN’s guideline
Standard, Code

- JIS: Japan Industrial Standards
  - Mostly compatible with other Standards (ISO...), but there are some discrepancies...
  - Japanese products should basically follow JIS.
    - Materials: metals, organic materials
    - Mechanics
    - Electricity

- Code for the D1 in terms of high pressure gas regulation: “Designated Equipment Inspection Code”
High Pressure Gas Regulation in Japan

- Fundamental law: “High Pressure Gas Safety Act”
  - **KHK** (not KEK...): The High Pressure Gas Safety Institute of Japan.
    - Inspection and certification for the equipment
  - **Local government** (Ibaraki Prefecture for KEK)
    - Approval for the equipment
- KEK MUST follow this Act. Following procedures are foreseen for the D1:
  - 9m-deep vertical cryostat modification: Inspection in progress
  - Horizontal HeII test facility (NEW): Plan
    - The facility: Procedure just once
  - D1 cold mass in cryostat for horizontal testing: Plan
    - Procedure necessary for “every” D1 equipment.
Concern of Horizontal Testing in Japan

• Procedure for the D1 horizontal testing
  *This is NOT for “testing”. This is for something like “construction of facility”.
  – D1 equipment (cold mass and cryostat) is categorized as “Designated Equipment” in “High Pressure Gas Safety Act”.
  – Equipment MUST be inspected by KHK at the fabrication processes, even from the beginning. If passed, “Designated Equipment Inspection Certificate” will be issued.
  – After “Completion inspection”, equipment is approved by local government.

• Procedure above usually takes quite a long time (e.g. 8 months for a J-PARC SC magnet system).
  – Bottleneck of delivery schedule: serious concern for the D1 horizontal testing.
• If NO horizontal testing in Japan, we can omit the procedure for KHK and local government...
  – Deliverables should be discussed and defined by KEK and CERN
• In any case, the D1 equipment must follow the CERN’s and/or European safety regulation.
• HX was broken at the pressure test in the LHC tunnel (Dec. 2006).
• Buckling of corrugated copper pipe: annealed by brazing.
• Proper pressure test was not performed before delivery to CERN.
Lessons from LHC IT: Magnet Support Failure

- MQXA was moved by 15 cm at the pressure test in the LHC tunnel. (Mar. 2007)
- Unbalanced force due to the difference of cross sections of pipes was not taken into account for the support design.
- Was specification of the pressure test defined well in the design/fabrication phase?

Broken bellows

“spider” support
Summary

• KEK has been engaged in the HL-LHC design study.

• Possible contribution has been discussed. Major in-kind contribution from Japan will be the D1 magnet system.

• Design study of the D1 is underway.
  – Design tools: ROXIE, OPERA, ANSYS, CAD/CAM
  – Development of 2m long model magnet

• Unique high pressure gas regulation in Japan
  – Difficulty of a series of horizontal testing for the D1

• Close communication and clear specification will be definitely necessary for successful delivery of the HL-LHC equipment as an international collaborative work.