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ALS-U
ADVANCED LIGHT SOURCE

Conceptual Design of Superbend and Hardbend Magnets for Advance Light Source Upgrade Project

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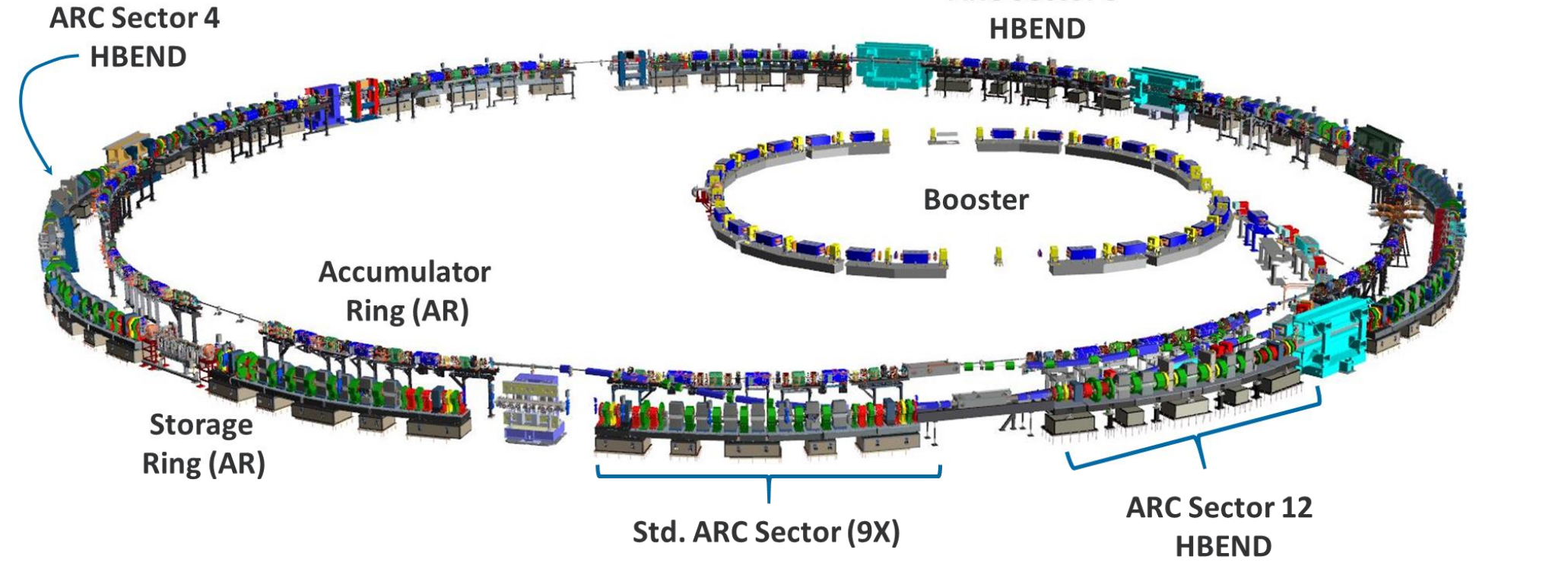
Introduction

The ALS-U project will upgrade the Advance Light Source into a 4th generation light source. The new Storage Ring will utilize a nine-bend-achromat (9BA) lattice design with on-axis injection from a full energy Accumulator Ring in order to achieve a diffraction-limited performance for soft x-rays. This will allow to increase the soft x-ray brightness by 2-3 orders of magnitude with respect to current ALS beam-lines capabilities.

Two magnet concepts were investigated to maintain support for medium energy x-ray beam-lines:

- Superconducting **Superbend** (SBEND) magnet using a Nb3Sn conductor, providing the magnetic field of 4.6 T at source points
- **Hardbend** (HBEND) magnet that uses permanent-magnet blocks made of a NdFeB material, providing 3.2 T field at source points



Superbend

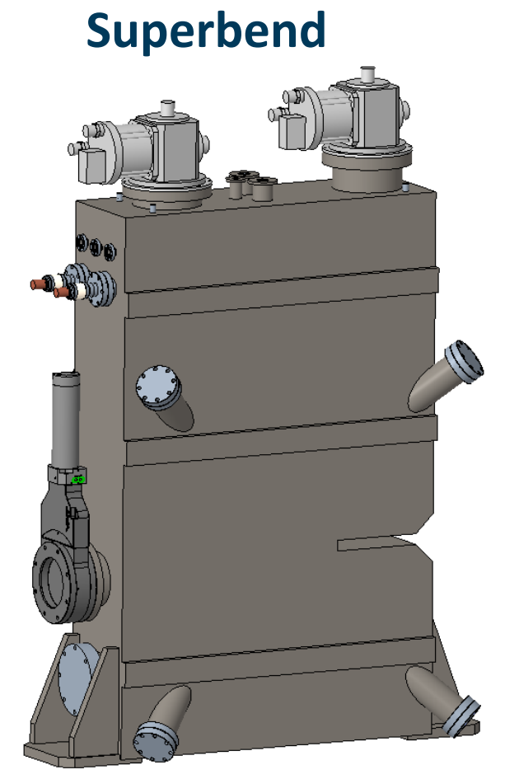
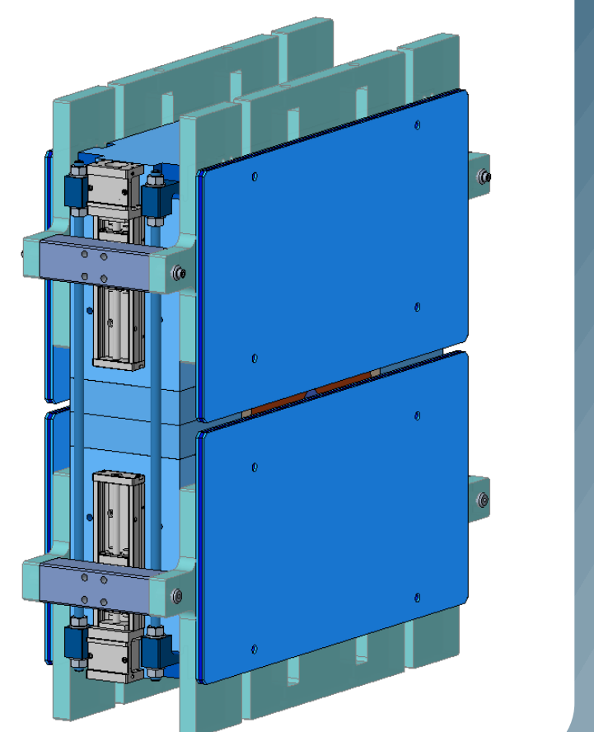


TABLE I
MAIN PARAMETERS OF ALS-U HIGH FIELD MAGNET CONCEPTS

Parameter	Superbend	Hardbend
Beam energy	2.0 GeV	
Bend angle	3.76°	
Field integral	0.438 Tm	
Source points	+/- 11 mRad	
Magnetic length	93 mm	137 mm
Field at source points	> 4.6 T	> 3.1 T
Maximum field	7.6 T in the coil 5.1 T in the bore	3.2 T
Transverse gradient	0 T/m	
Magnet topology	C-shape	H-frame
Magnetic field driver	Nb_3Sn coils[a]	NdFeB blocks[b]
Flux concentrator	Holmium pole Permendur interface	Permendur pole
Pole to pole distance	58.5 mm	10.5 mm

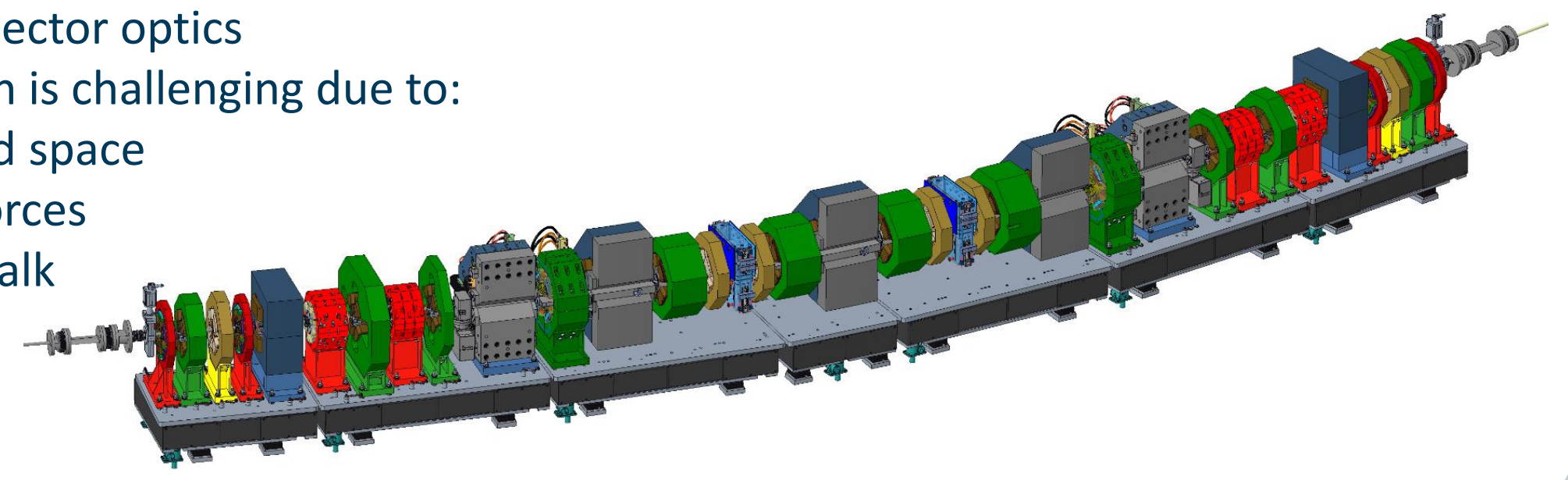
[a] Superconductor: rectangular internally-reinforced bronze-route Nb_3Sn wire
[b] Main blocks properties: $B_r = 1.35$ T, $H_c = 12.7$ kOe

Hardbend



High Field Magnets in the ALS-U Storage Ring

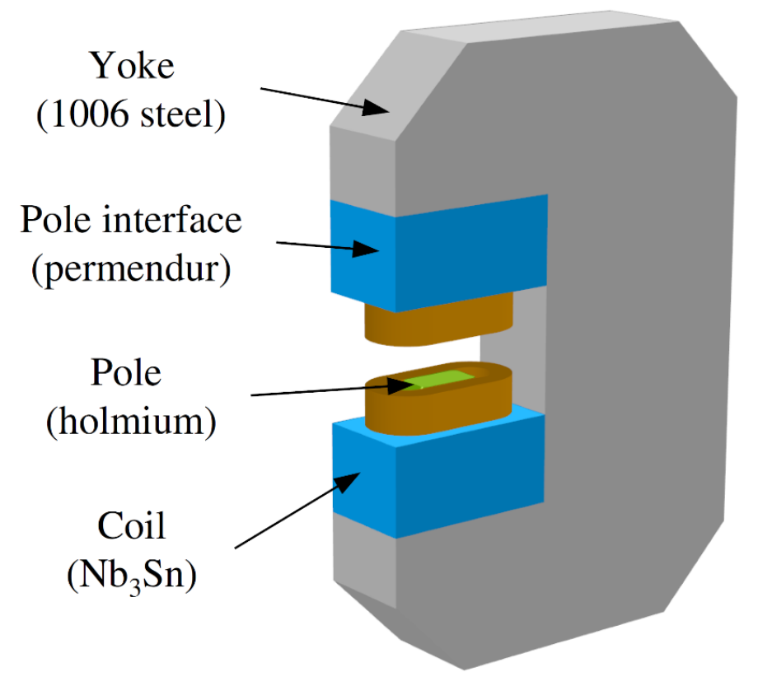
- Nominal Storage Ring lattice designed as a 12-fold symmetric Nine-Bend-Archomat lattice
- In three arc sectors, two gradient dipole magnets are replaced with high-field dipoles
- Each high field dipole magnet is accompanied by two, thin, defocusing gradrupoles to match the nominal arc sector optics
- High field magnet design is challenging due to:
  - Extremely limited space
  - High magnetic forces
  - Magnetic cross-talk

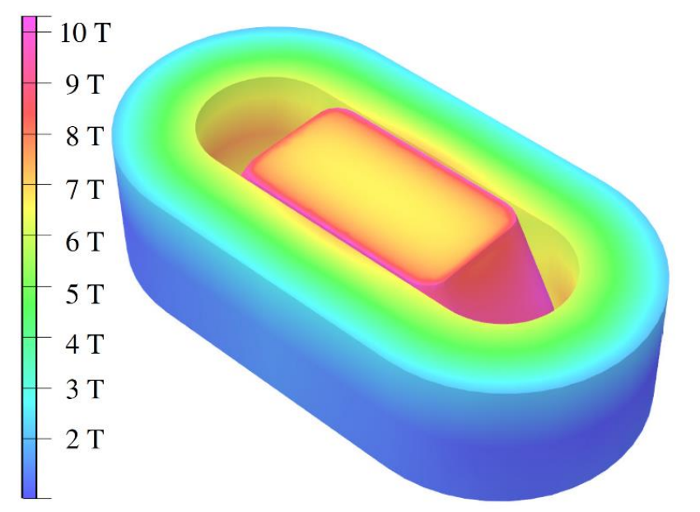


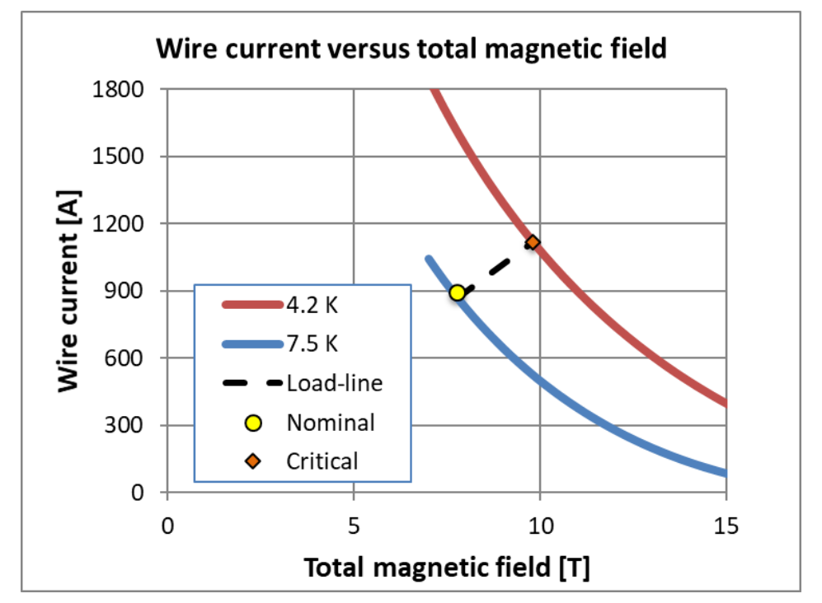
Superconducting SUPERBEND Magnet

Magnetic design

- Warm-bore design with a C-shape return yoke.
- Low-carbon steel (1006) yoke with permendur (50Fe-48Co-2V) pole interfaces.
- Two race-track coil made of a bronze route Nb3Sn superconductor are wound on a holmium pole, which acts as a flux concentrator.
- Design satisfied requirement of the dipole field integral and provides the source point field of 4.6 T.
- Peak magnetic field in the conductor is 7.6 T at an engineering current density of 328 A/mm2.







Internally reinforced superconductor requirement

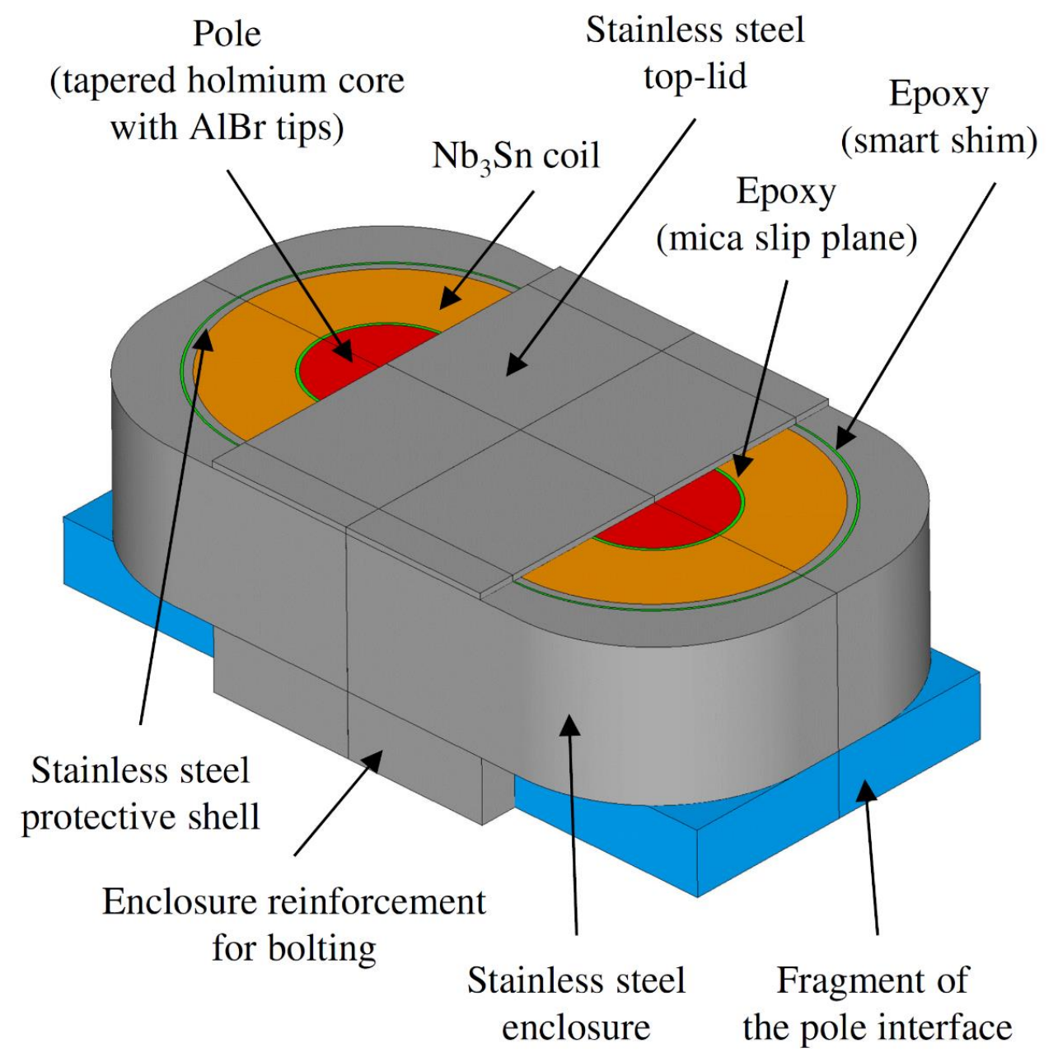
- High integrated magnetic forces
  - 177 kN over a straight-section
  - 81 kN over a return-end
- Rectangular bronze-route Nb3Sn superconductor with a CuNbTi core reinforcing internally the wire
  - High strength wire with typical yield stress of about 260 MPa at 4.2 K
  - Available data shows no degradation of a critical current up to about 150 MPa of tensile stress
- Wire dimensions of 1.13x1.70 mm assumed for performance evaluation
- Load-line operation point at 77.8% of critical current and 3.3 K temperature margin

Coil Design

- The coil is wound on a tapered dummy pole with aluminum-bronze pole-tips.
- Mica sheets between the pole and the conductor serve as a slip plane.
- Protective stainless steel shell is installed before the coil is reacted in a dedicated heat-treatment fixture.
- The holmium pole is installed before the coil is vacuum impregnated with an epoxy resin.

Stress Analysis

- Maximum tensile stress below 110 MPa in the high-field zone and below 56 MPa in low-field zone.
- Compressive stress in below 20 MPa in the return end and below 41 MPa in the straight section.
- Maximum stress at room temperature assembly and after cool-down is below 25 MPa.



Support Structure Design

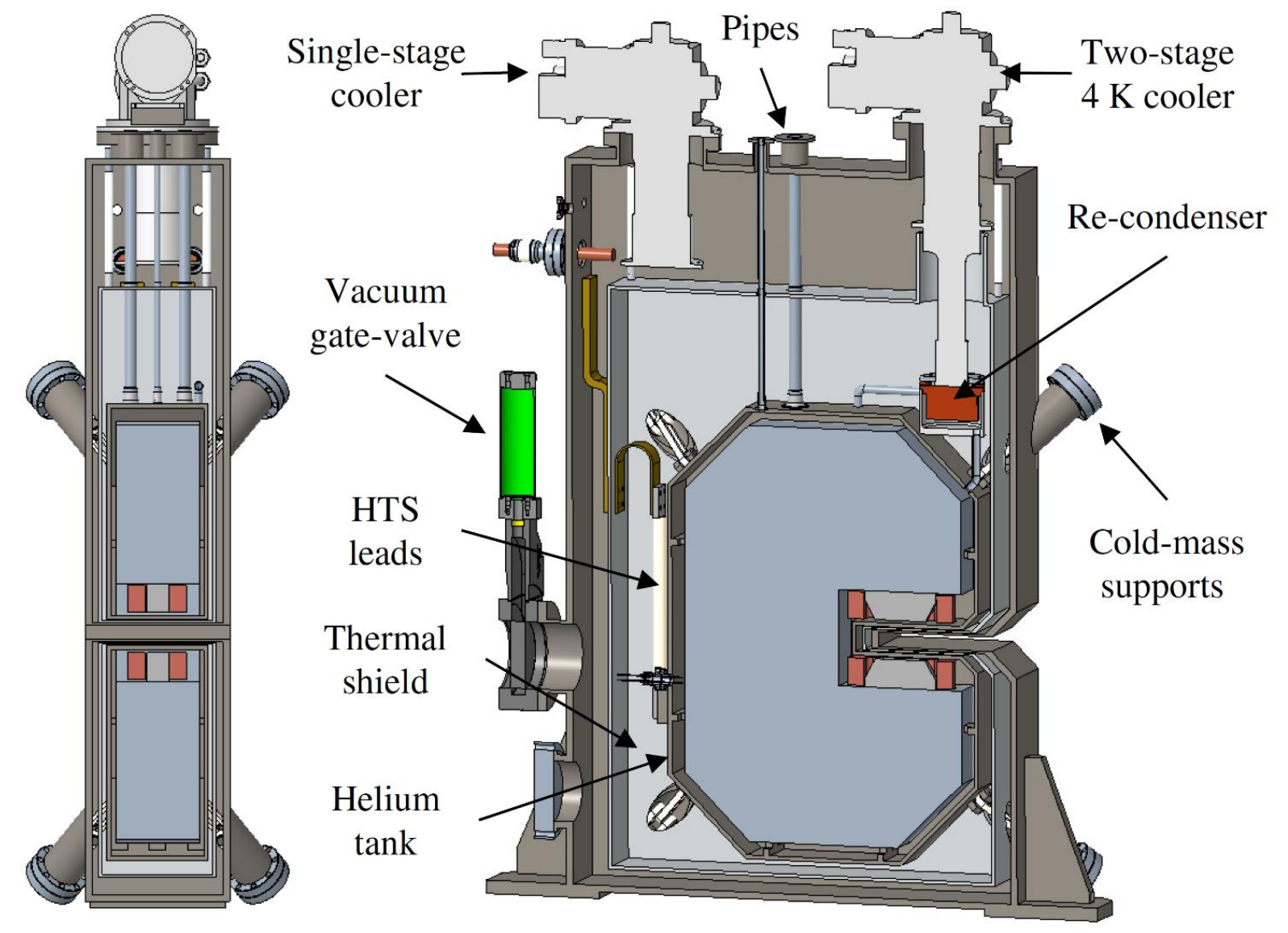
- Stainless steel race-track shape structure with side reinforcement extensions for bolting, removable top-lid for bridging straight sections.
- Bend-and-shim technique is used for assembling the magnet.
- The external shell is pre-bent to develop gaps along the coil straight section.
- Smart shims are inflated inside gaps with epoxy resin.

Stress Analysis

- At the nominal field the stress level in the stainless steel enclosure is below 100 MPa Maximum stress in the top-lid is below 220 MPa.
- The total tensile force on the set of side-bolts is 17.5 kN.

Cryostat design

- The magnet cold-mass is zero-evaporation cryo-cooler-cooled by using bath cooling in a liquid helium (LHe) vessel (re-condenser).
- The cryostat consists of the LHe vessel, a thermal shield, cold mass supports, binary leads, cryo-coolers, pipes, instruments and a vacuum chamber.
- Two cryo-coolers are adopted due to relatively large heat load of about 93 W at 40-50 K induced by one pair of 1 kA binary leads.
- Single-stage cooler – the thermal shield and warm-ends of HTS leads.
- Two-stage 4.2 K cooler – second-stage cold-head is used to re-condense the evaporated helium from the LHe vessel and cool the cold-ends of HTS leads.
- The LHe vessel is suspended in a vacuum chamber by eight, adjustable straps made of epoxy fiberglass with high strength and low thermal conductivity.
- The estimated heat loads at 4.2 K and 45 K are respectively about 0.7 W and 150 W considering contingency.



Summary

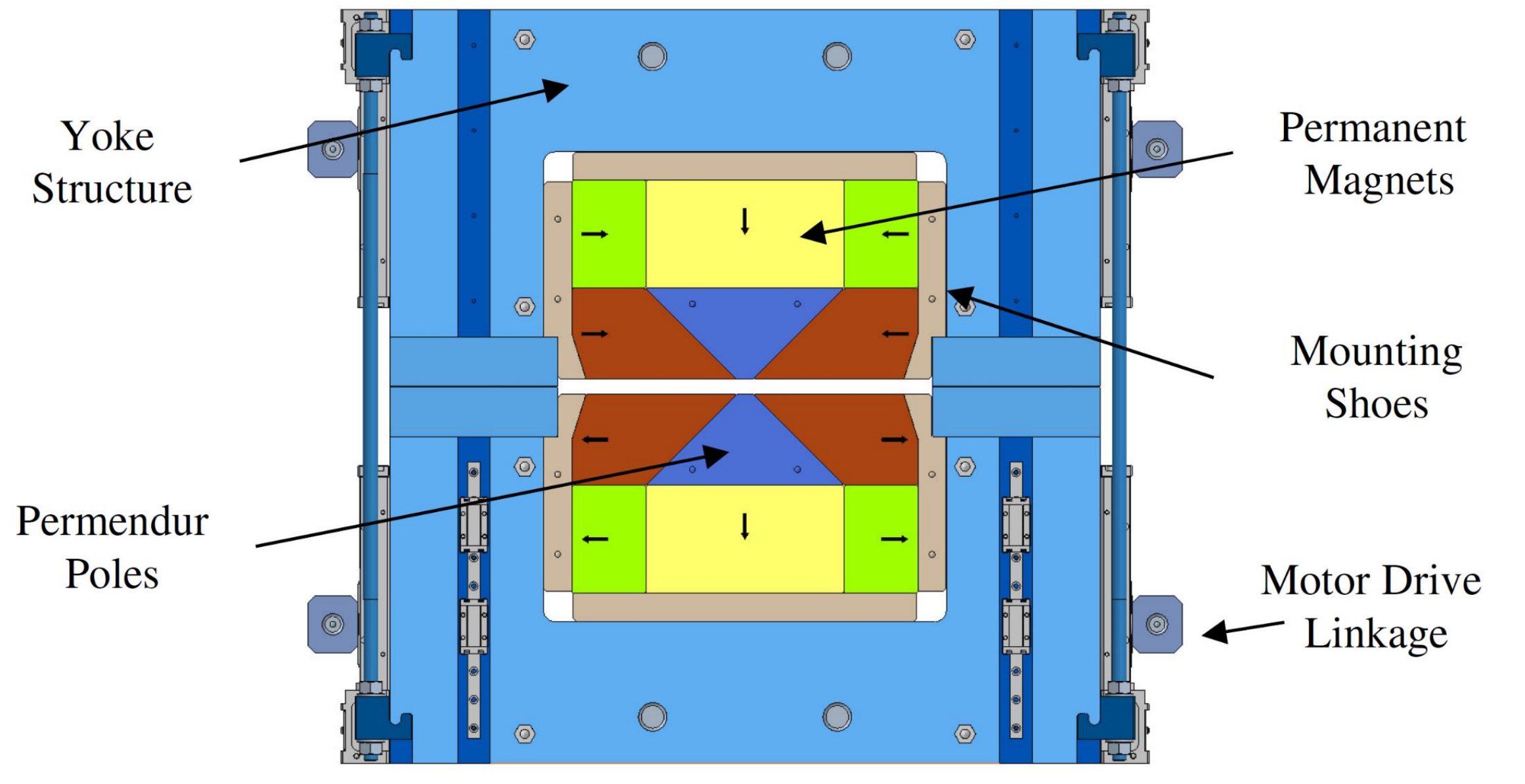
Superbend magnet concept was developed during a conceptual design phase of the ALS-U project. The design study demonstrated a feasibility of reaching 4.6 T source point field requirement. The requirement can be met by using a combination of permendur alloy for the pole interfaces, holmium poles and Nb_3Sn coils. The internally reinforced, high-strength superconducting wire and a compact, rigid support structure allow to minimize the coil stress and deformation. The compact, warm-bore cryo-stat design provides sufficient cooling contingency for a relatively large heat-load from the current leads.

Hardbend magnet concept, which is based on a permanent-magnet technology, was selected by the ALS-U project to be used in the high-field magnet arc-sector of the new Storage Ring. It is currently at a preliminary design phase. Accelerator physics compatibility, radiation requirement and engineering feasibility have been established. The effort is directed towards establishing manufacturing, assembly and installation methods and to proceed towards a prototype phase.

Permanent HARDBEND Magnet

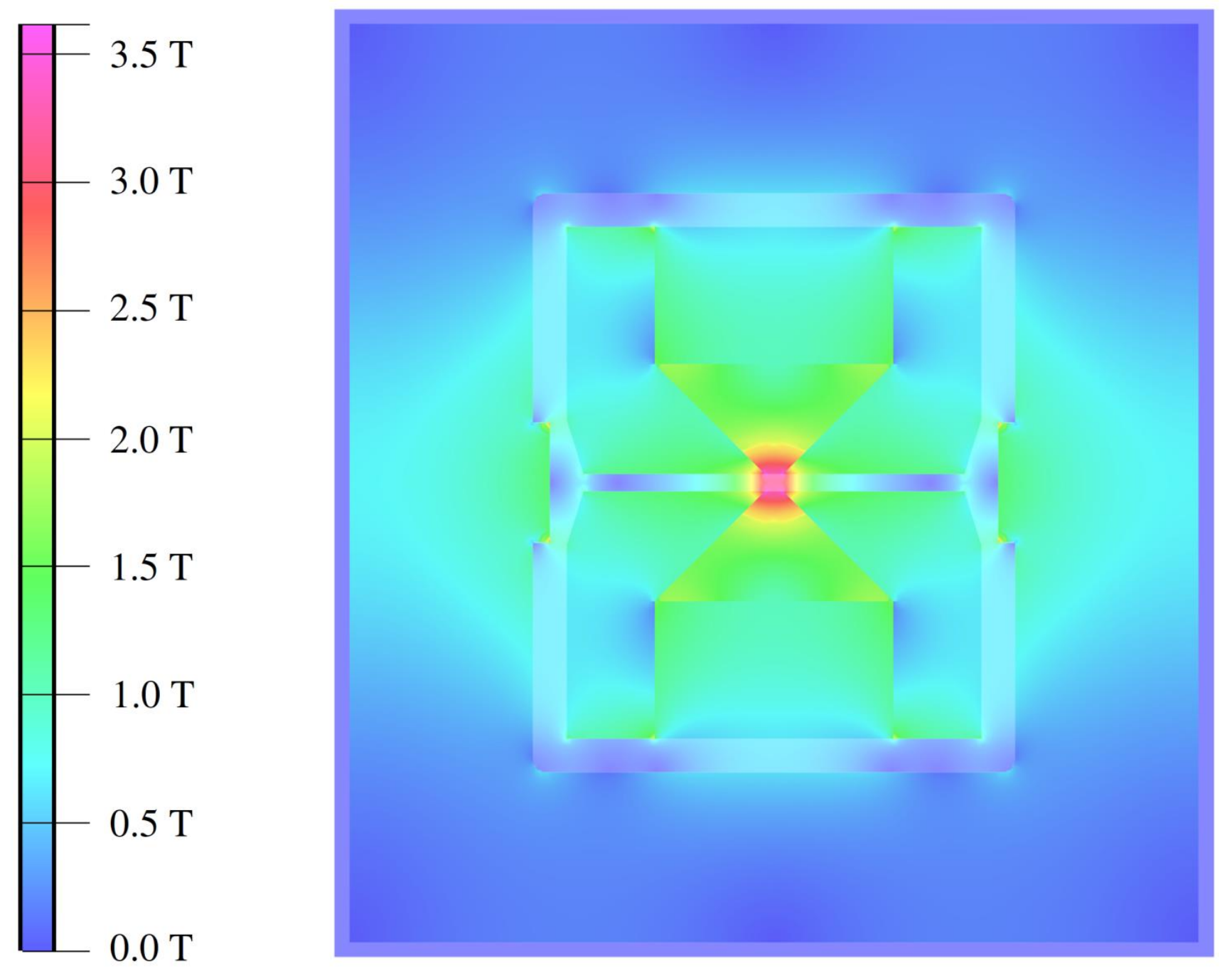
Magnet Concept

- Design was initiated as an alternative to superconducting magnet design.
- In June 2019, the ALS-U project determined that a 3.2 T dipole using permanent magnet technology was a preferred solution.
- Concept uses an H-frame type of magnet structure.
- Split yoke structure is used to accommodate for installation and magnet removal for maintenance or NEG coating activation.
- Field adjustability is required in case of construction or temperature variation errors and performance degradation due to radiation.
- Design requires axial field shielding to minimize cross-talk with neighboring magnets
- Transverse field shielding is required for general safety.



Magnetic Design

- Flux concentrating poles made of permendur alloy (50Fe-48Co-2V) are surrounded by a high coercivity NdFeB permanent-magnet blocks.
- Source point field requirement of 3.2 T results in a saturated pole design.
- Additional axially-align permanent magnet blocks increase achievable field by about 0.15 T.
- Vertical adjustor plates and position control system allow to use axial PM blocks to compensate for field errors and performance degradation.
- Composite iron-aluminum magnetic field clamps isolate the adjacent quadrupoles from the high-field dipole.
- Low-carbon magnetic-steel yoke enhances the field by roughly 0.15 T and provides a mechanical stress management and a magnetic shielding for safety during servicing of the ring.



Mechanical Design Concept

- Upper and lower permanent magnet assemblies are bonded-core constructions.
- Non-magnetic mounting-shoes are integral part of the pole assemblies.
- Mounting-shoes provide tooling interfaces facilitating installation and precise alignment inside carbon steel yokes
- Magnet yoke halves are aligned with each other with precision dowel pins and secured together with side clamps
- The axial permanent-magnet blocks are bonded with a vertical adjuster plates.
- Adjuster plates are part of the axial permanent-magnets position control system