PRELIMIARY DESIGN OF HEPS STORAGE RING VACUUM CHAMBERS AND COMPONENTS

P. He (IHEP)

5-9 March, FLS’2018, Shanghai, China

Content

- 1. Introduction: HEPS storage ring parameters
- 2. Vacuum chamber design
- 3. Special Hardware components Development
- 4. Conclusions

Introduction

Goals and the target performance of LS (Light Source) storage rings:

Constant delivery of a high quality, intense and stable photon beam to a large number of beamlines

High quality and intense photon beams: Often characterized in terms of

$$Brilliance = \frac{Photons}{Second \cdot mrad^2 \cdot mm^2 \cdot 0.1\% BW} \propto \frac{I}{\varepsilon_x \varepsilon_y}$$

I : Beam current, ε_u : Transverse emittance

Presently a big global wave for 3GLS → DLSR (Diffraction Limited Storage Rings or 4GLS)

Lowering of transverse beam emittance

Optimal ring structure from DBA, TBA lattice → MBA lattice

Ring-Based LS Future Trends

- A global wave today to construct (or *re-construct*) ring-based LSs having the horizontal emittance ε_H by **tens of factors** below the “nm·rad” range

<u>Basic principle used:</u>

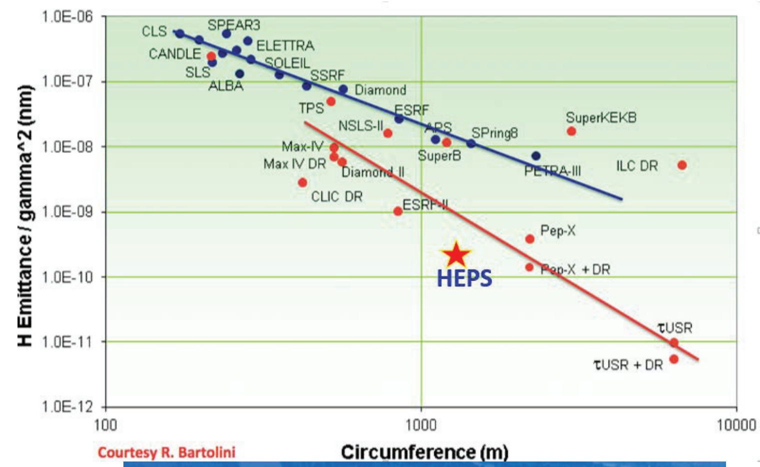
$$\left(\varepsilon_H\right)^{Theoretical}_{Minimum} \propto E^2 \cdot \theta^3$$

E: Beam energy, θ: Bending angle

Beam energy

$$\epsilon_0 \sim \frac{E^2}{(N_s M)^3}$$

Number of sectors   Dipoles per sector



HEPS

Challenges on vacuum systems for Low Emittance/DLSRs

Main Purpose of DLSRs_Vacuum System Design:
Have low dynamic pressure which gives good beam lifetime,
and to handle the power deposited by SR.

- High gradient quadruple → Small magnet bore aperture
  Vacuum Chamber designs compatible with magnet poles, photon extraction and beam stay clear conditions(space limitation)
- Handle the power deposited by SR →
  Integration of pumping ports, photon absorbers, collimators and crotches(high SR power)
- Small magnet bore aperture → Low profile vacuum chamber(Lumped pumping would not be as efficient in reducing the pressure)
  Detailed evaluation of vacuum profiles along the ring(conductance limitation)

→ NEG coating must be a very helpful method for DLSRs to provide distributed pumping

- Some specific hardware development in future DLSRs
  "Zero-impedance" flange, RF_shield Bellow, BPM etc…
- In-situ baking materials development
  thin Polyimide foil heater + Al coating polyimide foil

Vacuum System Design Options for 4th LS

Design Option	Impact on other systems	Risk	Cost for chambers, photon absorbers, distributed pumping
All NEG-coated copper chambers (MAX-IV, Sirius)	In-tunnel magnet disassembly or larger bore size could be required for installation and re-activation.	Medium	$17.5k/m
All antechambers and discretely located absorbers	Lattice and magnet geometry (more space between magnets and magnet coils).	Very Low	$10.6k/m
Hybrid	In-tunnel magnet disassembly may be required for re-activation.	Low	$12.8k/m

HEPS Storage Ring Parameters

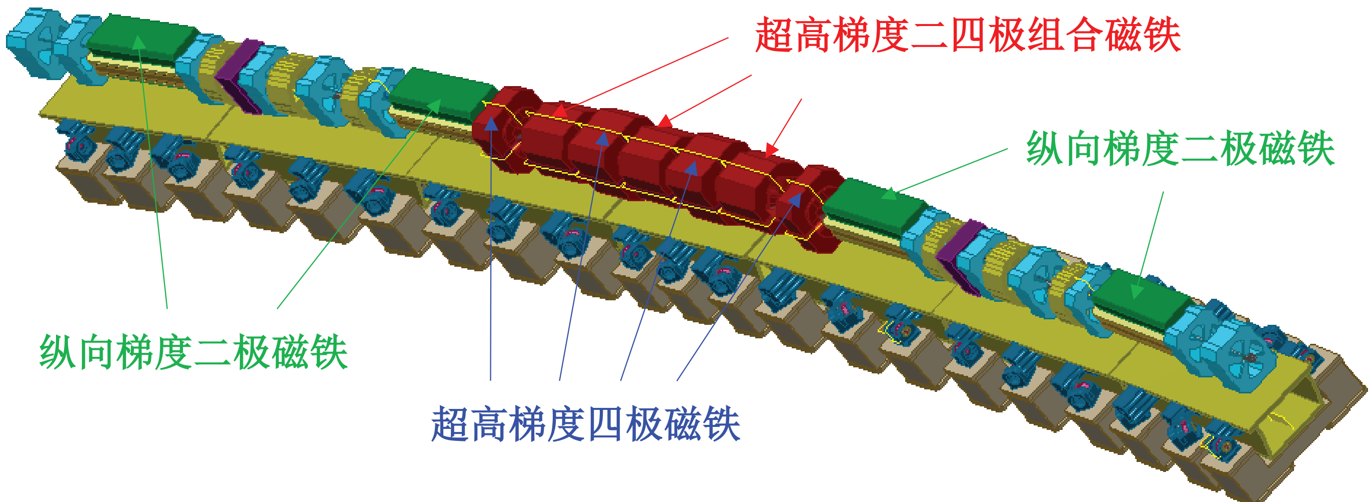
Beam Energy（GeV）	6
Current（mA）	200
Storage Ring（m）	1360.4
Booster（m）	453.5
Emittance（nm·rad）	0.06
Lattice	7BA
Straight Section Length（m）	6
Cell Number	48

Compare with other LS

Table 1: New Ring-Based LS's Parameters

Facility	C(m).	E(GeV)/I(A) Ɛx(pm.rad)	Mag. Bore(mm)	Chamber Material	Baking Method
MAX-IV (Sweden)	528 (20cell-7BA)	3/0.5 330	25	OFS Cu (100% NEG Coating)	Ex-situ
SIRIUS (Brazil)	518.4 (20cell-5BA)	3/0.5 250	28	OFS Cu (100% NEG Coating)	In-situ
EBS (France)	844 (32cell-7BA)	6/0.2 135	26	SST/Al (Partial NEG Coating)	In-situ
SPring-8_U (Japan)	1436 (48cell-5BA	6/0.1 140	26	SST (No NEG Coating)	Ex-situ
APS_U (USA)	1100 (40cell-7BA)	6/0.2 60	26	OFS Cu/Al (Partial NEG Coating)	Ex-situ

One Cell Layout of HEPS



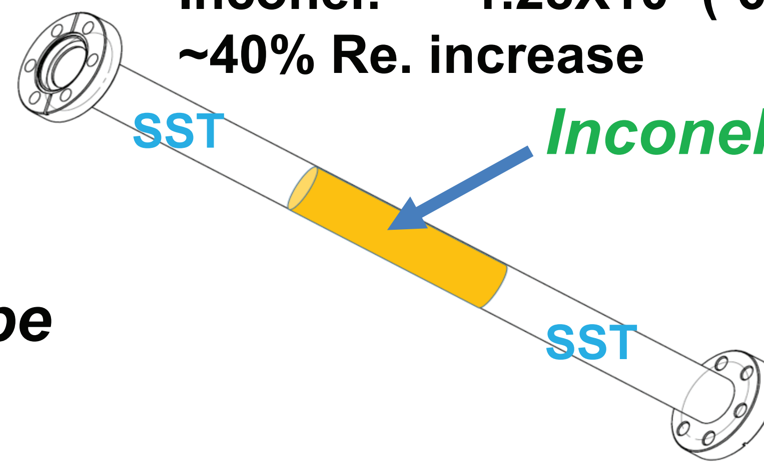
HEPS standard one cell lattice

According to magnet function, divided into:
Q-doublet, L-bend, Multiplet, and FODO sections.

Vacuum Chamber @ Fast Corrector

Fast corrector between two Quads

Resistivity:
316LN SST: 7.4x10^(-7)Ωm
Inconel: 1.28X10^(-6) Ωm
~40% Re. increase



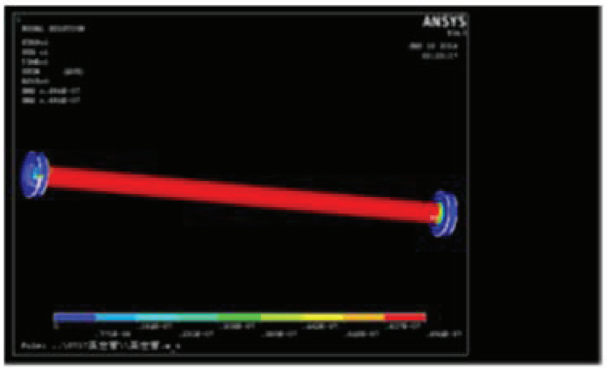
prototype

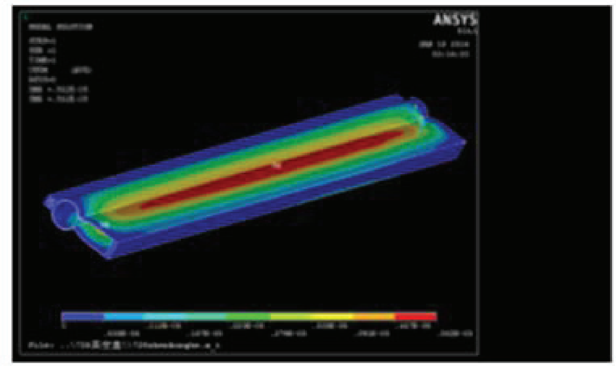
results：

1、tolerance meet specification；
2、leak rate<1E-10mbar.L/s；
3、after welding magnetic permeability<1.01。

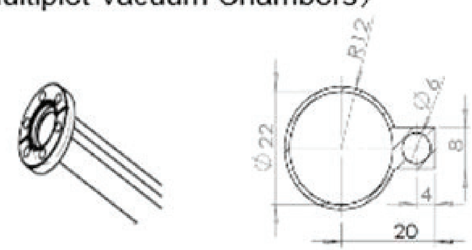
Multiplet Chamber

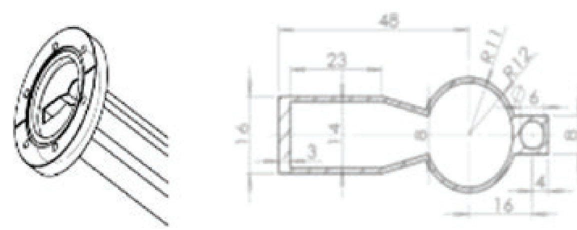
(Loading is uniformly distributed and amounts 0.1N/mm², which corresponds to the pressure of 1 atmosphere.)





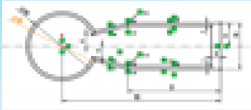
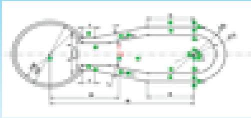
（Multiplet Vacuum Chambers） and （X-ray Extraction Chambers）

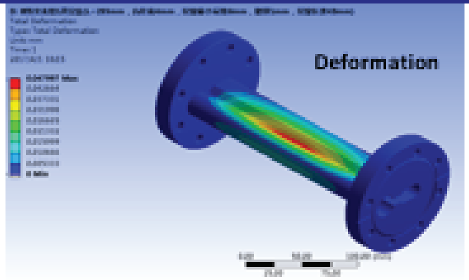


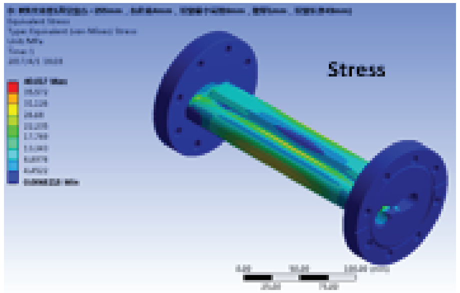


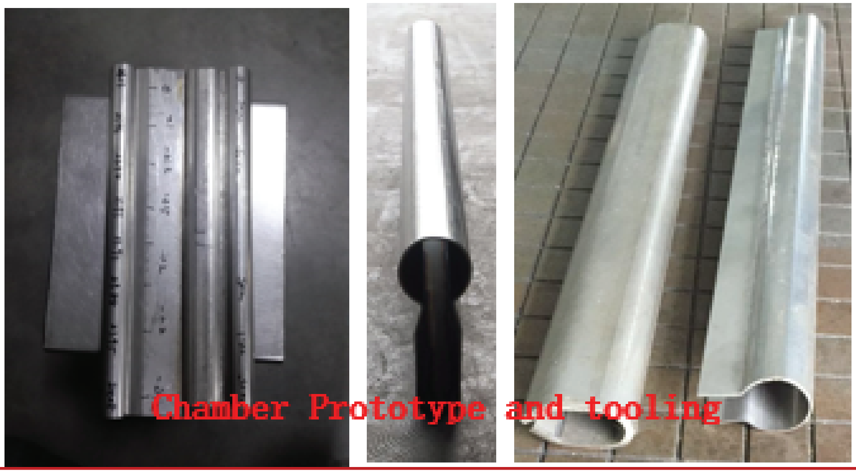
Chamber material: 316LN SST

X-ray Extraction Chamber（L=255mm）

type	Cross-section	Max. Defor. (mm)	Max. Stress (MPa)
	1mm equal thickness	0.215	146.99
	Non-uniform thickness	0.0514	44.282






Chamber Prototype and tooling

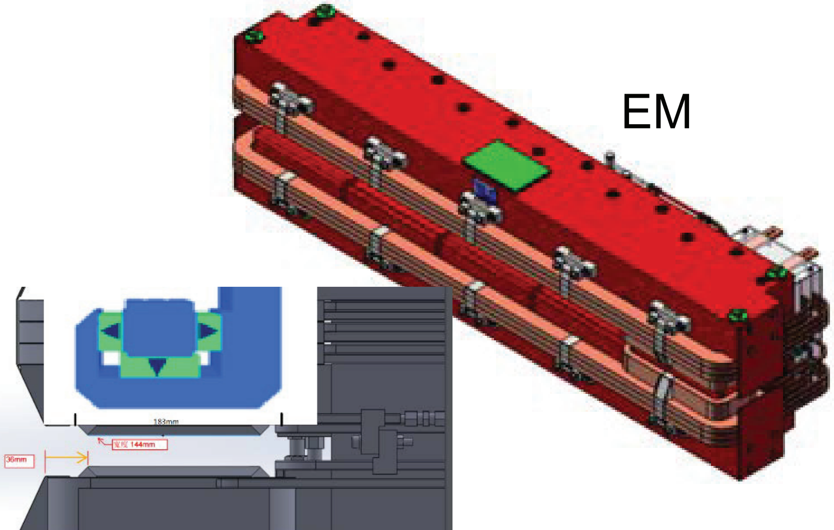
Results:

1、1st prototype(316L), the permeability>1.04, max. deformation 0.25mm（Spec. 0.1mm）;

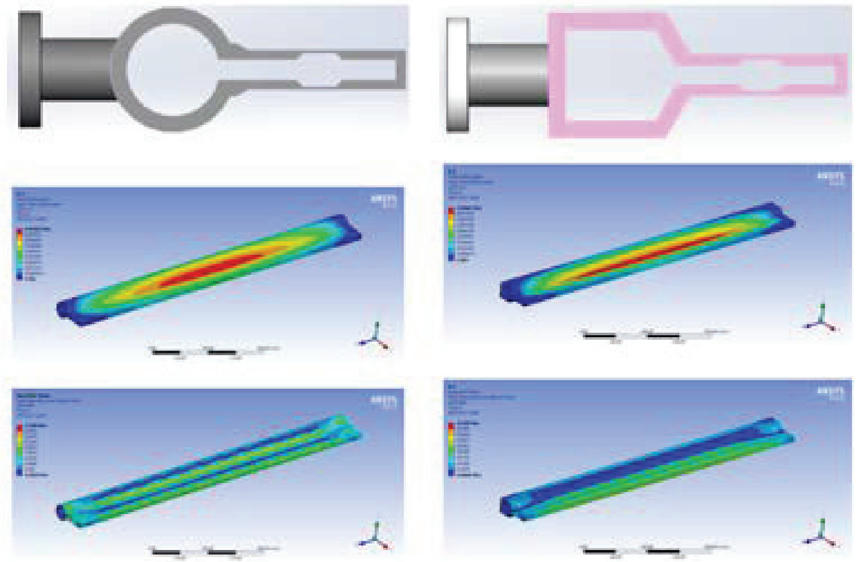
2、will measure again after welding flange, annealing, reshaping;

3、will modify tooling and then made from 316LN.

LGD Chamber (EM&PM)



EM



PM

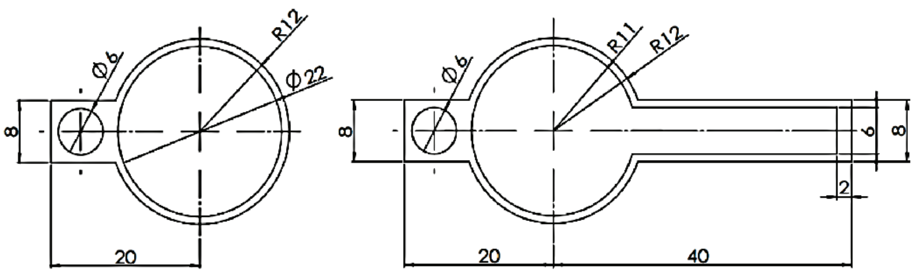
type	Def. mm	Str. MPa
Cir.	0.055	17.81
Rec.	0.086	44.92

FODO Section Chamber

- Copper chambers with water-cooling channels on outboard side. High power synchrotron radiation hits the chambers, distributed photon absorber may needed.
- Upstream chamber is same as Multiplet chamber. Downstream chamber may include photon extraction slot for BM beamline.
- NEG coating needed in the center part.

OFS Copper（C10700）vacuum tube

Cross section:



Difficulties:

- Spend long time to find right material
- Thin wall, small cross section, hard to machine

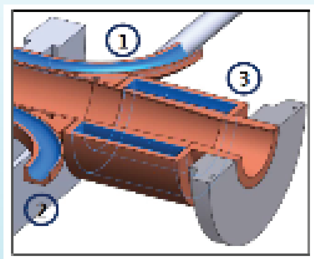
Gas brazing test, filler is not fully fill up

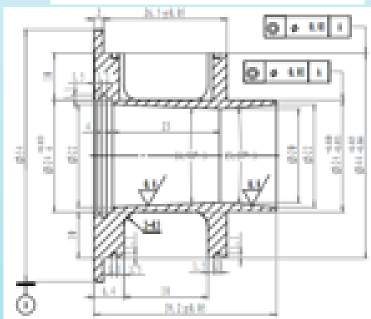
vendor@Shanghai

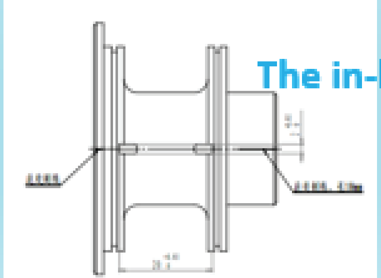
technique solution:

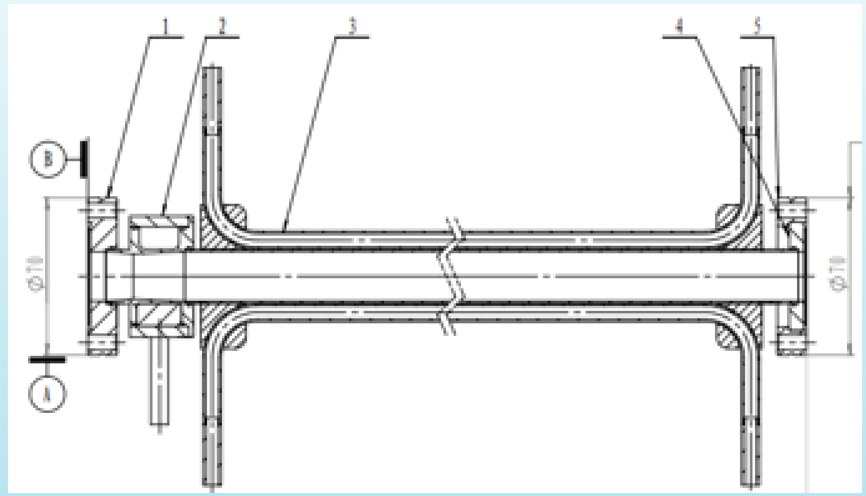
- Cir. and Rec. tube extruded together, and then brazing the cooling water channel

In-line GlidCop absorber copper tube



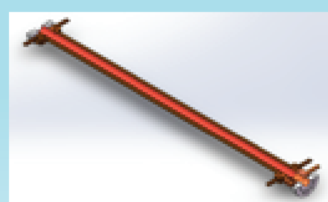


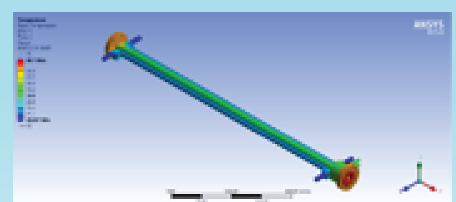




prototype is under fabricating, will delivery in the middle of next month.

The in-line distributed photon absorber in the end of the chamber





Connection Flanges consideration

Matsumoto-Ohtsuka (MO) -type flange

- No gap
- No step
- Smooth inner surface
- Beam only see copper

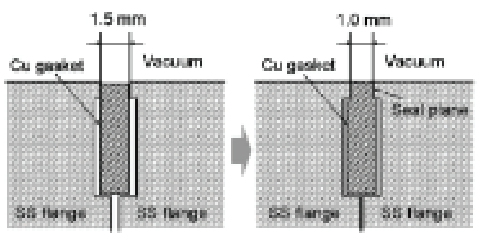
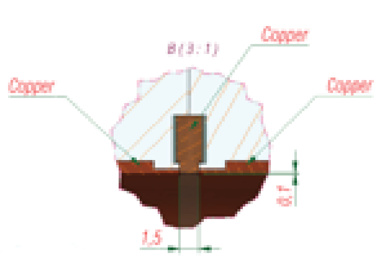
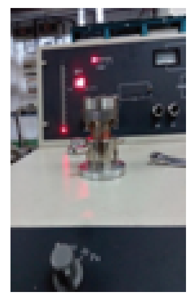
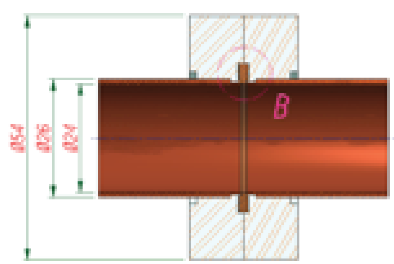


FIG. 2. Conceptual principle of the MO-type flange. The vacuum is sealed by a plane (seal plane) at just the inner surface.

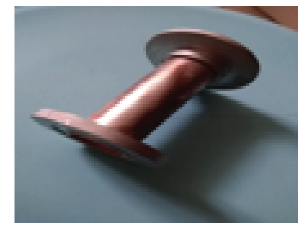


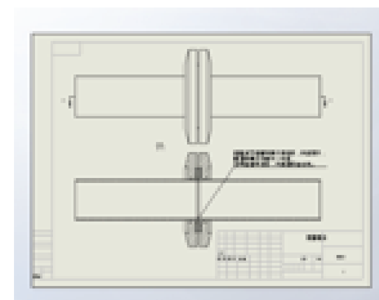
MO_type bolts





MO_type clamps



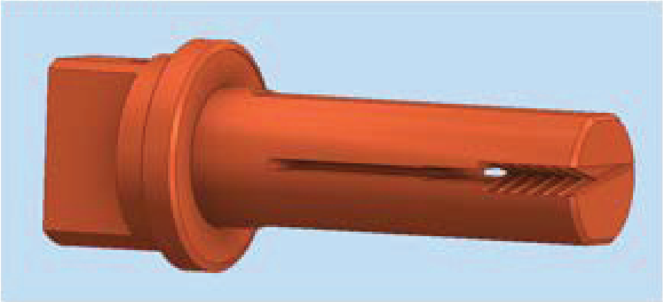


Photon Absorber

- GlidCop

Brazing GlidCop_AL_15 to stainless steel (SST) by using filler 50Au/50Cu in a vacuum furnace

- CrZrCu



100% machined, no brazing, no welding

Handle higher SR Power

Material Selection “Glidcop AL-15 Vs Copper Chromium Zirconium (C18150)”

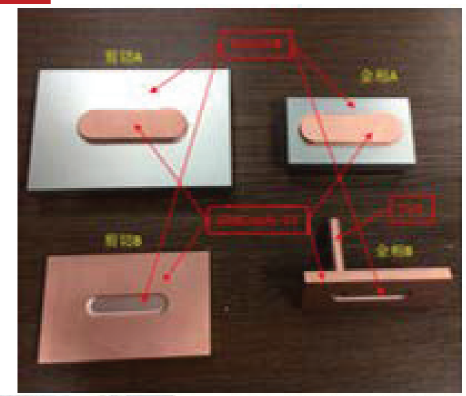
Material Properties

- *Thermal Conductivity (RT):*
  Glidcop Al25, Al15: 344 - 365 W/(m.K)
  Cu-Cr-Zr: 314 - 335 W/(m.K)
- *Elastic Modulus:*
  Glidcop Al15, Al25: 130 GPa
  Cu-Cr-Zr: 123 GPa
- *0.2 % Yield Strength, (RT, Cold Worked):*
  Glidcop Al15, Al25: 470 - 580 MPa
  Cu-Cr-Zr: 350 - 550 Mpa
- *Coefficient of Thermal Expansion:*
  Glidcop Al15, Al25: 16.6 μm/K
  Cu-Cr-Zr: 17.0 μm/K

- *Cu-Cr-Zr (C18150) is 1/4th the price of Glidcop AL-15.*
- *Cu-Cr-Zr is readily available in different forms and sizes from many suppliers.*
- *Cu-Cr-Zr loses its strength rapidly if exposed to sustained temperatures > 500°C*
- *Glidcop is the choice if brazing is required.*

Ref: Li M. and Zinkle S. J. (2012) Physical and Mechanical Properties of Copper and Copper alloys, Comprehensive Nuclear Materials, Vol. 4, pp 667-690

GlidCop absorber prototype



Brazing GlidCop_AL_15 to stainless steel (SST) by using filler 50Au/50Cu in a vacuum furnace

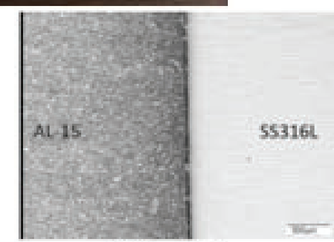
Sample Testing

Shear strength A 30MPa
Shear strength B 184MPa
SEM analysis A have no capillary action
SEM analysis B have capillary action but several voids

Vacuum leakage testing √

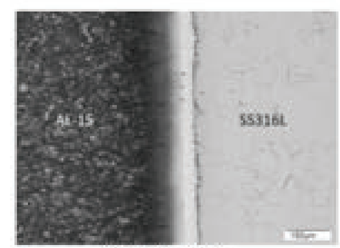
Vendor still work on the new brazing procedure

Shear strength A



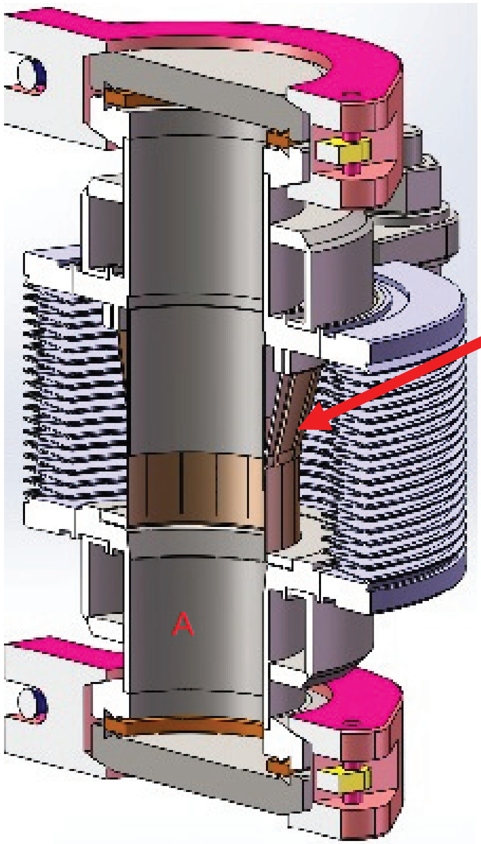
SEM analysis A

Shear strength B

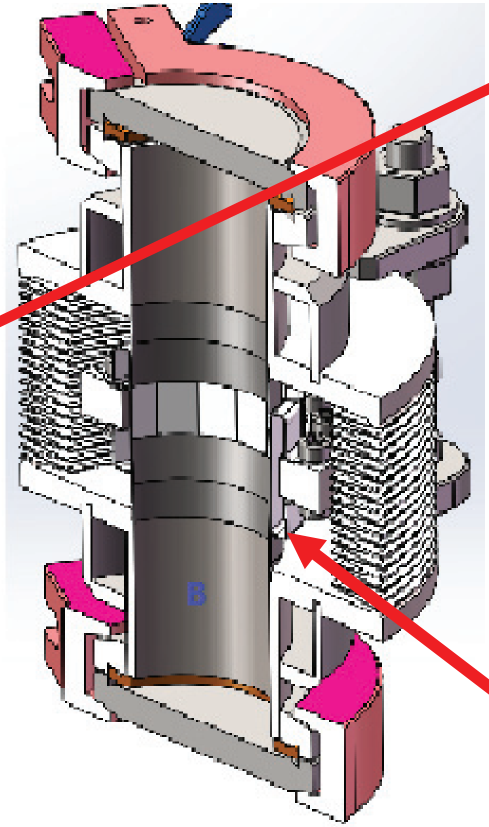


SEM analysis B

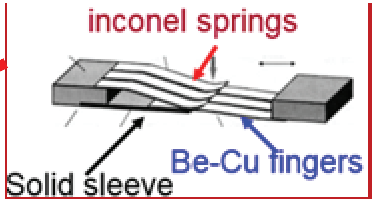
RF Shielded Bellow

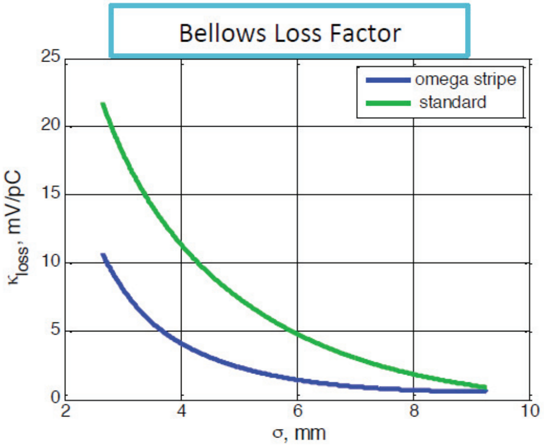


A. Outside Finger



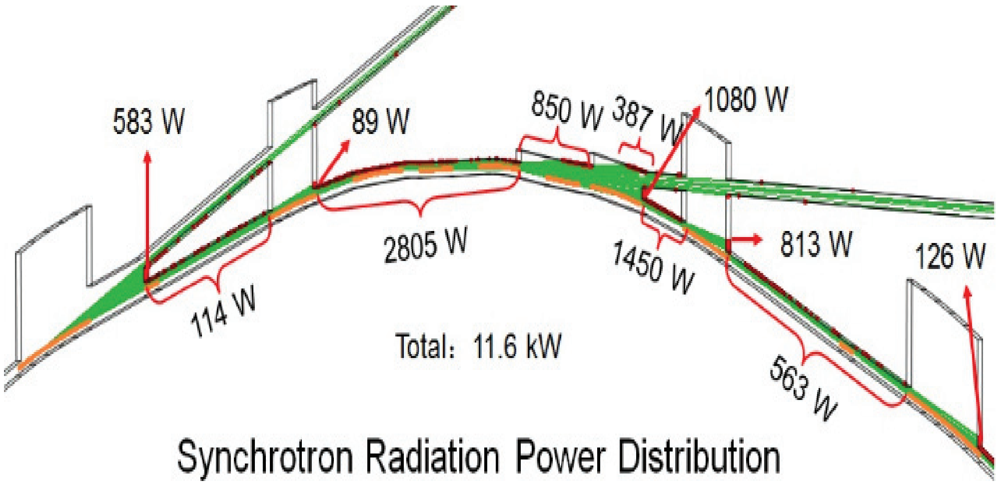
B. Omega Stripe





CuBe to be gold plated

SynRad Ray Trace Analysis



Synchrotron Radiation Power Distribution

The higher power radiation generated primarily in central section and at outer ends (near ID straight section). FODO chambers receive more than half of the total power. Straight multiplet chambers receive very little power.

These results provide much help to chamber and absorber design

Need more detail simulation and then optimize the design

Summary

- The HEPS vacuum system scope and interfaces with other systems are well defined.
- The vacuum system conceptual design for HEPS has been developed which meets the stated requirements. To cope with high synchrotron radiation, high photon flux, intense HOM excitation, strong collective effect, and so on.
- Major design alternatives have been considered.
- Risks have been accounted for.
- Vacuum hardware components prototype are under constructed.
- More R&D and analysis are necessary for mitigating the risks.

We have experienced various problems during the operation 3rd generation LSs, and learned lots of things. These experiences should be some of help for the future design of next-generation LSs.

Thank you for your attention

Vacuum Chamber Material

- 1. Elimination of aluminum-SS transition space.

Spring-8 experience

- 2. High mechanical strength resulting in a reduced chamber thickness.
- 3. Suppression of the electron beam vibration originating from vibrations of the chamber.
- 4. Low outgassing rate resulting in an increase in intervals between the NEG reactivation.