COPPER BRAID HEAT CONDUCTORS FOR SIRIUS CRYOGENIC X-RAY OPTICS

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MEDSI CHICAGO 2020

Abstract

The low emittance and high photon flux beam at the Sirius 4th-generation synchrotron light source beamlines result in high energy densities and high heat loads at some specific X-ray optics such as monochromators and white beam mirrors. This challenges the design of such systems since the introduction of thermal stresses may lead to optical surface deformation and beam degradation. Thus, to keep the systems within designed acceptable deformations, some of the optical elements are cryogenically cooled. However, this poses the requirement of decoupling the thermal sinks (cryostats) from the optics and their mechanisms to maintain their desired stability and degrees of freedom for alignment and dynamic operation. In this context we present the development of low-stiffness copper-braid-based heat conductors, summarizing the motivation and main aspects regarding their fabrication and application at the beamlines.

Introduction

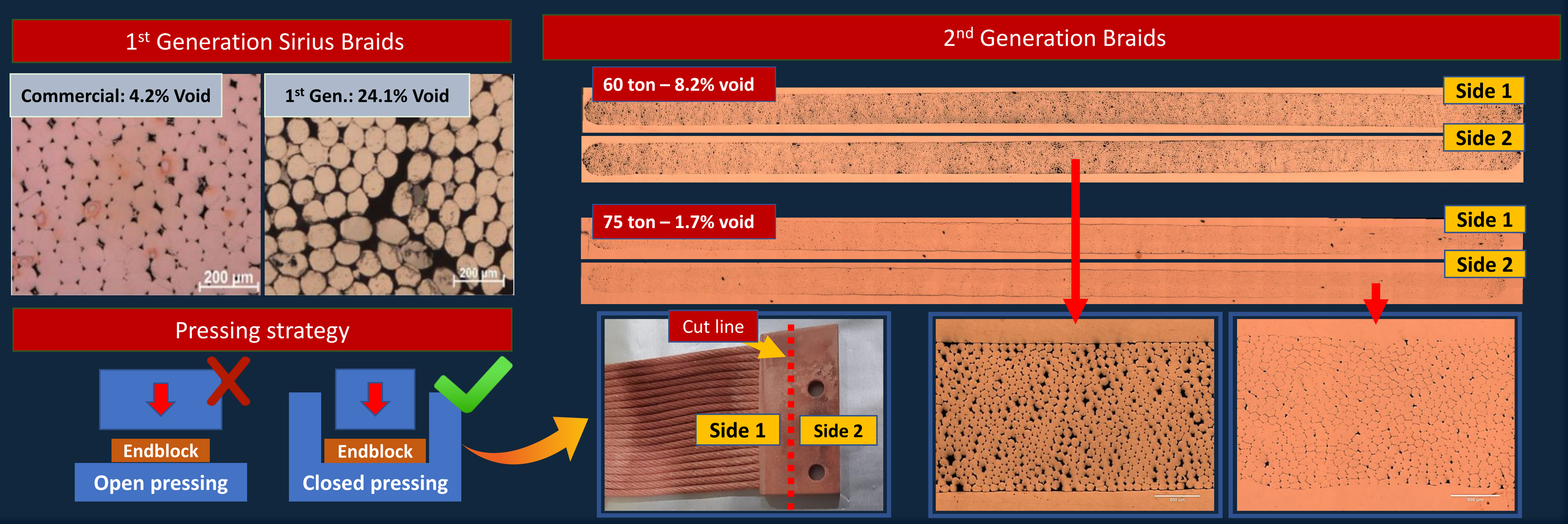
For high heat-loads monocrystalline silicon optics at Sirius beamlines, one of the standard design concepts for beam-load deformation suppression is the use of liquid nitrogen cryostats for cooling the elements down to near 125K, where their coefficient of thermal expansion is virtually zero. Copper braids are extensively used to couple the cryostats to the optics while yet maintaining their desired kinematics.

The main requirement for these braids are:

- **Low stiffness:** to decouple mechanical disturbances and preserve kinematics;
- **High thermal conductivity:** to ensure the final temperatures within the design budgets;
- **Ultra-high vacuum (UHV) compatibility:** for operation near the optics down to 1.10^{-9} mbar;
- **Low cost:** for compatibility with the projects budgets;

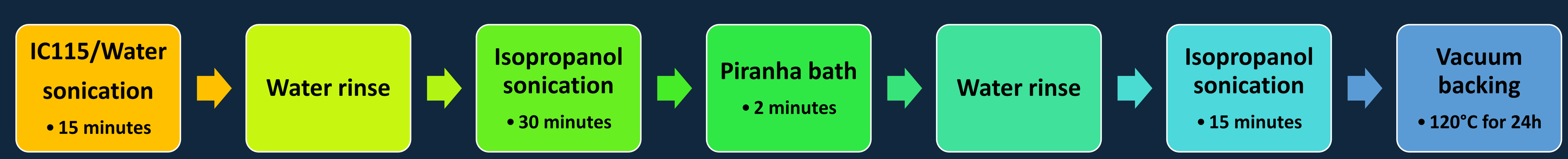
Manufacturing

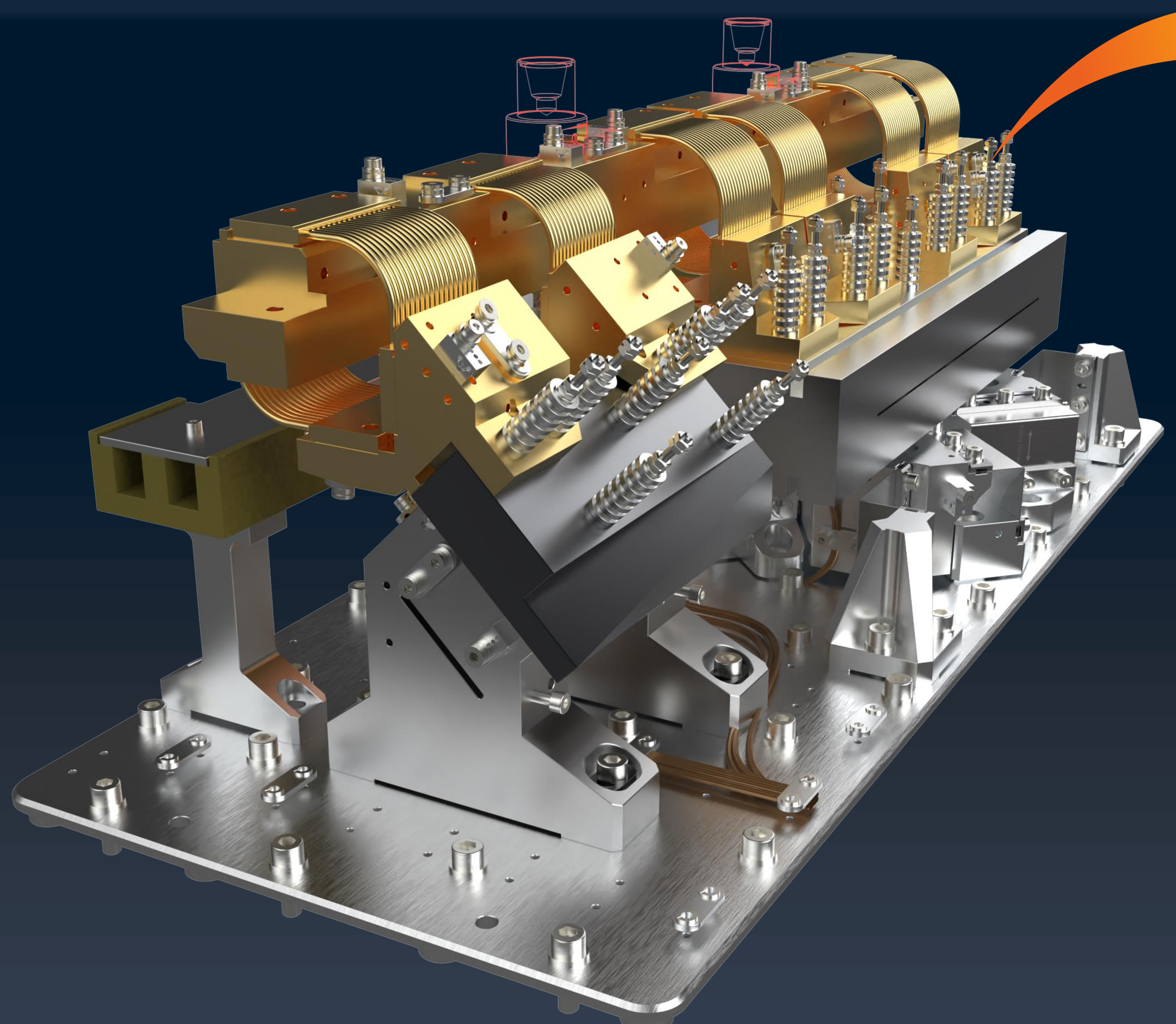
The basic manufacturing process consists in cold forging, or pressing, electrolytic tough pitch (ETP) copper ropes inside bulky oxygen-free high conductivity (OFHC) copper terminals. The final blocks are then machined for the final geometry and gold electroplated to reduce radiation heat transfer. The 1st Sirius generation braids, manufactured in a local partnership (Barbanera Qualità) between 2017 and 2019 lacked in conduction efficiency (57% of the theoretical value, CATERETÊ M1) due to the bad packing of the copper wires (up to 24.1% void density). Newer, 2nd generation braids developed with the same partner use a closed-die fashion for higher packing efficiency with void density as low as 1.7% for 570 MPa (75 Ton) pressing load. Their OFHC copper end-blocks were optimized for better load transfer to the wires by annealing and low stiffness geometry design. For reference, the final cost of an 18-braid 60mm module is $ 150.00 (2020).



UHV Conditioning

After pressing and machining, the braids are cleaned with a 1:1 Sulfuric Acid + Hydrogen Peroxide bath, aka. *Piranha* solution, according to the basic workflow below. Residual gas analyses (RGA) tests are performed up to 200 a.m.u. in which no contaminants should be detected. Some systems are currently working at < 5.10^{-10} mbar.





Brazing

In order to achieve a better thermal interface performance between the braids modules and the complementary copper parts for cryostat and optics coupling, efforts were made towards vacuum brazing and soldering with different fillers.

Despite better interfaces with Cusil and Palcusil fillers, the high brazing temperature resulted in heavy annealing and diffusion welding between the braid wires, increasing their stiffness.

Tin based Sn100CV and Sn100C fillers resulted in even interfaces, but were incompatible with vacuum due to phosphorus contaminant, with 0.73 and 0.68% w.t., respectively, in inductively coupled plasma (ICP) mass spectroscopy. Thus, pure indium was selected as the soldering filler, with an expected conductivity near 400 kW/m²K [1] .

Table 1: Brazing and soldering basic parameters

Filler Material	Filler Thickness (mm)	Temperature (°C)	Time (min)	Category
Palcusil 10	0,1	885	5	Brazing
Cusil	0,1	780	5	Brazing
Sn100C	0,3	227	30	Soldering
Sn100CV	0,3	227	30	Soldering
Indium	0,5	157	30	Soldering

Results

9- and 18-braid modules were tested by coupling one of the ends to a Janis ST-400 liquid nitrogen cryostat, applying controlled heating power to the other end, and measuring both temperatures. The procedure was done in vacuum (<5.10^{-6} mbar) and some of the results are summarized below:

Table 2: Basic braid modules conduction tests results

Braid ID	Braid n#	Length (mm)	Mean Temp. (K)	Power (W)	Conductivity (W/K)
SCB1806	18	60	111.4	5.55	0.314
SCB1806	18	60	131.0	9.78	0.293
SCB0910	9	100	111.0	2.35	0.101
SCB0910	9	100	139.6	5.25	0.094

Current systems

CARNAÚBA (CNB) M1 Mirror + Diagnostic System (XDU)

Currently, the largest braided systems is the CARNAÚBA M1 mirror set [2] with 12x 18-braid modules and an extracted power of about 77 W for a mirror temperature of 125 K [3]. The braids are still assembled with pressed indium as an early development, but will be Indium soldered soon. Other systems at CARNAÚBA – M2 mirror, secondary aperture and 4CM monochromator – and at IPÊ – M4 and M5 mirrors – also use the 2nd generation braids and are working successfully.

Conclusion

A manufacturing process for fabricating weld free, low-cost, high-efficiency flexible copper braids for cryogenic applications was developed in-house with the help of a local partner. The main challenge in achieving a high compaction at the braids solid end-blocks was solved with a closed die pressing process combined with optimized block geometries and copper annealing for lowering yield strength. The result is a void density as low as 1.7% when cold pressed with 570 MPa. Both the vacuum and thermal performances have been successfully validated, with systems working down to 5.10^{-10} mbar and conduction efficiency ranging from 82 to 91% of the theoretical value. Large optical systems at Sirius are already operating with the developed solution.

Acknowledgement

The authors would like to gratefully acknowledge the Brazilian Ministry of Science and Technology for the funding as well as all the engineering and science team members working for the Sirius project. A special thanks also goes to the people at Barbanera Qualità for all the shared effort towards developing the braid solution.

References

[1] R. Radebaugh, "Thermal conductance of indium solder joints at low temperatures," Review of Scientific Instruments, vol. 48, no. 1, 1977
[2] V.B. Zilli et al., "Installation and Commissioning of the Exactly-constrained X-Ray Mirror Systems for Sirius/LNLS," 2020.
[3] B. A. Francisco, "Thermal Model Validation for the Cryogenic Optical Systems for Sirius/LNLS," 2020.

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