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HIGH HEAT LOAD TRANSFOCATOR FOR THE NEW ID14 ESRF BEAMLINE

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Abstract

X ray refractive lenses (CRL) are powerful in line optics for focusing/collimating x-rays. They offer many advantages such as compactness, a comfortable working distance, robustness, and are suitable for use in a wide range of energy. In the scope of the new nuclear resonance ID14 beamline at ESRF, a new **white beam transfocator** (WBT) was developed. This transfocator benefits from the previous experience of ESRF's transfocator to withstand the high heat load power densities (645 W/mm^2) and total power (405 W) generated by the future CPMU18. A thermal load analysis was carried out to optimize the cooling design. The tight alignment specifications within the same CRL (Compound Refractive Lenses) stack assembly and between different assemblies was achieved thanks a good machining of both lenses unit mechanical assembly and reference V shaped rail. High positioning repeatability of CRLs actuator is assured thanks to an optimized flexor and a good alignment procedure. The transfocator vessel is installed on a granite and on a 4-DOF alignment table.

INTRODUCTION

The mission of new ID14 beamline at ESRF is to carry out nuclear resonance scattering experiments. ID14 have 2 optic hutch (OH1) and (OH2). OH1 is a white beam hutch used for pre-conditioning of the X-ray beam for downstream high resolution optics as high resolution monochromators and a Synchrotron Mossbauer Source installed in OH2.

OH1 LAYOUT

In OH1 a high-heat-load monochromator (HHLM), a **white-beam transfocator** (WBT) and a monochromatic-beam transfocator are installed (see Fig. 1).

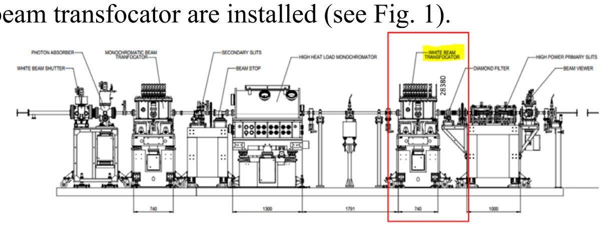

Figure 1: The white beam transfocator is installed in OH1 at 28.5 m from source.

WHITE BEAM TRANSFOCATOR OVERVIEW

The only purpose of the white beam transfocator installed on ID14 is to avoid flux loss by matching the divergence of the collimated beam into the acceptance of the Si(111) reflections used in HHLM. Figure 2 shows the collimation of the beam with 1D lenses.

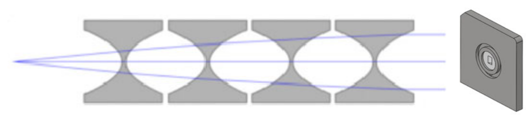

Figure 2: Use of Be CRL to collimate the beam.

Only a moderate, not an ultimate collimation is required to keep effective focusing. Focusing will be done downstream, in experimental hutches using KB mirrors. HHLM works in horizontal scattering plane so WBT collimates beam in horizontal plane only with 1D Beryllium lenses. Exceptions are 2D lenses for very high energies, where 1D lenses with very small radius (0.05) are not available. For the EBS machine, horizontal and vertical divergences are both about 14 µrad.

Table 1: Ω Angular Acceptance of HHLM - ΔΘ Divergence after Collimation [1] (Courtesy A. Chumakov)

Energy [keV]	type	R_A [mm]	N_{CRL}	T [%]	A [mm]	A_{eff} [mm]	$\Delta\theta$ [μrad]	Ω [μrad]	X
14.412	1D	0.50	3	93.6	1.39	1.35	6.8	17.5	0.45
21.541	1D	0.30	5	93.3	1.08	1.05	4.5	11.8	0.32
22.494	1D	0.20	4	94.7	0.88	0.86	3.5	11.3	0.25
23.879	1D	0.20	4	94.8	0.88	0.86	4.7	10.7	0.33
25.614	1D	0.20	5	93.8	0.88	0.86	3.9	10.0	0.28
27.78	1D	0.20	5	96.5	0.88	0.86	5.4	9.2	0.38
35.46	1D	0.20	12	88.0	0.88	0.83	3.6	7.2	0.10
37.13	1D	0.20	12	88.1	0.88	0.83	3.6	6.9	0.17
39.58	1D	0.20	12	88.4	0.88	0.83	3.6	6.5	0.27
67.408	2D	0.05	12	85.0	0.44	0.42	3.6	3.8	0
89.571	2D	0.05	21	76.9	0.44	0.41	3.6	2.9	0

As the Table 1 above shows, the type and number of lenses must be changed as the energy varies. This is the role of the transfocator (see Fig. 3). A maximum of 3 lenses casings are used simultaneously. They are installed next to each other.

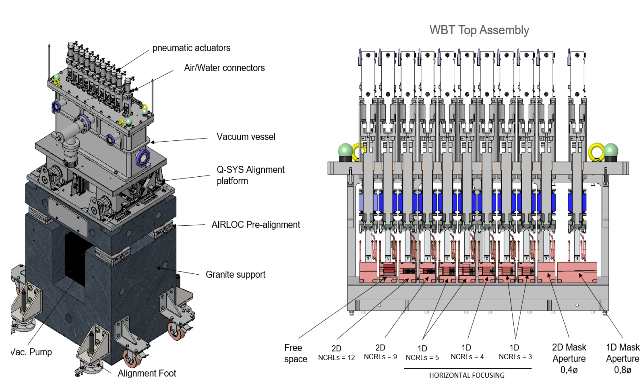

Figure 3: 11 axis water cooled transfocator.

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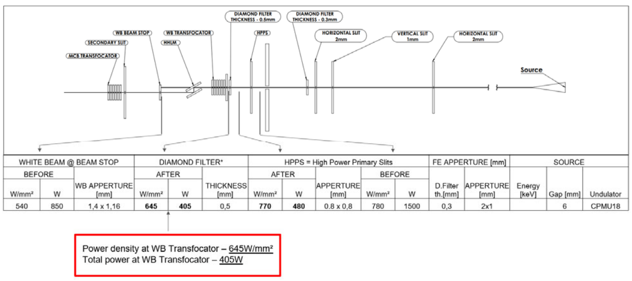
HEAT LOAD ANALYSIS

ID14 started operation with the former ID18 source, composed by three ex-vacuum U20/U27 revolver undulators but in future an **EBS-dedicated** single in vacuum Cryogenic Permanent Magnet Undulator (CPMU-18) will be installed. Heat load analysis (see Fig. 4) has been done with the most demanding configuration = CPMU18 undulator.



WHITE BEAM @ BEAM STOP			DIAMOND FILTER*			HPPS = High Power Primary Slits					FE APPERTURE [mm]		SOURCE		
BEFORE			AFTER			AFTER			BEFORE						
W/mm²	W	WB APPERTURE [mm]	W/mm²	W	THICKNESS [mm]	W/mm²	W	APPERTURE [mm]	W/mm²	W	D.Filter th.[mm]	APPERTURE [mm]	Energy [keV]	Gap [mm]	Undulator
540	850	1,4 x 1,16	**645**	**405**	0,5	**770**	**480**	0.8 x 0,8	780	1500	0,3	2x1		6	CPMU18

Figure 4: Front End and optical hutch heat loads configuration.

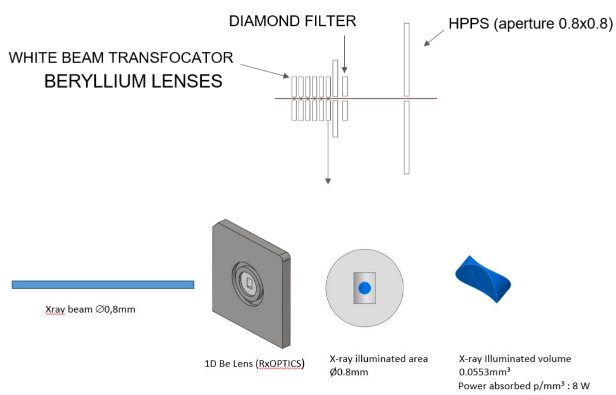


Figure 5: Power absorption at ID14 – Be lens = 8*0.0553= 0.45 W.

Figure 5 illustrates the beam absorption in 1D lens.

To have a reasonable safety margin we decided to add a water cooled 0.5 mm diamond window before the WBT in addition to the one (0.3 mm thick) already installed in the FE (Front End). Then the mechanical stress induced by thermal absorbed power is well below the yield limit of Beryllium (see Fig. 6).

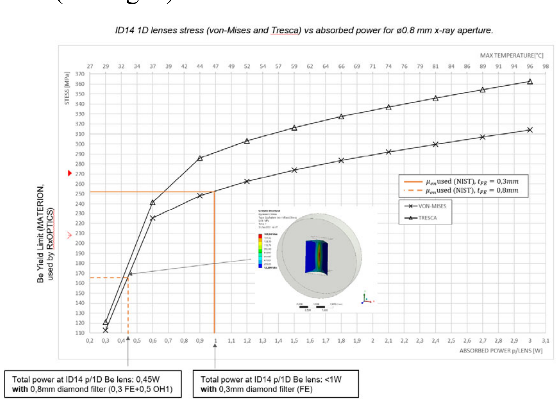


Figure 6: Thermal stress before/after 0.5 mm thick diamond window.

In this configuration and with appropriate thermal interfaces (we use a 0.2 mm thick graphite layer on 3 sides of the lenses to keep one reference side free for positioning and a copper foam layer on the front side of stack assembly) and a good mechanical pressure (we use spring washers to apply 0.85 MPa pressure), the temperatures of the lenses and masks are well below the critical temperature with good safety margins. Unfortunately, Kovar's poor thermal conductivity (17 W·m^{-1}·K^{-1}) limits the thermal cooling performance. Figure 7 shows the mechanical assemby of 1D lens.

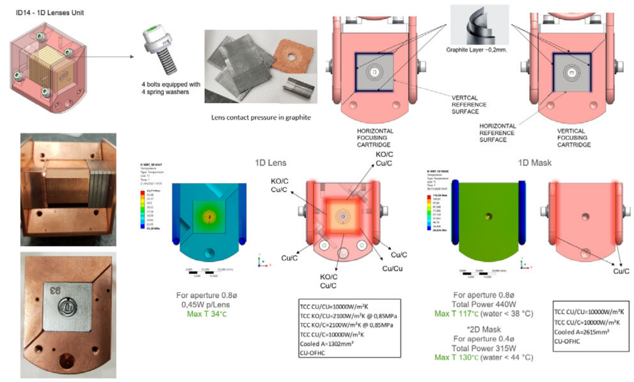


Figure 7: Lenses unit cooling optimization with spacer and thermal interfaces.

ALIGNMENT

In order to achieve optimum performance for focusing/collimating it is necessary to align the optical axes of individual lenses in a stack and between stack assemblies with micro-meter precision. We provide high precision lens casings and pneumatic actuator are used to push these casings on reference V shaped rail.

For 1D lenses, one side is used as reference (vertical or horizontal depending on the direction of the collimation), for 2D lenses the cylinder is pressed on two perpendicular flat surfaces – only half of the cylinder is used as thermal contact.

The copper lens casings are manufactured by wire erosion to a precision of better than 10 μm while straightness and accuracy of the 600 mm long v-rail is better than 3 μm in Y and Z after grinding. All parts have been carefully controlled with high precision three-dimensional measuring machine (see Fig. 8).

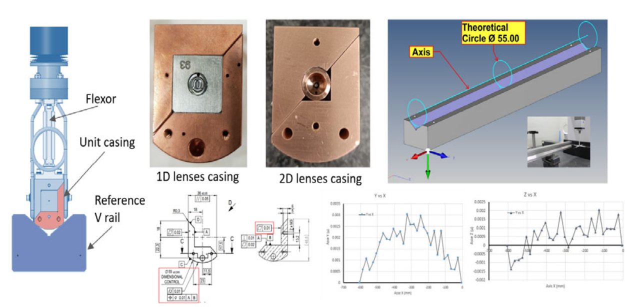


Figure 8: Manufacturing accuracy of 1D/2D casings and reference V rail.

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The transfocator needs to be aligned in four axes with respect to the X-ray beam : (2 translations Y,Z and 2 rotations ΘY, ΘZ). The motion platform designed by Q-SYS is based on two wedges driven by means of ballscrews with stepper motors and Harmonic drive gear. The platform has to carry 400 kg load and additionally 200 N external force (with offset) – 120 mm due to vacuum bellows. Figure 9 shows the alignment specification of the whole WBT in respect to the beam.

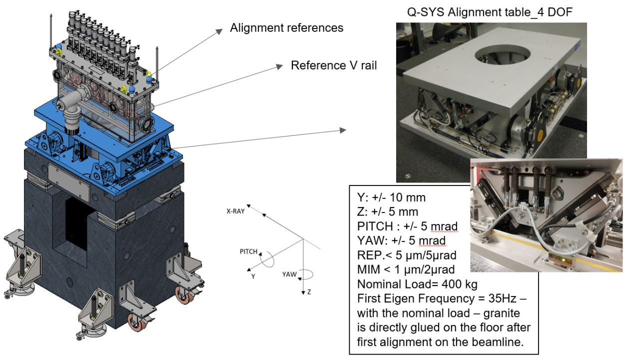

Figure 9: Alignment specifications for WBT (Reference V rail alignment/lenses units) with X-ray.

FLEXOR DESIGN AND REPEATABILITY

A flexor is used to move the lens casing cylinder (∅ 55 mm) in line with the reference V-rail to ensure that the casings are correctly positioned in relation to each other. After a manual pre alignment when the casing is in the operating position (in V rail) the flexor strokes can be limited to ±1 mm in Y (lateral) and ±10 mrad in pitch and yaw. The flexor design (see Fig. 10) below gives a good safety margin (>2).

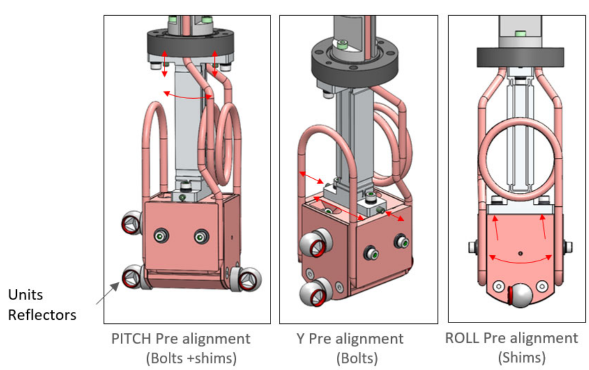

Figure 10: Pre-alignment to limit flexor strokes.

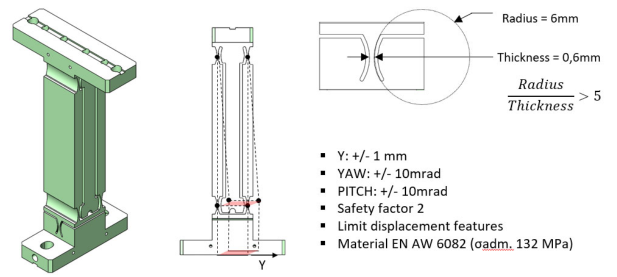

Figure 11: Flexor optimization.

Repeatability of lensing casing has been measured with both laser tracker (thanks to reflectors – see Fig. 11) and micrometers as shown in Fig. 12. Repeatability is better than 1 µm in Y, Z.

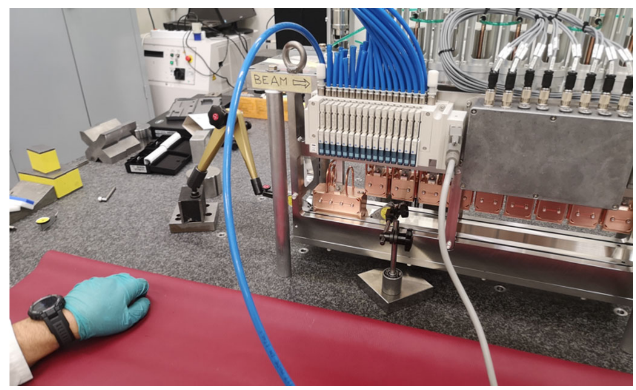

Figure 12: Repeatability measurement.

CONCLUSION

Despite an optimized cooling design of the Be CR lenses we had to insert a 0.5 mm thick diamond window to withstand the high thermal power (generated by the future Cryogenic Permanent Magnet Undulator (CPMU-18). Thanks to high precision machining of mechanical parts (lenses casing, reference positioning rail and flexor) – a compact design – we achieved a high accuracy positioning (<10 µm in one single casing and <20 µm between casings relative to X-ray beam) of cooled CR lenses.

REFERENCES

[1] "Technical Design Report for the Nuclear Resonance Beamline ID14 at the ESRF", ESRF, Grenoble, France, December 18, 2020.