ESRF FRONT-END EVOLUTION

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1 Introduction

Since the commissioning phase of ESRF storage ring, several front-end components have been modified due to the upgrade of machine performances (stored current increase, low gap 5 meters long straight chambers, in-vacuum undulators…).

A new high power front-end has been developed to withstand the power density generated by 5m long, 11mm gap undulators. The new design consists of the replacement of the x-ray absorber and the filtering system. An upstream pre-slit and a compact high heat load absorber have replaced the x-ray absorber.

A CVD diamond window has replaced the Beryllium window and graphite filters usually employed.

A dedicated test beam line to complete the tests of various components (front-end, storage ring, beam lines) and study the material resistance to the high synchrotron radiation heat load is being used.

2 Construction Phase

During the construction phase at the ESRF there were two types of ID's front-end:

-those designed for wigglers (large total power, medium power density)
-those for undulators (medium total power, high power density).

In both cases the maximum current was 100mA and the minimum magnetic gap was 20mm.

As a result the designed specifications were **15kW** total power and **140kWmrad^{-2}** power density therefore we had only one type of x-ray absorber.

Other than the few cases of UHV beam lines, nearly all FE's were equipped with Beryllium windows that needed carbon filters to limit stress and temperature rise in the beryllium.

3 Front-End configurations

In 1994 we had 15 front-ends and already many different configurations by mixing existing Beryllium windows and carbon filters.
In 1996 the machine current was increased from 100mA to 200mA in User Service Mode.
The front end horizontal aperture was reduced and the pyrographite filters were improved to sustain the corresponding increase of power.

Front-End ID's (±2.5mrad horizontal aperture)		Dipole Front End	
FE type	comment	FE type	comment
UHV (windowless)	-4 to 10mm vertical aperture (at 23m)	Standard	6mrad hor. Aperture
Standard	-Grafoil filter/Beryllium window (±2.5mrad horizontal aperture) -Pyrocarbon filter/Polished Be windo (130mm x 4 mm aperture)	UHV	6mrad hor. aperture
High Power filters	-High Power filters -Pyrographite Ø2mm /Be window Ø6mm polished - Higher coherency (Diamond filter/ Polished Beryllium window) - Polished Beryllium window	Wide beam	10mrad hor. Aperture

Table 1: Front-End configurations

4 Performance limitations

Since the commissioning phase, the upgrade insertion devices performances and the development of narrow gap chambers was such that the limiting part was front-end components.
In 1994 the minimum gap of an undulator was 20mm and the machine stored current 100mA.
Today with 200mA stored current, 10mm gap chambers and in-vacuum undulators a maximum power density of 400 kW/mrad2 can be achieved.

4.1 X-ray absorber limitation

With peak power density as high as 2 kW/mm2 at normal incidence, the x-ray absorber needed to be replaced. The opening angle of the radiation produced by an undulator is very small in both horizontal and vertical directions. The total power produced by undulators can therefore be collimated through a pre-slit in order to minimize the horizontal aperture of the x-ray absorber.

4.2 Filters/window limitation

For many ESRF beam lines the photon flux limitation is a result of the front-end carbon filter and beryllium window configuration which cannot absorb all low-energy X-ray power produced by the undulators.
A first step consisting of reducing the useful aperture of the beam and the stress level for the considered heat-load photon beam and consequently limiting the total power absorbed on the filters solved in some cases the heat-load problem but it was not possible to have more than 2 undulators (3.2m total length) closed at 16mm gap. On top of that, most of the elements located on the x-ray path can lead to coherence degradation of the photon source due to the surface roughness, impurities or porosities of the beryllium and carbon foils.
Several front-end Beryllium windows were then polished one to reduce that coherence degradation.

Rapidly it appears that the best option was to remove carbon filters and Beryllium windows and replaced them by CVD diamond foils.

5 Front-end evolution

5.1 X-ray absorber

An upstream pre-slit (2 mm horizontal aperture at 14 meters from the ID centre) and a compact high heat load absorber then replaced the original X-ray absorber.
Each of them can stop a maximum power of 12kW. The x-ray absorber is designed to stop more than 400kWmrad-2. The absorber is made using round pieces of Glidcop AL15 copper (SCM metal products Inc.) which have been machined into the required shape by the wire cutting process, to intercept the photon beam at an incidence angle of 1.2° in the vertical plane to the photon beam. The water cooling channels are made outside the vacuum. The advantages of this approach are that manufacturing is relatively simple; there is no water vacuum joint and only one layer of Glidcop between the coolant and the photon beam.

Design criteria:
Temperature:
$T_{max} < T_{melt}$ (T_{melt}=1083oC for copper)
$T_{wmax} < T_{boil}$ (T_{boil}=150oC at 5 bar for water)

Thermal stress σ_{abs}:
$\sigma_{abs} < \sigma_y$ (elastic strength)
$\sigma_{abs} < \sigma_f$ (fatigue strength)

Stress limit values:

OFHC copper	σ_y= 69 Mpa	Glidcop AL15	σ_y= 336 MPa
	σ_f= 262 Mpa		σ_f= 300 to 659 Mpa

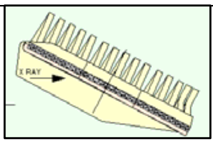
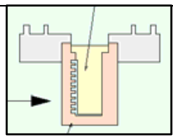
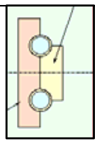
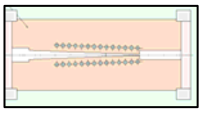
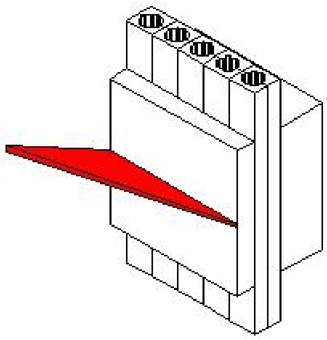
Absorber desig				
location	SR crotch	FE BM	FE old ID	FE High Power
material	Glidcop Al15	Glidcop Al15	Glidcop Al15	Glidcop Al15
P_l [Wmm^{-1}]	53 to65	26	84	105
Pa [Wmm^{-2}]		20	52	49 / 33
Ptot [W]	3474 to 7200	1330	3310x 2	6470
T max [degC]	326 to 480	143	326	284 / 199
Tw max [degC]		50	86	93 / 69
Svm [Mpa]	290 to370	177	456	412 / 289
T max [degC]	577 to 697	204	479	416/ 289
Tw max		65	119	130 / 94
Svm [Mpa]	351 / 616	266	684	618 / 420

Table 2: SR and FE x-ray absorbers data. Red values are calculated for 300mA current



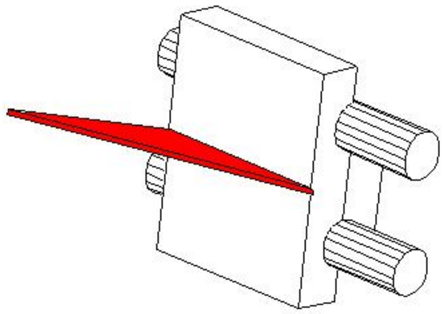


Fig 1: high power x-xay absorber design

(in red x-ray beam profile)

Fig 2 old x-xay absorber design

(in red x-ray beam profile)

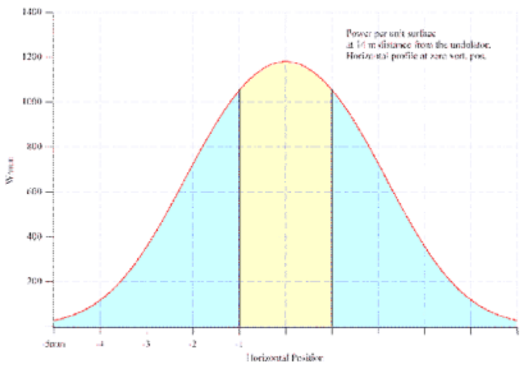


fig 3: horizontal x-ray beam power profile at 14 meters from source, blue part is stopped on pre-slit, yellow part (central cone stopped by x-ray absorber

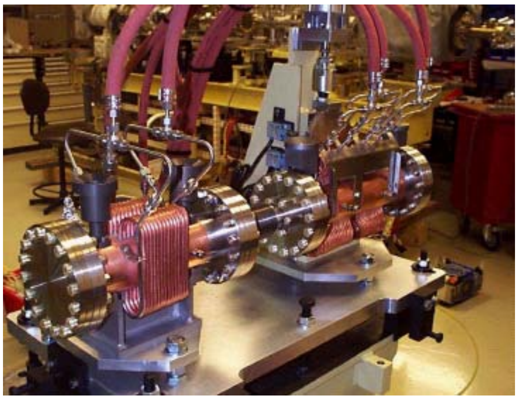


fig 4: x-ray high power absorber absorber and horzintal pre-slit

5.2 Filters

It was soon realized that surface roughness, impurities or porosities in the graphite were a source of small angle scattering (or decoherence) that prevented the beam lines from benefiting from the ultra low vertical emittance (30 nm in a routine operation, 9 nm at best).

Filters	absorbed power
Grafoil 130 x 4mm	few W/mm2 max (first material used at 100mA current
Pyrocarbon 130 x 4mm	25W/mm2 or 450W total power max (used for wiggler or single undulator)
Pyrographite useful Ø: 2mm max	45W/mm2 max---used for 2 2 undulators 15mm gap at 200mA current
CVD Diamond	few W/mm2 (used for better coherency) power limit due to mechanical stress

5.3 Diamond window

The Carbon filters and Be window configuration has been replaced by a CVD (chemical vapor deposition) diamond window. CVD diamond presents many advantages. It has a higher thermal conductivity, which limits the peak temperature in the window allowing the window to be leak tight even at full ID power. In addition, it dramatically reduces the small angle scattering and therefore preserves the high coherence of the photon beam. The window is composed of two parts, the diamond window and its water cooled copper chamber. The diamond part is made of a CVD foil 300µm thick that is sealed to two molybdenum rings by a diffusion bonding technique.

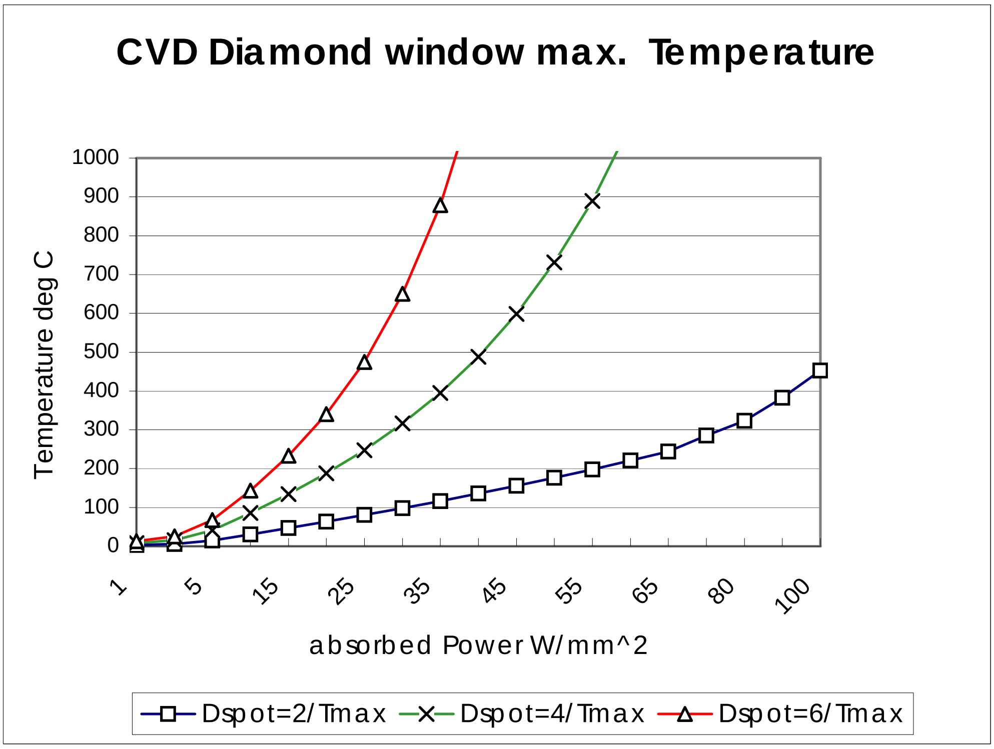


Fig 5: FE CVD diamond window temperature vs. absorbed power

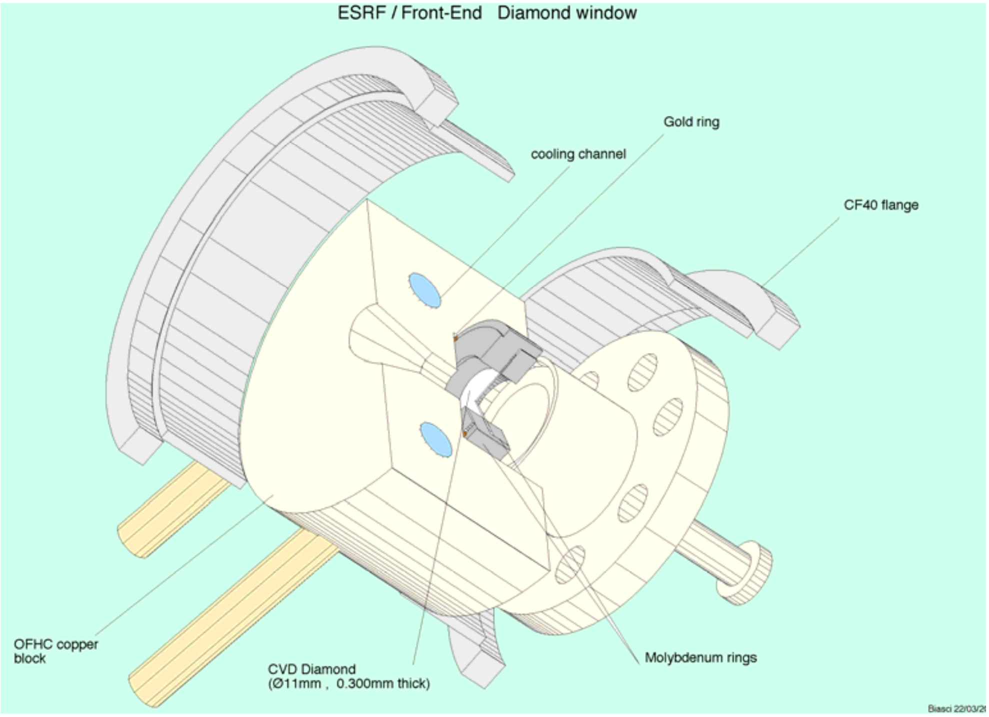


Fig 6: diamond window assembly schematic view

6 Installation Status

At the end of 2004 45 front-end are installed.

Front-end ID		Front-end Bending Magnet	
Standard	3	Standard	16
Standard UHV	5	UHV	1
High power	17		
High power UHV	3		

Table 2: installed front-end configurations

During 10 years of continuous operation the reliability of the front-ends has been an important parameter. Systematic tests during shutdown periods and preventive maintenance have been applied after the commissioning time.
Radiation damage is an important issue and regularly signals and power cables needs to be replaced.

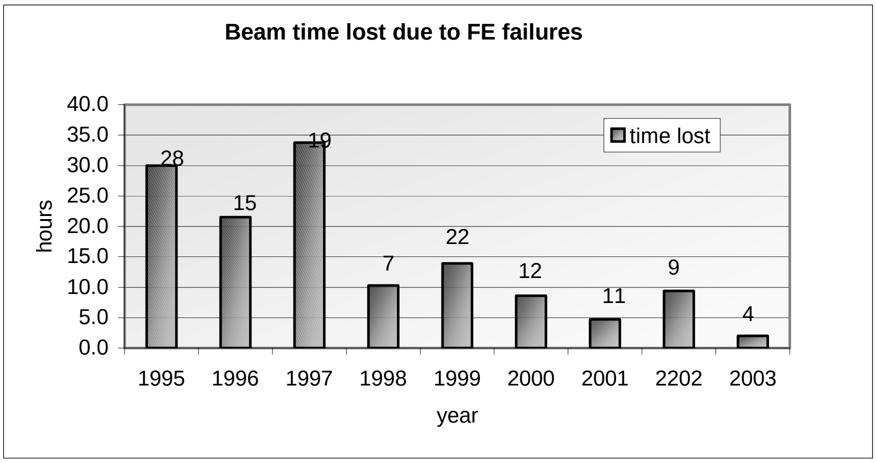


fig 7: Front-end failures statistics

7 Development

Glidcop Brazing:
Due to difficulties in brazing glidcop , tests have been initiated with external companies to find correct procedures and explore other techniques.
Theses tests were performed for different materials junctions;
-Glidcop/ Glidcop,
-Glidcop/OFHC
-Glidcop/Stainless Steel
(Brazing tests done with ACCEL and Thermo VG companies)

Welding & e-beam welding have also been developed to replace brazing conventional brazing technique.
These tests were successfully performed for different material junctions;
- Glidcop / Nickel & Glidcop 304L e-beam welding.
- OFHC copper/ Glidcop junction
- Stainless steel / Glidcop welding with filler wire (ER CU AL A1) Aluminum copper wire
(Welding tests done with SDMS company)

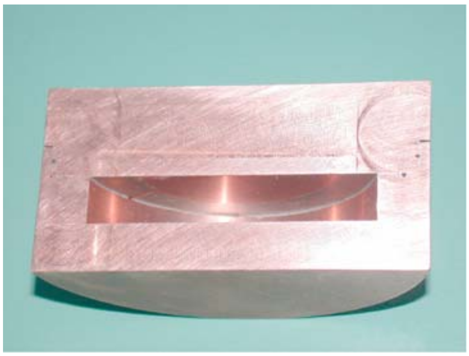


Fig 8: Glidcop/Glidcop junction brazing

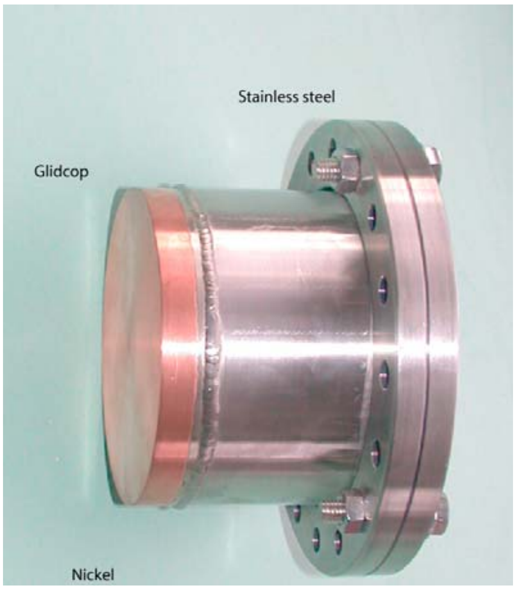


Fig 9: Stainless steel / Glidcop welding with filler wire (ER CU AL A1)

ID6 machine beam line is used for test purpose by different groups
Heat-load tests on windows filters x-ray absorbers crotches…
High level thermal stress Material comparison (Glidcop and OFHC copper)
5 meters long Aluminium neg coated chambers bremsstrahlung measurement
X-ray beam position monitor development (vibrating blade)

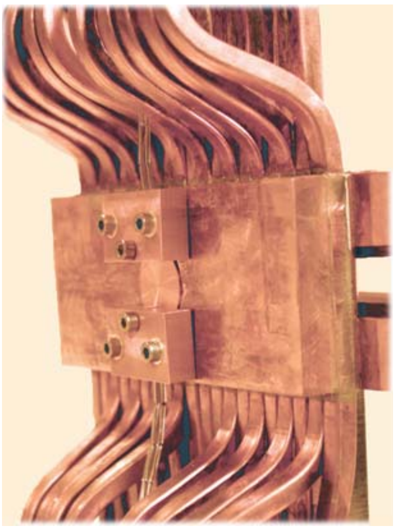


Fig 10: High level thermal stress Material comparison

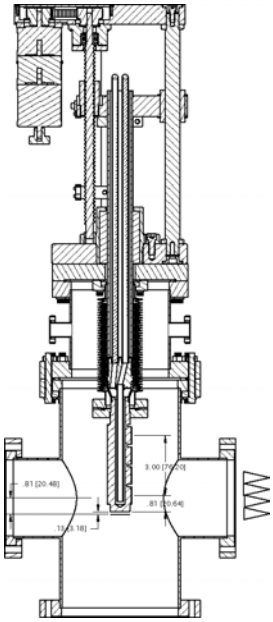


Fig 11: Glidcop fatigue tests (piece from APS laboratory)

8 Conclusion

Since the construction phase and during the last ten years of operation, 45 front-ends have been installed.
In parallel, a refurbishment of all ID's front-ends was initiated in 2000, to follow the machine performances upgrade and also to maintain a high level of reliability.
Further developments are necessary to anticipate better performances on the machine side and more requirements from beam line users.