SEE-LS: A 4th Generation Synchrotron Light Source for Science and Technology, Dieter Einfeld (ed.)
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13 Front end

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The front ends (FEs) are essential parts of a synchrotron light source facility. They connect the vacuum system of the storage ring with that of the beam lines. The front ends serve the following objectives:

(i) ensure radiation safety beyond the shielding wall during beam operation;

(ii) maintain the vacuum in the storage ring and protect it from any accidents that might occur during the operation of the experimental beam lines.

(iii) protect the optics and experimental stations from the synchrotron radiation power emitted from the bending magnet and insertion devices that are not used for the experiments;

(iv) monitor the photon beam position as well as the characteristics of the photon beam.

To understand the specifications of different components in the front ends, the characteristics of different insertion devices (IDs) are summarized in Table 13.1. P(tot) is the overall emitted radiation power and P(dens) is the power density in the normal direction. These powers are needed for the layout of the second absorber and the photon shutter.

Table 13.1: Characteristics of the insertion devices that could be used for phase-I beam lines at SEE-LS

Source	B(max) (T)	Period (mm)	Length (m)	K	Gap	P(dens) (kW/mrad^2)	P(tot) kW
Bend	1.42					0.249	
MPW	1.782	80	1.07	13.32	12.5	7.61	6.87
IVU	0.805	21.3	2	1.6	5.5	26.57	2.95
EU (hor)	0.92	71.36	1.655	6.14	15.5	7.63	3.28
EU (vert)	0.73	71.36	1.655	4.69	15.5	5.8	1.92
EU (circ)	0.56	71.36	1.655	3.75	15.5	3.32	2.44

Table 13.2 shows the opening angles of the radiation cones coming from the insertion devices (X' and Y') and the opening requirements of users ($\Delta\theta$ and $\Delta\psi$) for the photon beams in the beam lines. In all cases X' and Y' are greater than $\Delta\theta$ and $\Delta\psi$. The radiation cone not needed for users has to be absorbed into the second absorber of the front end.

Table 13.2: Opening angles of the radiation cones (X' and Y') from different insertion devices and the user-required opening angles ($\Delta\theta$ and $\Delta\psi$).

Source	X(max) (μm)	X' (max) (μrad)	Y(max) (μm)	Y' (max) (μrad)	$\Delta\theta$ (μrad)	$\Delta\psi$ (μrad)
Bend					±0.25	±0.25
MPW	28.1	2.26	0.01	0.5	±0.75	±0.13
IV U	0.9	0.4	0.01	0.4	±0.10	±0.03
EU (hor)	11.9	1.13	0.01	0.45	±0.15	±0.15
EU (vert)	0.01	0.45	9.11	0.86	±0.15	±0.15
EU (circ)	7.3	0.9	7.28	0.9	±0.15	±0.15

13.1 General layout of a front end

The general layout of a front end showing the arrangement of its different elements is given in Figs. 13.1 and 13.2. In the following the different components and their functions are described; note that at different light sources one or more components could be missing [13.1, 13.2].

1) **Gate valve** at the end of the vacuum system (beam pipe) of the storage ring: this is a manual valve used only for maintenance.

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2) **First fixed absorber** at the end of the beam pipe: this absorber is installed to protect the beam pipe against synchrotron radiation from the bending magnet, but it must have an opening through which all the radiation coming from the IDs can pass. This absorber is usually called the ‘crotch absorber’.

3) **Vacuum tube** with a length of up to 2 m and a diameter of 40 mm: this tube is needed to ensure enough space between the front end and the storage ring for the installation of front-end components. Also, a pumping unit has to be installed in this section to control the vacuum. The vacuum gauge of this unit controls the gate valve to the storage ring and is connected to the interlock system.

4) **Fluorescent screen** to monitor the radiation pattern from the IDs: this screen has to be inside the vacuum tube described above. Use of the fluorescent screen is possible only for small stored currents (around 5–10 mA) within the storage ring .The fluorescent screen will only be used for the commissioning of the beam line.

5) **First X-ray beam position monitor (XBPM)** to monitor the position of the radiation beam coming from the ID: this XBPM is at the end of the vacuum tube described in 3). In order to obtain a precise measurement of the position of the ID radiation, the whole radiation fan from the IDs has to reach the first XBPM. This means, again, that no ID radiation has to be stopped at the crotch absorber. During the commissioning of the beam line, the XBPM can be cross-checked against the fluorescent screen.

6) **Second fixed absorber** and **bellows**, which determine the aperture within the front end: the second fixed absorber more or less absorbs the main part of the radiation coming from the ID that is not needed for the experiments; it should be designed to absorb all the radiation coming from the IDs.

7) **Photon shutter**, which absorbs all the radiation coming from the IDs: the photon shutter completely intercepts the X-ray beam via a fast-acting mechanism in order to isolate the downstream components (beam line) from the source (storage ring). The photon shutter also acts as a safety device to protect the bremsstrahlung shutter from direct X-ray beam impingement. The photon shutter should be combined with the second fixed absorber, and both components should be combined with a pumping unit. The photon shutter is needed to protect subsequent valves from being irradiated with synchrotron radiation from the bending magnet and IDs. The time for closing the photon shutter is approximately 0.3–1 s.

8) **Second gate valve** in combination with a **fast valve**: this is the next unit in the arrangement. A pumping unit is also needed for both components, because the fast valve can be opened only if the pressure is roughly the same on both of its sides. This combination of gate and fast valve is needed to protect the storage ring against vacuum failures in the front end and beam line. The second gate valve should be as near as possible to the storage ring. The time for closing is approximately 8–10 ms for the fast valve and 1–2 s for the gate valve.

9) **Delay line** if needed: the aforementioned conductance pipe could be used as a delay line.

10) **Second XBPM** (if needed) to monitor the position of the radiation beam coming from the ID: the distance between the first and second XBPMs should be at least 4 m.

11) **Collimator** for absorbing some parts of the bremsstrahlung coming from the long straight sections. The transverse dimensions of the collimators are determined from ray-tracing calculations.

12) **Moveable aperture** to determine the aperture needed for special experiments.

13) Space for a **diaphragm** or **filter holder**.

14) **Bremsstrahlung shutter** in front of the shielding wall: the bremsstrahlung shutter is not cooled. The transverse dimensions of the bremsstrahlung shutter are determined from ray-tracing calculations.

15) **Gate valve** with pumping unit behind the shielding wall (inside the experimental hall): this unit must incorporate a fast pressure sensor for triggering the fast and gate valves as well as the photon and bremsstrahlung shutters.

16) **Beryllium window**.

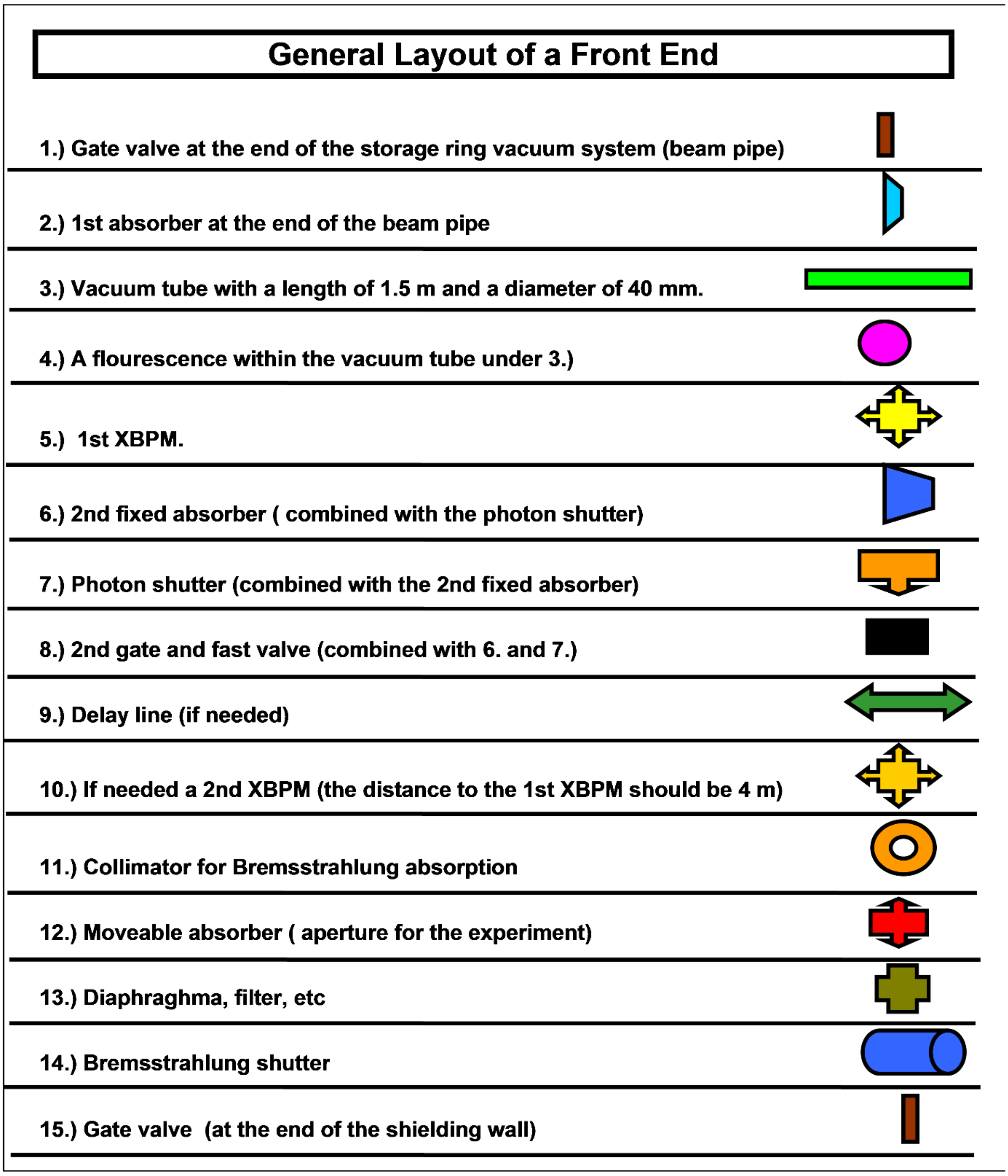

Fig. 13.1: Different elements used in front ends

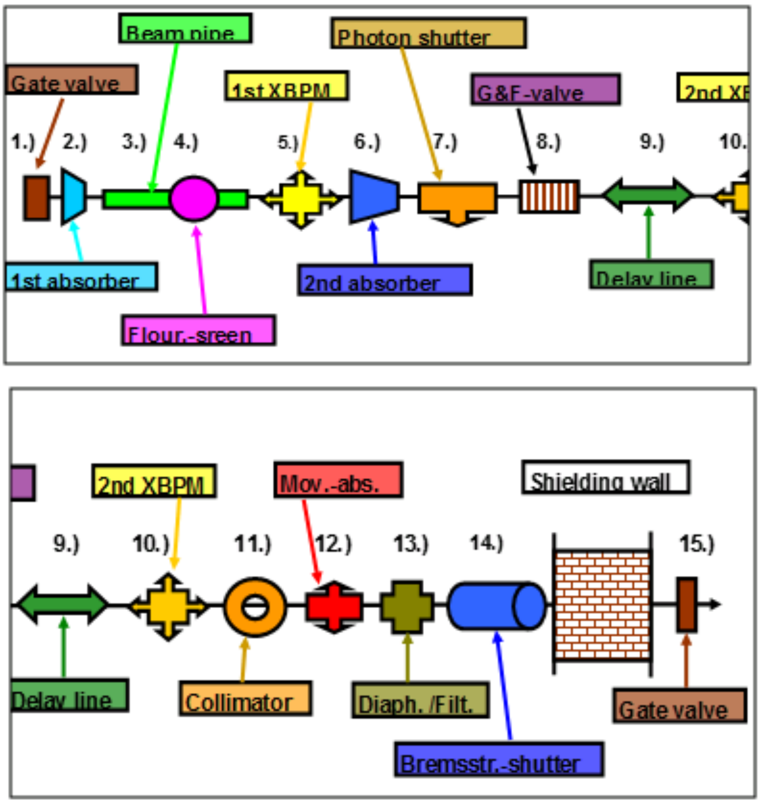

Fig. 13.2: Arrangements of elements in a front end

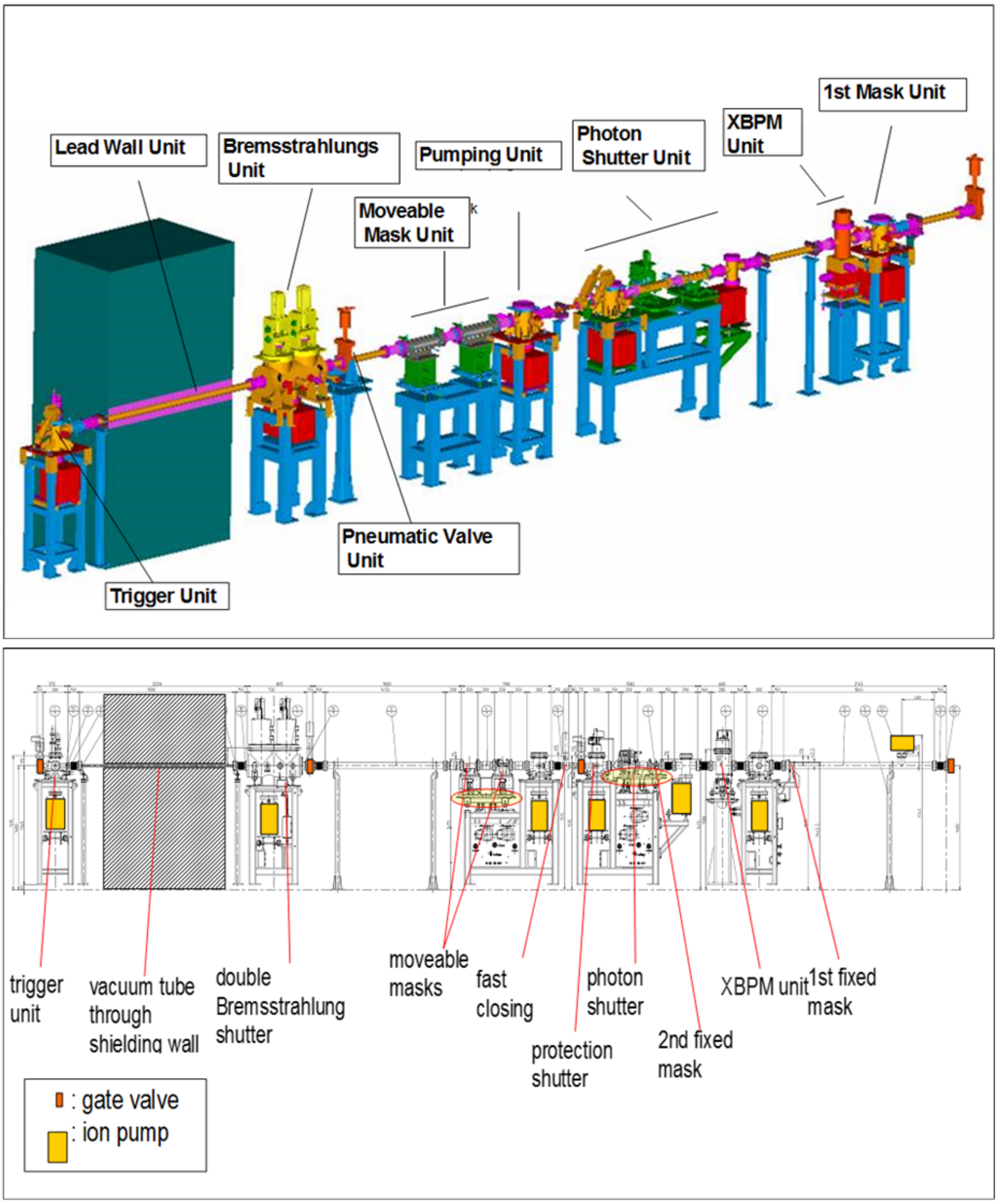

Fig. 13.3: Front-end components used in ALBA

13.2 A particular front-end layout

The layout of each individual FE has to be adapted to take into account the geometrical constraints defined by the available distance from the SR isolation valve to the front wall of the tunnel and by interference with adjacent elements (SR girders, RF cavities, cooling water pipes, etc.). Besides, radiation-absorbing elements have to be designed to meet the aperture and power load requirements imposed by both the characteristics of the photon source and the needs of users of the beam line. At the same time, an effort should be made to maintain a suitable degree of standardization between the components of different FEs. With these considerations, a modular design approach has been adopted.

The distance from the SR isolation valve to the front wall for phase-I FEs ranges from 7 to 9 m, but because of the proximity of the storage ring, the space available for the installation of FE components inside the tunnel is effectively 5–7 m. A typical layout of phase-I FEs is shown in Fig. 13.3, with the following sequence of components going from the SR isolation valve to the beam line: (1) first fixed mask, (2) XBPM, (3) second fixed mask, (4) photon shutter, (5) protection shutter, (6) fast-closing shutter (FCS), (7) movable masks, (8) double bremsstrahlung shutter, (9) vacuum pipe through the front wall, and (10) trigger unit. These elements are described below.

(1) **First fixed mask:** a first fixed mask is installed in all FEs with an ID as a source in order to protect downstream FE components from dipole radiation. This element consists of a 39 mm-thick copper block with internal water cooling, which is integrated into the first vacuum pipe connecting the SR isolation valve and the first pumping chamber of the FE. The copper block has an aperture that allows passage of the full ID radiation fan, taking into account the maximum allowed mis-steering of the e-beam.

(2) **XBPM:** each FE is equipped with one XBPM to monitor the position of the photon beam at a distance of 7–10 m from the source point. Monitors have been produced according to the designs developed by K. Holldack from BESSY in collaboration with FMB [13.3]. Each XBPM makes use of four narrow negatively biased blades which intercept the edges of the photon beam distribution. The photoelectrical currents generated at each blade are measured using a low-current monitor, and after being combined they allow an on-line determination of the horizontal and vertical positions of the centre of the beam. Two different blade configurations have been employed depending on the characteristics of the source. In the case of bending magnet sources, four copper blades in the so-called staggered pair monitor configuration have been used. This configuration allows only the determination of the vertical position of the beam, but on the other hand it provides an internal calibration standard. In the case of ID sources, four tungsten blades arranged in an X shape have been used, providing information on both horizontal and vertical planes. This configuration requires a proper calibration for each setting of the ID source. The size and geometry (distances and angles) of the tungsten blades have been adapted to the beam characteristics of each ID in order to optimize the sensitivity of the system.

(3) **Second fixed mask:** in all cases, second fixed masks consist of an out-of-vacuum copper body (either OFHC or Glidcop, depending on the situation) with an internal rectangular aperture defined by four inclined surfaces. Depending on the amount of power to be absorbed, different cooling schemes have been implemented. For small heat loads (less than 0.5 kW, bending magnet and IVU sources), a single cooling loop drilled around the aperture has been used. For medium heat loads (0.5–4 kW, such as EU and conventional wiggler sources) a ‘spiral cooling’ configuration has been used (Fig. 13.4, left), with a stainless steel cover (water box) brazed to the cylindrical body of the absorber, where a cooling channel in spiral form has been machined. For higher heat loads (greater than 4 kW, SCW source) a ‘side cooling’ configuration has been used (Fig. 13.4, right), with grooves machined next to each surface defining the aperture and a cover of the appropriate dimensions closing the machined cavity.

(4) **Photon shutter:** the photon shutter is responsible for interrupting the photon beam when necessary, protecting all downstream components from synchrotron radiation. In the case of bending magnet sources with associated power of less than 100 W, an in-vacuum pneumatically actuated absorber has been used. The absorber consists of a water-cooled plate of OFHC copper positioned at an acute angle (30°) to the incident beam. In the case of FEs with an ID as source (between 1.5 and 13.5 kW), an out-of-vacuum design based on the high-power absorber of ESRF [13.4] has been used. In this design two brazed Glidcop blocks define an internal aperture whose profile depends on its vertical position. When in open position the aperture consists of two lateral straight surfaces that allow the passage of the full radiation fan as defined by the second fixed mask. When in the closed position, the two lateral surfaces are tapered and water-cooled according to the ‘side cooling’ scheme (see Fig. 13.4) and stop the photon beam completely. The vertical stroke required in order to go from one

position to the other is 16 mm, and the pneumatic actuator that drives the system takes approximately 200 ms to close the shutter.

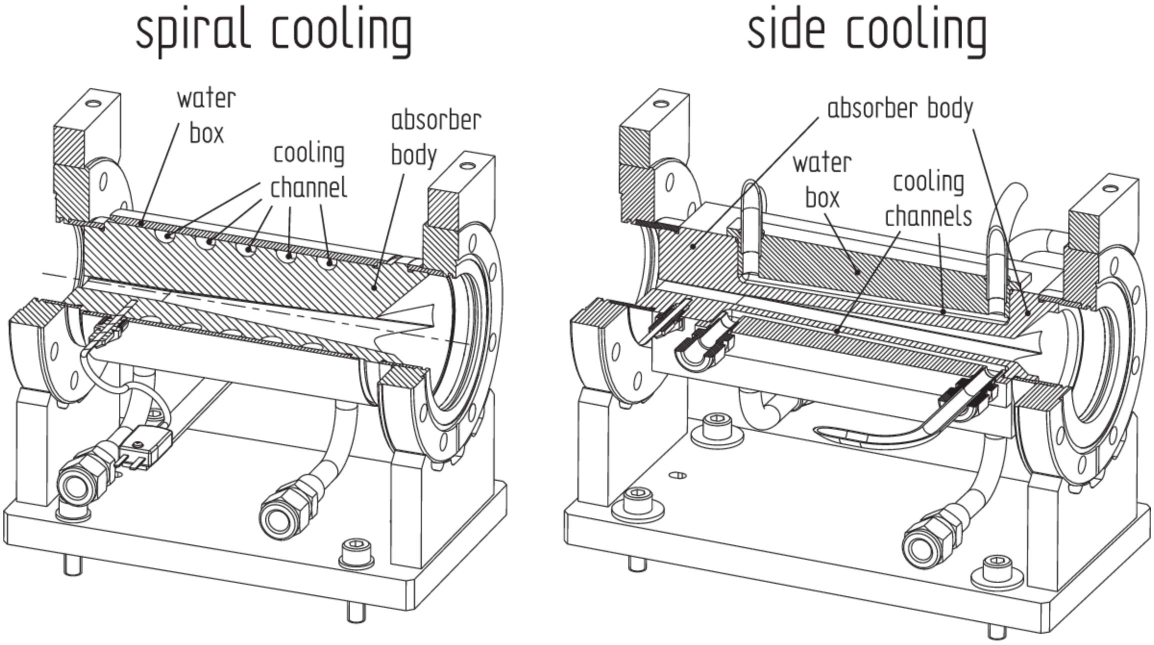

Figure 13.4: Second fixed masks for conventional wiggler sources (left) and superconducting wigglers (right), illustrating the ‘spiral cooling’ and ‘side cooling’ schemes.

(5) **Protection shutter:** this element consists of a pneumatic cylinder and an in-vacuum 10 mm-thick copper plate. It does not have any water cooling and completely blocks the photon beam when in closed position. It is triggered together with the FCS and has a closing time of around 50 ms, thus protecting the FCS from synchrotron radiation during the time lapse required for the photon shutter to close.

(6) **Fast-closing shutter (FCS):** this is a series 77 DN40 all-metal fast shutter which closes in less than 10 ms when triggered. The vacuum gauges providing the trigger signal for the FCS are located in the trigger unit, which is installed in the optics hutch of the beam line, thus protecting the SR against a vacuum failure in the beam line.

(7) **Movable masks:** movable masks allow users to define the photon beam delivered to the beam line. They consist of a pair of Glidcop blocks, each having a rectangular aperture with two tapered surfaces (top-left surfaces for mask 1 and bottom-right surfaces for mask 2) that intercept part of the photon beam. All inclined surfaces are water-cooled using the ‘side cooling’ scheme. Each mask is mounted on a motorized X–Y stage, and when combined the two masks delimit a aperture with rectangular cross-section of customizable size and position within the maximum aperture defined by the second fixed mask.

(8) **Double bremsstrahlung shutter:** this radiation safety element comprises two pneumatically actuated UHV-compatible tungsten-alloy blocks with a cross-section of 120 mm × 120 mm and a thickness of 200 mm. The two blocks are driven simultaneously but independently for redundancy reasons, and in combination with the photon shutter they provide users with safe access to the optics hutch of the beam line during operation.

(9) **Vacuum pipe through front wall:** this pipe has a rectangular cross-section and provides the connection between the accelerator tunnel and the optics hutch; it has a standard length of 1.9 m and an internal opening of 41 mm × 20 mm for all FEs that have a larger vertical aperture requirement.

(10) **Trigger unit:** the so-called trigger unit consists of a vacuum chamber where the two dedicated vacuum sensors that trigger the FCS are installed.

13.3 Cooling of front-end components

The design and validation of all power-absorbing elements have to be carried out in-house by means of finite-element analysis (FEA, ANSYS). As a rule of thumb, the incidence angle of the radiation on the cooled surfaces of the absorbers has to be decreased, reducing the maximum power density to 10–15 W/mm^2.

A cooling water velocity of 3 m/s has been considered in most of the cases, and it has been increased up to 4 m/s when required. The upper limits for the peak values of the different magnitudes considered within the FEA thermal analysis have been: (a) 100°C for the cooling water temperature; (b) 150°C for the temperature on the walls of the cooling channels; (c) 65–70 MPa stress and 0.1% strain in the case of OFHC copper absorber bodies; and (d) 250 MPa stress and 0.2% strain in the case of Glidcop absorber bodies.

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