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# High Power Photon Beamline Elements in the LBL/SSRL/EXXON Beamline VI

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*Abstract*

Beamline VI is a wiggler-based, multi-kilowatt, intense synchrotron radiation beamline installed on SPEAR. The thermal design parameters for this beamline are presented and then design considerations and construction descriptions are given for many of the high-power photon beamline elements.

## I. INTRODUCTION

Beamline VI, a joint design and construction effort between the Lawrence Berkeley Laboratory (LBL), the Stanford Synchrotron Radiation Laboratory (SSRL) and the EXXON Research and Engineering Company (EXXON), is a high-intensity synchrotron radiation facility presently operational at SSRL[1]. The radiation source for this beamline is a REC-steel hybrid wiggler with a variable-gap vacuum chamber installed on SPEAR[2]. This wiggler is capable of providing up to 7 kW of synchrotron radiation with intensities to 10 kW/mrad$^2$. Most of this power is absorbed in the downstream hard x-ray beamline components, which delivers 3–40 keV photons to users. Figure 1, a Phase 1 schematic showing the wiggler and the hard x-ray branchline, identifies the various components of the beamline. The design and engineering implementation of some of these components are discussed below. A more detailed engineering analysis of the thermal problems encountered is given elsewhere[3].

## II. THERMAL DESIGN PARAMETERS

The thermal design of Beamline VI is based on two sets of operating parameters for SPEAR, and the wiggler operating at its highest design field. Table 1 gives these operating parameters along with wiggler-output power and power density. These radiation beams have vertical opening angles of about 1/3 mrad and horizontal fan widths of 3-4 mrad. The photon power densities assume a zero-emittance electron beam.

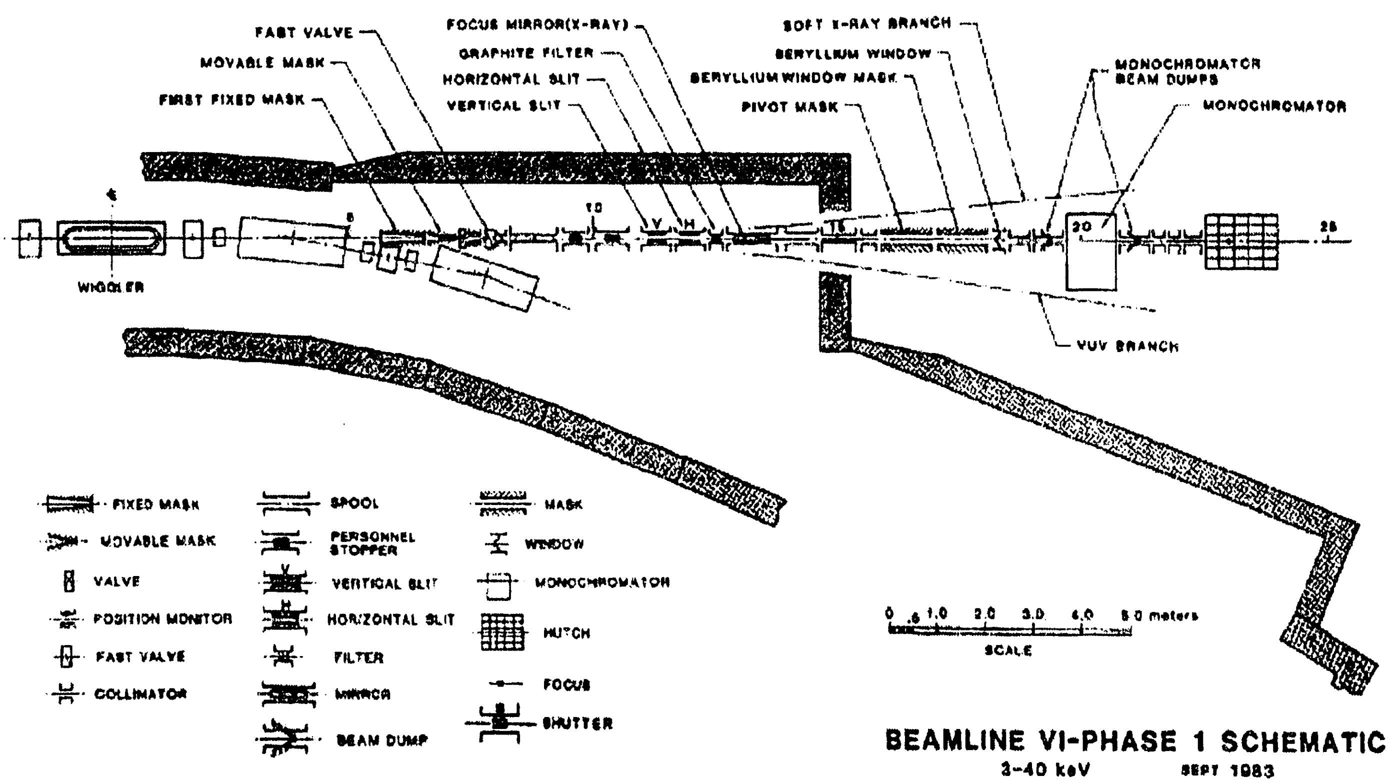


*FIG. 1. Beamline VI – Phase 1 schematic.*

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Table I. Beamline VI thermal design parameters.

| | Design Modes | |
|---|---|---|
| | A | B |
| SPEAR energy (GeV) | 3.00 | 3.75 |
| Electron current (mA) | 200.00 | 100.00 |
| Peak wiggler magnetic field (T) | 1.75 | 1.75 |
| Output power (kW) | 6.80 | 5.30 |
| Peak thermal power density (kW/mrad$^2$) | 8.50 | 10.30 |

Actual operating conditions to date (4/93) are given in Table II, and computed wiggler power and power density are included[4]. Only 19% of the design output power has been achieved, however 37% of the design peak power density has been reached. Again, the photon power densities assume zero emittance for the electron beam.

Table II. Beamline VI operating parameters and thermal output todate.

| | Todate Operating Modes | |
|---|---|---|
| | C | D |
| SPEAR energy (GeV) | 3.0 | 3.5 |
| Electronic current (mA) | 100.00 | 70.00 |
| Peak wiggler magnetic field (T) | 1.20 | 1.20 |
| Output power | 1.6 | 1.5 |
| Peak thermal power density (kW/mrad$^2$) | 2.9 | 3.8 |

Using the data from Table I, and component locations from the wiggler, peak intensity, normal to the photon, beam and peak surface intensity heating can be computed for beamline component geometry, as shown in Table III. The design thermal loading is generally based on Design Mode B, given in Table I, except the position monitor design thermal loading shown was based on lesser values.

Table III. Beamline VI component design thermal loading.

| Component | Distance from wiggler (m) | Peak intensity normal to beam (kW/cm$^2$) | Peak surface heating (kW/cm$^2$) |
|---|---|---|---|
| Fixed Mask | 6.50 | 23.50 | 0.67 |
| Moveable Mask | 6.90 | 20.90 | 1.17 |
| Position Monitor | 7.50 | 18.6 (5.6)* | 3.41* |
| Vertical Slits | 11.50 | 7.90 | 0.45 |
| Graphite Filter | 12.40 | 7.20 | 0.74 |
| Pivot Mask | 16.60 | 5.5** | 0.32** |
| Beryllium Mask | 17.60 | 7.5** | 0.31** |

* Designed for full photon beam impingment at 3.0 GeV, 100 mA & 1.3 T.

** Includes emittance and extended source effects.

The designs discussed in the following sections are based on the peak surface heating intensities tabulated in Table III.

## III. Masks and Slits

The masks and slits in the beamline are for protecting downstream beamline components during normal storage ring operation from the intense synchrotron radiation as well as in the event of storage ring electron beam missteering and for changing the beam size to meet the needs of the experimenters.

The basic engineering approach selected for the design and construction of the Beamline VI masks and slits was to:

- Utilize well understood materials with known straight forward fabricating procedures. OFHC copper was used for the heat absorbing surfaces and stainless steel for the structural support material and cooling tubes.
- Use a cooling approach compatible with the existing facility cooling system. Water cooling with maximum flow velocities of about 20 feet/sec was selected.
- Design the configurations so that the impinging high power beams are intersected at glancing angles and that the ensuing thermal stresses are within bounds for long component lifetime. The design basis for allowable thermal stress of the OFHC copper absorbers was 2/3 of the fatigue strength, +/- 18'000 psi at 100'000 cycles.
- For fabrication, brazed configurations were developed with the special feature that when the brazed joints reside in the UHV environment the braze joints were "guarded". The guarded braze joint is two joints in series; the first braze joint sees water on one side of the joint and air—or a guard vacuum—on the other; the second joint sees the same air, or guard vacuum, as the first joint and UHV on the other side so there are no direct water-to-UHV brazed connections.

The following is a brief description of some of the masks and slits in Beamline VI:

### *Fixed Mask*

This is the first element in the beamline which is a horizontal defining aperture for the beam. Figure 2 shows a cross-section of the fixed mask perpendicular to the beam direction. The side walls are sloped inward, when viewed in the beam direction, with 1.64 degree angles so as to reduce the peak beam intensity by a factor of 35. These walls utilize a multiple cooling channel configuration for reduced thermal stresses. The surface heating of 0.67 kW/cm$^2$ results in a peak thermal stress of +/- 7.2 ksi[5].

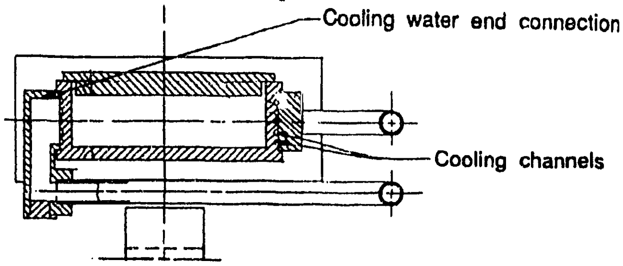


***FIG. 2. Fixed Mask cross-sectional view perpendicular to the photon beam.***

### *Moveable mask*

The moveable mask is the photon shutter for the beamline. When the beamline is closed, all the wiggler power must be absorbed in the moveable mask. Figure 3 shows a photograph of the radiation absorbing shutter blades that are completely within the UHV environment. Figure 4 shows a section thru the "V" configuration showing the guarded braze joint configuration. The horizontal absorber blades slope 3.2 degrees in the beam direction, reducing the peak intensity by a factor 17.5, which gives a peak surface heating of 1.17 kW/cm$^2$ and the corresponding peak thermal stress is +/- 12 ksi[6].

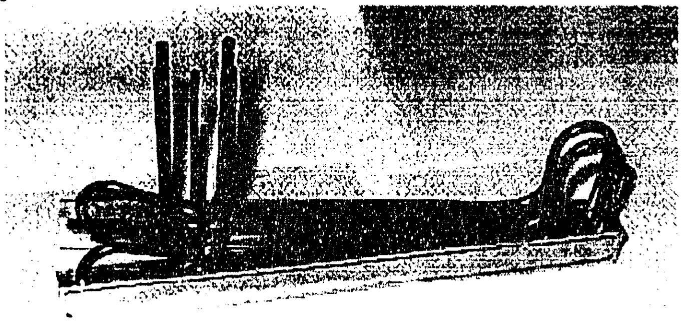

***FIG. 3. Moveable Mask heat absorbing blades with cooling and vent tubes.***

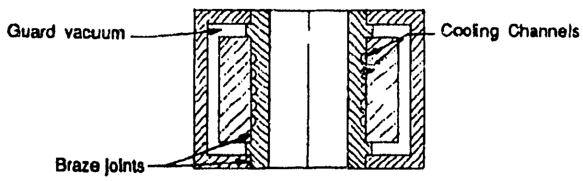


***FIG. 4. Moveable Mask cross-section showing cooling channels and braze configuration.***

### *Vertical and Horizontal Slits*

The vertical and horizontal slits allow changing the beam aperture and allows the beam to be moved in the two transverse dimensions. The heat absorbing slit blades are similar in construction to the Moveable Mask blades, except the vertical slit blades each have 22 cooling channels to cover the wider beam fan. To achieve the adjustability, the slits are hinged at the upstream ends and the downstream ends are articulated. All the motions are achieved through bellow assemblies driven with stepper motors.

### *Pivot Mask*

This mask is located downstream of the focussing mirror and absorbs a portion of the photon beam when the beamline is operating in an unfocussed mode ( e.g., the mirror is retracted) when beam bypasses the mirror, or when the beam is missteered in focussed-mode operation. Because the beam intensity is reduced at the pivot mask, external cooling is used on three of the mask walls with internally finned tubing, as shown in Figure 5. The tubes were first mechanically fastened to the walls by rolling over the thin copper lips, originally machined into the walls, then the entire assembly was brazed. Figure 6 shows the completed assembly.

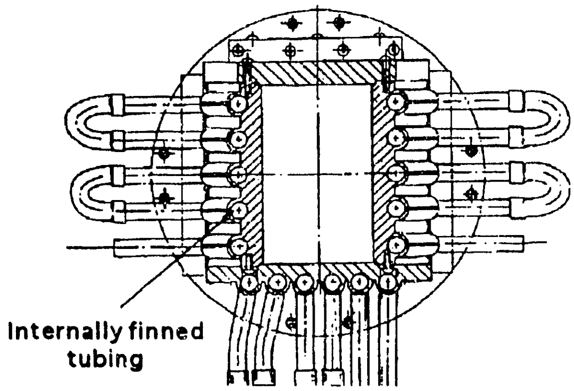


***FIG. 5. Pivot Mask, cross-sectional view—upstream direction.***

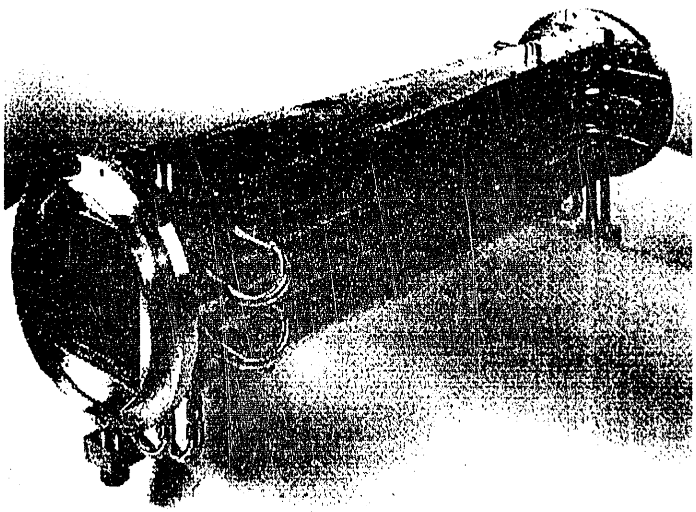

***FIG. 6. Completed pivot mask showing the external cooling circuits.***

### *Beryllium Window Mask*

The beryllium window mask absorbs considerable beam when the beamline operates in unfocussed mode, but the highest heating intensity occurs when focussed beam is missteered enroute to the beryllium window. A cross-section showing the angular cuts for the opening to the beryllium window, the cooling channels, and location of the braze wire, is shown in Figure 7. Seen in Figures 7 and 8 is the self-fixturing for brazing which is accomplished by assembling the entire mask with machine screws. The highest thermal stresses occur on the vertical angular cuts, where the angles have only 1.3 degrees slopes. With 0.31 kW/cm$^2$ peak surface heating, the resulting thermal stress computed is +/- 12 ksi[7]

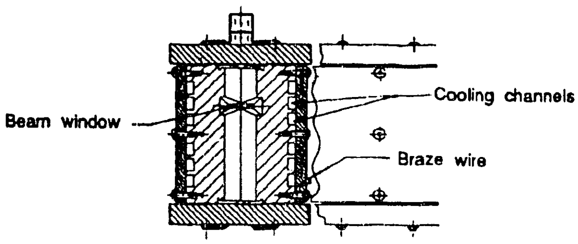


*FIG. 7. Beryllium window mask, cross-sectional view—downstream direction.*

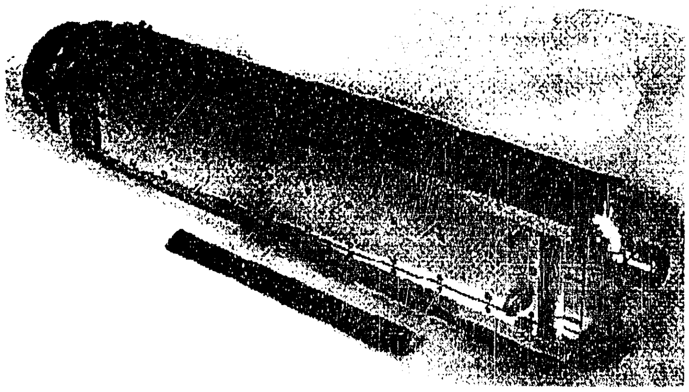

*FIG. 8. Completed beryllium window mask.*

## IV. Position Monitor

Beamline VI utilizes an in-vacuum position monitor to sense vertical position of the photon beam. Beam position is detected by sensing the difference in photoelectron current generated in the two blades where one is positioned above the midplane and the other symmetrically below the midplane. Figure 9 shows the position monitor. The blades are fabricated from tungsten and brazed to water-cooled copper heat sinks and electrically isolated. These blades were designed for full-beam impingement at 3.0 GeV, 100 mA, and 1.3 T, which corresponds to a peak photon beam intensity, normal to the beam, of 5.6 kW/cm$^2$. The peak impingement surface heating is 3.4 kW/cm$^2$, because the forward edge of the blades are chamfered.

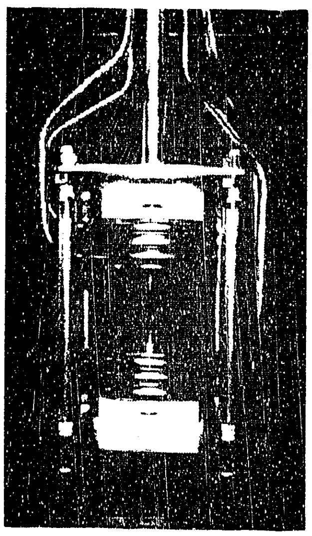

*FIG. 9. Beam view of the UHV position monitor showing the thin beam sensing blades.*

## V. Graphite Filter

The graphite filter removes the low-energy spectrum as well as reduces the thermal heating on the downstream mirror and beryllium window. The filter is made up of a series of very thin and fragile pyrolytic graphite foils placed normal to the photon beam.

Criteria for size, thickness, and the number of pyrolytic foils for the filter assembly are[8]:

- The downstream beryllium window heating, at 250 microns thick, cannot exceed 36.7 W/cm.
- Evaporation of the foils is limited to 10%/year, which limits the peak filter temperature to about 1900 degree K for a 5 micron filter.
- Heat transfer is based on radiation cooling.
- Stress levels to be a factor of 3 less than the ultimate strength of pyrolytic graphite.
- Available pyrolytic graphite foil thicknesses are 5–50 microns.
- Two foils can fail and the downstream beryllium window must still be safe.

An example filter configuration, operating at 3.75 GeV, 100 mA, and 1.75 T, where the peak photon beam intensity—normal to the beam—is 6.7 kW/cm$^2$, would be one with the first filter at 5 microns thickness, which would absorb 0.124 kW with a peak surface heating of 0.096 kW/cm$^2$. Thirty foils would be required with a total thickness of 1170 microns, and the total power absorbed in the assembly would be 1.95 kW.

A foil cartridge is shown in Figure 10. The fragile pyrolytic foil(s) is placed in a tantalum holder which is subsequently spot welded together. Figure 11 shows the water-cooled graphite filter unit without the filters inserted. The unit consists of two insertable water-cooled assemblies, each capable of holding 11 cartridges. This arrangement allows for four different filter thickness combinations: 1) no filters with both assemblies retracted, 2) a filter combination with just the first assembly inserted, 3) a different combination with just the second filter inserted, and 4) with both assemblies inserted together.

*FIG. 10. Graphite Filter foil cartridge.*

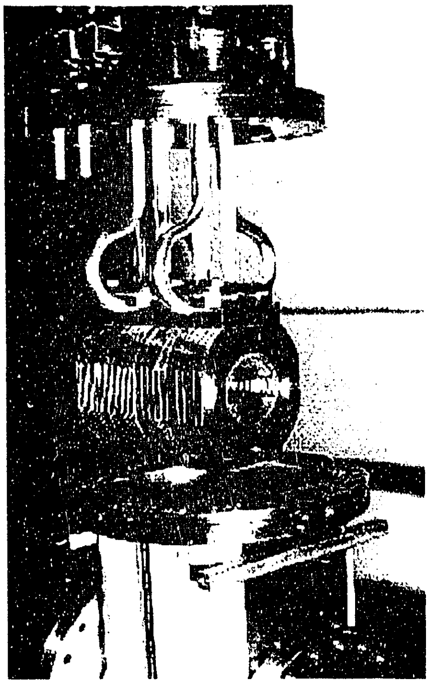

***FIG. 11. Graphite Filter showing insertable assemblies with cartridges removed.***

## VI. Conclusion

For the Beamline VI, the thermal design requirements have been presented and the successful design and construction implementation of many of the high-power, photon-beamline components has been described.

For the synchrotron radiation instrumentation field, Beamline VI ushered in a number of new developments which include:

- The first variable gap, permanent magnet, steel hybrid configured insertion device which was successfully implemented to produce high-intensity synchrotron radiation.
- Implementation of a variable gap insertion device vacuum chamber allowing high fields to be achieved with short period insertion devices.
- Successful beam position control with the 2-blade configured position monitor in UHV.
- Design and fabrication of high-power beamline elements capable of handling photon beam powers to 7 kW.

## VII. References


1. E. Hoyer, et al., "A New Wiggler Beamline for SSRL," NIM 208 (1983) 117-125.
2. E. Hoyer, et al., "The Beamline VI REC-Steel Hybrid Wiggler for SSRL," IEEE Transactions, Nuclear Science, NS-30, 3118 (1983).
3. R. Avery, "Thermal Problems on High Flux Beamlines," NIM 22 (1984) 146- 158.
4. H. Winick, private communication.
5. R. Avery, "First Fixed Mask—Engineering Design," LBL Engr. Note M5971, (LBID 604).
6. R. Avery, "Moveable Mask—Design 'H';" Engineering Design, LBL Engr. Note M5972, (LBID 615).
7. E. Hoyer, "Beryllium Window Mask," LBL Engr. Note M6150, (LBID 792).
8. E. Hoyer, "Pyrolytic Graphite Foil System at 12.3 m," LBL Engr. Note M6043, (LBID 677)

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