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Precision White-Beam Slit Design for High Power Density X-ray Undulator Beamlines at the Advanced Photon Source

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Abstract

A set of precision horizontal and vertical white-beam slits has been designed for the Advanced Photon Source (APS) X-ray undulator beamlines at Argonne National Laboratory. There are several new design concepts applied in this slit set, including: grazing-incidence knife-edge configuration to minimize the scattering of X-rays downstream, enhanced heat transfer tubing to provide water cooling, and a secondary slit to eliminate the thermal distortion on the slit knife edge.

The novel aspect of this design is the use of two L-shaped knife-edge assemblies, which are manipulated by two precision X-Z stepping linear actuators.

The principal and structural details of the design for this slit set are presented in this paper.

DISCLAIMER

1. Introduction

A third-generation synchrotron radiation source, such as the 7-GeV Advanced Photon Source (APS)[1], will generate high brilliance and intense synchrotron radiation from its insertion devices (IDs). There are many challenging tasks in the design of the ID beamlines instrumentation, related to high-heat-load and high-heat-flux problems. One component is the precision white beam slit for undulator beamlines.

Most of the undulator beamlines contain a set of white-beam slits upstream of the first optical element such as a mirror or monochromator. The major design challenges for the APS white-beam undulator slits are the following:

-- high-heat-flux undulator beam on the slits,

-- high precision and geometric stability requirements for the slits,

-- minimization of the downstream scattered X-rays from the slits,

-- control the slit edge fuzziness for hard X-rays.

To meet these challenging design requirements, a novel L-shaped grazing-incidence, knife-edge slit assembly has been developed for the APS. In this paper, we will discuss the principal and structural details of the design of this slit assembly, called L5 in the APS standard components library [2].

2. Design Specifications

Table 1 shows the major design specifications for the undulator white-beam precision slits, L5. At a typical beamline, the L5 slits will be located in the first optics enclosure (FOE) area about 27.5 meters from the undulator source. Using one of the standard APS insertion devices, called Undulator A, the L5 slits will be impinged by a X-ray beam with 3800 watts total power and 350 watts/mm^2 peak heat flux in the worst case [3].

3. The L5 slits design

3.1. Main Components

As shown in Fig. 1, the L5 undulator white-beam slit assembly consists of six main components. Two X-Z stepping-motor-driven actuators (1) and (2) are mounted on top of the vacuum vessel (3). Slit cooling assemblies (4) and (5) are mounted on the bottom of each X-Z actuator in the vacuum vessel. On the front of the vacuum vessel, a fixed mask (6) confine the incident beam with an aperture 7 mm X 7 mm to avoid the missteered beam damage to the slit holders.

The vacuum vessel and its ion pump are supported on a standard APS precision kinematic mounting table [4], which provides five-dimensional remote adjustment capability to align the slits.

3.2. The L-shaped Slits Configuration

If one looks at the front of the slit along the beam direction, two L-shaped half-slits perform the same function as slits that have four independent knife-edge blades. With different positions of the two halves, which are controlled by the X-Z actuators, the slits can be manipulated into many shapes, from a vertical slit to a horizontal slit or a rectangular aperture sized from 7 mm X 7 mm down to 0.1 mm X 0.1 mm (as shown in Fig. 2).

3.3. Grazing-Incidence Knife-Edge Configuration

The knife-edge slit has minimum downstream X-ray scattering if the normal incident surface of the slit blade is facing the beam (Fig. 3a). Unfortunately, it is very difficult to design such a simple slit block because of the thermal load and high heat flux on the slit from the Undulator A beam. To solve this problem, we turned the slit front surface around the Y axis by an angle so that the X-ray beam will impinge the slit front surface with a grazing incident angle Θ as shown in Fig. 3b. To keep the same real recess angle α, the grazing-incidence, knife-edge block will have a back cutting angle ß and will have :

$$\tan \alpha = \tan \Theta * \tan ß \qquad (1)$$

3.4. Thermal Geometric Stability and Double Slits Configuration

According to the finite element thermal-stress and displacement analysis [5], the maximum nonlinear distortion on the L5 primary slit grazing-incidence knife-edge may be over 70 micrometers in the worst case. To improve the slit thermal geometric stability, a secondary knife-edge was introduced to the L5 slit assembly. The secondary knife-edge is mounted downstream of the primary slit in such a way that it only blocks about a 100 micrometers X-ray beam on the edge. Thus, a simple normal-incident tungsten slit will be able to handle the Undulator A thermal load, and there will be only a few micrometer nonlinear thermal distortion on the knife-edge(Fig. 4).

Fig. 5 shows the details of the slit cooling assembly. On the bottom part of each cooling assembly, there is one primary molybdenum L-shaped half-slit block (a) and one pair of tungsten knife-edge blocks (b) and (c). The tungsten blocks are assembled as a L-shaped secondary half-slit and mounted on the back of the molybdenum block with good thermal contact by using silver shims. An OFHC coaxial enhanced water-cooling tube (d)[5] is brazed (or tightly fitted with good thermal contact) into the central hole in the molybdenum half-slit block (a). An explosion bonded unit (e) provides the vacuum seal between the OFHC cooling tube and the stainless steel flange (f).

4. Fuzziness of the Hard X-ray Knife-Edge

It is important to study the knife-edge fuzziness for a hard X-ray slit to determine an optimized real recess angle. If we define the ratio of output to input photon flux I/I0 equal to or less than 0.001 as the edge of the slit fuzzy area, we will have:

$$t = -\ln(1/1000) / \mu \qquad (2)$$

and

$$w = t \times \tan \alpha, \qquad (3)$$

where α is the real recess angle, t is the depth to stop the beam (to 1/1000), and w is the knife-edge fuzziness (1/1000 definition).

Fig. 6 shows the knife-edge slit fuzziness as a function of the photon energy with 0.5 degree real recess angle and different slit materials.

5. Discussion and Conclusions

A precision white-beam slit assembly for the APS high power density X-ray beamlines has been designed, and a prototype has been built. Fig. 7 shows the molybdenum primary slit block.

Fig. 8 shows an optional design for the grazing-incidence L-shaped slits that uses a fixed mask cooling base to mount the slits. This design requires more space along the beam direction, but may have a lower cost.

6. Acknowledgments

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References

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[2] D. Shu et al., Design of the Beamline Standard Components at the Advanced Photon Source, SRI 94, Stony Brook (1994).

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[4] J. Barraza et al., Nucl. Instru. and Meth., A347 (1994)591-597.

[5] J. Chang et al., Design of a New Coaxial Water-Cooled Photon Shutter, SPIE, Vol.1977, pp.451-458 (1993).

Figure Captions

Fig. 1, APS L5 Undulator White Beam Horizontal and Vertical Slits General Assembly. (1)(2) X-Z Stepping motor driven actuator, (3) Vacuum vessel, (4)(5) Slits water-cooling assembly, (6) Fixed mask, (7) Ion Pump, (8) APS standard precision kinematic mounting table.

Fig. 2, 3-D view and Front view of the L5 slits.

Fig. 3a, Regular normal incidence knife-edge slit blade.

Fig. 3b, grazing incidence knife-edge slit block.

Fig. 4, Double slits configuration.

Fig. 5, L5 Slit cooling assembly. (a) primary molybdenum L-shaped half-slit block, (b) and (c) tungsten knife-edge blocks, (d) OFHC coaxial enhanced water-cooling tube, (e) explosion bonded unit, (f) stainless steel flange.

Fig. 6, Knife-edge fuzziness as a function of the photon energy with 0.5 degree real recess angle and different slit material.

Fig. 7, APS L5 molybdenum primary slit block.

Fig. 8, An optional design for the grazing-incidence L-shaped slits.

Fig. 1

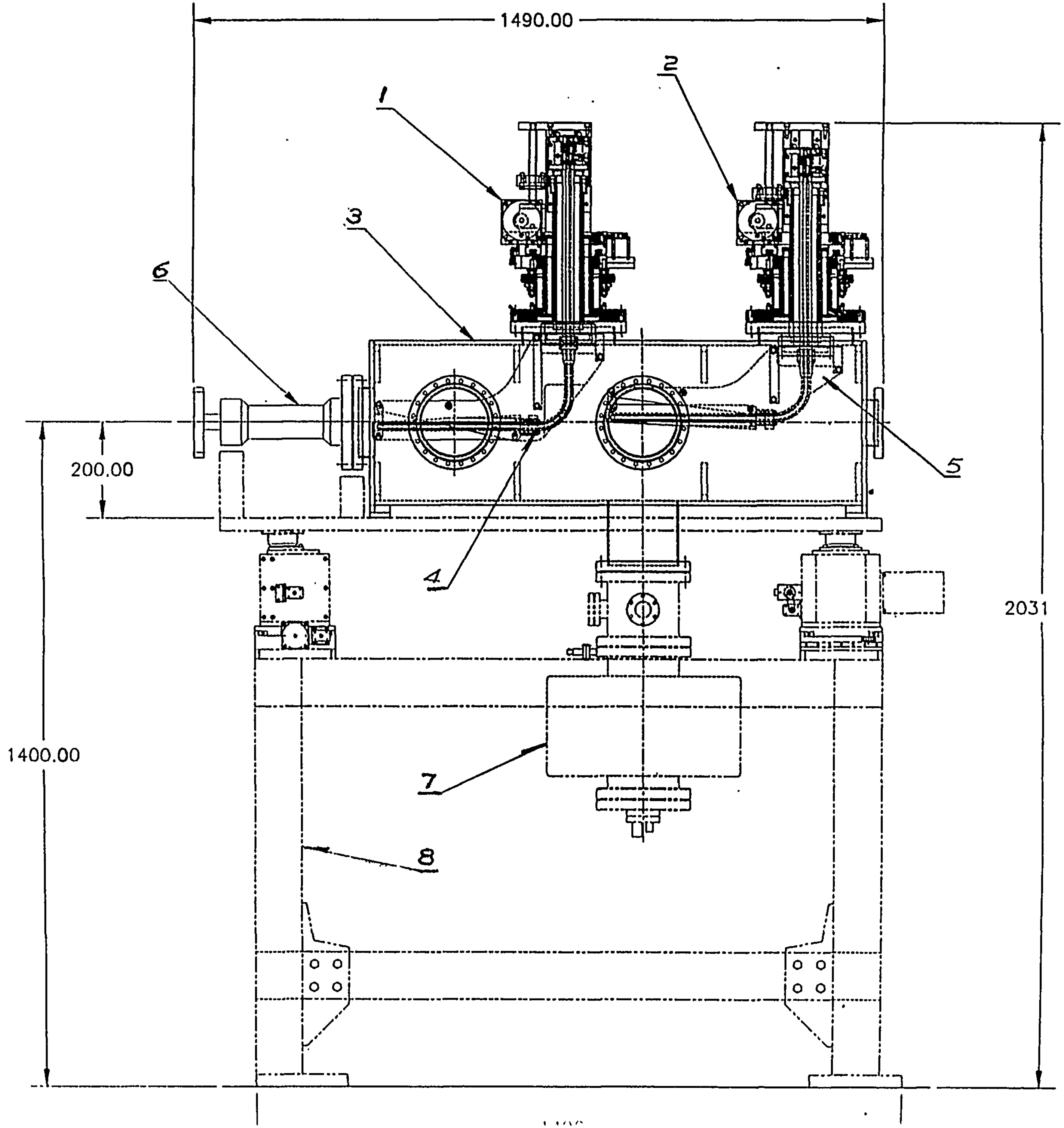
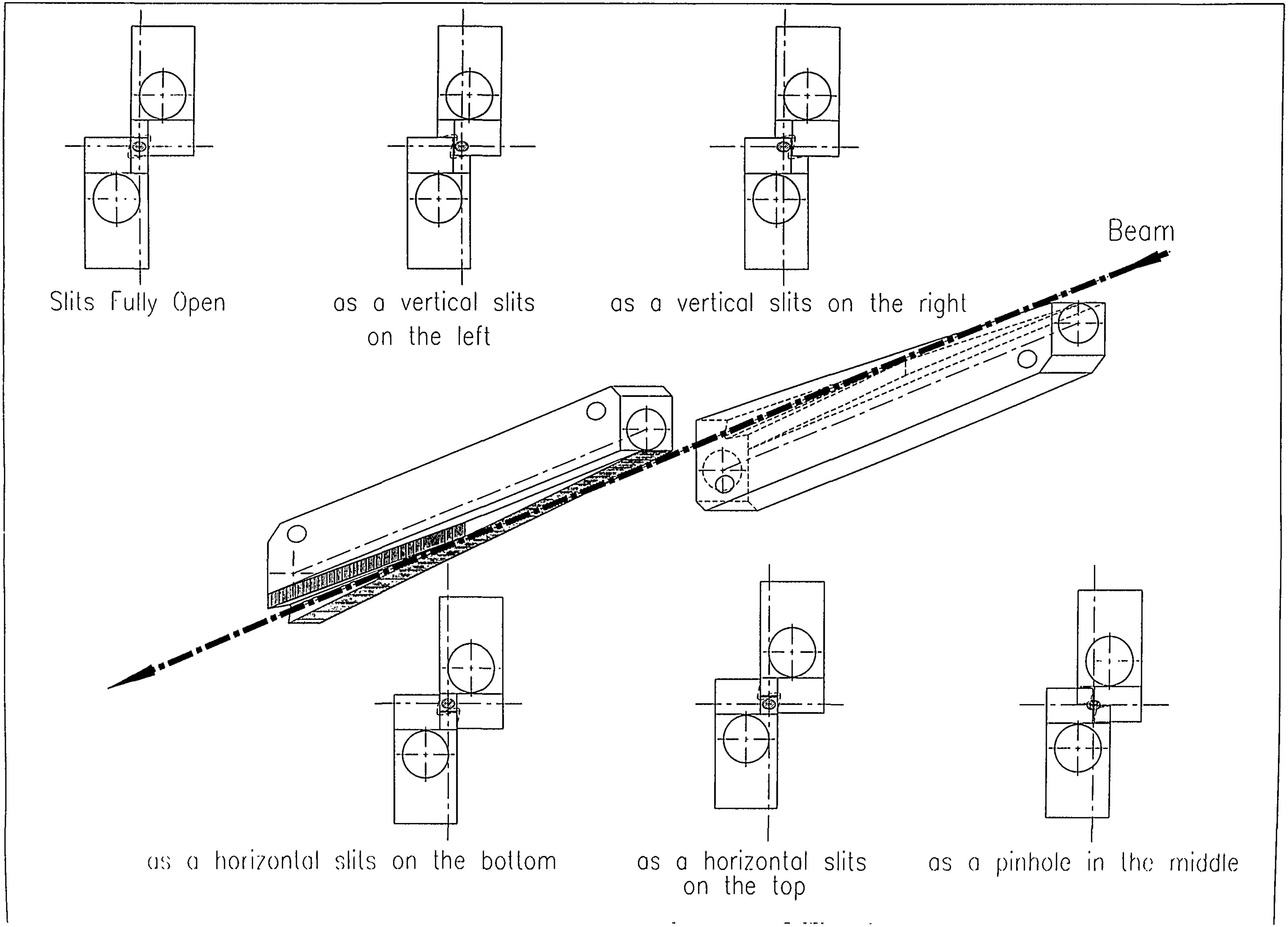


Fig. 2


Beam
Slits Fully Open
as a vertical slits on the left
as a vertical slits on the right
as a horizontal slits on the bottom
as a horizontal slits on the top
as a pinhole in the middle

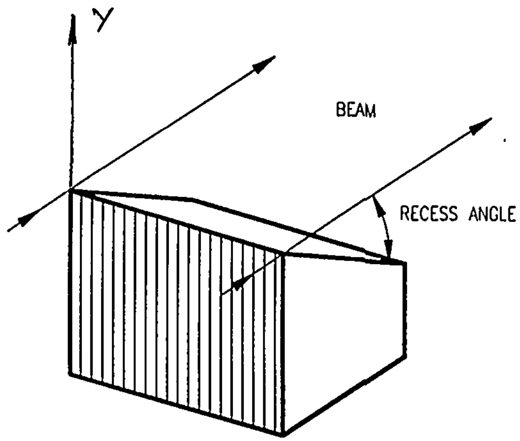
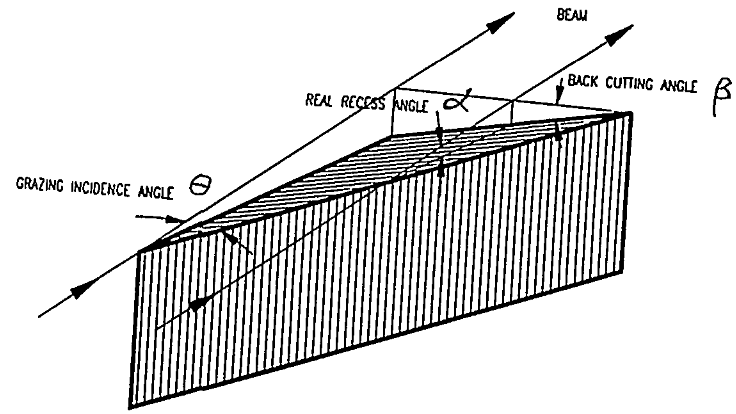


Fig. 3a



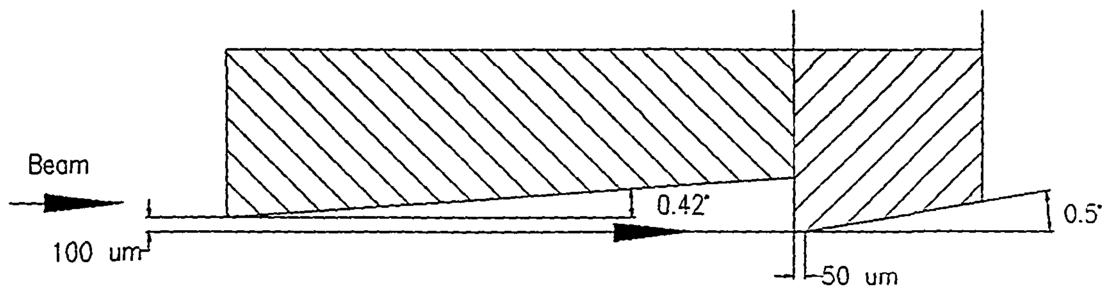
α REAL RECESS ANGLE - 0.5 °

θ GRAZING INCIDENCE ANGLE - 2.5 °

β BACK CUTTING ANGLE - 9.49 °

Fig. 3b.

Fig. 4



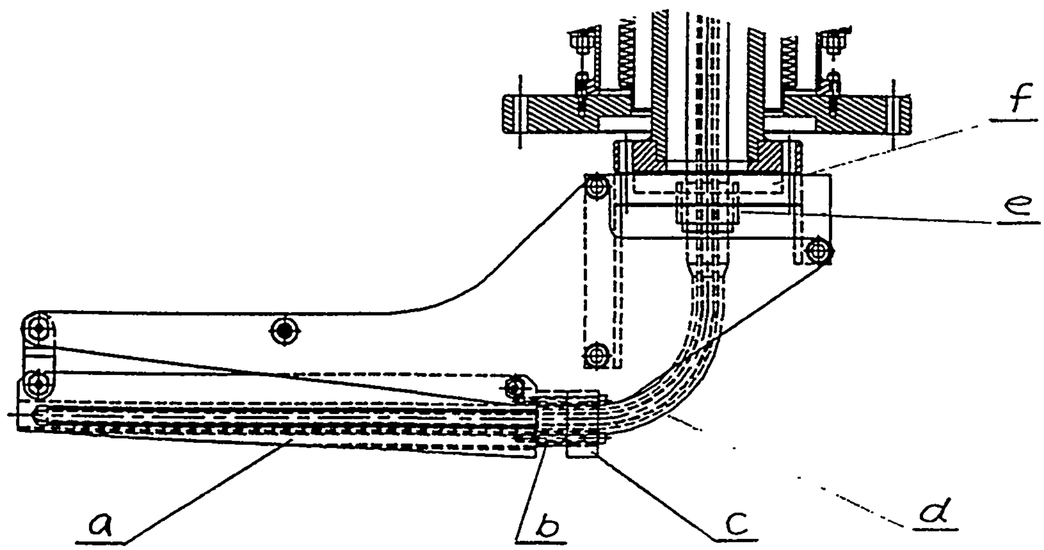
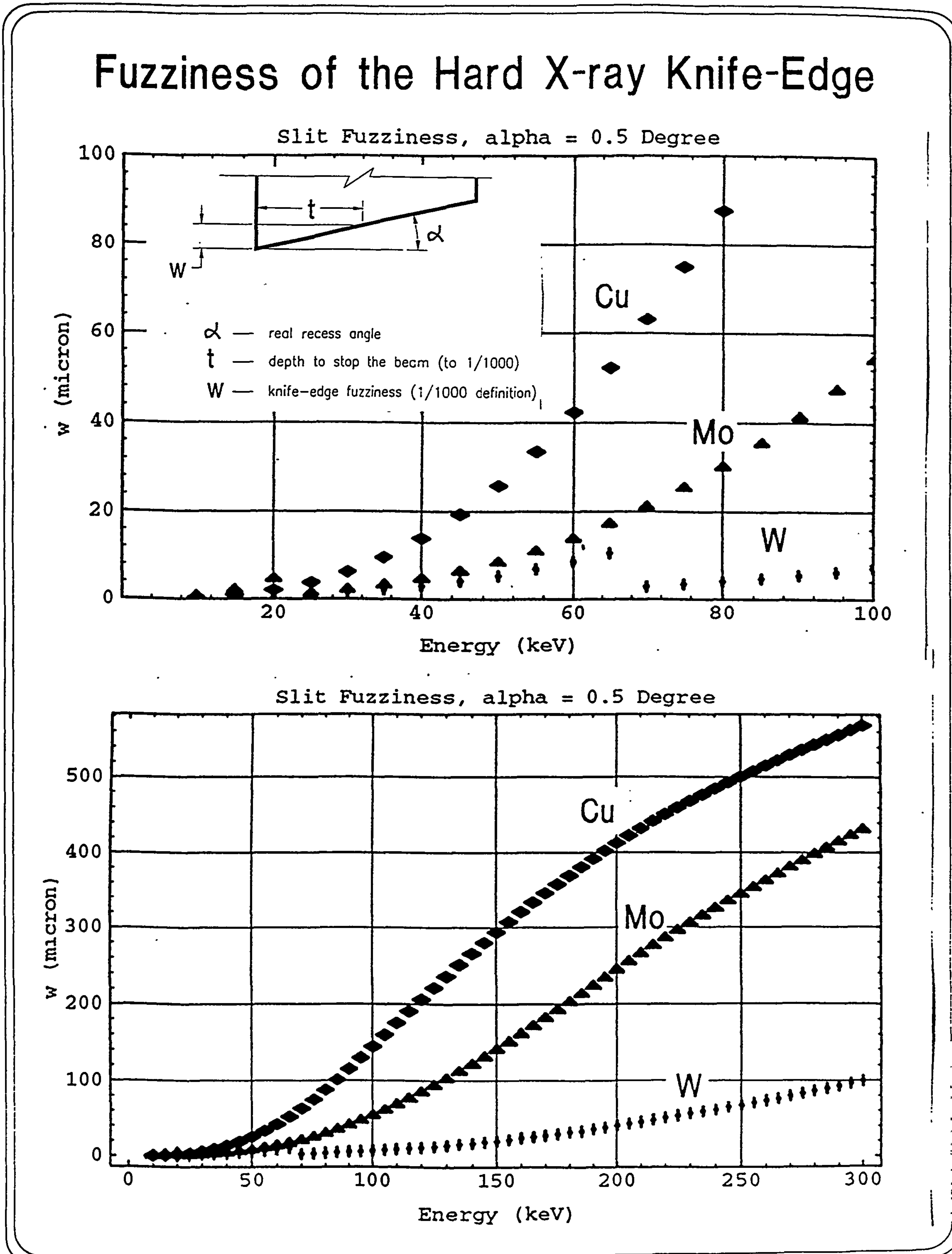


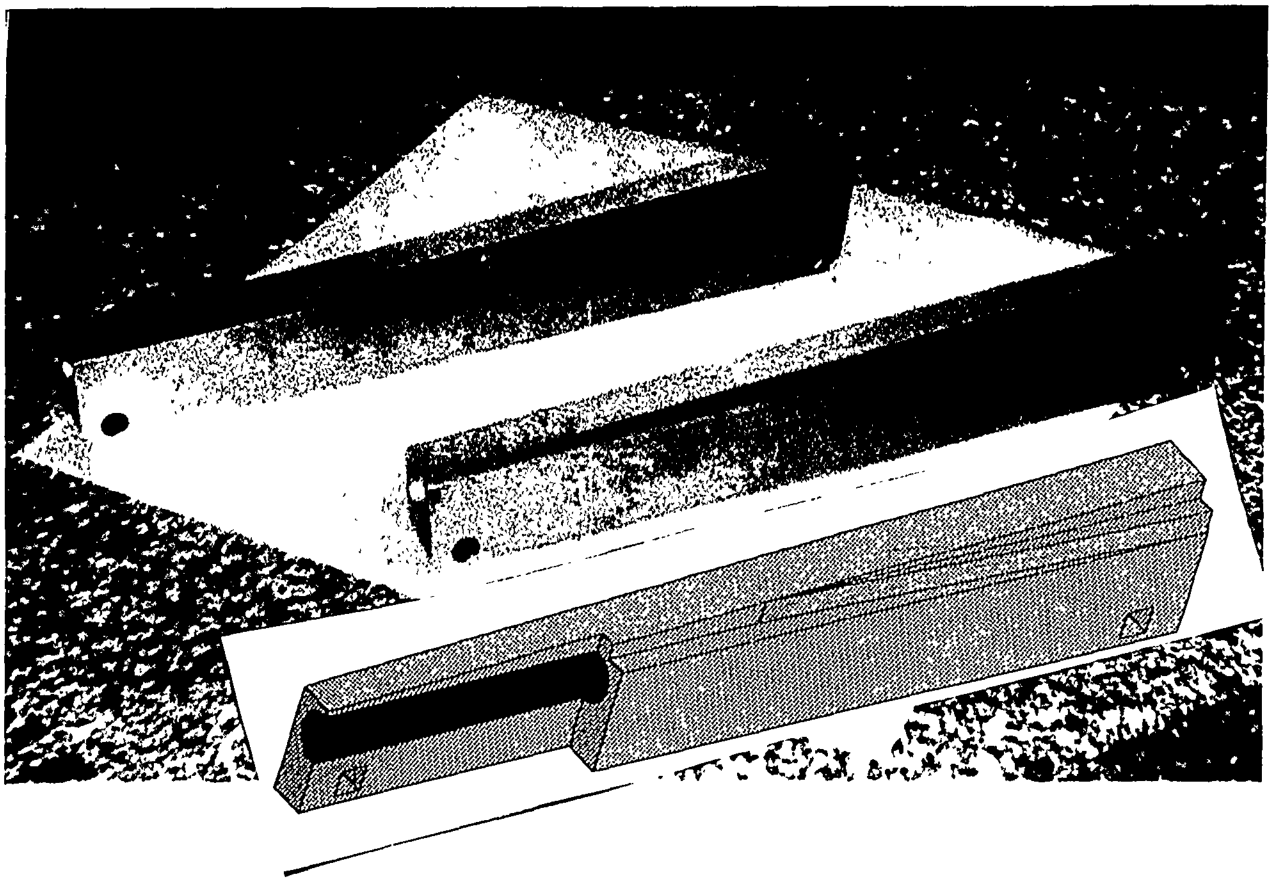
Fig. 5



Fuzziness of the Hard X-ray Knife-Edge
Slit Fuzziness, alpha = 0.5 Degree
t
α
W
α — real recess angle
t — depth to stop the beam (to 1/1000)
W — knife-edge fuzziness (1/1000 definition)
Cu
Mo
W
w (micron)
Energy (keV)
0
20
40
60
80
100
Slit Fuzziness, alpha = 0.5 Degree
Cu
Mo
W
w (micron)
Energy (keV)
0
50
100
150
200
250
300
400
500

Fig. 6

Fig. 7 (B&W)



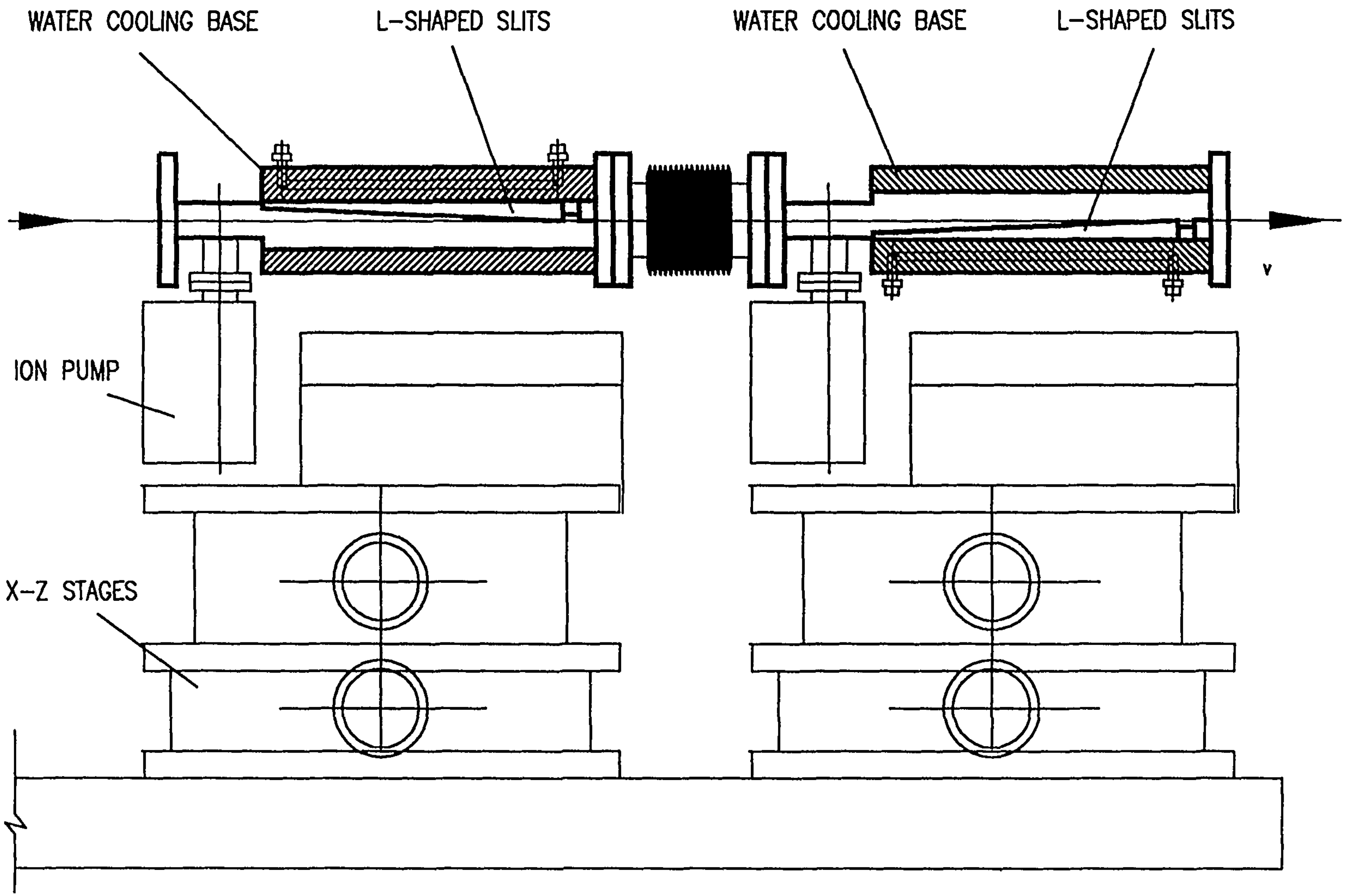


Fig. 8 OPTIONAL DESIGN FOR L-SHAPED SLITS