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A Double-Multilayer Monochromator Using a Modular Design for the Advanced Photon Source

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Abstract

A novel double-multilayer monochromator has been designed for the Advanced Photon Source X-ray undulator beamline at Argonne National Laboratory. The monochromator consists of two ultra high-vacuum (UHV) compatible modular vessels, each with a sine-bar driving structure and a water-cooled multilayer holder. A high precision Y-Z stage is used to provide compensating motion for the second multilayer from outside the vacuum chamber so that the monochromator can fix the output monochromatic beam direction and angle during the energy scan in a narrow range.

The design details for this monochromator are presented in this paper.

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1. Introduction

Multilayer monochromators are important synchrotron radiation instruments and are useful for many applications. The typical energy bandwidth is about a few percent and matches well with the bandwidth of a typical undulator harmonic radiation. The energy bandwidth is about two orders of magnitude more than that of a double-crystal Si monochromator [1] and, therefore, can provide more flux for experiments than a Si monochromator. Experiments that benefit from an X-ray beam with large flux and moderate resolution include, to name a few, fluorescence analysis, small-angle scattering, and time-resolved X-ray scattering. An X-ray multilayer monochromator can also be used as a power filter [2]. This application may be particularly important for mitigating the high-heat-load problem encountered with third-generation synchrotron sources. The heat flux on a multilayer from an incident X-ray beam is many times smaller than that on a Si crystal because the X-ray incidence angle is much smaller for a multilayer monochromator than for a Si monochromator. The combination of the relatively small heat flux and freedom from the restriction of using high quality crystals for substrate materials offers interesting possibilities of using a multilayer monochromator to reduce the thermal loading problem for a Si monochromator.

In this paper, we report the design of the vacuum and mechanical parts of a double-multilayer monochromator. The multilayer monochromator is designed to have an X-ray tuning range of 3 - 40 keV using multilayers of d-spacing between 20 - 50 A. The multilayer monochromator is designed to be UHV compatible, which is useful when it is used as a first optical component on a beamline if a vacuum barrier is required between a none-UHV-compatible first optical component and the storage ring. Under certain conditions, the required vacuum barrier may be very difficult to design.

2. Design Objectives

Several desirable features incorporated in the design include: (1) X-ray energy tuning range: 3 - 40 keV, (2) selectable energy bandwidth: 0.5 % - 5 %, (3) small offset between the incident and diffracted beams, (4) UHV compatible, and (5) modular design.

Table 1 shows the incidence angle as a function of X-ray wavelength for different multilayer d-spacings. The sine-bar driving main shaft of the multilayer monochromator has an angular rotation range from 0.2 to 4.19 degrees, which will cover the desired energy tuning range of 3 to 40 keV when multilayers with proper d-spacing are used.

The multilayer monochromator consists of two modularly designed, high-precision main spindle assemblies. A high precision Y-Z stage is used to provide compensating motion for the second multilayer assembly from outside vacuum so that this monochromator can have a fixed offset in the diffracted monochromatic beam over a reasonable range of energy scan. The Y-motion range of this compensating motion is 200 mm, and the Z motion range is 74 mm. Table 2 lists the compensation energy ranges for different multilayer d-spacing with different X-ray energies. Figure 1 shows the general layout of the multilayer monochromator.

3. Modular Design of the Monochromator

As shown in Figure 2, the UHV-compatible structural design is simplified by using two modular vacuum chambers, (1) and (2), for each multilayer. The compensating motion of the second multilayer chamber (2) is accomplished by high precision vertical and horizontal translation stages, (3) and (4), so that the second multilayer can be translated independently of the first. Angular scanning of each multilayer is performed by the two sine-bar mechanisms (5), explained below. The vacuum chambers are coupled by the welded bellows (6), permitting large flexible translations during compensating motion. This structure is supported by a rigid frame (7), which is mounted on a high precision kinematic mount table (8) for precision alignment and positioning of both vacuum chambers.

Figure 3 shows the detailed cross-sectional front and side views of the modular, multilayer mechanical and vacuum chamber design. The multilayer (1) is attached to an APS standard kinematic mount holder (2), which is cradled by the spindle structure (3). A precision hollow shaft (4) supported by two sets of shaft bearings inside a precisely machined rigid housing permits stable angular rotation of the multilayer by means of the sine-bar mechanism (5). The sine bar is clamped to the shaft (4) by a conical junction (6) for maximum rigidity and extends to atmosphere through the flexible vacuum bellows (7), permitting the sine bar to have a large radius of rotation for increased angular resolution. Because the angular motion is critical to the function of the multilayer, the sine-bar arm is fabricated from low expansion, super-invar material, minimizing the angular motion resulting from temperature changes and maximizing its stiffness. Using a hardened ruby ball (8) as a precision contact point, the sine-bar arm is driven by a commercial linear positioning stage (9) that has 0.1 micron positional resolution, yielding high angular resolution of the multilayer.

The multilayer is water cooled using radiation resistant flexible cooling tubes (10) shrouded by a vacuum bellows (11) used in reversed pressure. With this style of water connection, the direct vacuum to water junction is avoided, eliminating the risk of contaminating the UHV environment.

Two compact chambers comprise the vacuum structure. One chamber (12) houses and supports the rotation spindle assembly and provides the entry transition to the sine-bar arm and the water-cooling lines. The other chamber (13) houses the multilayer and mounting assembly and supports the ion vacuum pump. This design demonstrates the advantage of having easy access to the multilayer by removing one vacuum flange (14).

4. Summary

We have presented the design of a novel APS double-multilayer monochromator and described key features in its design which, offer several advantages. These advantages include: the use of compact and modular vacuum chambers for each multilayer; all motion actuators are kept outside the vacuum chambers; a fixed exit for the diffracted beam over a reasonable energy scan; easy access to the multilayer itself; and UHV compatability. Additionally, this design offers the advantage of increasing the multilayer resolution by adding a second multilayer monochromator as shown in Figure 4. It is also worth to point out that the design can be used as a high energy X-ray monochromator if a Si crystal is used instead of a multilayer, an energy coverage of 20 - 250 keV may be obtained using the design presented in this paper.

5. Acknowledgments

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References

[1] G. B. Stephenson, Time-Resolved X-ray Scattering Using a High-Intensity Multilayer Monochromator, Nucl. Instr. and Meth A266 (1988) 447-451.

[2] J. Underwood and T.W. Barbee,Jr., Layered Synthetic Microstructures as Bragg Diffractors for X-rays and Extreme Ultraviolet: Theory and Predicted Performance, Applied Optics, Vol.20, P3027 (1991).

Figure Captions

Table 1. Incidence Angle as a Function of X-ray Wavelength for Different D-Spacings

Table 2. The compensation X-ray energy ranges for different multilayer d-spacing with different beam offset.

Figure 1. Optical schematic of the multilayer monochromator with different beam offset and second multilayer compensation motion.

Figure 2. General layout of the multilayer monochromator.

Figure 3. The detailed cross-sectional front and side views of the modular multilayer mechancal and vacuum chamber design.

Figure 4. Four multilayer monochromator using the modular design.

Table 1

glancing incidence angle / X-ray / D-spacing	4 Å	2 Å	1 Å	0.5 Å	0.31 Å
	3.1 keV	6.2 keV	12.4 keV	24.8 keV	40 keV
20 Å	5.71	2.86	1.43	0.72	0.44
30 Å	3.81	1.91	0.95	0.48	0.30
40 Å	2.86	1.43	0.72	0.44	
50 Å	2.29	1.15	0.57		

Table 2

offset / glancing incidence angle / X-ray energy (keV) / D-spacing	9.21 mm		37 mm		73.7 mm	
	0.754	1.056	3.026	4.232	6.01	8.38
20 Å	23.55	16.82	5.87	4.20	2.96	2.13
30 Å	15.7	11.2	3.91	2.80	1.97	1.42
40 Å	11.8	8.41	2.94	2.10	1.48	1.06
50 Å	9.42	6.73	2.35	1.68	1.18	0.85

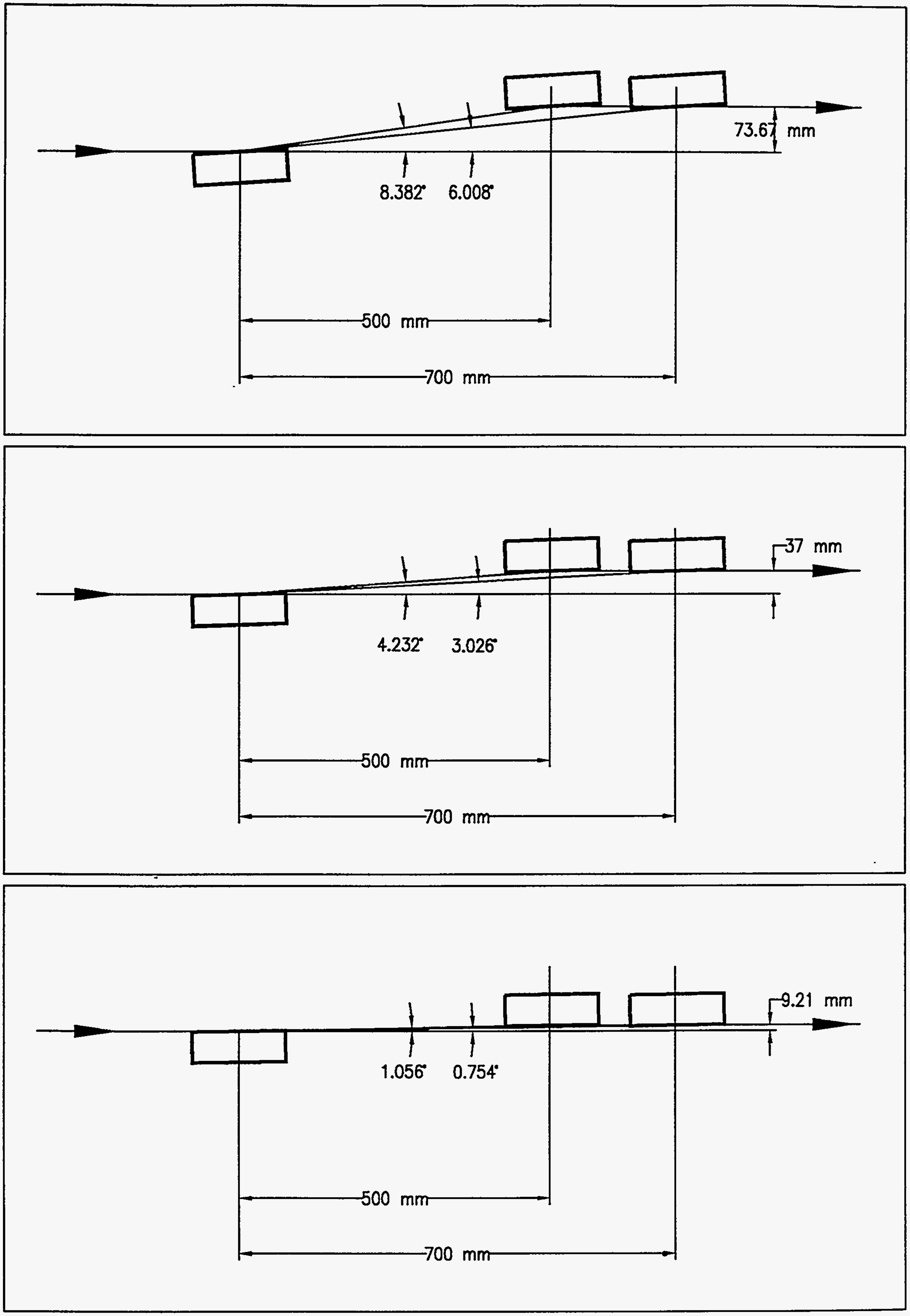
8.382°
6.008°
73.67 mm
500 mm
700 mm
4.232°
3.026°
37 mm
500 mm
700 mm
1.056°
0.754°
9.21 mm
500 mm
700 mm

Fig. 1

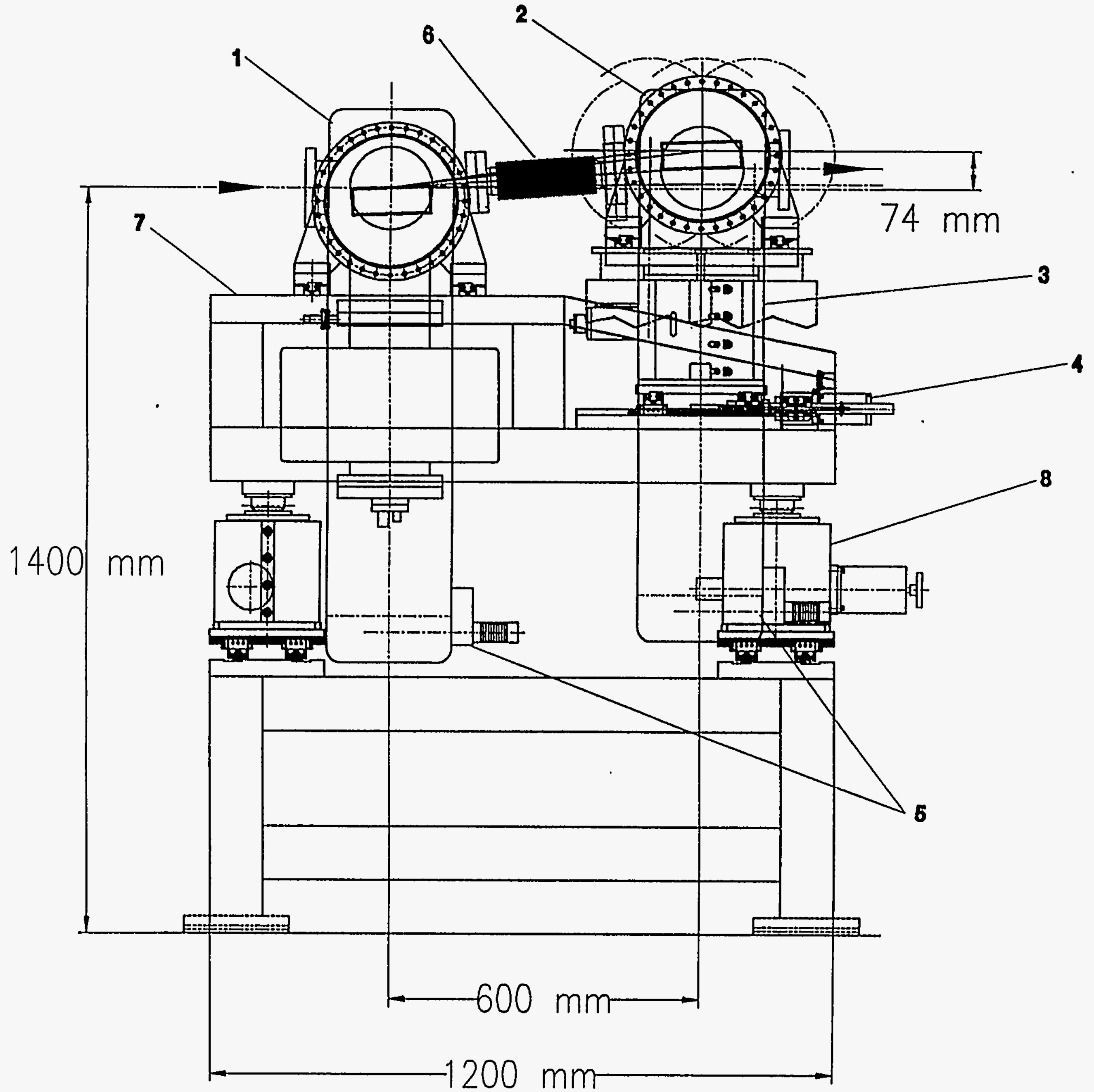

FIGURE 2

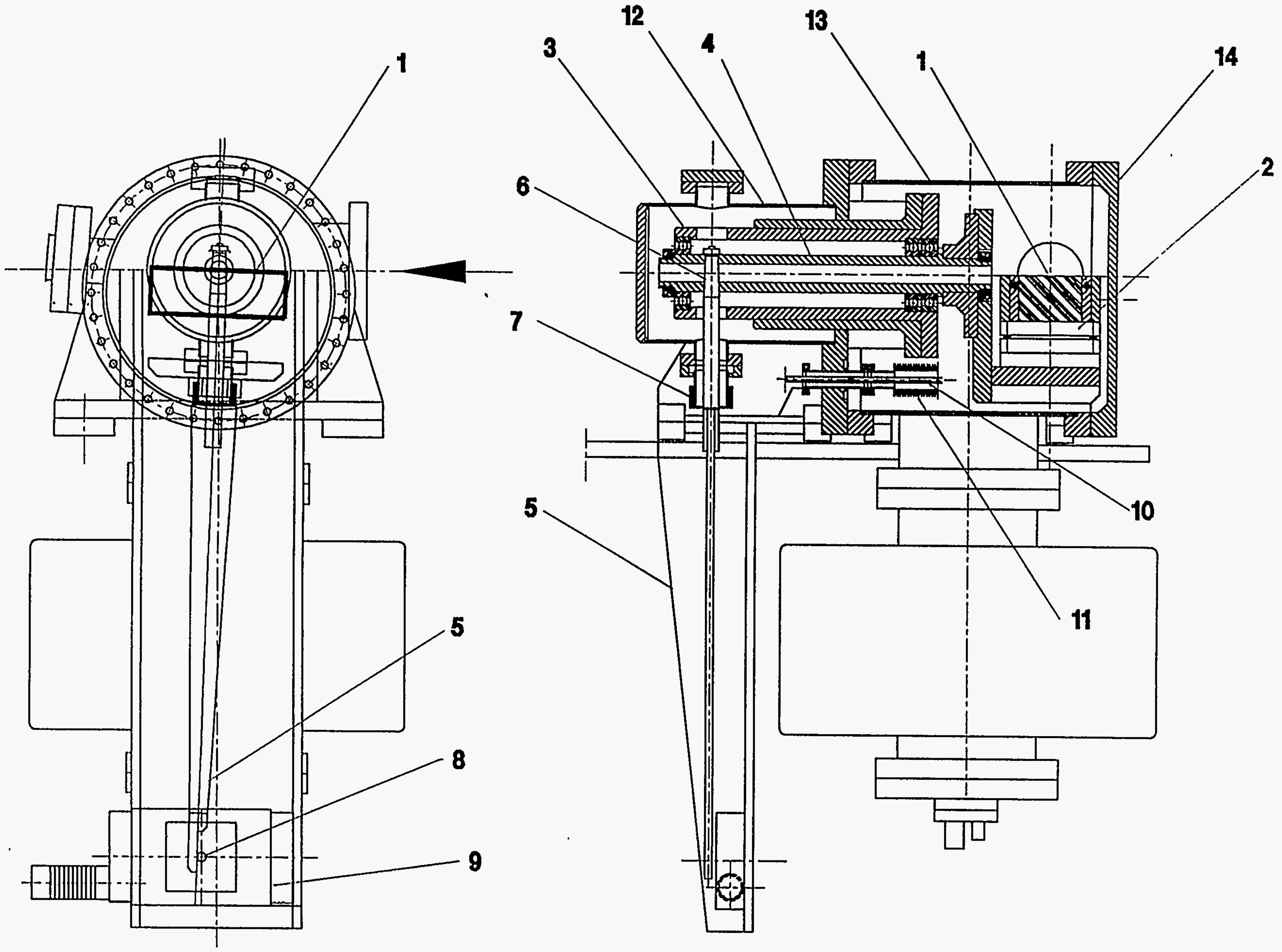

FIGURE 3

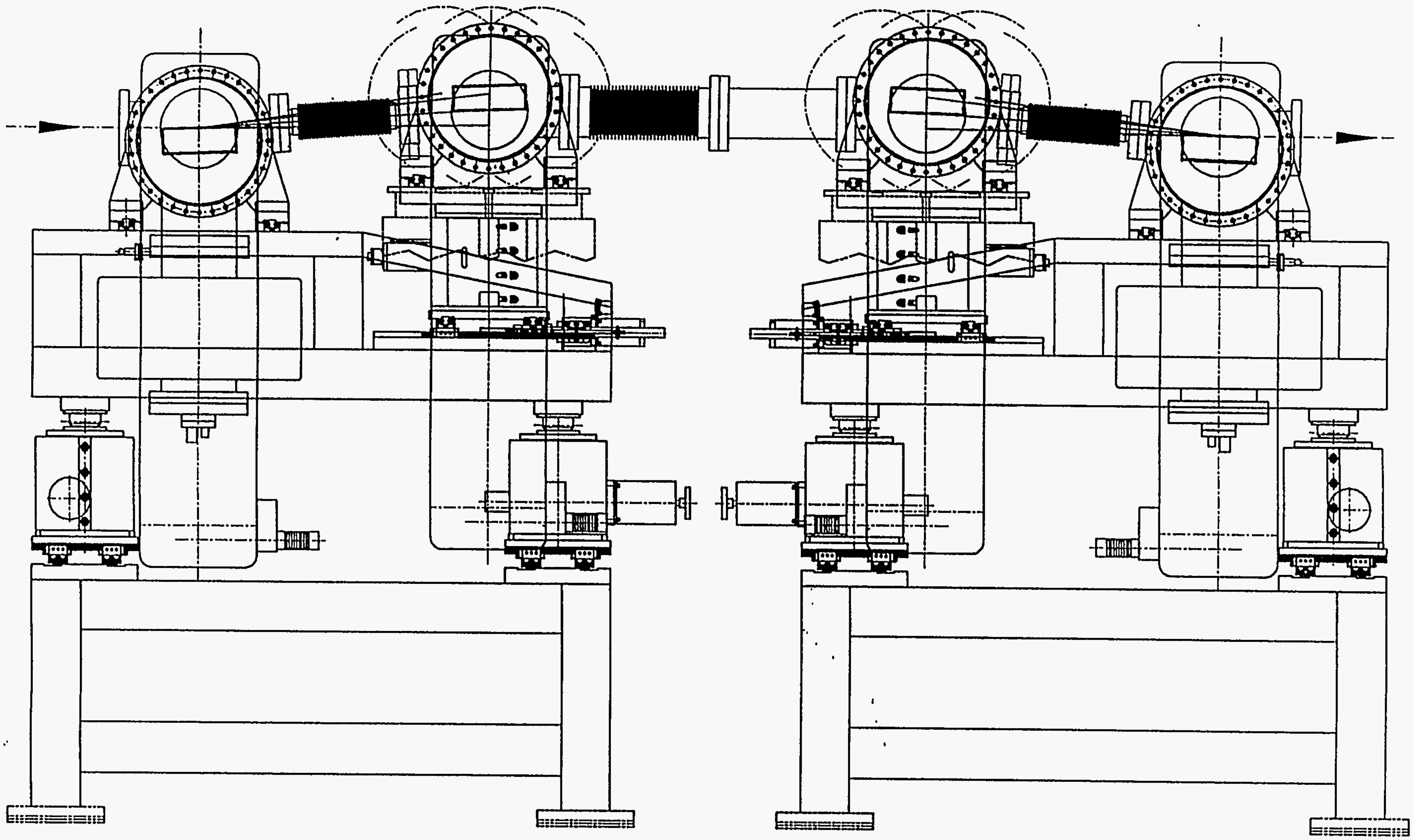

FIGURE 4