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Virtual Sine Arm Kinematic Mount System

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ABSTRACT

A novel kinematic mount system for a vertical focusing mirror of the soft x-ray spectroscopy beamline at the Advanced Photon Source is described. The system contains three points in a horizontal plane. Each point consists of two horizontal linear precision stages, a spherical ball bearing, and a vertical precision stage. The horizontal linear stages are aligned orthogonally and are conjoined by a spherical ball bearing, supported by the vertical linear stage at each point. The position of each confined horizontal stage is controlled by a motorized micrometer head by spring-loading the flat tip of the micrometer head onto a tooling ball fixing on the carriage of the stage. A virtual sine arm is formed by tilting the upstream horizontal stage down and the two downstream horizontal stages up by a small angle. The fine pitch motion is achieved by adjusting the upstream stage. This supporting structure is extremely steady due to a relatively large span across the supporting points and yields extremely high resolution on the pitch motion. With a one degree tilt and a microstepping motor, we achieved a 0.4 nanoradian resolution on the mirror pitch motion.

Keywords: kinematic mount, sine arm, x-ray mirror, synchrotron radiation.

1. INTRODUCTION

The soft x-ray spectroscopy beamline at the 7 GeV Advanced Photon Source (APS) covers the photon energy from 0.5 to 3 keV[1] and is based on the spherical grating monochromator (SGM) design. In order to preserve the source polarization, grazing-incidence optics are used. Due to the inherently large size of the APS high energy storage ring, the beamline length from the center of the undulator to the first experimental end station is 58 meters.

Among the optics used on the beamline, the vertical focusing mirror of the SGM focuses the x-ray beam from the APS soft x-ray undulator onto the entrance slit with a grazing-incidence angle of 1°. The full width half maximum of the beam at the entrance slit (located 4.5 meters downstream from the mirror) is about 35 μm. The opening of the slit varies continuously from 100 to 5 μm, which defines the specifications for the mirror pitch adjustment resolution and its mechanical and thermal stability. Also, the mirror has two reflecting surfaces: a rhodium coating and the bare silicon substrate to suppress the high-order harmonic radiation from the undulator before reaching the grating. The mirror manipulation system must be capable of horizontal translation while keeping the mirror surface height and pitch virtually unchanged.

The absorbed power in the mirror is less than 20 watts. However, the grazing-incidence angle gives rise to a tighter specification for the mirror slope figure. In order to minimize the mirror slope figure under the beam heat load, the mirror is cooled by a pair of water-cooled copper pads clamped onto the sides of the mirror near the mirror surface. However, the grazing-incidence angle means that the beam direction is insensitive to the mirror roll motion. Therefore, the mirror roll motion is not required during normal operation making it possible to fix the mirror and its cooling system within a vacuum vessel. The vacuum vessel can be decoupled from the rest of the beamline through a pair of flexible vacuum couplings, and the mirror roll angle can be surveyed into position before the couplings are connected. In this way, the design can be simplified by keeping the manipulation system outside of the vacuum. Nevertheless, the constraints imposed upon the design of the vertical focusing mirror supporting and manipulation system were extremely taut, particularly for the mirror fine pitch adjustment. The supporting and manipulation system described in this paper solves the problem by using a novel virtual sine arm kinematic mount system.

2. ENGINEERING DESIGN

The kinematic mount system is a well-constrained system with six degrees of confined freedom. Our kinematic mount system is formed by a three-point suspension. Each of the points consists two horizontal precision linear motion stages,[2] a spherical ball bearing, and a vertical precision linear motion stage.[3] A schematic top view layout of the system (shown in

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fig. 1) exhibits the confined horizontal motions (motion #1, motion #2, and motion #3). All three vertical motions are confined (motion #4, motion #5, and motion #6). At each point, it is designed in such a way that the horizontal linear stages are aligned orthogonally and are conjoined by a spherical ball bearing, supported by the vertical linear stage as shown in fig. 2. Placing the spherical ball bearing in between the horizontal linear stages makes it possible to have the driving system of the stages, stepping motors and precision micrometer heads[4] in this case, fixed onto the stationary bases. The position of each confined horizontal stage is controlled by a motorized micrometer head. The micrometer head has a built-in encoder. The flat tip of the micrometer head is spring-loaded onto a tooling ball that is fixed on the carriage of the stage as shown in the insert of fig. 2.

The vertical linear stages can change the mirror vertical position, as well as the pitch and roll angles, while the cross horizontal linear stages can horizontally translate the mirror orthogonally to the beam to have different coatings of the mirror surface exposed to the beam plus can adjust the mirror yaw angle. In practice, due to the vacuum flexible couplings on both sides of the vacuum vessel, the mirror roll angle is surveyed into position and no motion is allowed during normal operation. This will not affect the mirror performance due to the mirror grazing incidence angle as indicated in section 1.

A fine pitch angle motion with 10 nanoradian resolution was required for the system. It is important that the pitch motion be independent of all other motions. The use of a sine arm to accomplish fine angle motion has been known for a long time. It provides reliable and accurate rotational adjustment and has been widely used in the synchrotron community. A sine arm is essentially a transformation of linear motion to angular motion. To increase the resolution of a sine arm system, one has either to increase the length of the sine arm or increase the resolution of the linear motion. However, a real sine arm system is subject to the instability of a long arm if nanoradian scale resolution is required, particularly for a heavy system, such as a metal vacuum vessel loaded with a 120 liter-per-second ion pump in this case. In order to solve the problem, we further designed our kinematic mount system by tilting the upstream horizontal stage down and the two downstream horizontal stages up by an angle a as shown in fig. 3. Along with the upstream horizontal stage (motion #1), this formed a virtual sine arm system. The length of the arm is $L = A/2\mathrm{Sin}a$, where A is the span across the upstream and downstream points. The fine pitch motion is achieved by adjusting linear motion #1. It is very important to have the upstream and downstream horizontal linear stages tilt at the same angle with the opposite direction if the optic is centered between the supporting points. This guarantees that the height of the mirror is essentially identical during the pitch motion, and the footprint of the beam is therefore centered on the optic surface during adjustment.

In practice, we used $a \cong 0.8^{\circ}$ and $A = 0.84$ meter, yielding a virtual sine arm L of approximately 29 meters. With a microstepping motor of 50,000 steps per revolution and a 40-pitch-per-inch micrometer head, we have been able to achieve a 0.4 nanoradian resolution of the pitch motion. We used an autocollimator, an interferometer, and a tilt sensor to test the system. The results show that this supporting structure is extremely steady. Mechanically, the relatively large span across the supporting points yields a lowest frequency of 20 Hz. Thermally, the equal height of all supporting points minimizes the angle change due to the change of environmental temperature. The pitch angle change is within 500 nanoradian noise level of the testing apparatus during a period of 4 hours. The test verifies the system fine pitch motion resolution of 0.4 nanoradian.

3. SUMMARY

We have described the design of a novel virtual sine arm kinematic mount system for the vertical focusing mirror of the soft x-ray spectroscopy beamline at the APS. The system is of 0.4 nanoradian angle motion resolution. It has extremely high mechanical and thermal stability and load capacity. The system can be used for supporting and manipulation of different kind of objects that require extremely high angle resolution and stability, such as, among others, mirrors, gratings, and crystal assemblies.

ACKNOWLEDGMENTS

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REFERENCES

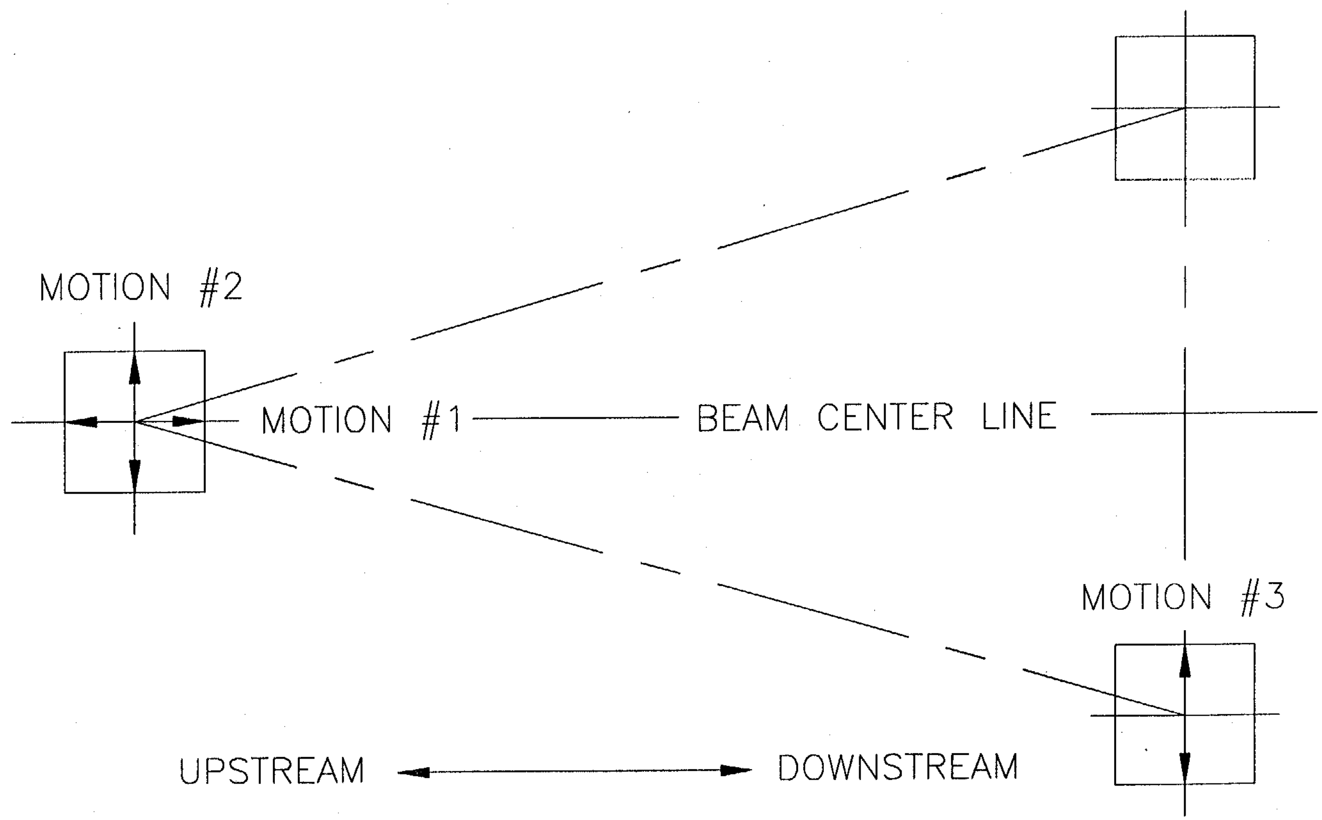
1. K.J. Randall, E. Gluskin, and Z. Xu, "Spectroscopy beamline at the Advanced Photon Source for the photon energy region from 0.5 to 3 keV," Rev. Sci. Instrum. **66**, 4081 (1995)
2. Schneeberger Type NH Frictionless Tables. They are made of steel and are comprised of square upper and lower sections with type R linear bearings and type AC roller cages.
3. APS low profile, high load vertical rolling positioning stage (U.S. patent number 5,526,903).
4. Mitutoyo Non-Rotating Spindle Digimatic Micrometer Head 164-172.

FIGURE CAPTIONS

Fig. 1. Schematic top view layout of the kinematic mount system. Motions #1, #2, and #3 are confined motions.

Fig. 2. Side view of the up-stream point of the kinematic mount system. (1) horizontal linear stage (motion #1), (2) spherical bearing, (3) horizontal linear stage (motion #2), (4) vertical linear stage (motion #4), (5) micrometer head, (6) flexible coupling, (7) stepping motor, (8) tooling ball, (9) micrometer head spindle clamp, (10) mircrometer head clamp, (11) mircometer head spindle, (12) ball joint rod end, (13) belleville washers.

Fig. 3. Side view of the kinematic mount system. (4) vertical linear stages, (14) supporting table, (15) ion pump, (16) vacuum flexible couplings, (17) vacuum vessel. a is the angle of the horizontal linear stages tilted from the level position.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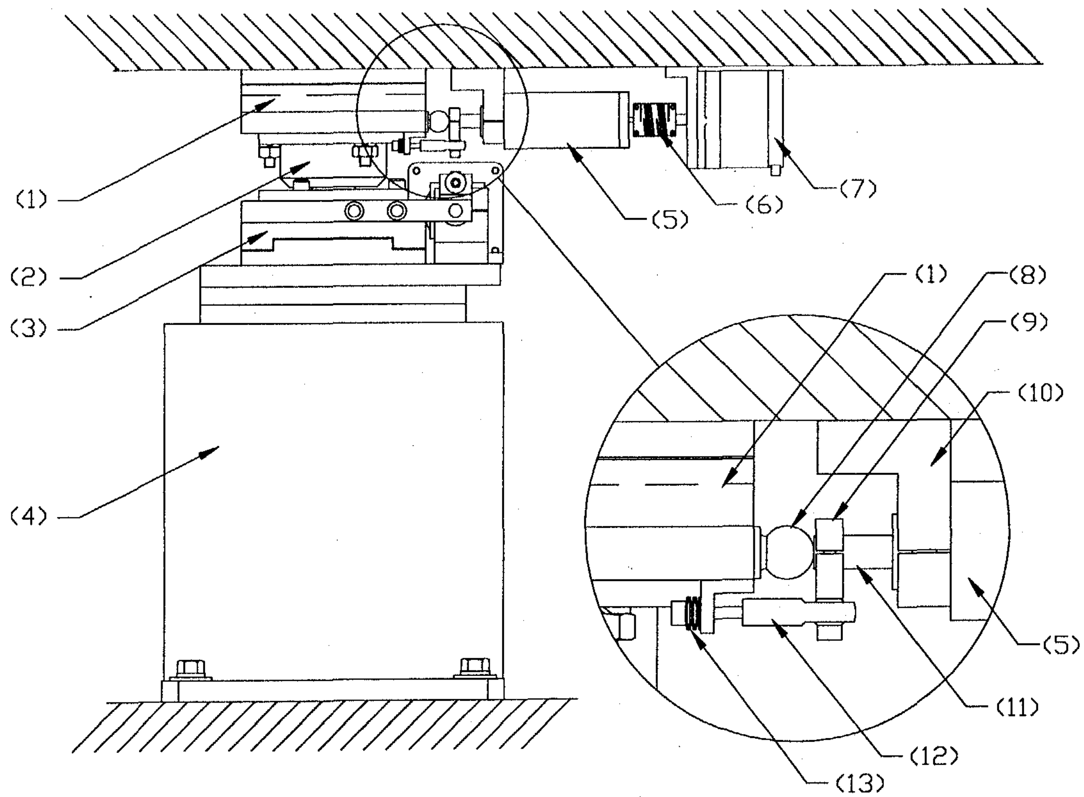
BEAM CENTER LINE
MOTION #3
UPSTREAM
DOWNSTREAM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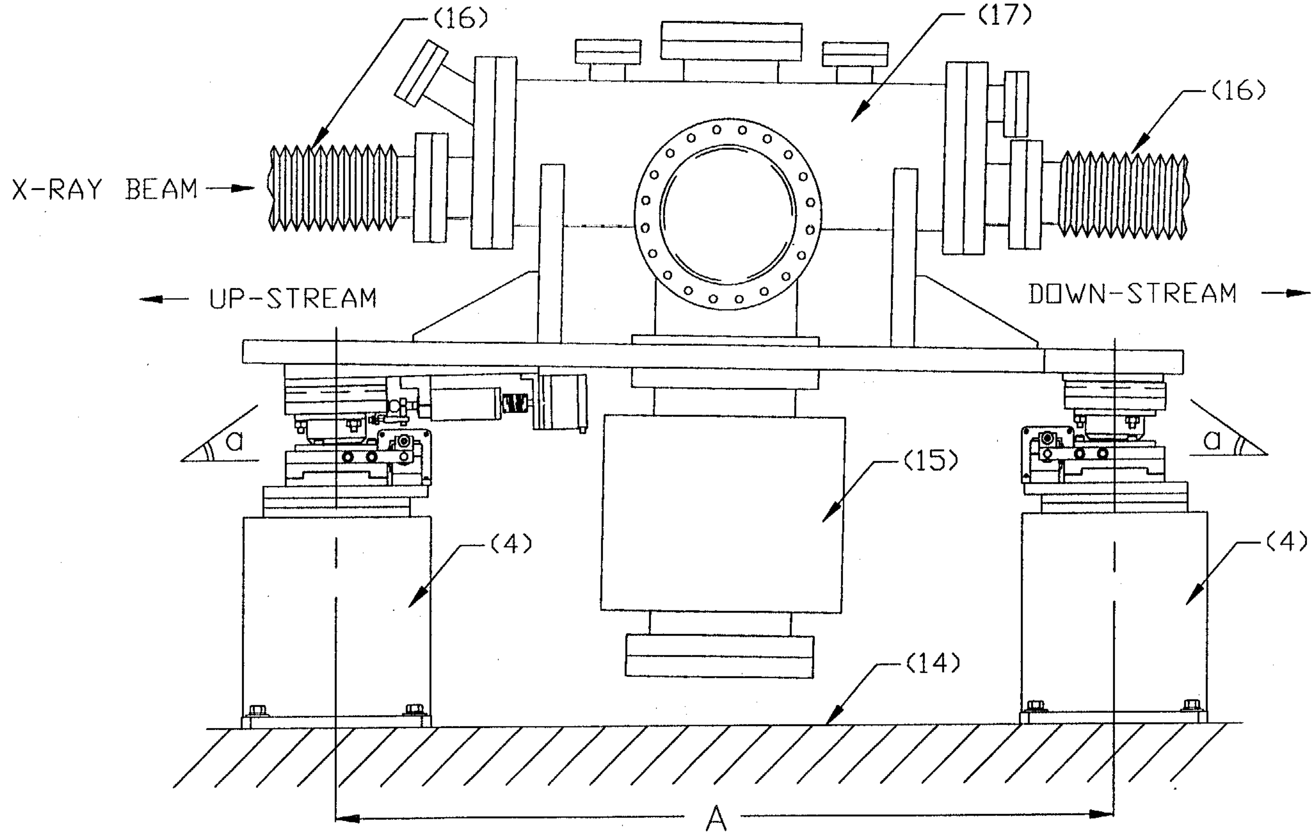

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