DESIGN OF A ROBOT-BASED DETECTOR MANIPULATOR FOR A HARD X-RAY NANOPROBE INSTRUMENT SYSTEM

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INSTRUCTIONS

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) is a national user facility for synchrotron radiation research. The high-brilliance x-ray beams of this third-generation synchrotron radiation source provide powerful tools for forefront basic and applied research in many fields of scientific research. A hard x-ray nanoprobe beamline is being developed at the APS. The beamline will house a hard x-ray nanoprobe instrument, one of the centerpieces of the characterization facilities of the Center for Nanoscale Materials (CNM) being constructed at ANL. The instrument will combine a scanning probe mode with a full-field transmission mode. It uses: x-ray fluorescence for trace-element mapping and spectroscopy; x-ray diffraction to obtain local structural information such as crystallographic phase and strain texture; and x-ray transmission in phase and absorption to image internal structures of complex devices [1]. The combination of diffraction, fluorescence, and phase contrast in a single tool will provide unique characterization capabilities for nanoscience.

This new probe will cover an energy range of 3-30 keV. The working distance between the nanofocusing optics and the sample will typically be in the range of 10-30 mm. With advances in the fabrication of zone-plate optics and an optimized beamline design, we expect to be able to achieve 30-nm resolution at the nanoprobe. The system is designed to accommodate x-ray optics with a resolution limit of 10 nm; therefore, it requires staging of x-ray optics and specimens with a mechanical repeatability of better than 5 nm.

This paper presents the design of three robot-based detector manipulators for microdiffraction applications with the hard x-ray nanoprobe instrument system.

TABLE 1. Design specifications for the Cartesian/articulate hybrid detector robot-arm

	Horizontal 2-D linear stages	**Vertical 2-D linear robot arms**
Overall Dimension (mm)	1500 (X) x 650 (Y) x 123 (Z)	604 (X) x 878 (Y) x 1217 (Z)
Normal Load Capacity (kg)	500	12
Stage type	Stepping motor with planetary gearhead	Servo motor
Encoder type	Linear encoder	Linear encoder
Travel range (mm)	1050 (X) x 200 (Y)	600 (Y) x 800 (Z)
Min. incremental motion (micron)	0.02	0.5
Unidirectional repeatability (micron)	+/- 5	+/- 10
Max. speed (mm/sec)	50	100
	Base rotary stage	**Detector bay rotary stage**
Overall Dimension (mm)	350 (X) x 336 (Y) x 118 (Z)	49 (X) x 166 (Y) x 108 (Z)
Load Capacity (kg)	360	10
Stage type	Stepping motor	Stepping motor
Travel range (degree)	90	65
Min. incremental motion (degree)	0.001	0.002
Unidirectional repeatability (degree)	+/- 0.001	+/- 0.001
Max. speed (degree/sec)	10	10

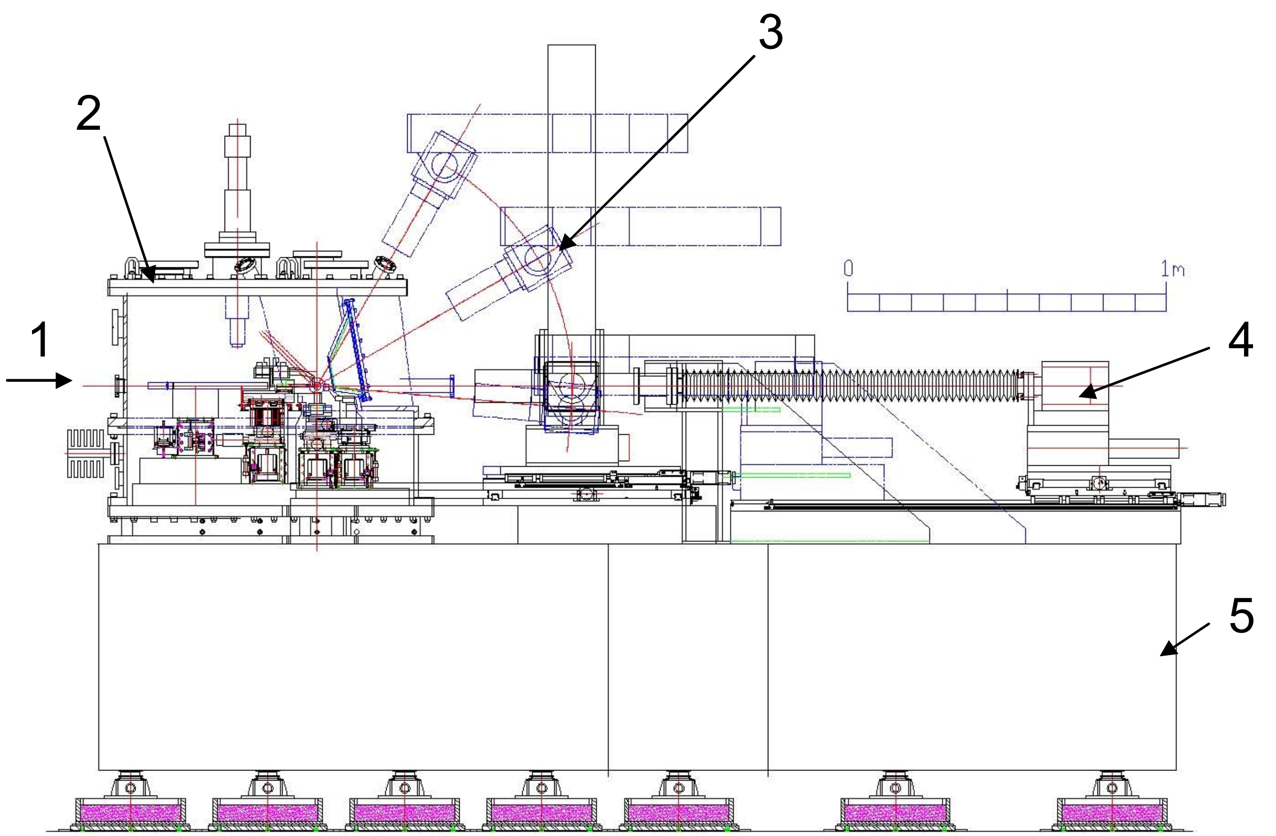

FIGURE 1. Side view of the hard x-ray nanoprobe instrument. (1) Incident x-ray beam; (2) Instrument chamber; (3) Robot-based manipulator for diffraction detector; (4) Transmission imaging detector; (5) Granite base.

GENERAL LAYOUT OF THE NANOPROBE INSTRUMENT

The nanoprobe instrument will combine a scanning probe mode with a transmission mode. The scanning probe mode will provide fluorescence spectroscopy and microdiffraction applications. The full-field transmission mode will allow 2-D imaging and tomography. Diffractive optics, such as zone plates, will be used for focusing and imaging in this instrument. High-resolution positioning and scanning is performed using the stage group for zone plate optics in a high-vacuum-compatible instrument chamber. In the same vacuum vessel, a specimen stage group is used for coarse positioning only [2].

As show in Fig. 1, the optomechanical structure for the nanoprobe presented here consists of the following major component groups: a nanoprobe instrument chamber (2), a granite base (5) to minimize the vibrations excited from the ground, a customized industrial robot-arm-based detector manipulator (3) for microdiffraction applications, and a translation stage system for the transmission imaging detector (4).

ROBOT-BASED DETECTOR MANIPULATOR FOR MICRODIFFRACTION

Limited by the geometric configuration of the nanoprobe instrument, it is not feasible to use a traditional goniometer to achieve the motions needed for a microdiffraction detector. Robot-based detector manipulators have been developed for a variety of microdiffraction detectors weighing from less than 1.5 kg up to 100 kg in three configurations. To fully support the diffraction detector when it is rotated around the specimen position, the nanoprobe instrument table has been widened significantly on the outboard side to optimize the support of the diffraction detector during rotation around the Y axis.

Detector manipulator with 12-kg load capacity

Figure 2 shows a custom-built Cartesian/articulate hybrid robot arm for detector manipulation with 12-kg load capacity and +/- 10-micron positioning repeatability. It is a combination of four linear stages and two rotary stages. A THK™ custom-built 2-D horizontal stage (2) and a Huber™ 420 single-circle goniometer (3) are mounted on a granite base (1) to perform a circular motion centered on the sample position in the horizontal plane [3,4]. A pair of IAI™ 2-D vertical Cartesian robot arms (4, 5) is mounted on the top of the Huber™ 420 goniometer to provide a circular motion centered on the sample position in a vertical plane [5]. Doubled linear robot arms are used to improve the system stiffness and repeatability. A special mechanical linkage and control scheme will be developed to ensure the synchronization between the doubled arms. The detector (7) is mounted in a U-shaped detector bay driven by a Huber™ 408 single-circle goniometer (6). Table 1 summarizes the technical specifications of the stages used in the hybrid robot-arm system.

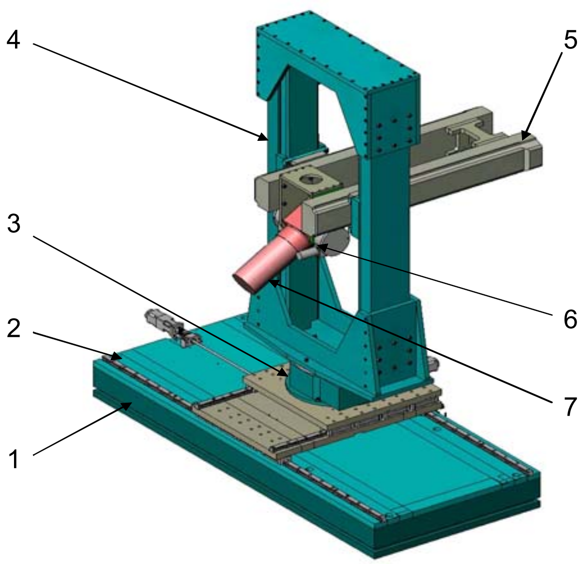

FIGURE 2. A 3-D model of the Cartesian/articulate hybrid robot-arm with 12-kg load capacity.

Detector manipulator with 1.5-kg load capacity

For detectors with a mass less than 1.5 kg, an industrial articulate robot arm could be applied to perform the circular motion in the vertical plane as shown in Fig. 3. In this configuration, a Mitsubishi™ RV-1A articulate robot arm is mounted on the top of the THK™ 2-D horizontal stage to obtain a horizontal circular motion larger than the reachable range of the RV-1A robot arm [6]. A +/- 20-micron positioning repeatability is expected for this detector manipulator system.

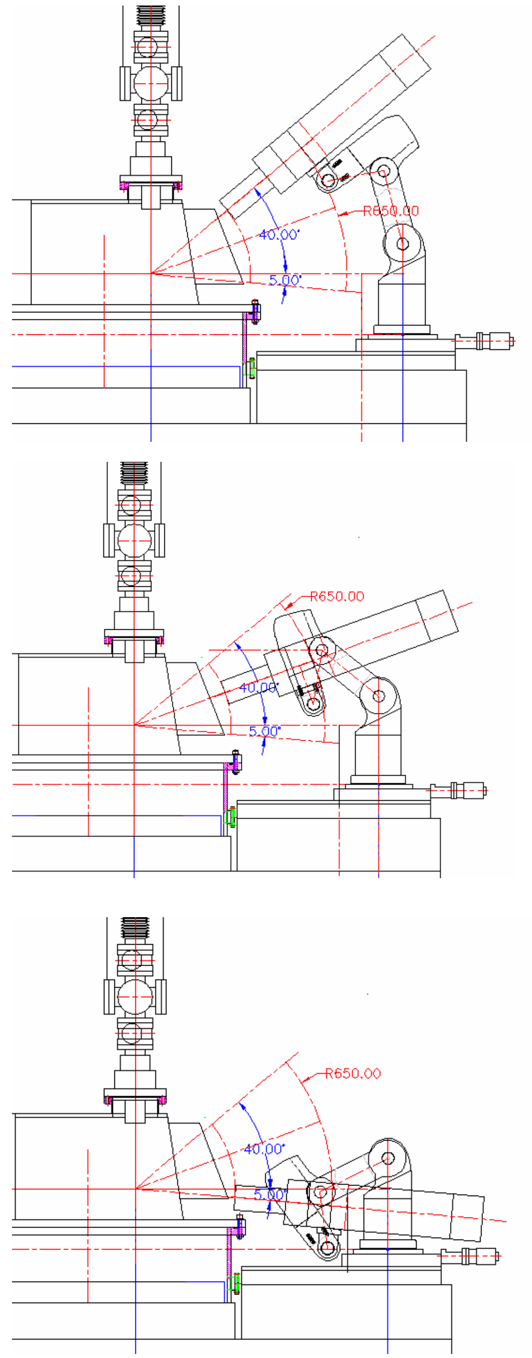

FIGURE 3. Vertical circular motion simulation with an industrial robot-arm for a 1.5-kg detector.

Detector manipulator with 100-kg load capacity

In certain microdiffraction applications, large x-ray detectors, such as the MAR^{TM}345 imaging plate or the MAR^{TM}165 CCD detector from Mar Research GmbH, will be used in the nanoprobe microdiffraction system [7]. These detectors may weigh 20 – 100 kg. Since they have large vertical acceptance, the detector manipulator only needs to provide a horizontal circular motion, as show in Fig. 4.

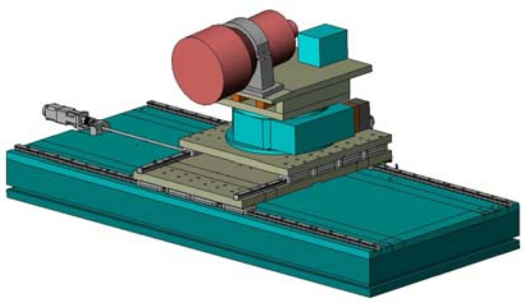

FIGURE 4. A 3-D model of the detector manipulator with 100-kg load capacity.

MASS CENTER DYNAMIC BALANCE FOR THE DETECTOR MANIPULATOR

To optimize the nanoprobe instrument positioning stability, several heavy metal balance blocks are applied on the nanoproe supporting system. They are mounted on motorized stages under the granite table. Synchronized with the detector manipulator motion, the balancing blocks keep the nanoprobe mass center position stable.

SUMMARY

This paper presents the design of a robot-based detector manipulator for microdiffraction applications with the hard x-ray nanoprobe instrument system at the APS. Applications for detectors weighing from 1.5 kg to 100 kg were discussed in three configurations.

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