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Design of a Miniature Hydraulic Compression Load Frame for Microdiffraction Tests at the Advanced Photon Source

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Abstract. In support of the x-ray synchrotron radiation microdiffraction project of Los Alamos National Laboratory at the Advanced Photon Source (APS), we have designed and fabricated a miniature hydraulic compression load frame with 20000 N load capacity for metal specimen tests at the APS. The compact design allows the load frame to sit on the center of a 6-circle goniometer with six degrees of freedom and maximum solid angle accessibility for the incoming x-ray beam and diffraction beam detectors. A set of compact precision stages with submicron resolution has been designed for the load frame positioning to compensate the sample internal elastic and/or plastic deformation during the loading process. The system design, specifications, and test results are presented.

INTRODUCTION

In support of the x-ray synchrotron radiation microdiffraction project of Los Alamos National Laboratory at the Advanced Photon Source (APS)[1], we designed and fabricated a miniature compression load frame for metal specimen tests at an APS synchrotron radiation beamline.

It is a challenge to design a precision variable load frame with 20000 N maximum compression load capacity in a limited space. The design task is more difficult because the load frame needs to be set on the center of a 6-circle goniometer with six degrees of freedom and maximum solid angle accessibility for the incoming x-ray beam and diffraction beam detectors. For the microdiffraction experiment, it is critical to keep the microbeam focused on the same crystal grain. A set of compact precision stages with submicron resolution is necessary for the load frame positioning to compensate the sample internal elastic and/or plastic deformation during the loading process.

Here we report our progress towards the development of the miniature hydraulic compression load frame and its control system. Preliminary test results with this load frame are also discussed.

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Figure 1. Schematic diagram for the load frame system.

SYSTEM CONFIGURATION

The structure size plays a significant part in the design of a load frame for micro-diffraction applications with synchrotron radiation. The load frame has to be compact enough, so that the whole structure of the load frame, plus the x-y-z motorized stages, can be mounted on the top of a phi-circle in a Huber [2] 6-circle goniometer. Restricting the loads on the phi-circle goniometer and the x-y-z stages places constraints on the total weight of the load frame. These are the major reasons that we chose a high-pressure hydraulic cylinder as a loading device for this load frame.

The miniature hydraulic load frame consists of three functional parts: a load-frame mechanical structure, a hydraulic control system, and a set of compact x-y-z motorized stages. Fig. 1 shows a diagram for the load-frame system.

LOAD-FRAME STRUCTURE DESIGN

The load frame has a duo-post mechanical structure to maximize the beam accessibility. Fig. 2 shows a section view of the structure. Two posts (1), made from high-strength stainless steel, link the base plate (2) and top plate (3) together and form a rigid frame. A commercial high-pressure hydraulic cylinder (4) is mounted on the top plate. An Omega [3] load-cell (5) measures the compressive force applied to the sample (6) through the sample holders (7). A pair of spherical washers (8) perform a loading interface between the hydraulic cylinder and the sample holder, and compensates any possible misalignment in the loading structure. Fig. 3 is a photograph of the miniature load frame assembled on a Huber 6-circle goniometer. Table I shows the parameters of the load frame structure.

TABLE 1. Dimensional Parameters of the Load Frame Structure	
Maximum Load	20000 N
Vertical Access Angle	+ 45° and - 27°
Horizontal Access Angle	+/- 77.5°
Base-to-Sample center distance	35 - 44 mm
Weight	4.97 kg
Overall Dimension	70 mm (L) x 121 mm (W) x 158 mm (H)

Figure 2. Section view of the load frame structure

Figure 3. Photograph of the miniature load frame assembled on a Huber 6-circle goniometer

HYDRAULIC SYSTEM WITH CLOSED-LOOP CONTROL

The hydraulic cylinder mounted on the top plate has a 25.4-mm inner diameter and is rated for 69-MPa (10-kpsi) maximum hydraulic pressure use. To optimize the control performance, we have designed two independent hydraulic pumping systems to cover the 250 N to 20000 N loading range. In the loading range of 250 N to 10000 N, a DC-servo hydraulic pump provides a maximum of 20-MPa base pressure to a precision servo-valve. The servo-valve then controls the supply pressure on the cylinder. Fig. 4 shows a typical result of the load frame stability test in this operating mode.

Figure 4. Result of the load frame stability test in servo valve operating mode.

In the loading range of 9000 N to 20000 N, a special digitally controlled high-pressure pumping system has been developed. This novel pumping system consists of a high-pressure piston pump and a digitally controlled pulsed AC driver. With this new design, we are able to drive the piston pump stroke by stroke, so that we can operate the piston pump like a "stepping pump." Fig. 5 shows a series of the single-stroke pumping pulse in the range near 20000 N load. In this operating mode, the servo-valve is acting as a safety valve to prevent system overloading. The pump is controlled in a closed-loop feedback with load cell input. The digitally controlled pumping system provides better stability performance and energy efficiency in this loading range. Fig. 6 shows a stability test result of this pumping system with closed-loop feedback control.

Figure 5. A series of single-stroke pumping pulse in the range of near 20000 N load.

COMPACT X-Y-Z STAGE WITH SUBMICRON RESOLUTION

A set of compact x-y-z stages is very important to the microdiffraction experiment. These stages were conceptualized at the APS, custom built by Kohzu-Seiki Co., Japan [4], and tested at the APS. They are designed to have 10-kg load capacity with sub-

micron vertical motion resolution. Table 2 shows the APS design specifications for the compact stages.

TABLE 2. APS Design Specification for the Compact x-y-z Stages	
Vertical Load Capacity	10 kg
Vertical Travel Range	5 mm
Vertical Motion Resolution	0.25 μm
Vertical Motion Repeatability	2 μm (open-loop)
Horizontal Travel Range	5 mm
Horizontal Motion Resolution	1 μm
Horizontal Motion Repeatability	2 μm (open-loop)
Weight	4.1 kg
Overall Dimension (without motors)	70 mm (L) x 70 mm (W) x 66 mm (H)

Figure 6. Stability test result of this pumping system with closed-loop feedback control.

SUMMARY

We have designed and fabricated a miniature hydraulic compression load frame with 20000 N load capacity for metal specimen tests at the APS. A novel digitally controlled pumping system demonstrated a good loading stability under high pressure. A diffraction experiment using this load frame has been started at the APS synchrotron radiation beamline and at a test station with a rotary-anode x-ray source.

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