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THE DESIGN OF HIGH STABILITY DOUBLE CRYSTAL MONOCHROMATOR FOR HALF

Zhanglang Xu, Jie Chen, Yang Peng, Xuewei Du, Qiuping Wang, National Synchrotron Radiation Laboratory (NSRL), University of Science and Technology of China (USTC), Hefei 230026, China

Abstract

The monochromator is known to be one of the most critical optical elements of a synchrotron beamline, since it directly affects the beam quality with respect to energy and position. Naturally, the new 4th generation machines, with emittances in the range of order of 100 pm rad, require even higher stability performances. A high stability DCM (Double Crystal Monochromator) is under development at the HALF, the new 4th generation synchrotron. In order to achieve high stability of tens of nano radians, as well as to prevent unpredicted mounting and clamping distortions, simulation are proposed for crystal angular vibration and thermal management. This paper gives an overview of the DCM prototype project including specifications, Mechanical design, heat load management and stability consideration.

INTRODUCTION

In the recent years it has become clear to the Diffraction Limit Storage Rings (DLSR) that the stability performance of DCMs would turn out to be one of the main bottlenecks in the overall performance of many X-rays beamlines. With the arrival of the diffraction-limited ring, This is because the instabilities in the DCM affect the position and the size of the virtual source, and, consequently, the spot size and the position of the beam at the sample. The angular instability between the two crystals is the most critical one because its effects on the virtual source scales with the lever-arm between the monochromator and the source [1].

Of the ten lines in the HAFL pre-construction, two of them use crystal monochromators. One of them has an energy range of 2-8 keV, and they both have high requirements for stability. In order to ensure that the stability required to meet the target requirements, this paper briefly describes the design of the DCM from the convenience of mechanical structure design, thermal stability analysis (1st crystal slope and temperature distribution of the core module) and vibration analysis. Detailed finite element analysis ensures that stability requirements and optical requirements (energy range, resolution and luminous flux) can be met. This prototype is designed to meet basic engineering needs.

SPECIFICATIONS

Depending on the energy, stability and coherence requirements of the beamline, an prototype of a high stability vertical DCM (Double Crystal Monochromator) with angular range between 14 and 81 degrees (equivalent to 2 to 8 keV with Si(111)) has been developed at the National Synchrotron Radiation Laboratory. Table 1 summarizes the main functional specifications of this DCM.

Table 1: Main Specifications for the DCM Prototype

Parameter	Description
type	Vertical DCM
Beam offset	20 mm
Angular range	14° - 81°
Angular resolution	0.5 μrad
Crystal	Si (111): 2 to 8 keV
Crystal Cooling	1st crystal: Indirect LN2
	2nd crystal: Copper straps
Beam size	4×3.3 mm^2
Input power	38.9 W

STRUCTURE DESIGN

The DCM can be divided in the following parts: support, vacuum vessel, rotary system and core (Fig. 1). The DCM is divided into the following parts: support, vacuum chamber, rotation system and core mechanism. The main axis mainly realises the crystal Bragg angle adjustment for energy selection and regulation. The crystal assembly contains the clamping, cooling, and adjustment of the first and second crystals, which directly affects the face shape, stability, and adjustment accuracy of the crystals. The granite support pedestal mainly realises attitude adjustment, provides support, ensures high stability, and at the same time carries out the exchange of crystals to achieve energy expansion. The cooling pipeline mainly provides liquid nitrogen delivery, and the reasonable design can control the vibration problem caused by the fluid. Cavity components mainly contain vacuum chamber, providing various types of vacuum interfaces and monitoring role.

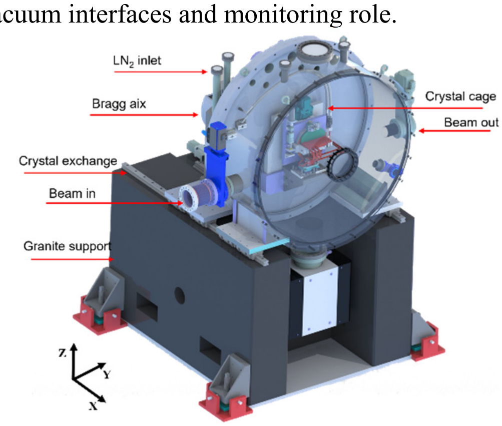

Figure 1: DCM assembly.

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Crystal Cage

All motorized movements of the optics (common horizontal, crystal gap translation, roll2, and pitch2) are integrated to the vacuum vessel. Those mechanics are mounted onto a shaft rigidly fixed to the monochromator support assembly (Fig. 2).

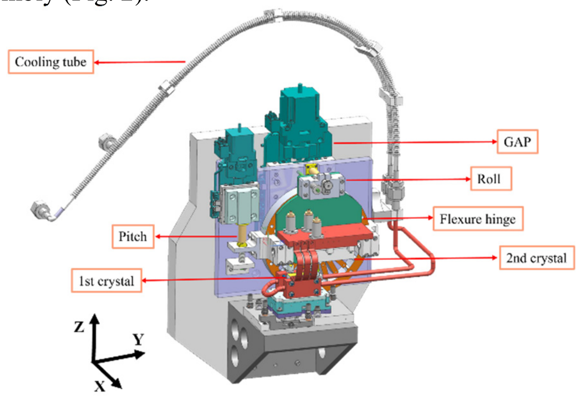

Figure 2: Schematic view of crystal cage.

In order to keep the fixed exit condition whilst changing the energy a gap translation varying the distance between 1st and 2nd crystal is used for the 2nd crystal assembly. The stage design uses two slides based on cross roller bearings driven by a stepper actuated recirculating ball screw assembly. The entire stage is preloaded. During assembly the stage is pre-characterized and optimized to reduce the parasitic movements of the axis down to a minimum in order to achieve high parallelism between 1st and 2nd crystal when scanning the energy (combined motion of Bragg and gap). For high stiffness of the stage the width between the rails as well as their length is enlarged as much as reasonably possible.

For parallelizing the reflecting surfaces of 1st and 2nd crystal a fine adjustment is placed on top of the 2nd optics gap translation. This stage rotates the 2nd crystal surface around an axis parallel to the Bragg axis. A preloaded flexure hinge stage is integrated and actuated with a stepper and piezo via a sine bar. The flexure hinge mechanism for the pitch consists of a number of bars connected to an outer (movable) ring on which the piezo actuates and an inner (fixed) ring by means of flexures on both ends (cartwheel design). All bars are directed to the center of the two rings which is the center of rotation for the pitch, coinciding with the 2nd optics surface. The entire flexure mechanism is made from one single part by means of precision EDM wire erosion. For the pitch stage a combination of stepper motor (gear reduced) driven spindle and piezo is used to allow for coarse adjustment over a wide range and for high-resolution fine adjustment over a limited range facilitating RC scans and the possibility to integrate the pitch stage into a position or intensity feedback system.

The in-vacuum mechanics contains a roll movement parallelizing 1st and 2nd optics around the beam direction. The rotation in roll is realized by means of a cradle with two cross flexure bearings providing a stiff and backlash free mechanical connection. This cradle is actuated by means of a stepper motor (gear reduced) driven spindle and a piezo as well. The actuation mechanism is again a sine bar with an additional reversing element changing the direction of actuation by 90°. This is done to allow for integration of the roll actuator in horizontal. Both piezos for pitch and roll can be operated in closed loop feeding back on the real angular position of the pitch and roll stage monitored by an external encoder. For that the piezo driver is equipped with an encoder input on which the feedback loop of the piezo driver works on. The resolution of the piezo actuator being < 2E-6 of the full stroke is sufficiently large to provide increments of < 0.01 µrad. The used piezo actuators are strongly pre-loaded to provide high stiffness in the actuation mechanism.

Thermal Management

From long term experience as well as the results of the preliminary FEA indicate, a heat load of up to 300 Watts and power densities of ~3 Watts / mm² (projected, worst case consideration) can still be coped with an indirect cooling of the 1st crystal mount assuming sufficiently large cooling surface. In order to provide sufficient cooling for the 1st crystal the substrate is clamped between two copper heat exchangers [2, 3]. Cu tubing is brazed to those heat exchangers to let the LN2 flow through for cooling. The thermal contact is enhanced using a layer of thin Indium foil between Si substrate and the Cu heat exchanger. The FEA, referring to the heat leakage from thermal conduction and radiation, was performed, so that the structure of the cryo-area was optimized. The result shows that under the clamping cooling method, the residual slope error has reduced down to 0.01µrad whose thermal deformation is shown (Fig. 3).

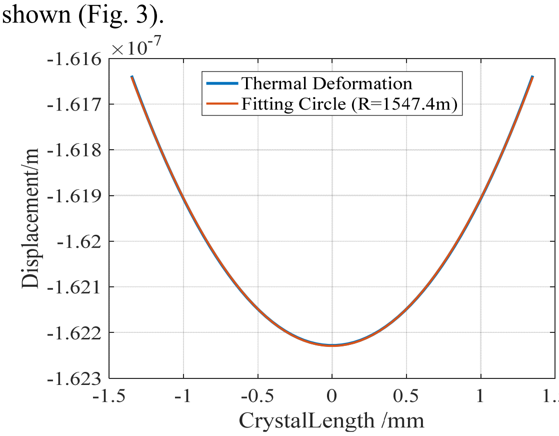

Figure 3: Surface height of 1st crystal.

In order to stabilize the main mechanics also in temperature providing a high thermal stability of the system heaters are integrated to the mechanics. This thermal stabilization avoids long term thermal variations due to (a) drifts introduced by the cryogenically cooled parts mounted close to the mechanics. In particular for the parts and adjustment units positioned very close to the cryogenically cooled crystal assemblies the stabilization system supports the thermal isolation between cooled parts and the mechanics at ambient temperature. (b) changing thermal conditions in the crystal assemblies and their shields due to changing heat loads (varying ID gap, changing the energy)

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(c) temperature fluctuations of the environment. After finite element thermal analysis, The temperature distribution of the core area of the DCM is as Fig. 4. Thermal isolation is achieved between the crystal, the core mechanism and the environment.

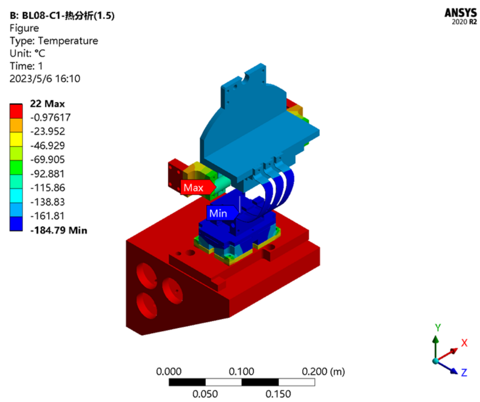

Figure 4: Temperature distribution of the core area.

Vibration Analysis

After vibration simulation analysis, the vibration data from the HALF ground was used as input to obtain the absolute angular vibration. in the pitch direction of the first crystal as 17.8 nrad, the absolute angular vibration of the second crystal as 11.5 nrad, and the relative angular vibration of the crystal as 10.2 nrad (Fig. 5).

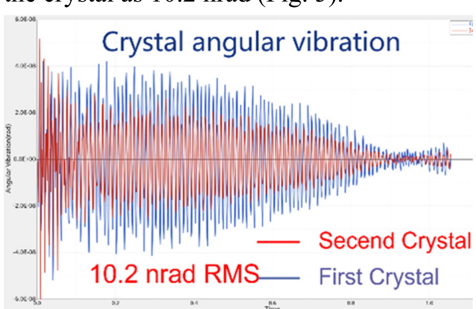

Figure 5: Crystal angular vibration.

CONCLUSIONS

This paper briefly described the DCM design and thermal management for the DCM for HALF. Several analytical and numerical tools have been used in order to design them with specific targets regarding slope errors, thermal response, and crystal vibration.

ACKNOWLEDGEMENT

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