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PERFORMANCE OF A DOUBLE CRYSTAL MONOCHROMATOR PROTOTYPE FOR HEPS UNDER WATER COOLING CONDITION AT A WIGGLER BEAMLINE OF BSRF

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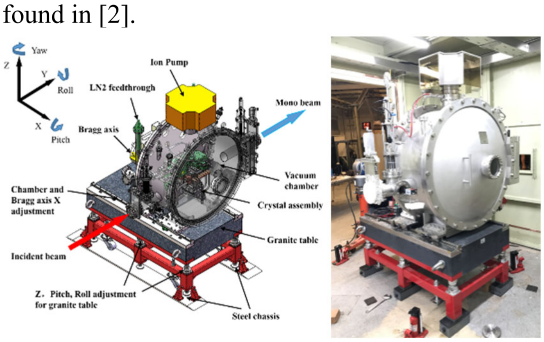
Abstract

The performance of monochromator is crucial to the performance of a beamline, especially for a 4th generation synchrotron light source. To find out the performance of the monochromator prototype built for the HEPS project, it was tested at a wiggler beamline of BSRF with water cooling. The cooling of the crystals was measured by rocking curve broadening at different energy and cooling seems to be not enough due to indium foils. The repeatability in 1 hour was about 0.1 eV. The energy drift in 9 hours after the beam hit the beamline was 0.4 eV at the Cu K edge. The short-term stability was tested with synchrotron beam under various cooling condition, and results between 4.4 nrad to around 400 nrad were observed. In conclusion, some performances are satisfying, but further improvements should be carried out in the future.

INTRODUCTION

HEPS is a new generation light source which employs multi-bend achromat lattices and aims to reach emittance as low as 60 pm•rad with a circumference of about 1360 m [1]. A double crystal monochromator prototype was built for the HEPS project, as shown in Fig 1. It went through a series of offline and online test with LN2 cooling during 2016~2019, some key performances were tested. The prototype has a stability of 40 nrad RMS with a LN2 flow rate of about 4.5 L/min. The LN2 cooling works fine under 800 watts of heat load provided by a heater. Other performances such as mechanical resolution, repeatability, vacuum, motion functions are all up to design requirements. Details can be found in [2].



(a) (b)

Figure 1: DCM design model (a) and prototype (b).

However, it's still not guaranteed that it will really work for demanding experiments such as XAFS. In order to find out its reliability, it was installed in 3W1 of BSRF, a wiggler beamline. It was tested only under water cooling condition, since BSRF does not have dedicated LN2 distribution lines. XAFS experiments requires good repeatability of the energy, and good energy stability. Test methods were also developed for such kinds of requirements.

The following sections will share the test conditions, methods and results.

TEST CONDITIONS

The new 3W1 test beamline layout is shown in Fig. 2. The original 3W1 was dismantled for optics testing. The DCM is 20.8 meters from the source, before the DCM is a collimating mirror, which will reduce the heat load irradiated to the monochromator. By measurement of cooling water temperature rise, the heat load is about 35W. After the DCM is a toroidal mirror at 23 meter. The focal point is 32 meter from the source. The monochromator was cooled by a water chiller made in China, LX series from Coolium Instruments [3], which has a cooling capability of 1000 watts.

Most of the tests and experiments were done under XAFS mode, as shown in Fig. 3. Two Ion Chambers and diamond XBPM were used to measure intensity before and after sample. An ADC [4] were used to take data at high speed in order to measure vibration level.

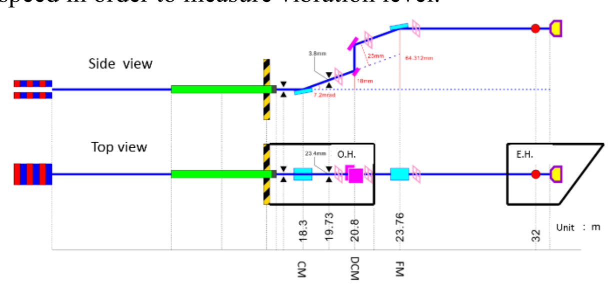


Figure 2: Test beamline layout.

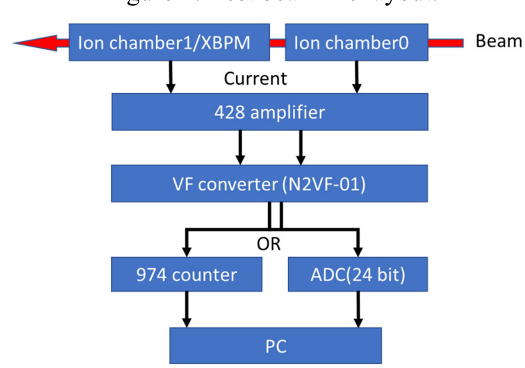


Figure 3: Data acquisition equipment.

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TEST RESULTS

Cooling Performance

The cooling performance was measured by rocking curves. Figure 4 shows that intensity drops when flow rate drops from 4 L/min to 2 L/min. At flow rate of 0.3 L/min the intensity drops further. Also there are shifts of peaks, indicating insufficient cooling of crystals and further thermal deformation has taken place. Figure 5 Compares all results with theory calculation, it shows that FWHM of rocking curve is slightly larger than theory calculation at higher energies, with a flow rate of 4 L/min. At lower energies the difference is not that obvious, but still larger than LN2 cooling. The results may indicate that thermal contact resistance of indium foils is too high for water cooling. A contact interface made of indium-gallium eutectic is better for water cooling.

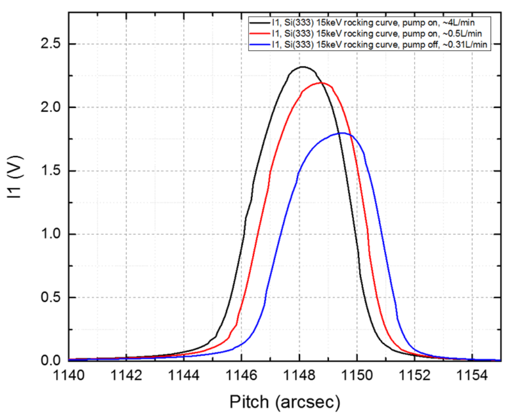

Figure 4: Rocking curves.

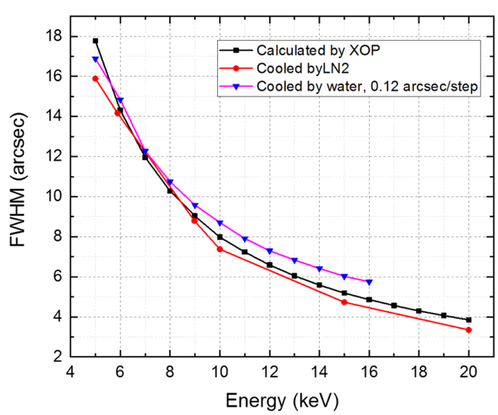

Figure 5: FWHM of rocking curves.

Short-Term Repeatability

The repeatability of a monochromator is very important for XAFS application, good repeatability leads to better data quality. Repeatability is determined by the mechanical repeatability of the Bragg goniometer and thermal deformation, if any. The short-term repeatability was measured by non-stop Cu K edge scans. It is about 0.1 eV for a period of 1 hour.

Long-Term Stability

The long-term energy stability is crucial for XAFS application. The overall repeatability of a long period can be estimated by adding up the short-term repeatability and energy drift. By using 2 ion chambers we can easily get the absorption ratio for a Copper foil under different energy. Fix the energy at one point where the relationship between absorption ratio and energy is known, energy drift can be calculated by measuring the abortion ratio. Test result in Fig. 6 shows that a 0.4eV drift from a "cold state" beamline to 9 hours after beam on, this is mainly due to the thermal deformation of the whole beamline and monochromator. Another reason maybe the surrounding temperature variation during this period, which is about 0.1℃ in the hutch as shown in Fig. 7, could lead to a thermal deformation both in the support of mirror and the monochromator, possibly also the source. At the final stage the drift speed is less than 0.013eV/hour. Another thing to be noticed is that the hutch temperature is passively controlled without any ventilation or air conditioning.

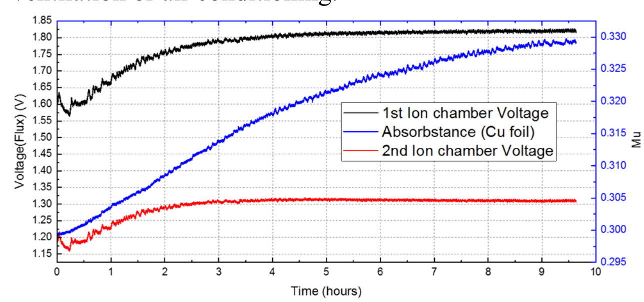

Figure 6: Cu K edge flux and absorption ratio for 9 hours.

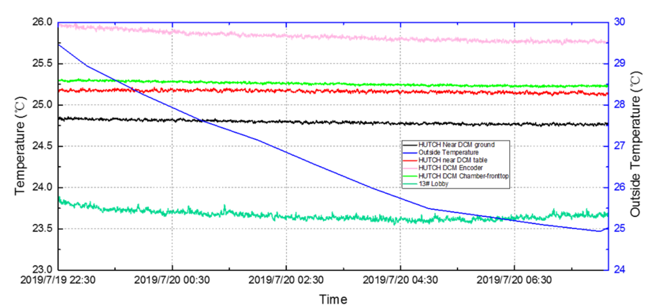

Figure 7: Temperature recordings during long-term stability test.

Short-Term Stability

The short-term stability is crucial to position sensitive experiments, also influencing the intensity and coherence of the beam. To measure the stability, intensity data of ion chamber 0 was acquired by an ADC with a sampling rate of 2kHz, then converted to rocking angle of the second crystal [5, 6]. Figure 8 shows ion chamber readings under different cooling conditions. The black curve stands for intensity cooled by chiller at a flow rate of 4 L/min, in the middle section of the black curve the pump for cooling circuit was turned off, but the refrigerant pump is still on, the intensity fluctuation quickly drops to a much lower level. When the pump was turned on again, the intensity fluctuation resumed to its previous level. The red curve stands for

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intensity cooled by chiller at a flow rate of 0.5 L/min, the intensity fluctuation is much smaller than that of 4 L/min, which agrees well with prediction. the bottom line in blue stands for gravity cooling with a flow rate about 0.31 L/min. The intensity fluctuation can barely be observed, indicating very good stability.

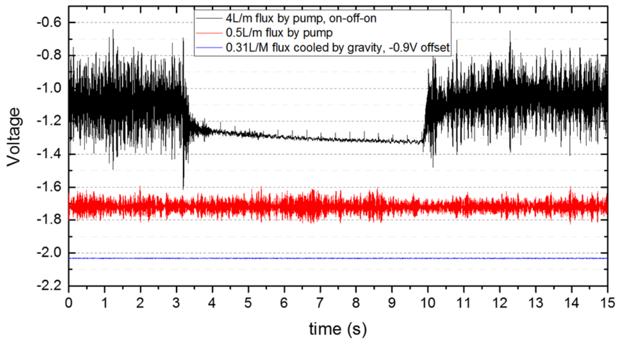

Figure 8: Ion chamber readings under different conditions.

After converting the intensity to angular vibration, then by data processing using FFT, the integrated angular displacement is shown in Fig. 9. Total RMS vibration with chiller ranging from 100 to 500 nrad. The main cause is the vibration from the chiller's motor, which can be observed at 100 and 200 Hz. Flow induced vibration contributed around 90 Hz and around 120 Hz. Comparing this result to previous LN2 cooling result, the resonance peaks slightly moves to lower frequency. The cause of this might be the difference of density between water and liquid nitrogen, or due to structural change we made to the support of liquid nitrogen lines.

With gravity cooling, best result is about 4 nrad. Explanation on this could be that without the disturbance from the pump the system performs better. Another way to look at this is that the flow state has changed from turbulence flow to laminar flow. The main cause of vibration at 50 Hz comes from a vacuum pump transmitted by the floor. It shows great potentials for gravity cooling. As introduced before, cooling efficiency is not enough for gravity cooling due to the low flow rate and high thermal contact resistance of indium foils. Solutions could be a bigger difference in height of the inlet and outlet of the cooling circuit and indium-gallium eutectic thermal conducting material between cooling blocks and crystal.

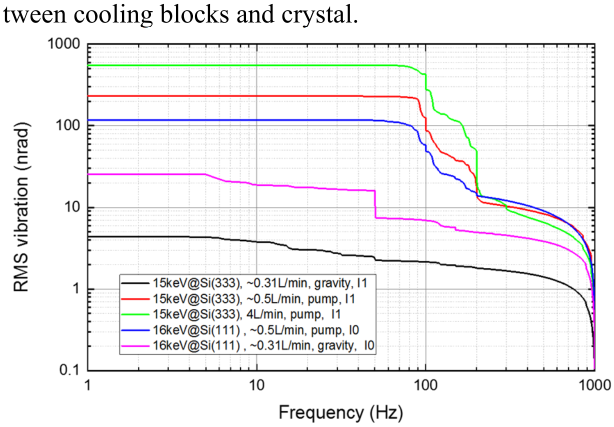

Figure 9: Integrated RMS displacement.

One thing to be noticed is that the data acquisition system seems have a lot of noise above 200Hz, this could be the limit of the hardware such as ion chamber or ADC. Higher energy could also be a cause for higher noise level. However, 200 Hz is enough for vibration measurement of a monochromator.

CONCLUSION

A series of tests were carried out for the DCM, all results seems to satisfy XAFS requirements. The test equipment served all tests well, with some difficulty above 200 Hz of vibration due to hardware limits, but served all tests well. The repeatability and energy stability should be carefully looked after in the future. Water cooling seems not enough for this beamline, due to the thermal contact resistance of indium foils. Cooling by the chiller induced a high level of vibration for the monochromator, the main cause is the pump. Future work could focus on how to reduce the fluctuation induced by the pump, such as vibration absorption techniques. Gravity cooling turns out to have great benefit for stability since it does not involve pumping in the cooling circuit. The cooling capability of gravity cooling is determined by height difference between inlet and outlet of cooling circuit. For high heat load condition, the flow rate must be raised and thermal contact resistance reduced. These tests provided useful information for future development of monochromators or other beamline instruments, such as cooling methods or temperature control level in order to get desired stability.

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