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Mechanical Design of Multilayer Kirkpatrick-Baez (KB) Mirror System for Structural Dynamics Beamline (SDB) at High Energy Photon Source (HEPS)

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Abstract

SDB aims in-situ real-time diagnosis in dynamic compression science and additive manufacturing. Nano-experimental environment requires highly multilayer KB mirror system in thermal deformation and stability of mechanism. This paper illustrates the KB cooling scheme and mechanical design. Only using variable-length water cooling to control the temperature and thermal deformation of mirror has limitations here. First, the installation of cooling system should be non-contact so that the surface shape can be sophisticatedly controlled without deformation of chucking power. Second, the distance between the HKB and the sample stage is too small to arrange the cooling pipe. Third, the KB mirror has multi-dimensional attitude adjustment. Cu water cooling pipe would be dragged with adjustment thus it has to be bent for motion decoupling, which occupies considerable space. Thus, the Cu cooling block and water cooling pipe are connected by copper braid. Eutectic Gallium-Indium fills a 100 μm gap between the cooling block and KB mirror to avoid chunking power deformation.

Mechanical Structure Design

The overview of mechanical structure design is shown in Fig.1. The length, width, and height of the whole KB mirror system are 1430 mm, 740 mm, and 1150 mm re-spectively. The size of horizontal Kirkpatrick-Baez (HKB) is 70 mm × 40 mm × 50 mm and of vertical Kirkpatrick-Baez (VKB) is 120 mm × 40 mm × 40 mm shown in Fig.2. Except for the KB mirror, the multilayer KB mirror system includes pose adjustment mechanism, a gantry, and cooling system. The fishbone flexure hinge and U-frame flexure hinge mechanism are used for position and attitude adjustment respectively, which fulfill the movement requirement in Table 1.

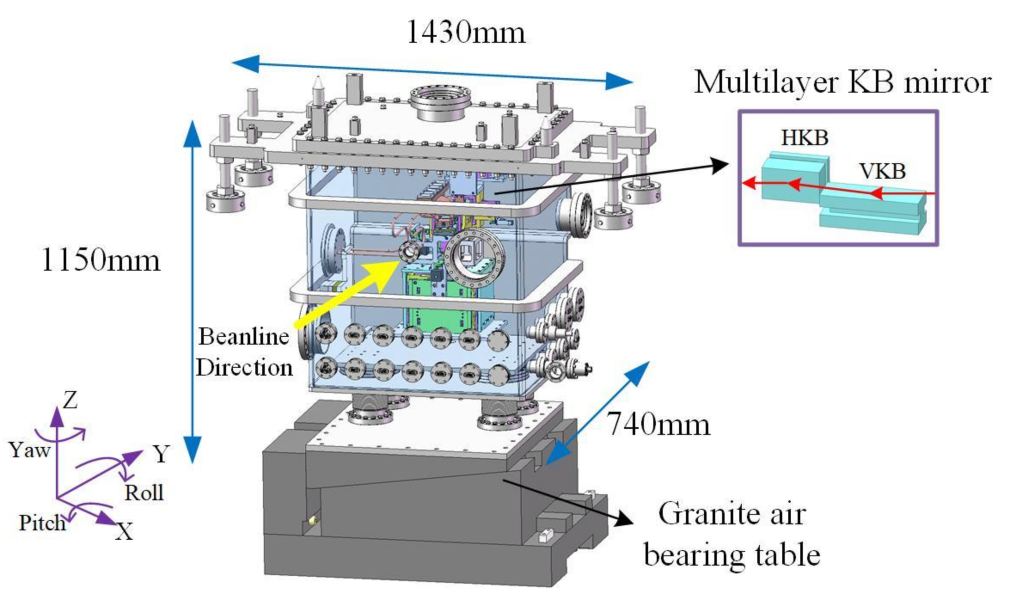

Fig. 1: The mechanical structure. (a) The external overview. (b) The multilayer KB mirror system.

Table 1: Adjustment parameter index for HKB, VKB, and whole KB mirror system

	Movement	Resolution	Range
HKB	X-axis	1μm	±0.5mm
	Yaw	1μrad	±10mrad
VKB	Z-axis	1μm	±0.5mm
	Y-axis	1μm	±0.5mm
	Pitch	1μrad	±10mrad
	Roll	10μrad	±20mrad
Whole System	X-axis	1μm	±5mm
	Z-axis	1μm	±5mm

Cooling Scheme

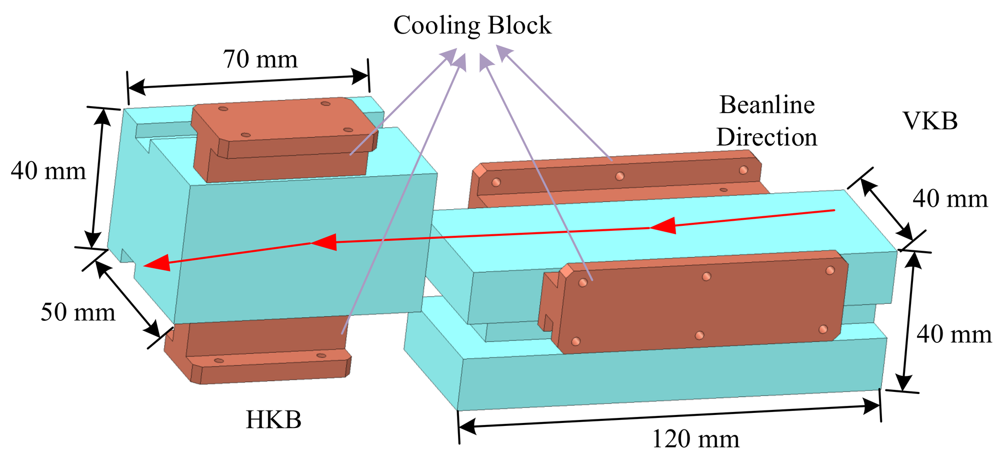

Fig. 2: The distribution of Cu cooling block of HKB and VKB.

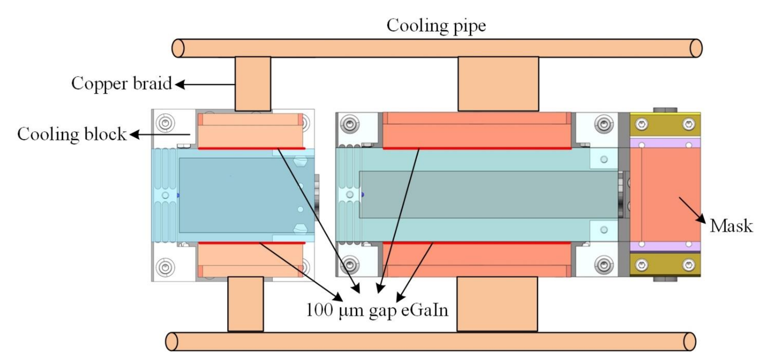

Fig. 3: The mechanical structure of the cooling part.

By efficient thermal deformation optimization iteration analysis, a variable-length water cooling scheme was adopted. The distribution of Cu cooling block of HKB and VKB is shown in Fig.2. A 100 μm gap between the cooling block and KB mirror is reserved, which is filled with eutectic Gallium-Indium (eGaIn). The eGaIn has a good thermal conductivity, whose thermal conductance is larger than 105 W/(m2K). Therefore, a cooling scheme of copper braid & eGaIn is proposed. The mechanical structure of cooling part is shown in Fig. 3, which consists of HKB and VKB Cu cooling block, cooling pipe, copper braids, and a mask. The mask protects the mirror from the X-ray source.

Thermal Deformation Simulation

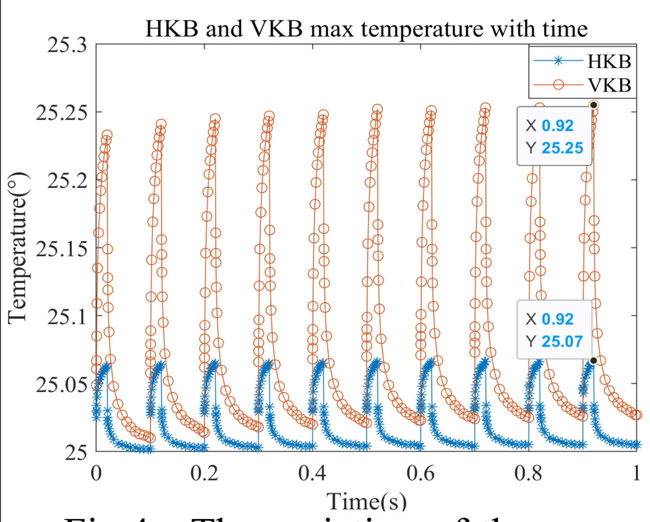

Fig.4 : The variation of the max temperature in HKB and VKB surfaces with time.

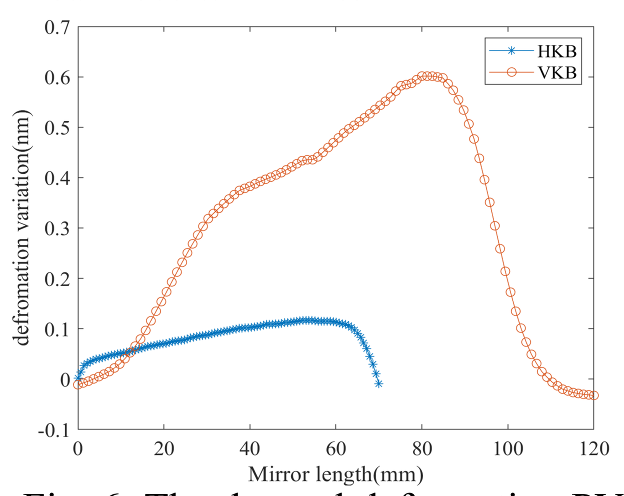

Fig. 6: The thermal deformation PV difference at the meridional plane.

The cooling scheme of the copper braids with 5 mm thickness is utilized, and the thermal transient analysis of this scheme is given. The period of the heat source is 100 ms and the duty ratio is 0.2. In the simulation, the max temperature variation with time is shown in Fig.4. In a period cycle, the max temperature values of HKB and VKB are about 25.07° and 25.25° respectively. Considering the mirror fix method, the thermal deformation difference on HKB and VKB mirror surface between the peak and valley (PV) situations is given in Fig. 5. The thermal deformation pv difference on the meridional plane is shown in Fig.6. The PV value of HKB is 0.11 nm and of VKB is 0.60 nm, which fulfills the experimental requirement.

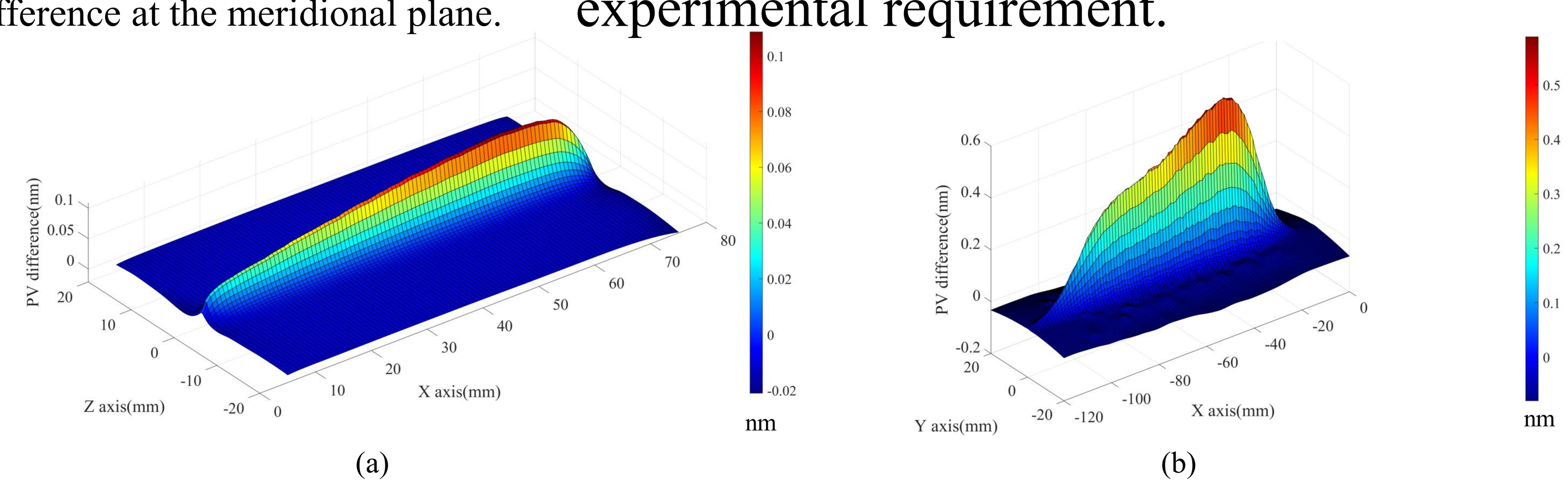

Fig. 5: The thermal deformation PV difference on the mirror surface of HKB (a) and VKB (b).

Conclusion

The mechanical structure of multilayer KB mirror system for SDB at HEPS is designed. According to practical engineering cases, the water cooling system is adjusted. The structure and thermal FEA simulation is given. The analysis results fulfill the requirement.

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