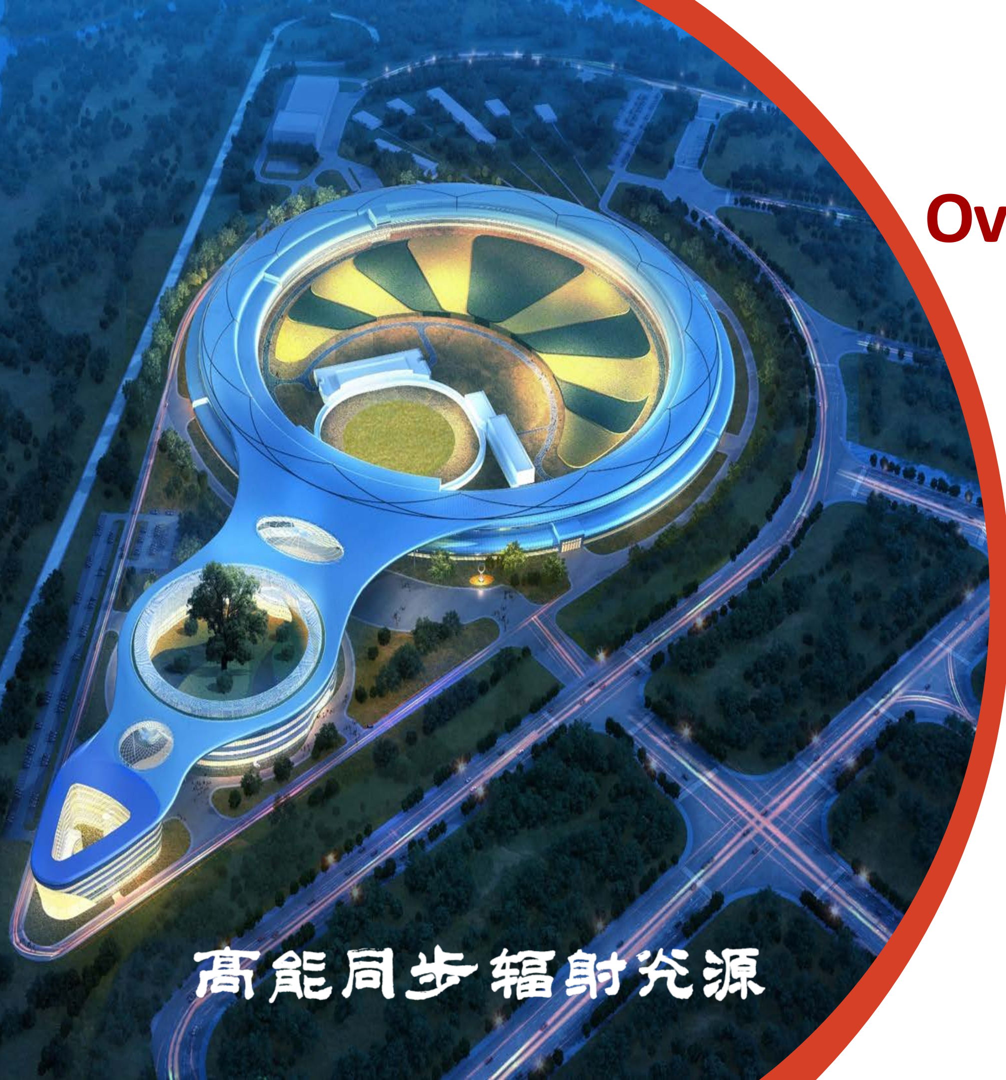

MEDSI 2023
Beijing
Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation

Overall progress on development of X-ray optics mechanical systems at HEPS

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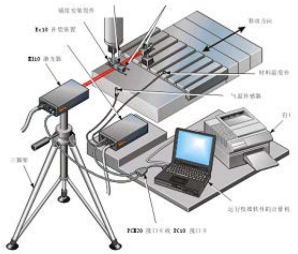
BEIJING, Nov 9th 2023

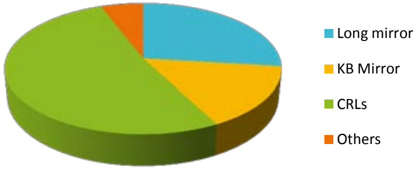
Outline

- Introduction
- Overall design strategy
- Generic mirror mechanical system (GMMS) design
- A customized GMMS-based design
- Manufacture, assembly and test
- Conclusion



I Introduction

- HEPS
  - is a new and under construction 4th generation synchrotron radiation facility. It has a 6GeV storage ring with a circumference of 1360.4 m and a natural emittance of 34.2 pm. The ground stability of vibration should be required to 25nm @1~100Hz.
- Beamlines: 15
  - 14 ID (included 3 long BLs)
  - 1 Bender
- Optics/mirrors device: ≥50 set
  - Long mirror: 14
  - KB mirror: 8
  - CRLs: 27
  - Others: 3



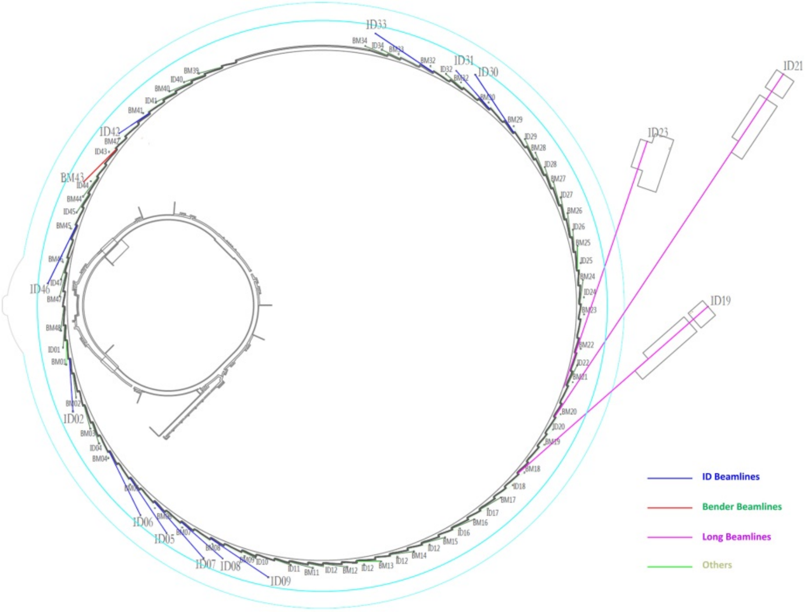


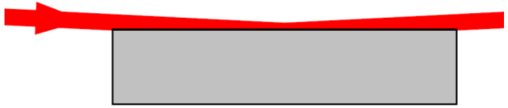
Fig. 1: The layout of HEPS beamlines in Phase I

Optomechanical engineering TASK is important and huge!!!

I Introduction

- Typical optics/mirrors:
  - ① Long mirror (or watercooled)
  - ② KB mirror
  - ③ Bender
  - ④ CRLs

①



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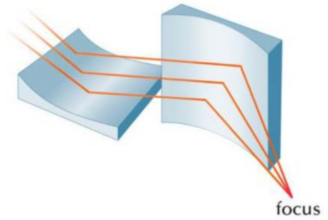
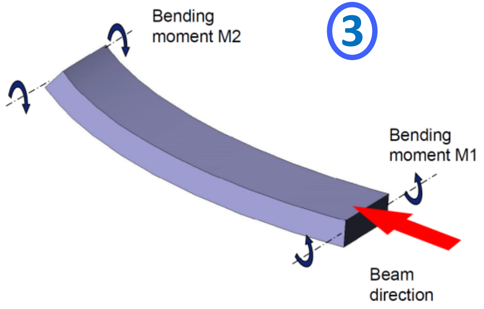


P. Kirkpatrick, A.V. Baez, J. Opt. Soc. Am. 38, 766 (1948)

Challenges:

- **Extreme stable & Multi-DOF**
- **Variety mechanical structure**
- **High requirements of surface slope error:**
  - **Watercooled**
  - **Bender**
  - **Clamping…**

③



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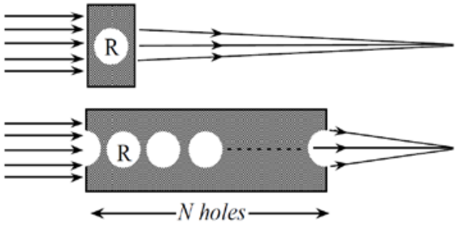
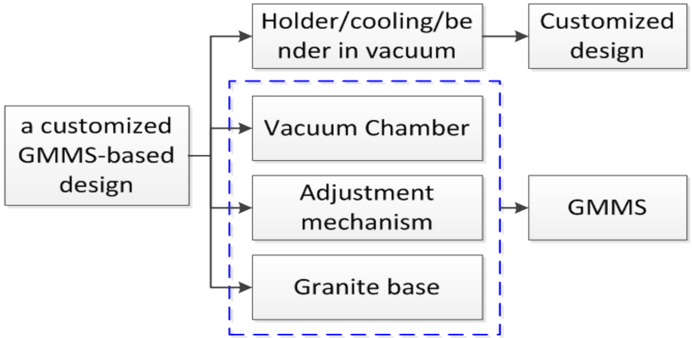


A. Snigirev et al. Nature, 384 (1996)

II Overall design strategy

- Extreme stable generic mirror mechanical system (GMMS) is first developed, as shown in Fig.2.

- Customized GMMS-based mechanical design
  - Clamping or watercooled or bender in vacuum design



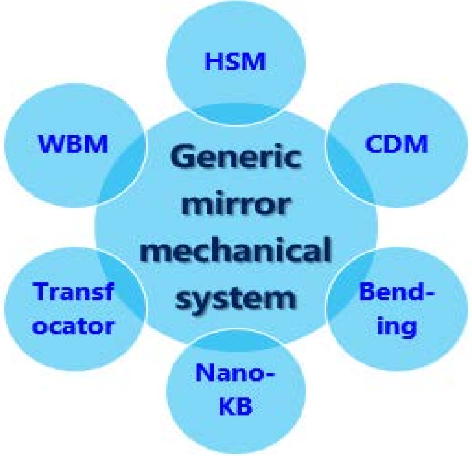
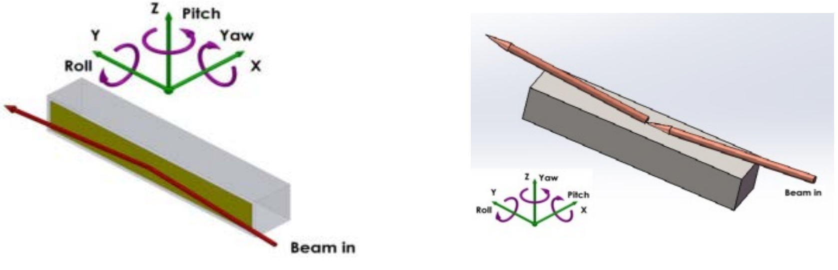


Fig. 2: The promoting strategy of design for MMS

III Generic mirror mechanical system (GMMS) design

- General requirements of GMMS
  - Vibration stability: ≤25 nrad rms@1-120Hz
  - 1st Mode eigenfrequency: ≥80Hz
  - 5-DOF motorized
  - Compatible to two layouts of horizontal and vertical reflection as shown in Fig. 3
  - Vacuum parameter: 1e-7Pa
  - Beam height (standard): 1400mm



(a) (b)

Figure 3: Layouts of horizontal and vertical reflection mirrors. (a) Horizontal reflection. (b) Vertical reflection.

III Generic mirror mechanical system (GMMS) design

- According to the standard coordinate system defined by HEPS beamlines as shown in Fig.3, the main parameters of 5-DOF is shown in Table 1.

Table 1: Main parameters of 5-DOF for GMMS

	Parameter	Resolution	Range	Type
1	Horiz.Translation (Tx)	≤1 μm	±10mm	motorized
2	Vert. Translation (Tz)	≤1 μm	±10mm	motorized
3	Horiz.angle (Rz)	≤0.1 μrad	±10mrad	motorized
4	Vert.angle (Rx)	≤0.1 μrad	±10mrad	motorized
5	Roll (Ry)	≤10μrad	±17.5mrad	motorized

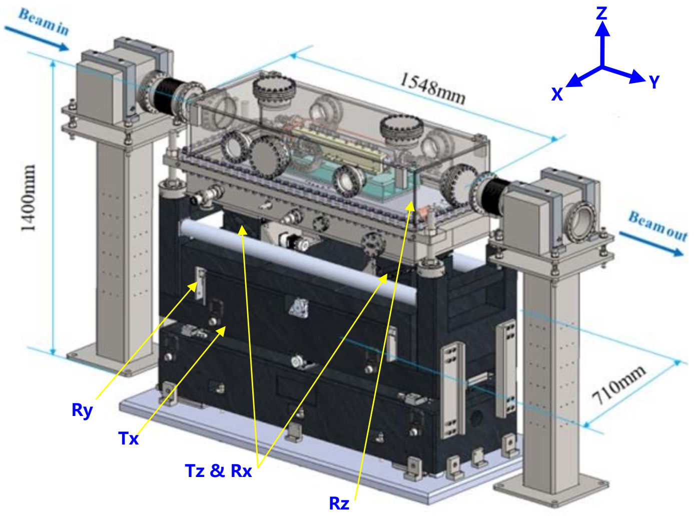


Figure 4: The overview of the typical design of GMMS.

III Generic mirror mechanical system (GMMS) design

- Highlight design:
  - a multi-layer granite adjustment mechanism
  - The granite wedges lifter based on sine bar method are employed for adjustments of the height Tz and angle Rx instead of the traditional cantilever support structure.
  - High stiffness guideway & sider, e.g. cross roller bearing, wider guide rail, flexure joint…
  - Self-locking after adjustments
  - Simplified double-disc flexure hinge angle mechanism, Monolithic machining instead of assembling, as shown in Fig.5.
  - Lateral damping structure

Compensation flexure hinge

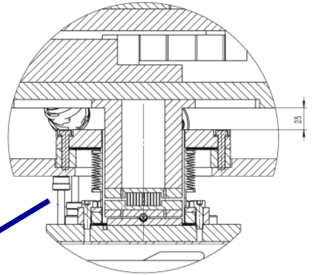
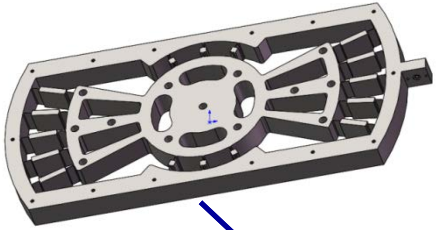
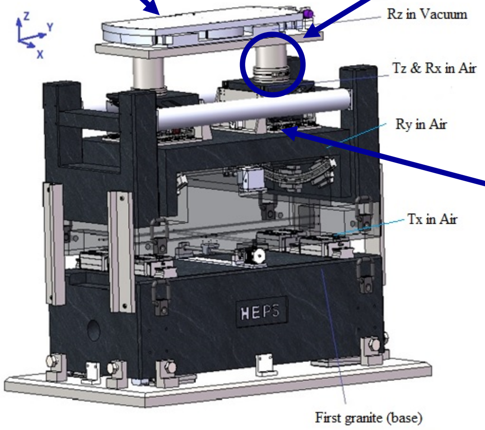
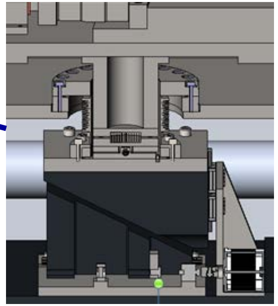


Figure 5: Monolithic flexure hinge







Wedges lifter

III Generic mirror mechanical system (GMMS) design

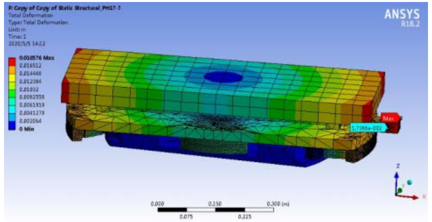
- FEA Modal analysis for overall system:
  - Load 200kg
  - Structure design and iteration optimization
  - 1st mode eigenfrequency: 80Hz

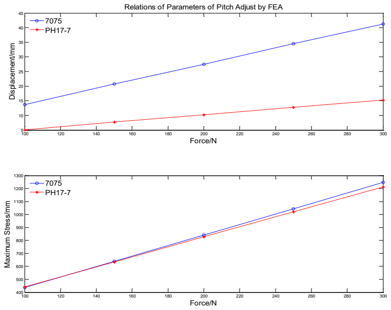
- FEA for Key adjustment mechanism

  Force-deformation curves by simulation

  Optimization for structural design

Admittedly, FEA analysis may be not accurate, but there is not more effective way during design. So, it is still needed.





Relationship of force and displacement by FEA

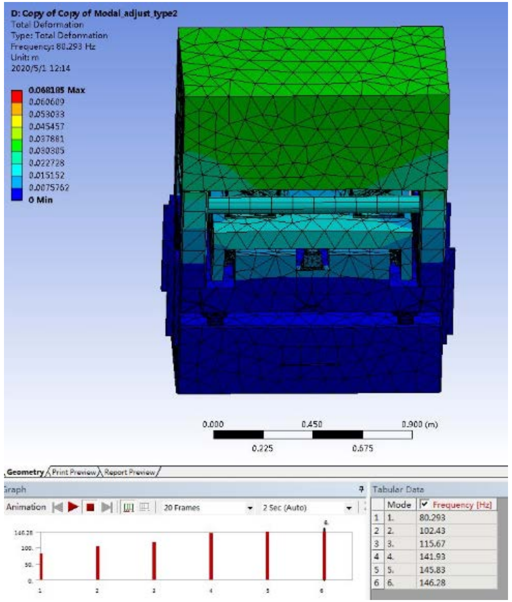


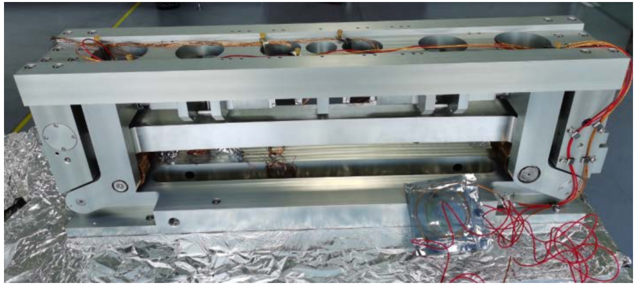
Figure 6: FEA-Modal simulation

IV A customized GMMS-based design

- As is mentioned above, specified mechanical structure in vacuum need to be a customized GMMS-based de-signed, especially
- bender,
- watercooled
- mounting or double mirrors assembly unit.
- …

IV A customized GMMS-based design

- Main design considerations for bender:
  - Four-shaft type
  - Independent of two bending moments
  - Soft-hard interface using beryllium bronze as press roller
  - Adaptive optical surface by using cam shaft design
- Characteristics
  - High stiffness & high stability compared to leaf spring type
  - Variable shape, e.g. asymmetric parabolic cylinder
  - Eliminating twist impact



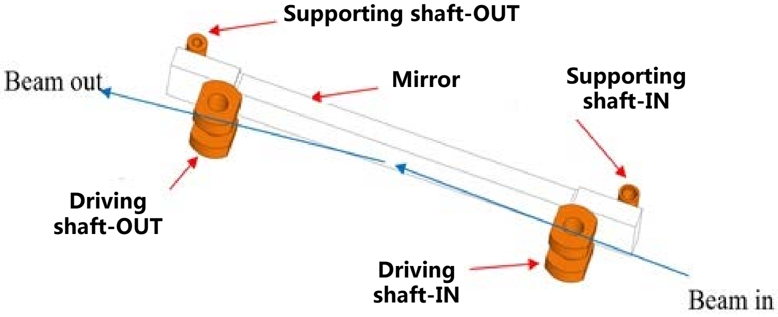
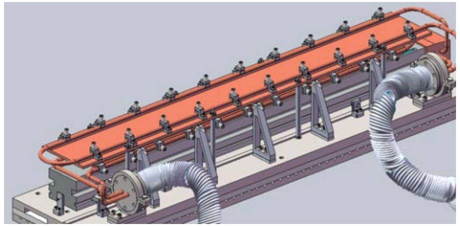


Figure 7: Principle diagram of an independent four-shaft bending

IV A customized GMMS-based design

- Challenges for watercooled scheme:
  - High heat load 1000kw, e.g. BE-WBM
  - Fluid and pipe vibration impact
  - Variable heat load and power density distribution due to different energy work state
- Main design considerations:
  - A bath watercooled structure filled eutectic Ga-In alloy
  - a novel coating of tungsten (W) for anti-corrosion
  - Vibration transfer analysis and control based on fluid-solid coupling



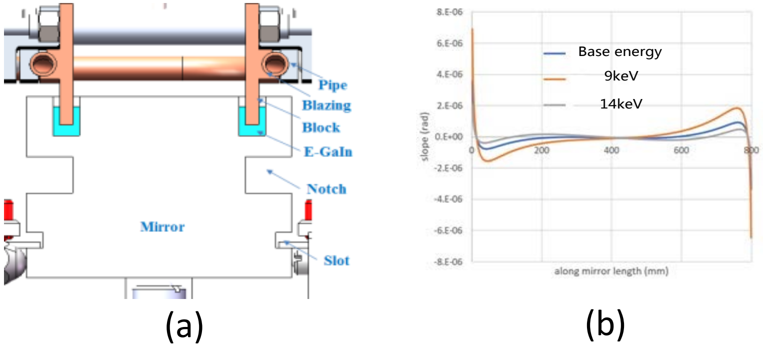


Figure 8:Principle diagram of a bath watercooled structure filled eutectic Ga-In alloy. (a) Structure. (b) Thermal deformation controlled based on geometrical optimized by FEA

IV A customized GMMS-based design

- Clamping and combination: BB-CDM, BD-HSM
  - quasi-static structure: holder or mechanical stitching for two mirrors
  - Support: removing gravitational deformation
  - Mounting: Free-stress by elastic holder design
- Double mirrors mechanism: B8-HSM
  - Kinetic structure: motion&clamping
  - Type design: a fixed exited height of harmonic suppression mirrors (HSM)
  - Compensating height variable caused CCM similar to the T-type compensation mechanism of monochromators

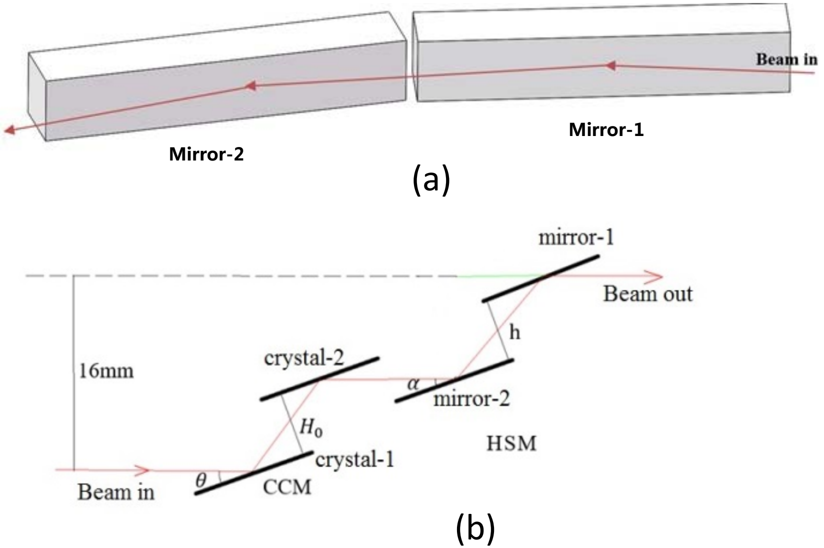
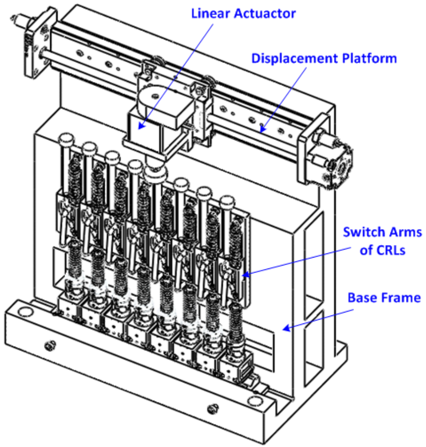


Figure 9: Principle diagram of the double mirrors system. (a) CDM. (b) Complicated HSM for the height compensation of the channel cut mono. (CCM) at B8-XAS beamline.

IV A customized GMMS-based design

- A compact CRL Transfocator design
  - Orthogonal parallel design scheme instead of traditional series structure
  - Two sets motors or actuators instead N sets for N arms
  - A self-locking and state-keeping mechanism
- Advantages
  - Compact
  - Larger work distance
  - Simplified structure



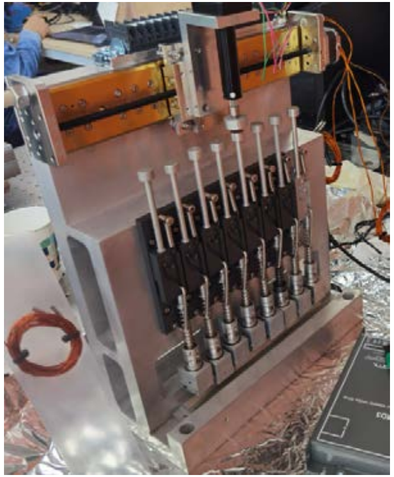
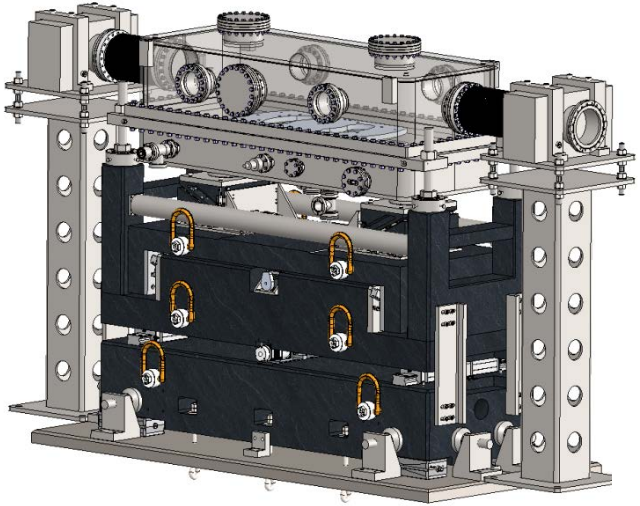


Figure 10: A compact Transfocator

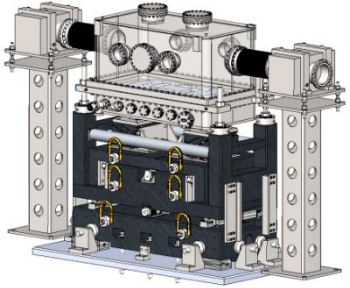
Besides, an in-vacuum motion mechanism similar to the above HSM is designed for the LDBM of B1-EM beamline. This is so that the GMMS can also be applied here.

IV A customized GMMS-based design

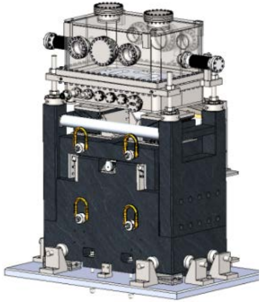
- Serialization design



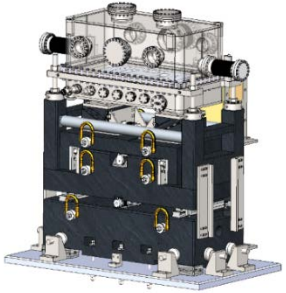
BB-CDM-V



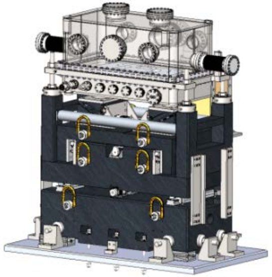
B8-WBM-V-watercooled & bender



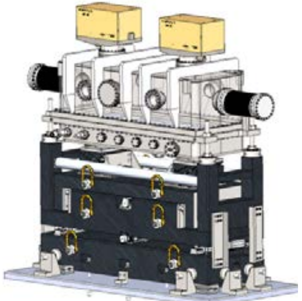
BD-HSM



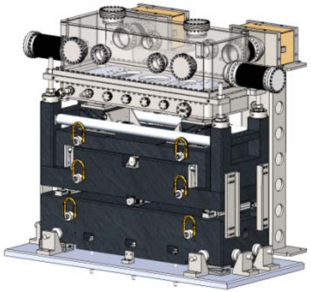
B8-FM-V-bender



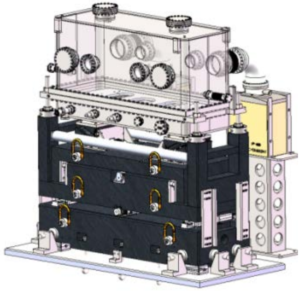
BE-FM-V-bender



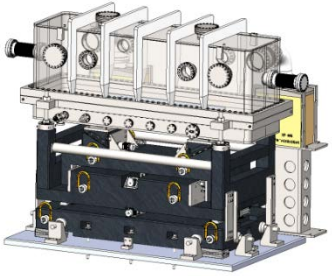
BD-WBM-V-watercooled & bender



BD-FM-V-bender



BA Transfocator1#



B8-HSM

V Manufacture, assembly and test

First customized GMMS (BE-WBM):

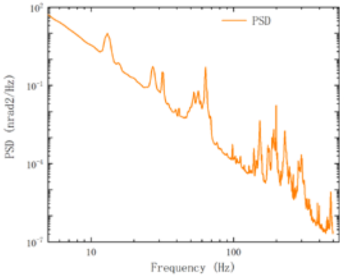
- Manufactured and delivered in Dec. 2022
- Stability(Test): 14nrad RMS@5-500Hz
- Positioning: 5-DOF, accuracy is OK

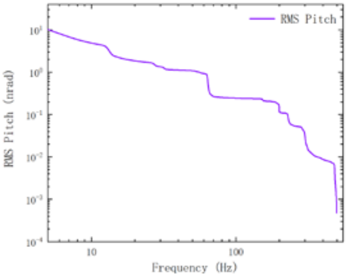
1st batch GMMS (9 sets):

- FAT finished
- Manufactured and delivered in Jul. 2023
- Indicates the design, manufacture, and assembly are available

2st batch GMMS (9 sets):

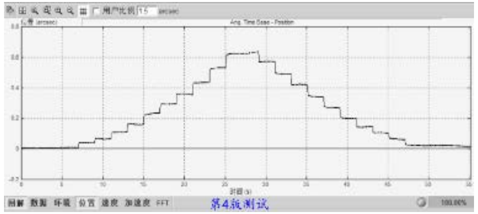
- Planed to be delivered in the middle of next year
- Installation time will be a key factor





Pitch stability (RMS@5-500Hz): 13.7nrad, at 20230901 22:48 by AM

First GMMS for BE WBM



0.25urad angular step test results

V Manufacture, assembly and test

Figure 11: FAT pictures of first batch of GMMS.

VI Conclusion

A promoting strategy of MMS is presented for the development of large quantity and variety type optomechanical systems. And the corresponding conclusions are as follows:

1) A customized GMMS-based design strategy has been implemented for beamlines at HEPS, in which generic and specific are both effectively considered.

2) Progress on GMMS manufacturing and assembling imply that an ultra-stable and 5-DOF mechanical system is achievable and fine so that the first batch has been already delivered.

3) The various mirror benders or clamping & water-cooling or special-mechanisms in vacuum are also smooth in process of design and fabrication.

References

[1] T. Mairs, R. Baker, C. Clavel, et al, “Upgrading beamline performance: ultra stable mirror developments at ESRF”, in *Proc.* MEDSI-6, DLS, UK, 2010.

[2] R. Baker, R. Barrett, C. Clavel, et al, “New generation mirror systems for the ESRF upgrade beamlines”, J. Phys.:Conf.Ser. 425 052015, 2013.

[3] R. R. Geraldes, G. V. Claudiano, L. M. Volpe, et al, “The design of exactly-constrainted X-ray mirror systems for SIRIUS”, in *Proc.* MEDSI 2018-WEOAMA04, Paris, France, 2018.

[4] R. R. Geraldes, A. Sikorski, C. S. N. C. Bueno, et al, “Granite benches for SIRIUS X-ray optical systems”, in *Proc.* MEDSI 2018-THPH12, Paris, France, 2018.

[5] S. Bean, V. De Andrade, A. Deriy, et al, “A new ultra-stable variable projection microscope for the APS upgrade of 32-ID”, in *Proc.* MEDSI 2020-TUPC15, Chicago, USA, 2020.

[6] C. A. Preissner, S. J. Bean, M. Erdmann, et al, “A family of high-stability granite stages for synchrotron appllication”, in *Proc.* MEDSI 2020-THOA01, Chicago, USA, 2020.

[7] G. B. Z. L. Moreno, S. A. L. Luiz, A. C. Pinto, et al. “Tolerance-budgeting for ultra-stable KB systems”, J. Phys.:Conf.Ser. 2380 012074, 2022.

[8] L. Zhang, R. Barrett, K. Friedrich, et al, “Thermal distortion minimzation by geometry optimization for water-cooled white beam mirror or multilayer optics”, J. Phys.:Conf.Ser. 425 052029, 2013.

[9] Z. Qiao, J. Anto, L. Assoufid, et al , “Surface twist characterization and compensation of anelliptically bent hard X-ray mirror”, in *Proc.* MEDSI 2020-TUOA01, Chicago, USA, 2020.

[10] Y. Jiao, G. Xu, X. H. Cui, et al., “The HEPS project.” J. Synchrotron. Radiat, 2018, 25, 1611-1618. doi:10.1107/ S1600577518012110

[11] Shanzhi Tang, Tian He, Haihan Yu, et al. “A novel coating to avoid corrosion effect between eutectic gallium–indium alloy and heat sink metal for X-ray optics cooling”, Rev. Sci. Instrum. 2022, 93, 12, 123102-1

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- Cooperation team:
  - Optical design
  - Front end
  - General mechanical system & vacuum
  - Beamline control
  - …

Thank you for your attention!