Institute of High Energy Physics
Chinese Academy of Sciences

A HIGH HEAT LOAD DOUBLE-XTAL MONOCHROMATOR AND ITS CRYO COOLING SYSTEM FOR HIGH ENERGY PHOTON SOURCE IN CHINA

Hao LIANG
On behalf of the mono team.

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Outline

- Introduction
- Part 1: Considerations and mechanical design of DCM
  - Targets/mechanical requirements.
  - Xtal cooling & FEA simulation.
  - Structure & features.
- Part 2: R&D of cryo cooling system
  - Objectives.
  - Flow-process control.
  - Engineering design.
- Part 3: Test results: offline & online.
  - Offline tests, heat load test and vibration measurement;
  - Pressure stability of the cryo cooling system;
  - Online test of rocking curve & position stability of mono;

High heat load double xtal monochromator project

Why build them ourselves?

A batch of LN2 cooled monos will be needed in the future HEPS (96 beamlines in total).

No cyo cooled optics in BSRF before. Uncertainties!

Objections:

Develop prototypes of high heat load DCM and its cryo cooling system.

Get a better understanding of the technical details and challenges.

Budget control at a reasonable level (if possible).

Strategy:

Proven technology. Successful running is main goal.

Collaboration with qualified labs and companies.

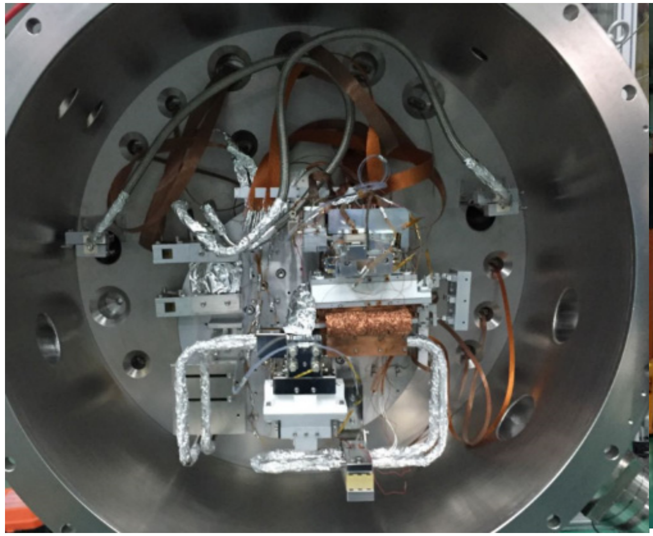
Timeline:

1st version: 2+ years from design to prototype.

Offline tests: found vibration, pressure instability.

Upgrades: 8 months to final parts, minor modifications.

Offline and online tests. 11 months (limited beam time).



High Heat Load DCM

Cryo Cooling System

Targets and geometry

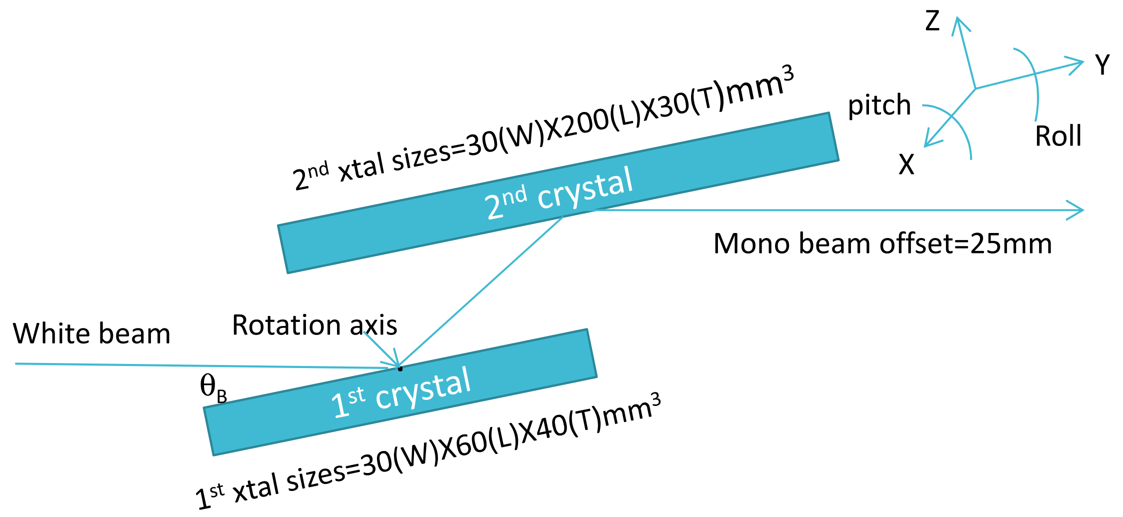
Tunable photon energy range:	5-20keV
Offset:	25mm
Angular instability of exit beam:	100nrad(?)
Heat load to be handled:	<10Watts/mm^2 @800Watts
Rocking-curve broadening:	<10%
Vacuum:	10^{-5}Pa

For HEPS of 6GeV @200mA,

Handle heat load from IDs up to 10Watts/mm^2 @800Watts,

Have good angular stability for mono beam,

And present excellent repeatability when tuning energy.



Two Si(111) crystals parallel to each other on one goniometer.

Bragg axis is oriented on surface of 1st xtal.

Perpendicular translation of 2nd crystal for fixed exit.

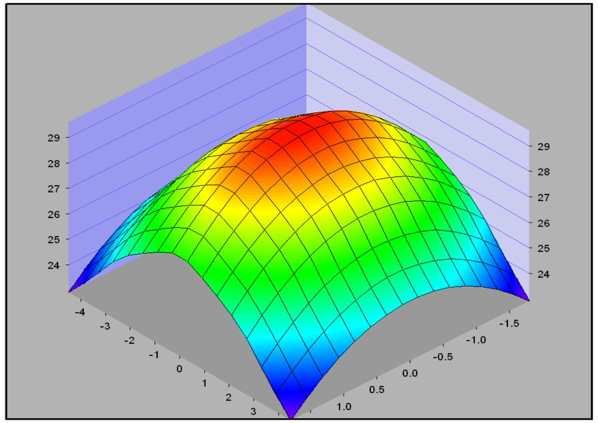
Longer 2nd crystal to accommodate beam walking.

Pitch and roll adjustments for 2nd xtal.

Hypothetical heat load with 2D Gaussian distributions

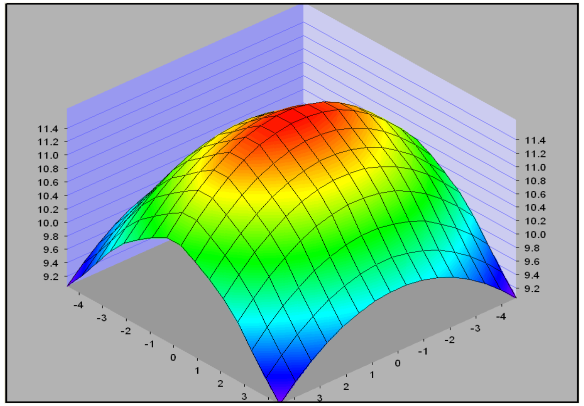
- E=6GeV, I =200mA, source: U20, distance: 60 meters, accept ±3σ of central cone.
- Assuming distribution of heat load absorbed on the surface of 1st xtal is shown below. (surface absorption)
- Evaluate behaviors of 1st xtal via FEA under heat load of 870 Watts.

See WEPH09



Total power:
870Watts
Power density:
29.6W/mm^2
Divergencies(RMS):
25(H)X10(V) μrad^2

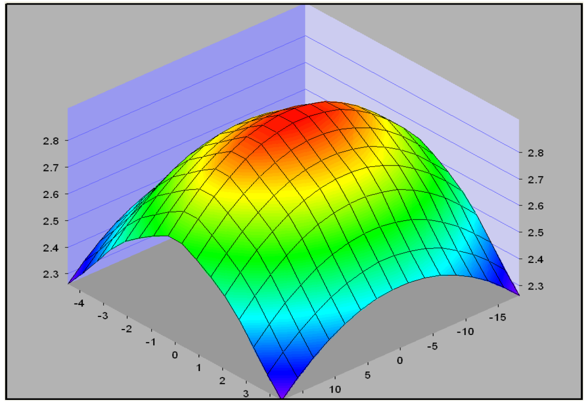
- Illuminate arbitrarily such a load onto 1st xtal at two Bragg angles corresponding to photon energies of both 5 and 20keV, respectively



Power density:
11.7Watts/mm^2

Bragg angle:
θ_B =23.30°@5keV

Footprint on 1st xtal:
9(W)X9(L)mm^2



Power density:
2.9Watts/mm^2

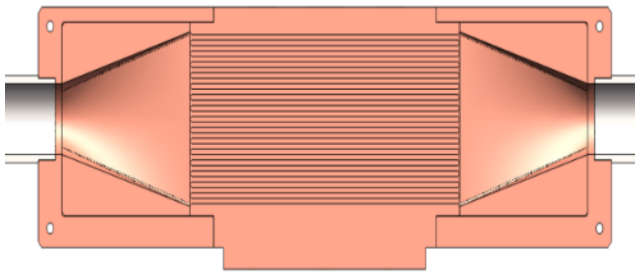
Bragg angle:
θ_B =5.67°@20keV

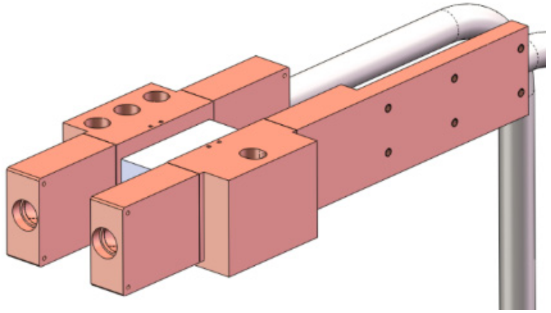
Footprint on 1st xtal:
9(W)X36(L)mm^2

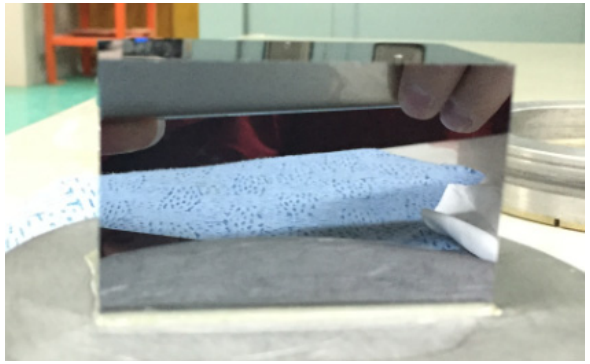
Enhanced heat transfer on the manifolds of 1st xtals

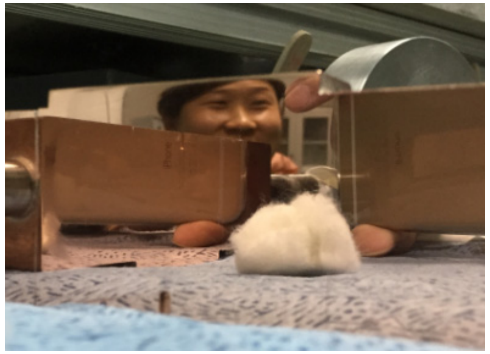
Arrangement of the multiple slots for enlargement of the surface area of heat convection.

No sealing gaskets.







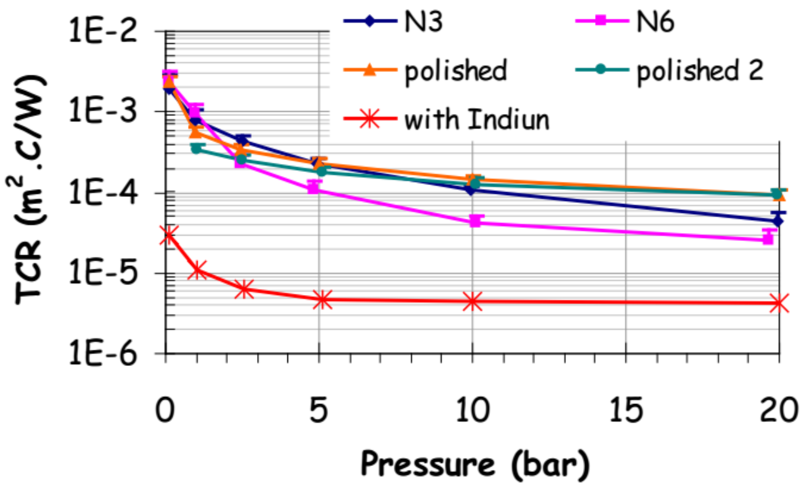


In the case of LN_2 @10.5Litters/min

Reynolds Number: 13250 (turbulent flow)
Prandtl Number: 2.14
Nusselt Number: 63.38
Heat transfer coefficient: 5000W/m^2K

As for fabrication of manifolds:

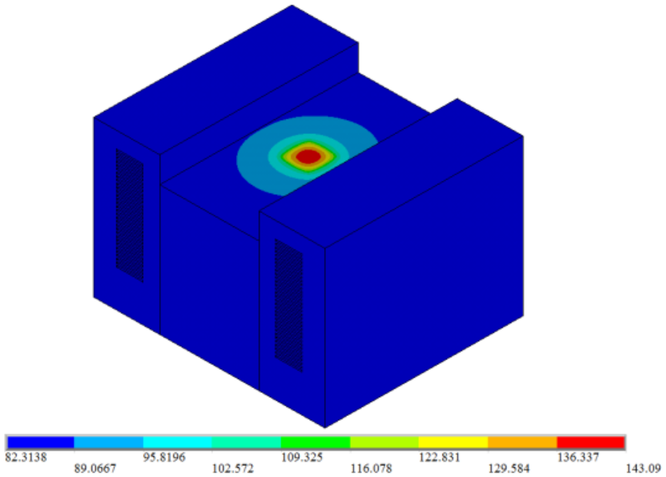
Wire Electrical Discharge Machining (WEDM),
Incorporate blocks with nozzles by brazing, and
Grinding and polishing surfaces of manifolds and crystal for good contact.

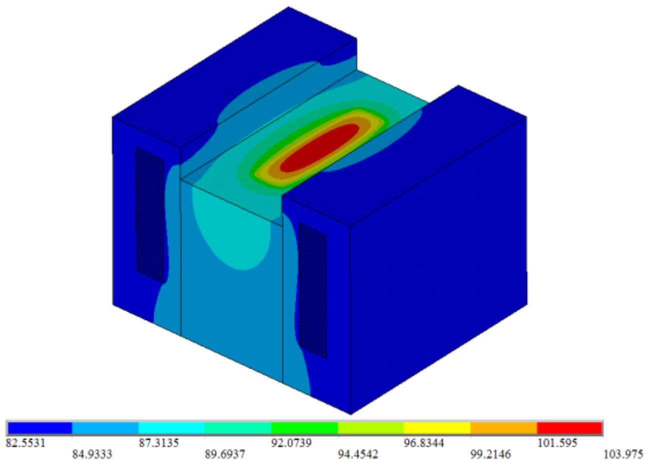


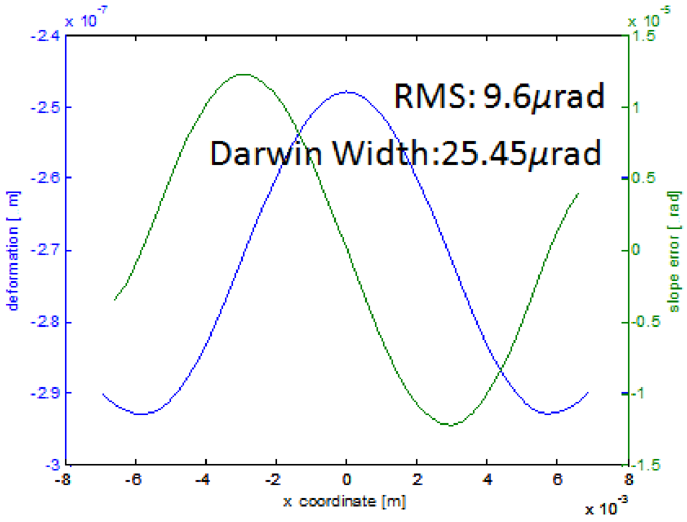
* TCR decreases when pressure increases.
* Indium foil can improve thermal contact.

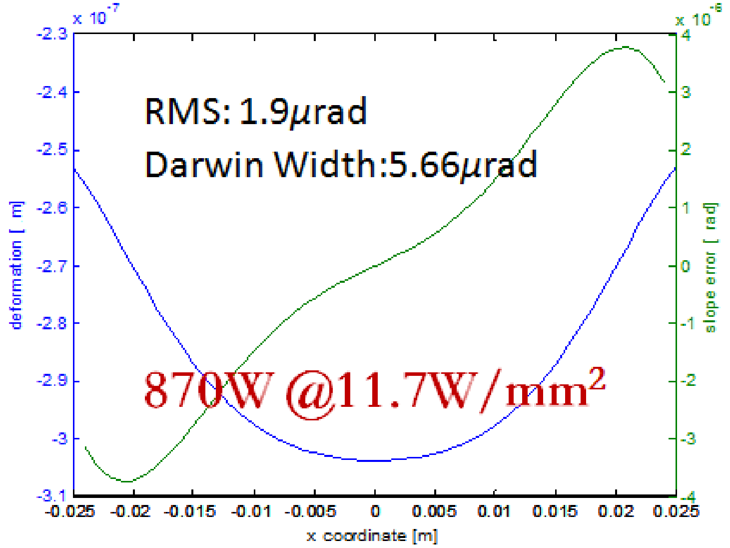
By courtesy of L. ZHANG

Simulation of 1st crystal distortion









Inlet temperature: 77.4K

Internal Pressure: 0.4MPa

Maximum flow rate: 10.5L/min

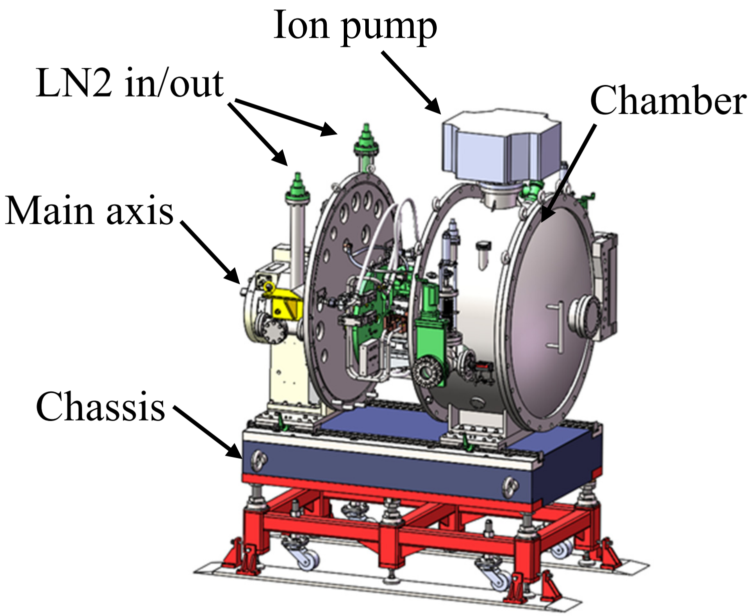
Heat transfer coefficient: 5000W/m^{2}K

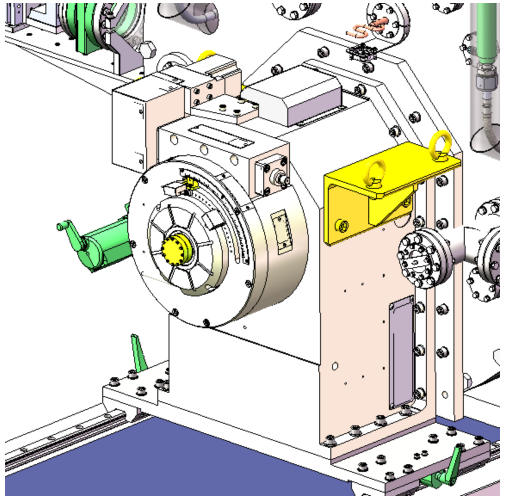
TCR: 5X10^{-6}m^{2}K/Watts

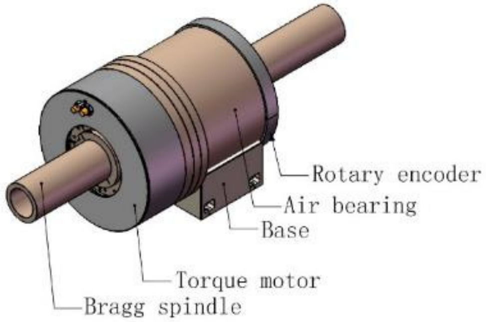
Maximum Temp. of wet walls: 86K

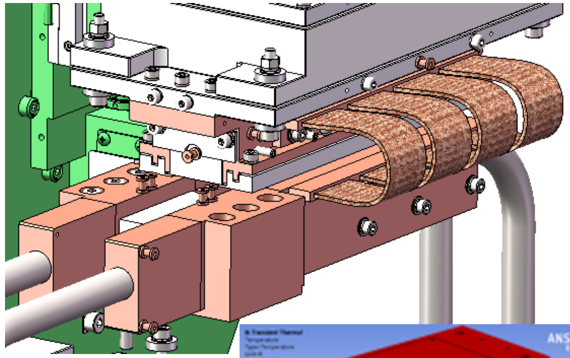
See WEPH09

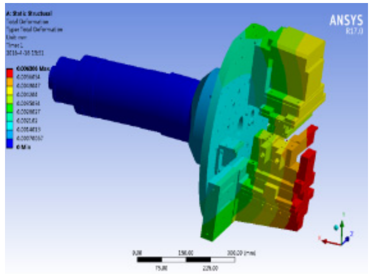
DCM design considerations

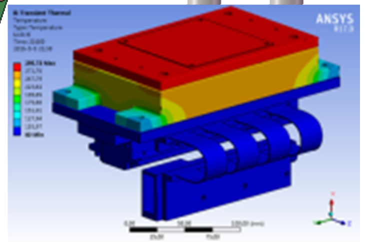






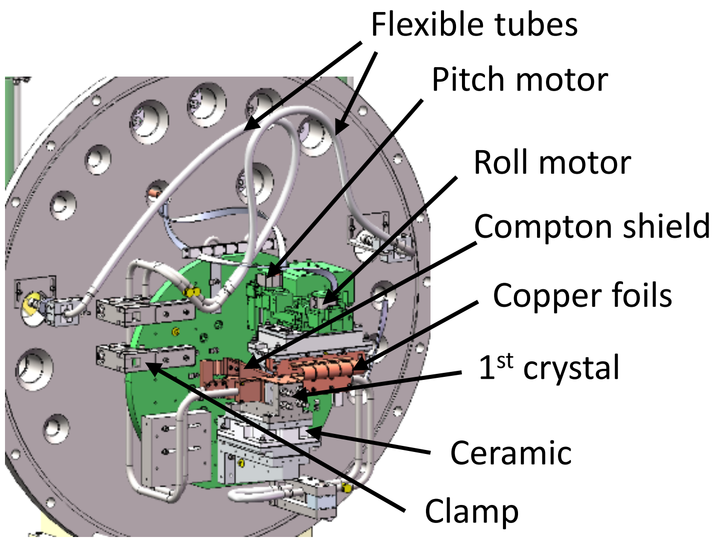


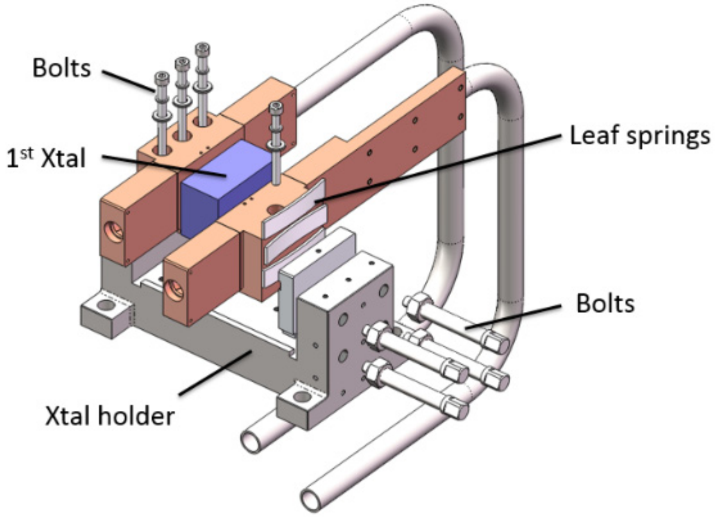


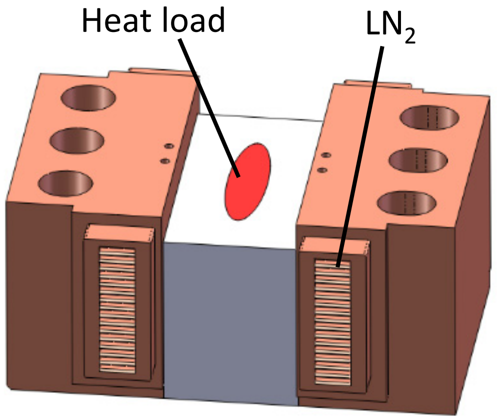


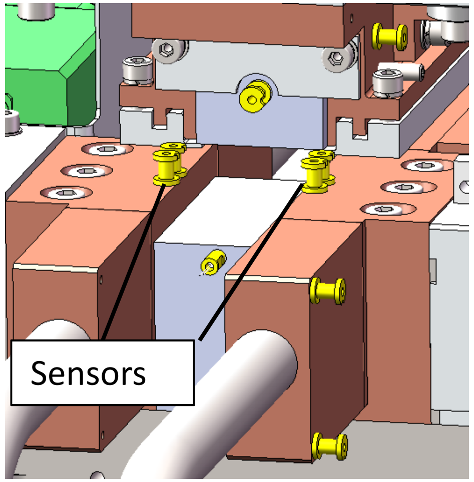
- Worm-wheel mechanism for strong Bragg spindle sealed by ferro fluid, even though a direct-drive brushless DC torque motor may be optional for better performances.
- Back plate of cage is stiff enough to minimize its distortion under heavy load.
- Cage is rigidly mounted, and no elastic linkages included to avoid from vibration at high cryogenically pumping frequency when cooling.
- LN_2 cycles at a high pump frequency of 60Hz for maximum heat load of 800W.
- Indirect cooling 1st xtal by using enhanced heat convection for manifolds.
- Copper braids cooling 2nd xtal for good stability.
- Temperature difference between two crystals <100K.

Features

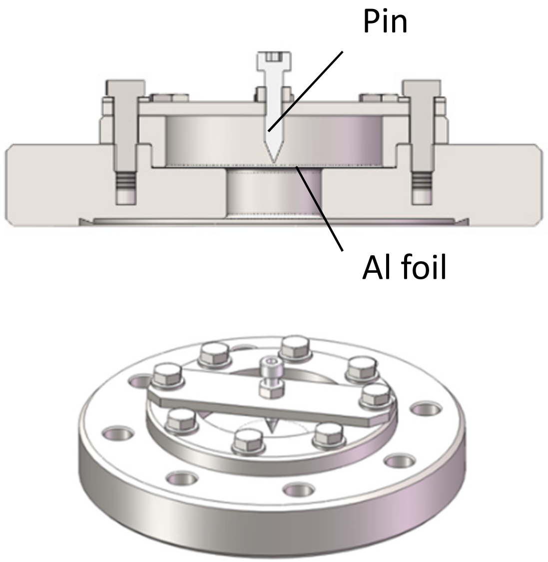








1. Flexible tubes with mesh inside and outside from OSAKA RASENKAN KOGYO CO.,LTD.
2. Ceramic heat isolator.
3. Pitch and roll by stepping motors.
4. Counter weight to keep balance, avoid distortion.
5. Compton scattering shield.
6. Copper foils to cool 2nd crystal.



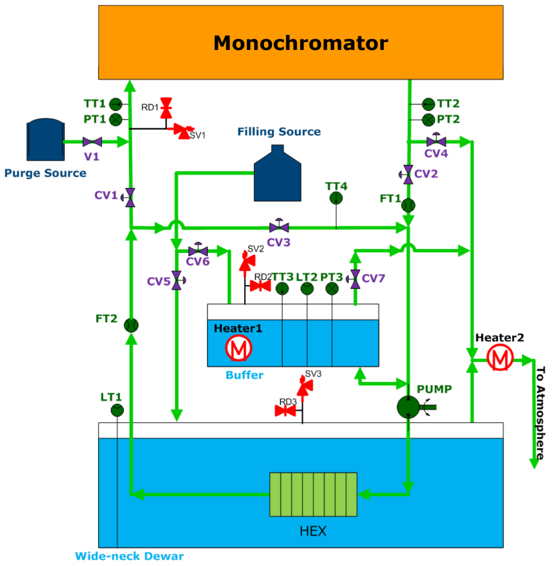
7. Clamps to reduce vibration by tubes.
8. Width of crystal is adjustable.
9. Leaf springs to keep contact under low temperature
10. Colling channels higher than surface of crystal.
11. Pt 100 temperature sensors.
12. Aluminum "burst" window to prevent over pressure in case of LN2 leakage.

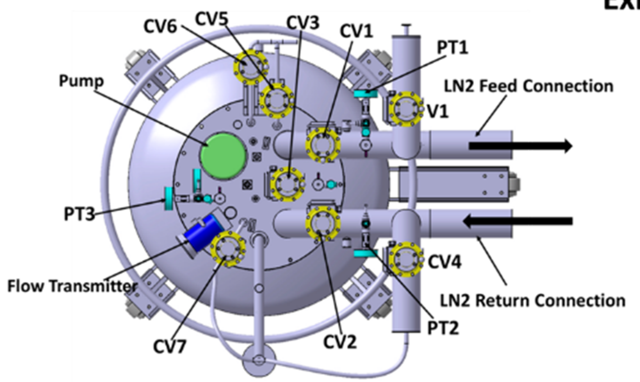
Objectives for cryo cooling system

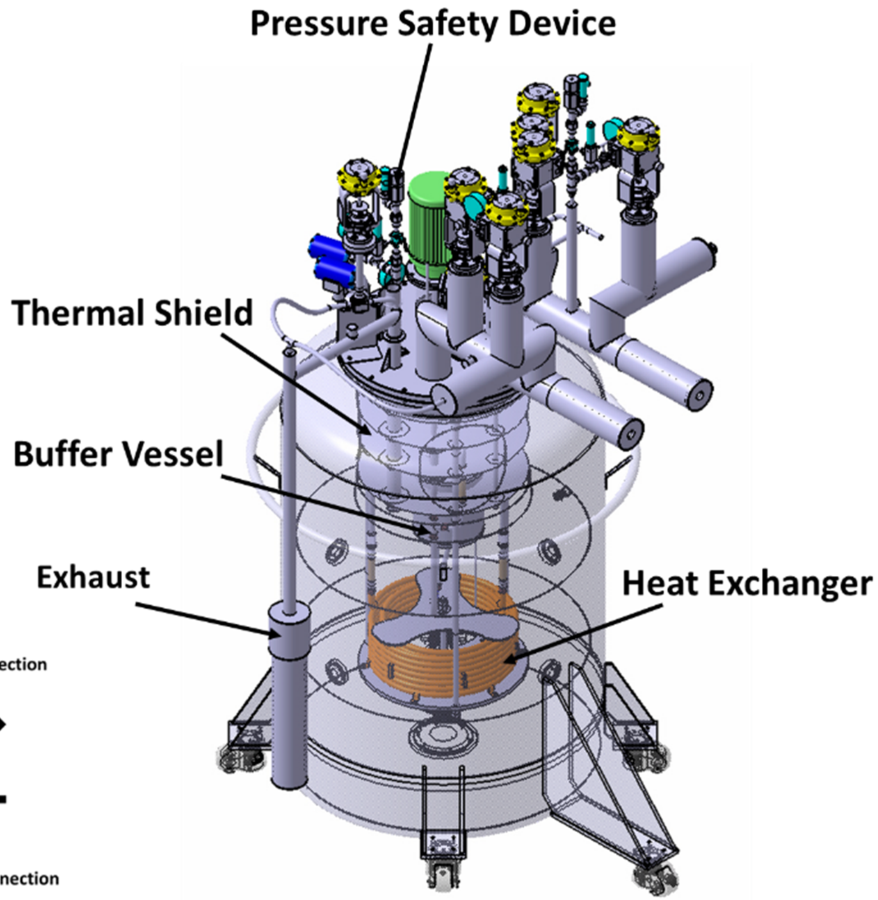
Parameters	Specifications
Maximum cooling power	2500W
Big dewar capacity	500L
Pressure of closed loop	< 0.6MPa
Pressure of open loop	0.1Mpa
Pressure stability	≤±600Pa
Pump speed	0~100Hz
Maximum flow rate	10 L/min
Liquid Nitrogen consumption	2.24L/hour @100W

- Designed cooling power of 800 Watts, up to 2500 Watts upon necessary.
- Constant temperature of feeding LN_2 for the mono.
- Pressure instability less than 4‰.
- Adjustable flow via variable frequency pump and bypass.
- High pressure (4 bar) operation mode to avoid boiling.
- Remote control of all functions (valves, pump, and heater) and monitor signals (temperature, flow and pressure).
- Automated process operation (purge, filling, cool down and warm up).

Design of the cryo cooling system



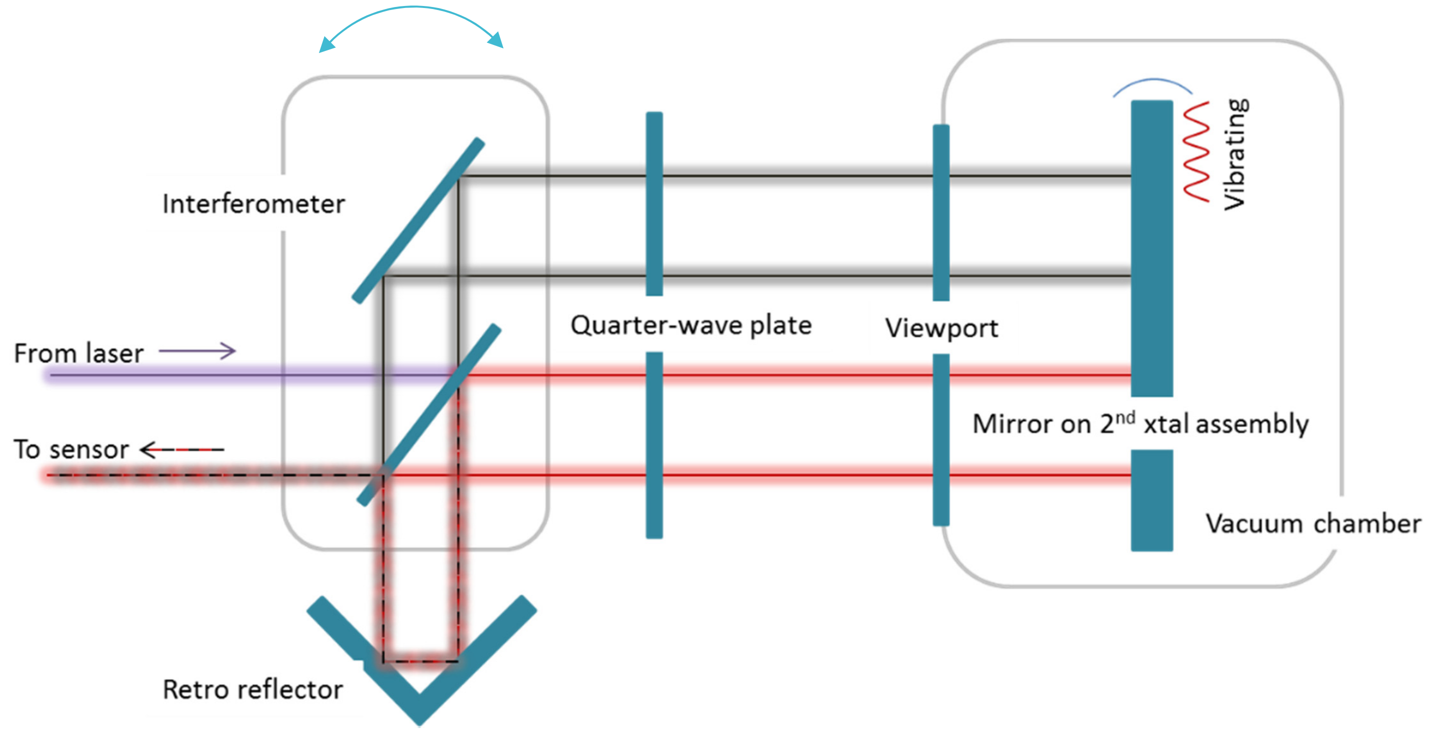




- The system consists of closed loop circuit and vacuum insulated wide-neck Dewar.
- The closed loop circuit removes the heat from mono, the heat is exchanged by copper coil submerged in Dewar.
- Nitrogen gas, generated by the boiling liquid nitrogen in Dewar, is warmed and ducted outside to avoid risk of asphyxiation.
- A buffer is installed in the circuit to maintain the pressure stability of the system.
- A heater is immersed in the buffer to adjust the pressure in the closed loop circuit.
- Every relevant section of the cooling system is protected from overpressure by a relief valve followed by a burst disc.

Absolute pitch vibration measurements

For purpose of measurement of absolute pitch vibration of xtal cage, one interferometer available commercially, with a frequency range of 0-50kHz, will be used during cryo cooling system running and heat load applied.

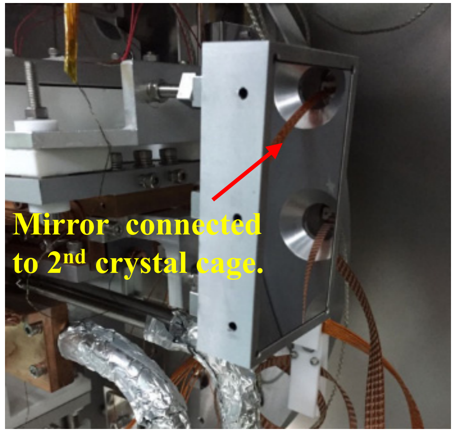


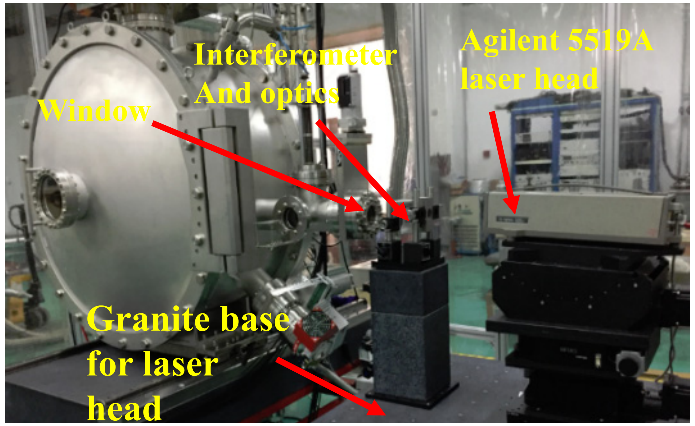
- The vibration of the interferometer is also counted in the final result.
- The air flow of the optical path induce irregular low frequency fluctuation of the measured results. Better to keep the path protected.

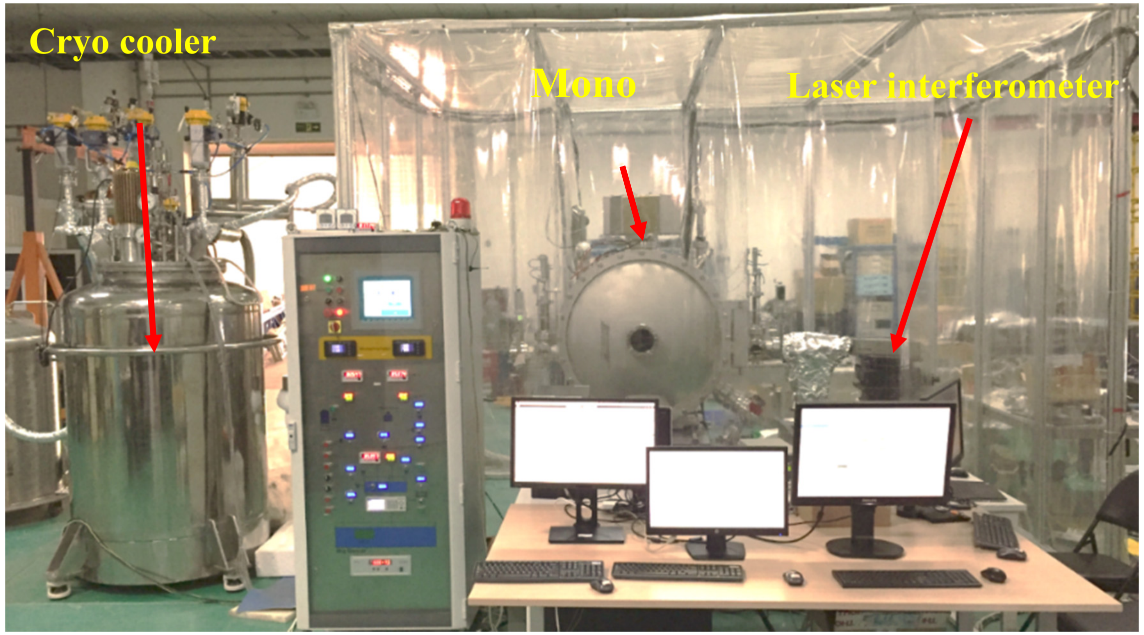
Paw Kristiansen, Jan Horbach, Ralph Dohrmann and Joachim Heuer. Vibration measurements of high-heat-load monochromators for DESY PETRA III extension. J. Synchrotron Rad. (2015). 22, 879–885.

Absolute vibration measurement layout

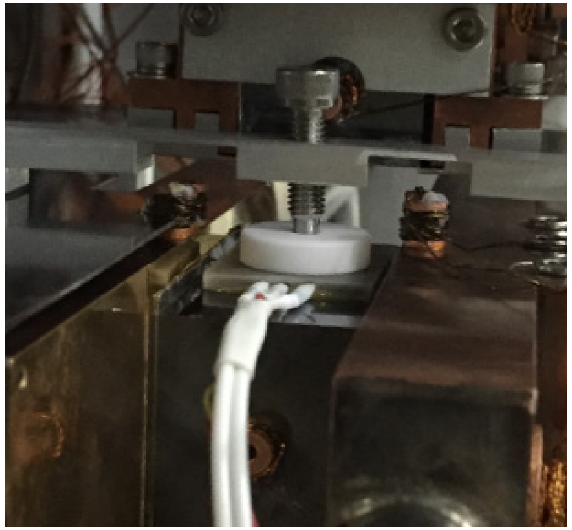
- Mirror in vacuum, hard connected to 2nd crystal assembly.
- Tripod of the laser head was replaced by a granite table after showing 200 nrad RMS vibration result.
- Shock absorber pads from Sorbothane.
- Steel chassis and steel levelers for the mono.
- Steel levelers for the laser head granite table.
- Optical path protected by aluminum foils.
- Big cryo lines hanged by ropes to the roof.

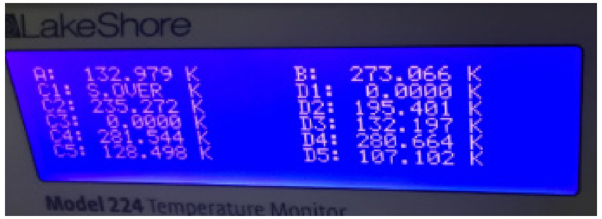


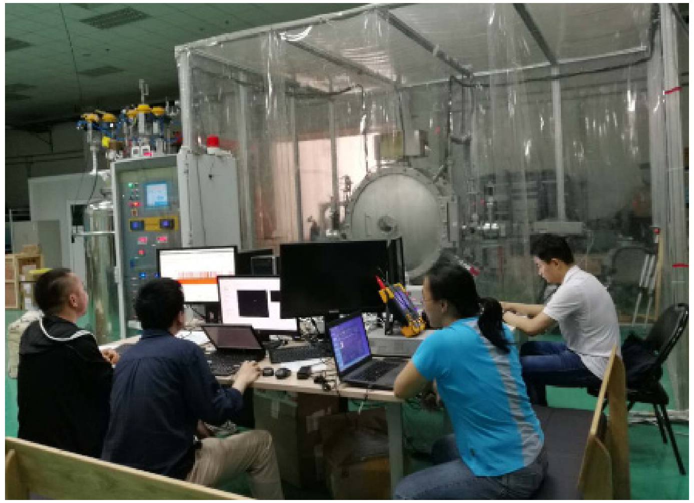




Heat load test

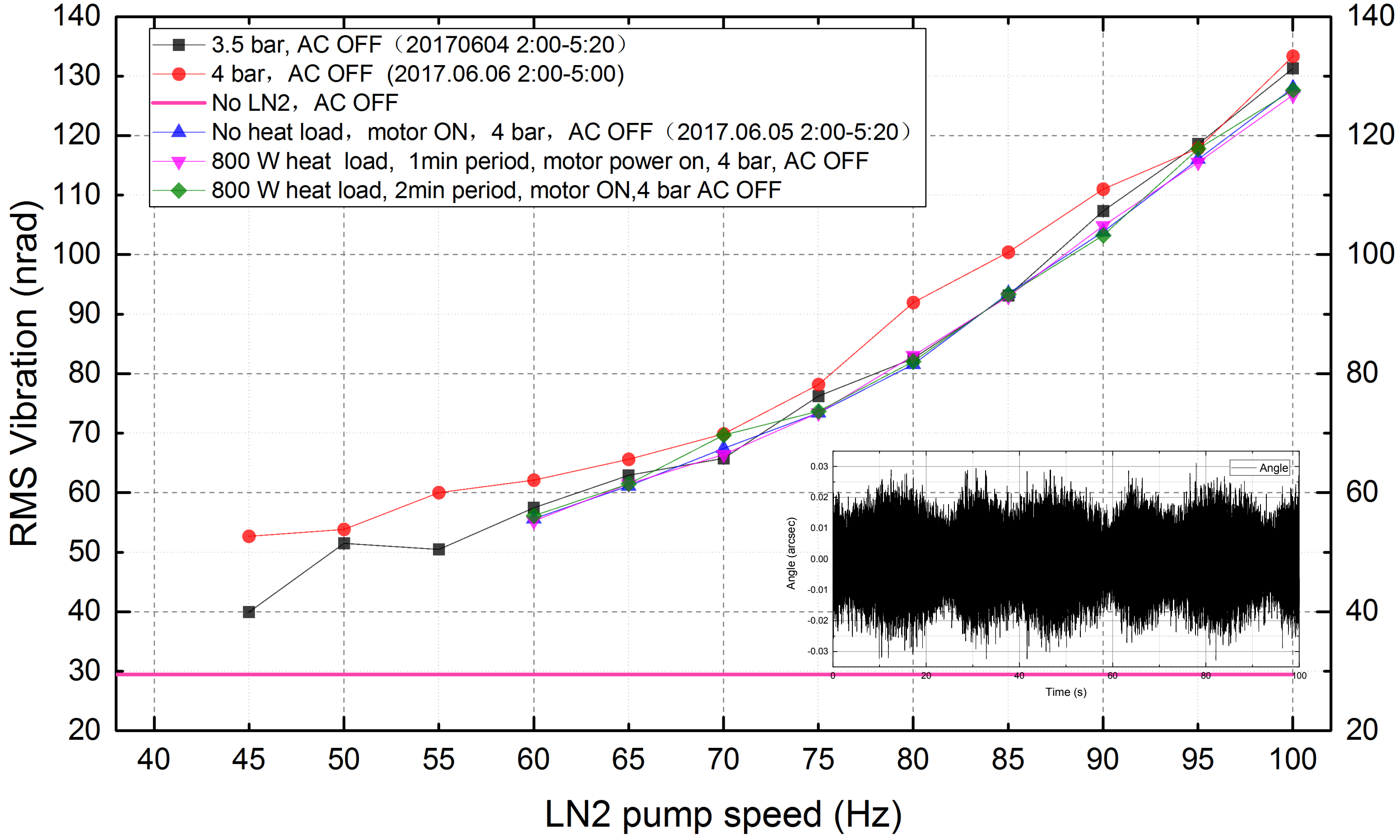


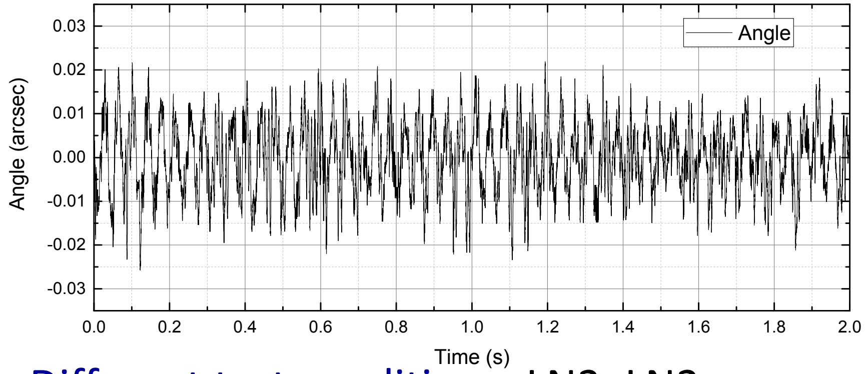




- No beamline up to 800W in China.
- Use ceramic heater from Watlow to see if the cooling works.
- Can not measure deformation due to heater.
- Apiezon N used for good conduction.
- Temperature of heater, crystals, and vacuum are monitored.
- Heat load: 214V*3.9A=834W
- Temperature rise about 21K. Not accurate due to gradient.

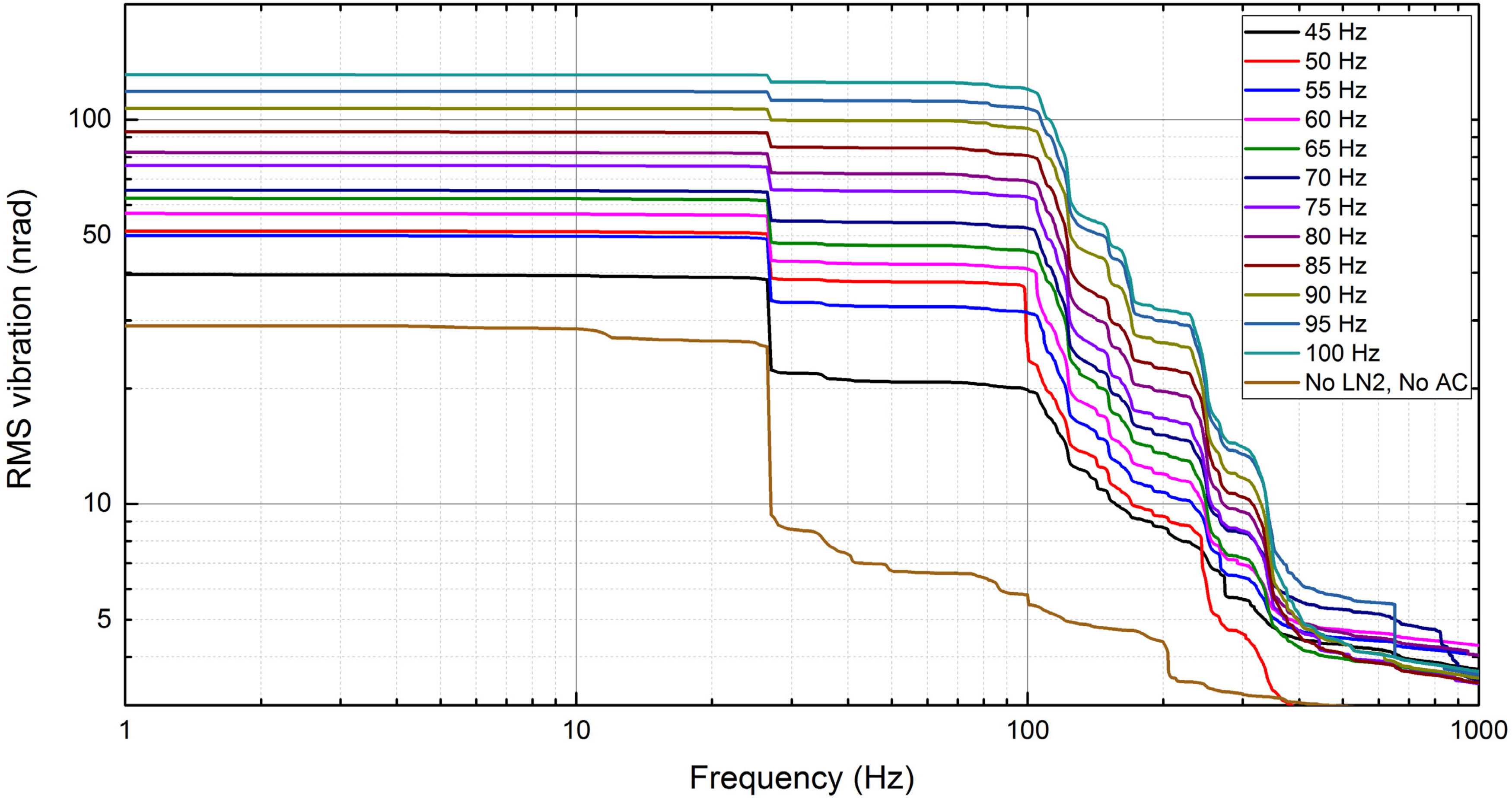
Vibration measurement results





- Different test conditions: LN2, LN2 pumping speed, heat load.
- Sampling rate: 10kHz, 1M points (limited by software) .
- Absolute vibration: 41 nrad (σ) @ 45 Hz of LN2 pump speed (400 watts cooling ability); 55 nrad @ 60Hz, while a heat load of 800 watts was applied to the surface of 1st crystal, indicates no boiling.

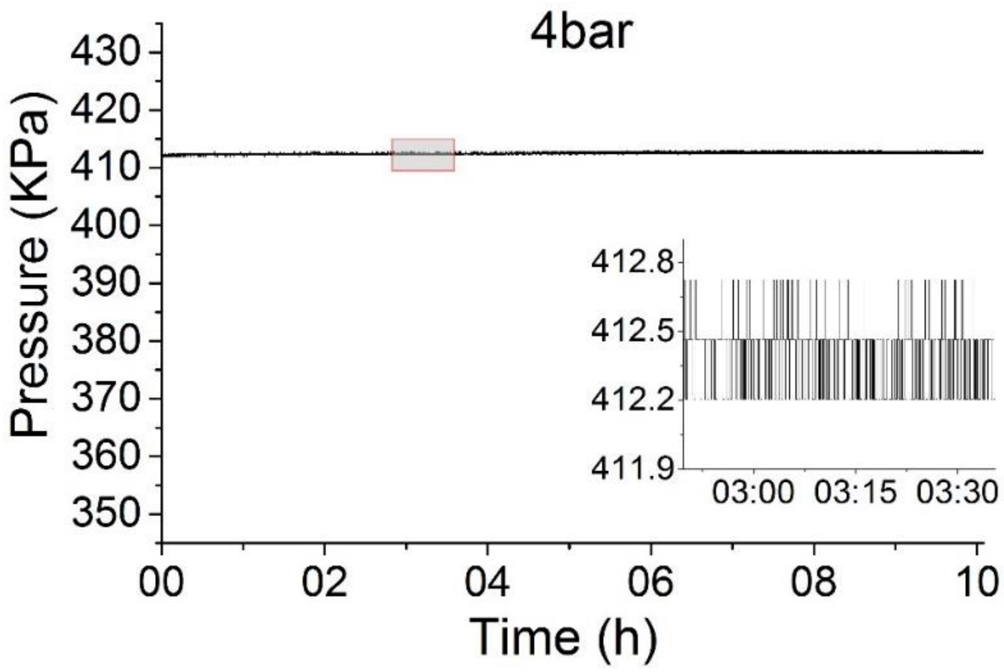
Main frequencies and causes

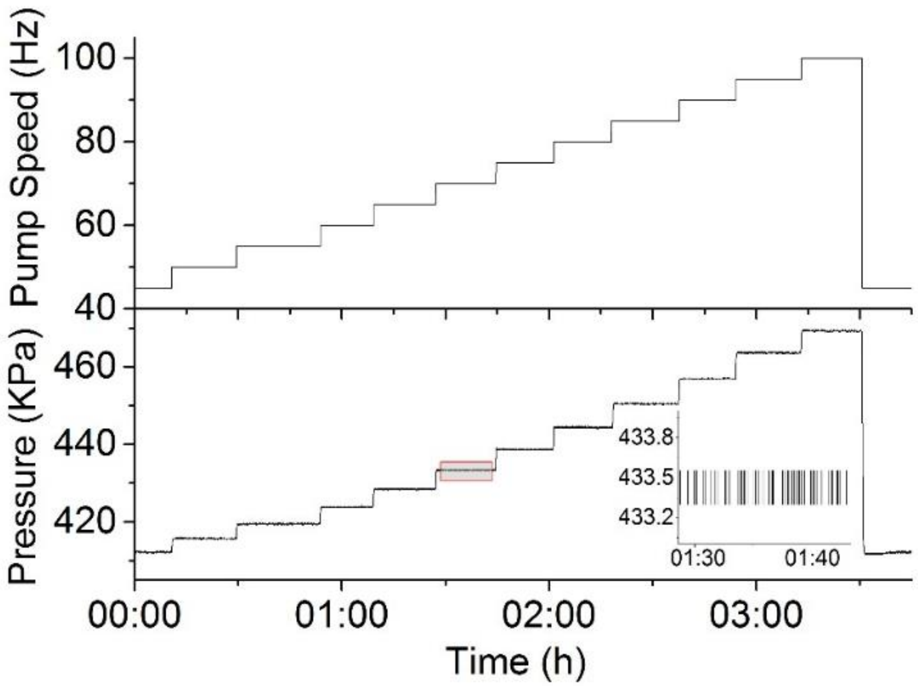


- At 25 Hz: vibration doesn't go up with the pump speed. Maybe a it's a ground motion or from laser interferometer optics.
- At about 110Hz, increased with the pump speed. May consider it the first eigen frequency.
- At about 150Hz, 250Hz, 340Hz is clearly caused by the liquid nitrogen flow.

Pressure stability of cryo cooling system

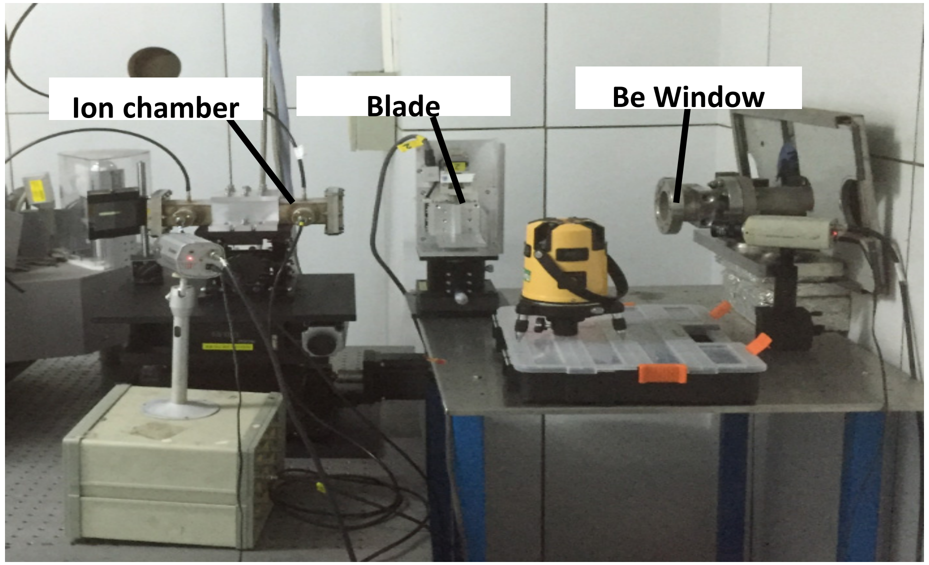
- The cyo cooling system has been running for more than 100 days, which proves reliability.
- Pressure stability is achieved in long (over several days) and short term.
- The measured values of pressure difference stability are in the range of < ±6 mbar (peak to valley) and < 2 mbar (RMS).
- The results are achieved over a wide range of parameters (varying pressure, varying pump speed)

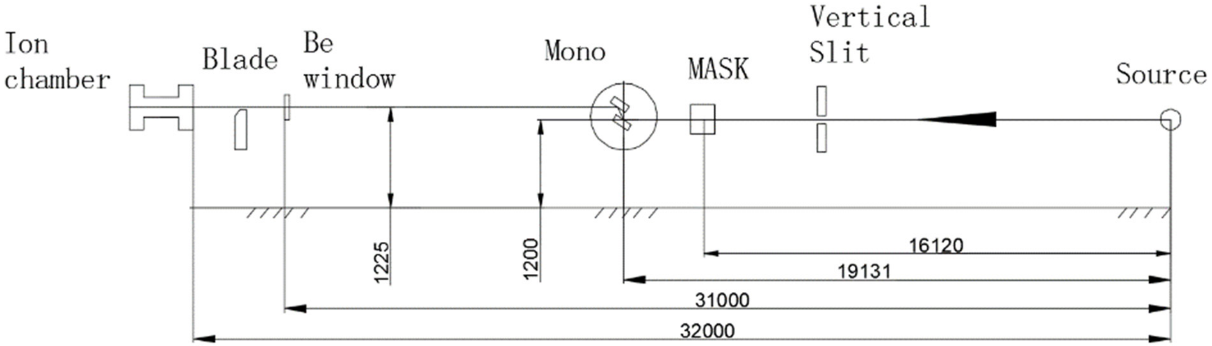




Online tests

- Simple tests to find out if it really works.
- Test Energy range, rocking curve and measure position accuracy of exit beam.
- Total heat load 150 watts by calculation, however only 80 watts measured(temperature rise of LN2).
- Power density 0.706W/mm² @5keV, 0.178W/mm² @ 20keV.





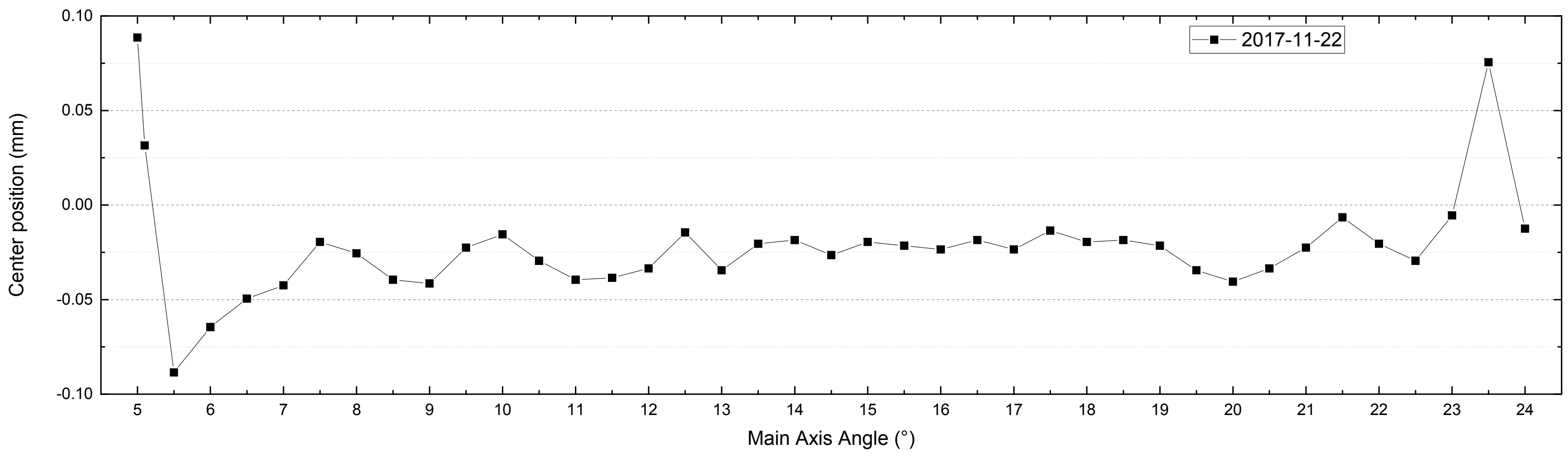
Test beamline layout, at 3W1 beamline of BSRF.

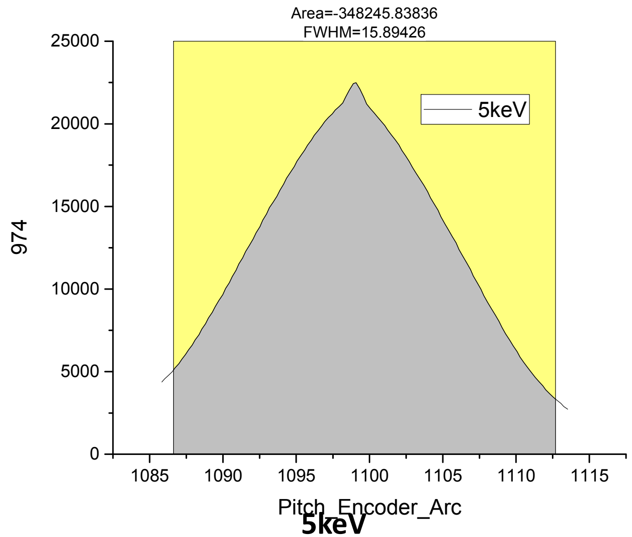
- Energy range was tested by K edges of Ti and Mo.
- Rocking curve signal were recorded by the ion chamber.
- Fixed exit accuracy was measured every 0.5° of bagg angle, then scan with a blade driven by Kohzu stage. The distribution of the beam can be calculated and take the FWHM center as the beam center.

Test results

- Rocking curve measurement by pitch scan of the 2nd crystal.
- Rocking curve slightly smaller than calculated value.
- Peaks from Si<333> can be found.
- Fixed exit in the range of ±0.089 mm (PV) @5-24°. σ = 0.03 mm.

Energy	5keV	8.979keV	10keV	15keV	20keV
Calculated(")	17.78	8.98	7.98	5.19	3.85
Measured(")	15.89	8.79	7.38	4.73	3.35





5keV

(small bump of 15keV diffracted by Si<333>)

Conclusion

- Prototypes of a high heat load DCM and cryo cooling system were proposed and developed.
- FEA results shows the DCM is capable of cooling 800 watts heat load. Ceramic heater were used for 800 watts cooling test with no boiling.
- Off line stability test:
  - DCM 2nd Xtal stability around 40nrad RMS @ 45 Hz of LN_2 pump speed.
  - Cryo cooling system pressure stability < 2 mbar (RMS).
- Online results shows it works (cooling, basic functions and crystal mounting).
- Generally it showed the expected performance and gained our experience.
- Lessons: should learn more from the community, good cryo lines, etch the crystal, careful with mounting, be careful with the sensors, good control software, etc.
- Cost: huge amount of manpower. On the money side is more or less the same.
- Further improvements:
  - Granite chassis? Vibration isolation of cryo lines, ACs, water pumps (25 Hz?). Lower speed of LN2 pump. Better floor. Temperature control. Air bearing?
- Suggestions?

Acknowledgements

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- The community.
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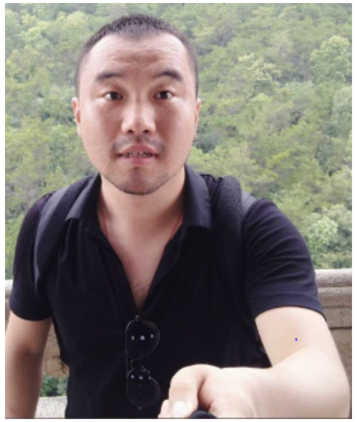
- JJJ vac for their support during fabrication phase.
- BSRF colleagues who helped a lot during all phases.

Weifan SHENG
Supervisor

Aiyu ZHOU
Control Engineer



Yongcheng JIANG
Cryogenic Engineer

Hao LIANG
Mechanical Engineer

Lidan GAO
FEA Engineer

Yaxiang LIANG
Control Engineer

The end

Thank you for you attention.