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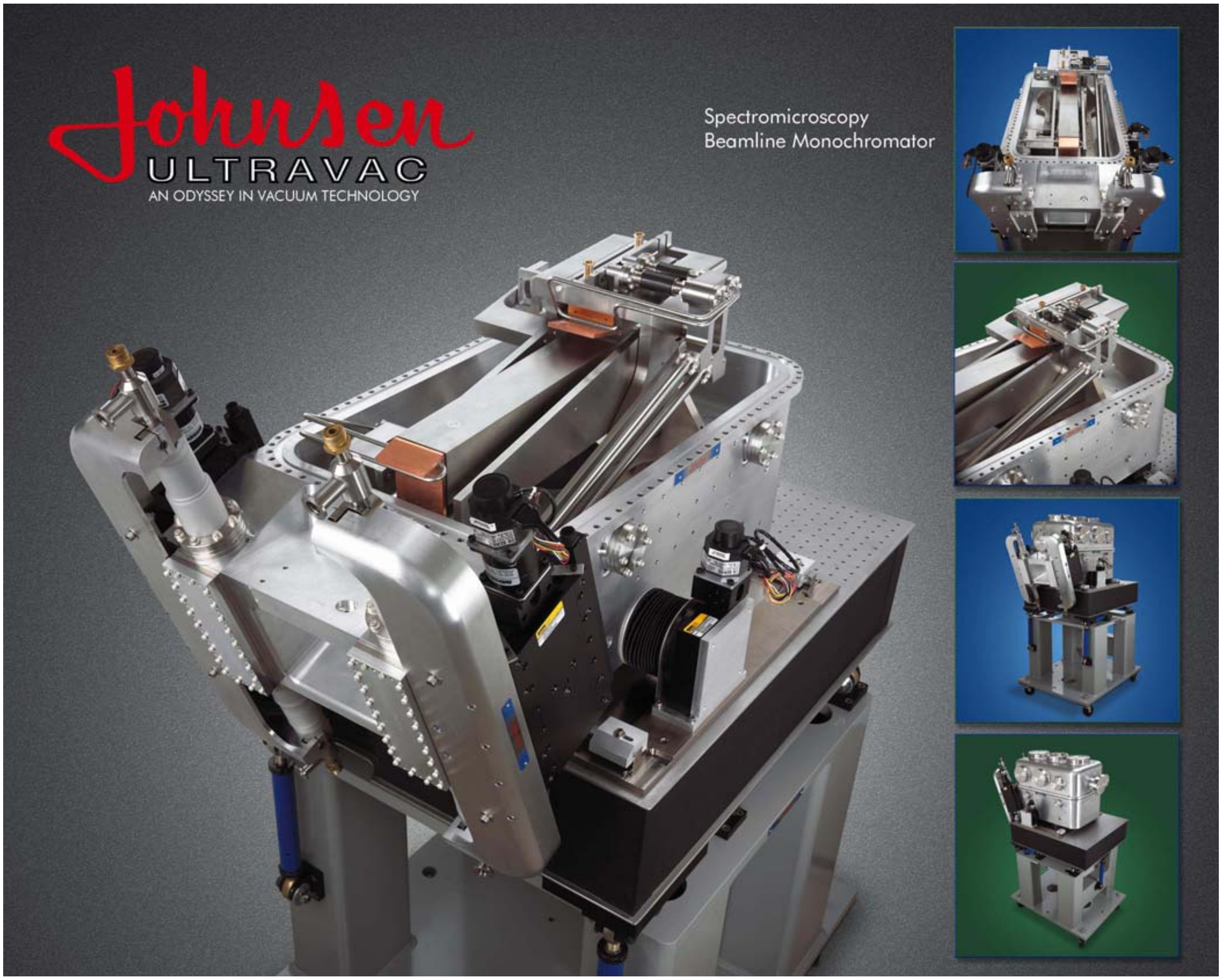

Production stage photo of JUV Monochromator (shown with lid removed and installed dummy optics).

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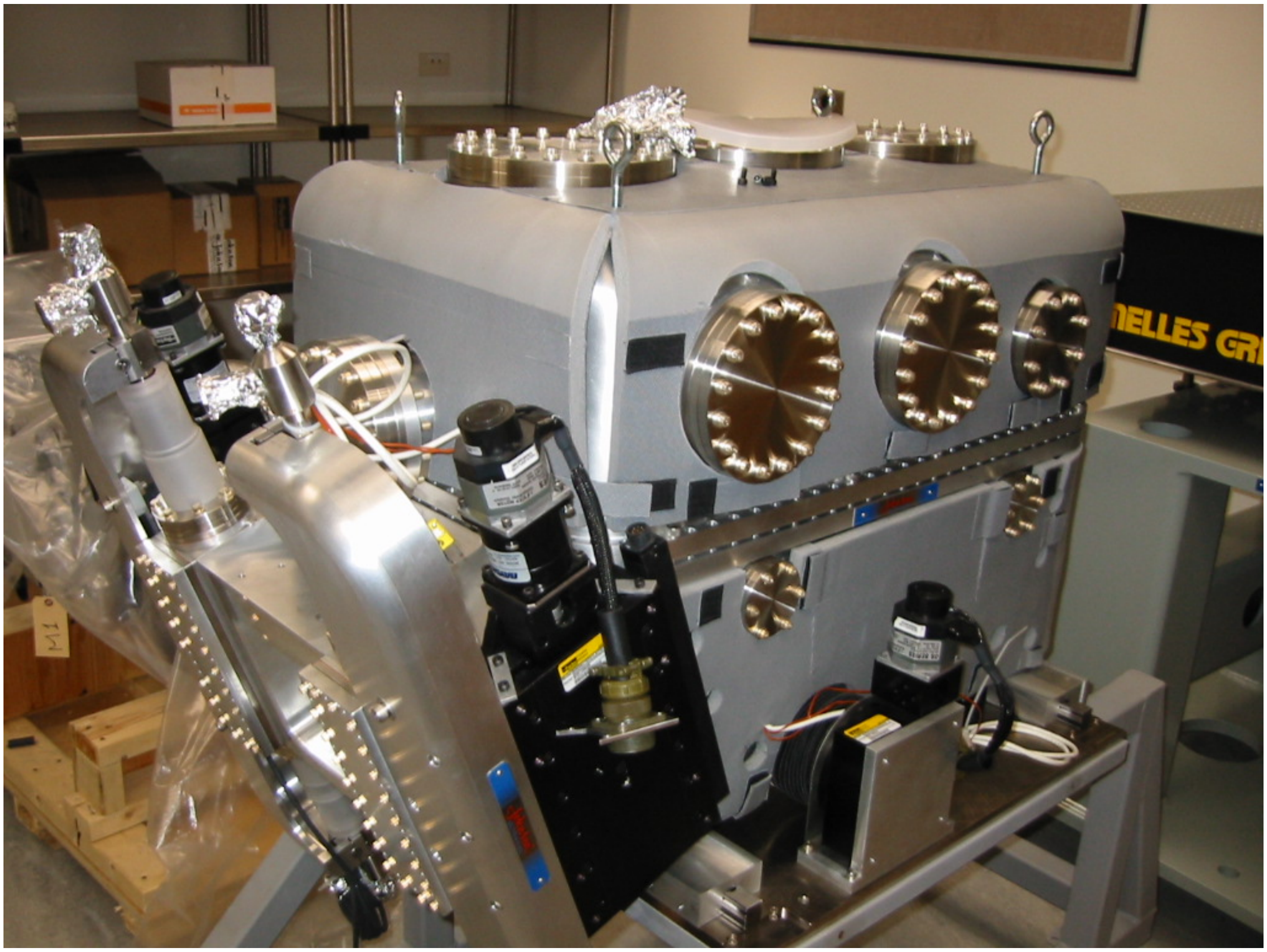
Technical Description of The JUV PGM

JUV Soft X-Ray Plane-Grating Monochromator
Specification/ Description of System Components



1. <u>General Description</u>

A monochromator module is a genetic plane mirror – plane grating scanning unit. It is specifically designed for a soft x-ray energy range and intended to be used as a part of synchrotron beam line at a third generation SR source, where high heat load, energy resolution and calibration stability are the most demanding. PGM scanning mechanism consists of two, fixed-axis rotation scanners that can independently control the rotation of the plane mirror and the grating using external linear stages.

The monochromator dispersion plane is vertical with incoming and outgoing light horizontal and offset by 15.0 mm. The accuracy and reproducibility for each movement are to exceed 0.4μrad. Such resolution and reproducibility of the mutual movements are essential to satisfy the 10 000 resolving power, although details depend on a particular beam line design.

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The internal water cooled mirror is 80(w)*450(l)*75(th)mm, internal water cooled grating has 76(w)*168(l)*50 (th)mm substrate and might have up to three different groove regions etched in. Optics can be procured separately or from a Johnsen Ultravac (JUV) recommended supplier. The scanning mechanism has the following limits:

- mirror angle range = +0.5 to +5 deg. to horizontal,
- grating angle range = -0.5 to +7 deg.

These limits are compatible with a photon energy range of 75-2000 eV, accessible in both negative and positive order. Modification of a mono scanning unit for a different scanning range is possible, as well as an implementation of different optical mono design principles such as: plane mirror- spherical grating mono, variable line spacing monochromator or their variations.

The mono has a 1.2 (along the beam)*0.9 (sideway)m^2 footprint, the beam height at 1.4m. Its operation requires main electrical, stabilized water and low vacuum service lines, as described below. The mono is rated to 10^{-10} Torr operation pressure and is bakeable up to 150C with built-in heating jacket. The mono Control System provides the operation of three stepper motors, read out of optical encoders and energy calibration and ensures a safe operation of mono. As a mono control system is usually a part of a beam line operation system, JUV can supply the drivers for various components, a total custom-made operation system or is willing to collaborate with customers on the design of their own operational system, if preferred.

1) Optical Design and Principle of Operation

Following the successful design and implementation of SX-700 at Bessy [H. Petersen, Optical Com. 40 (19982), p.402], a plane grating monochromator becomes a mono of choice for a soft x-ray range at different SR centers.

A third generation SR source offers both small electron beam size and at the same time, high position stability. The slit-less design, combined with infinity corrected pre-optics further improve PGM optical performance. Different (cff, energy) operation curves, optimized for high order suppression, high throughput, or ultimate energy resolution can be dynamically changed depending on experimental need. Such a versatile approach gives a new “universal” character for soft x-ray beamline design [R. Follath, F. Senf, NIM A 390 (1997), p.388-394] and is successfully implemented at several SR labs.

Ideal PGM operation requires a synchronous scan of the grating around the horizontal axis passing through its pole, accompanied by a plane mirror translation and rotation, in such a manner that the incoming beam, after reflection by the plane mirror, will always illuminate the center of the grating. The plane mirror movement can be further simplified as a pure rotation of a lengthier mirror around horizontal axis offset with respect to the grating axis [A.V. Pimpale, S.K. Deshpande, V.G. Bhinde, Applied Optics 30 (1991), p.1591-1594]. In this case, there is a beam wiggling at the grating, and therefore an associated energy shift. The choice of two axis offset defines the energy range, where such a shift is kept to a minimum. The JUV mono has two axis vertically displaced by ~7.5mm, and associated energy shift is smaller that 10meV for the entire energy range.
To extend the operation to 75-2000eV the mirror optical length is enlarged to 420mm, the grating -150mm and intercepted SR ray pupil is not smaller than 15 (h)*5(v) mm. This is consistent with undulator based beam line design, but a modification for band magnet radiation is possible. As the optics are 75mm wide, up to three grooved strips can be fabricated on a single grating substrate to optimize grating efficiency and dispersion. 3” side movement of PGM chamber is used to illuminate different grating regions.

As the mono becomes closely integrated in beam line design, the optical performance is defined by overall optical scheme. For both CLS and ALS beamlines, where such mono was implemented, the energy resolution has been

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limited by aberrations of refocusing mirror, rather than of mechanical design of mono. Resolving power of >7500 has been demonstrated for N edge with power load of 500W.

Plane mirror technical specification

Substrate: Internally water-cooled brazed assembly
Material: Si
Physical dimensions: 450(l)*80(w)*75(th) mm.
Cooling: 32 channels combined into 4 groups of 8 channels each with a channel width/ height of 1/5mm machined in a face plate. The hot wall thickness is about 1.5mm.
Clear aperture: 420 mm * 70 mm
Finished polishing (with hardened Ni ad layer) slope errors (RMS):
Tangential (along lengthier edge): 0.5µrad
Sagittal (along shorter edge): 10µrad
Microroughness (RMS): 0.5nm
Optical coating: Pt; 60nm+/-5nm

Grating technical specification

Substrate: Internally water-cooled brazed assembly
Material: Glidcop
Physical dimensions: 168(l)*78(w)*50(th) mm.
Cooling: 8 channels, 3.1mm (width) *9.6mm (height), with remaining hot wall ~4mm thick.
Clear aperture: 158 mm * 66 mm
Finished polishing (with hardened Ni ad layer) slope errors (RMS):
Tangential (along lengthier edge): 1µrad
Sagittal (along shorter edge): 15µrad
Microroughness (RMS): 0.8nm
Three pattern strips, with ruling direction along the short edge. Strips (groove direction) should be parallel within 0.5mrad accuracy.

	Grating pattern I	Grating pattern II	Grating pattern III
Effective area	158 mm* 20 mm	158 mm* 20 mm	158 mm* 20 mm
Groove density	1250 lines/mm+/-5%	500 lines/mm+/-5%	250 lines/mm+/-5%
Groove uniformity	smaller that 10^{-4}	smaller that 10^{-4}	smaller that 10^{-4}
Groove profile	lamella	lamella	lamella
depth	6 nm+/- 0.8 nm	14 nm+/- 1.5 nm	30 nm+/- 3.0 nm
land width (top) to groove period ratio	40%+/- 5% (groove bottom width ~500nm, groove top width~333nm).	30%+/- 10% (groove bottom ~1400nm, groove top (land) ~600nm).	35%+/- 3% (groove bottom (land) ~2600nm, groove top ~1400nm)
Coating	gold 50nm+/-5nm	gold 50nm+/-5nm	nickel 50nm+/-5nm

2) Mechanical Design

The Plane Grating Monochromator consists of:

- an L shaped invar frame, which holds two cradles with flexures
- sine bars (short for mirror and long for grating on the other side of the frame) connected to linear stages with water cooling tubes running along the sine bars
- vacuum chamber base, which holds the L-shaped frame
- two C-shaped yokes, attached to linear stages
- chamber lid, which is sealed against the chamber base with a Helicoflex seal
- two linear optical encoders, outside of main vacuum chamber
- the translational stage, which mounts on the vacuum chamber bottom and provide a side translation of the entire vacuum chamber to access different groove regions of the grating
- the PGM stand, which holds the entire PGM assembly with an adjustable 6 strut system.

Other auxiliary systems include the Ion Pump with Ti sublimation pump build in, motors with encoders and travel limit switches, outside water supply lines for cooling the grating and mirror, zero order baffles and permanently mounted bakeout jacket.

2.1 PGM Chamber and Vacuum Components

The scanning unit is housed in rectangular shaped custom made aluminum chamber ~480(w)*760(l)*520(h)mm. 175mm thick bottom plate provides a structural rigidity to the mono scanning frame. There are two ports for grating and mirror sine bars protruding forward and covered by rectangular shape (VAT type) flanges. Base of Parker Daedal linear stage 806010CTEPD1L2C7M1E1 is side mounted directly to mono body and drives C shape yoke up and down. Heidenhain optical linear encoder is mounted underneath C yoke and gives a precise measurement of such translation. For further reduction of minimum step size the stages are equipped with a Parker Zenith Gearbox NEN023-010.

There are five CF flanges in mono base. One side mounted 2 ¾" OD CF flange is used for roughing valve, three other flanges are blanked. Fiduciary marks for mono initial mono alignment are machined directly into the mono base. Initial roll alignment of mono body can be verified by single axis protractor mounted upstream (mounted alignment plate is supplied). Bottom mounted 8"OD CF flange is coupled to flex below and used for ion pump mounting.
The mono base is mounted on custom made Melles Griot Optical Table with KO Rails and Linear Rollers LRWH25C2R660T1SP. Kuroda GP series Ball Screw GP1205DS-BALR-0300B-C3S coupled to a Parker Daedal Rotary stage 20505RTEPH1C4M1E1T3 provides a precise side shift in the range of +/-1.25".

The top part is designed as a removable lid and provides an easy access to mono internal parts.

There are four lift hooks provided to facilitate lid removal. There are three 8"OD CF flanges (one with glass window, two blanked) for mirror visual inspection, four side mounted 6"OD CF flanges,
and three 4 ½"OD CF flanges, which can be used to install complimentary optical diagnostic and vacuum equipment.

Entrance and exit flanges are 6" OD CF. The top and bottom parts are sealed by Heliflex aluminum gasket, placed in a polished groove and guided to its place by four pins. JUV recommends a temporary use of a Viton O-ring for testing and shipping. Spare Garlock Helicoflex gaskets could be supplied by JU, or purchased directly from BF Goodrich.

A DIVISION OF JOHNSEN MACHINE COMPANY LIMITED

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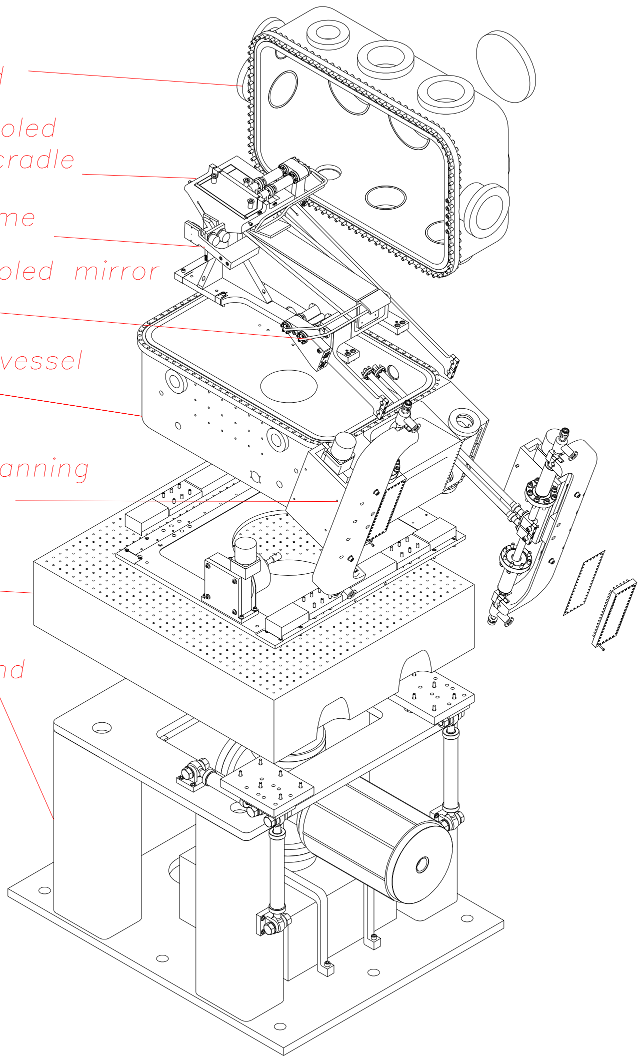

Zero- order stop is a fixed water cooled copper mask with opening 15(h)*68(w)mm, built as 6"OD CF spool mounted on the PGM exit flange. A 90 degree viewport can be used to attach a CCD camera.

A six strut system has +/-10mm travel range to adjust the mono height and keep it horizontal.
Standard vacuum components included in the mono supply are: 500 l/s Varian Star Cell combination ion pump with Ti sublimation unit, UHV gauge and 2 ¾"OD CF all metal angle valve for bakeout.

The vacuum equipment can be ordered with mono or procured separately.

Bake out system includes 1.5 (bottom) and 1.1(lid) kW 110VAC permanently mounted heating jackets and programmable control unit.

2.2 Mirror & Grating Scanning Unit

To prevent temperature variation, minimize vibration and enforce rigid geometry, the mirror and the grating cradles are mounted on an L-shaped invar frame. Its long side is pinned close to the location of translational stage to minimize the distance to outside mounted optical encoder. Another side (base) of invar frame is left free to slide with build-in flexure. Flexural pivots provide backlash free up to +/-10^o rotation of optic cradles. To keep two rotational axis collinear flexural pivots are aligned and pinned on a special cam adjuster.

C shape yokes provide a rigid envelope for a drive shaft. Two shafts enter vacuum from above and below with identical bellows to eliminate the vacuum load on a drive mechanism. Drive shafts are coupled to the sine bar through the flexure to enforce a rigid mounting of the sine bar. Water lines go inside the shafts and along the sine bar.

Water manifolds are rigidly mounted to the optic cradle rather than optics to minimize its influence. Special compensator designed on a water line seal inside the bellows assembly eliminates the water pressure stress applied directly to the optics. To prevent water to vacuum leak, water lines are enclosed into low vacuum (air)-guard. Low vacuum (better that of 100mtorr on intake) oil free line shall be directly connected to KF16 at C-yoke ends. Water lines are terminated with Swagelock.

The mono performance at high heat load is defined by a thermal elastic deformation of the optics and by the efficiency of the cooling scheme. The internal water cooled optics are chosen for their uncompromised performance. It is recommended to use a dedicated chiller with 0.1 degree stabilized water and two separate circuits. The plane mirror water cooling line consumes up to 2G/min, the grating – 1.5G/min. Pressure drop for plane mirror circuit is 65psi and grating is 50psi. This water flow should provide an adequate cooling for 150W off mirror applied power. The resulting energy degradation depends on (cff, energy) setting, but calculation suggests the resolving power should not degrade below 4000.

A long arm of the sinus mechanism (~720mm) combined with optical linear encoder (4μ period, 50x fold divider) gives an ultimate angular resolution of 0.1μrad. The reproducibility measurements (against ZYGO interferometer) reconfirm high stability of angular travel with error smaller that 0.4μrad. It was also found, that deviation from absolute calibration remains stable and do not exceed 15μrad, which is mainly due to the absolute accuracy of the optical encoders (+/-3μ) and elastic strain in flexures (~10μ). The resultant energy shift in absolute calibration, as shown by ALS commissioning experience, stays within 100meV and can be further corrected.

The water-cooled plane mirror and the water-cooled plane grating are mounted inside their respective cradles. The plane mirror optical surface is face up, a typical scanning angle is 1.5 to 5 degrees with middle travel position set to 2.5degree. The mirror may also be moved parallel to the horizontal plane as needed for initial alignment.

A three “ball in groove” mounting provides a stress free support of the optics and freedom for initial alignment. The grating surface is facing down, and grating scanning angle make a full swing of -0.5 to 7 degree.

As all gratings are patterned on the same substrate, there is no need for their mutual mechanical alignment. The remaining alignment of the grating dispersion plane is done by stressing the built in flexure (yaw rotation) of the stage and needs to be reconfirmed with laser light prior to an operation. Side shift of entire PGM vessel changes the grating.

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The roll was found to be smaller than 20μrad and ensures energy reproducibility between grating changes better that 100meV.

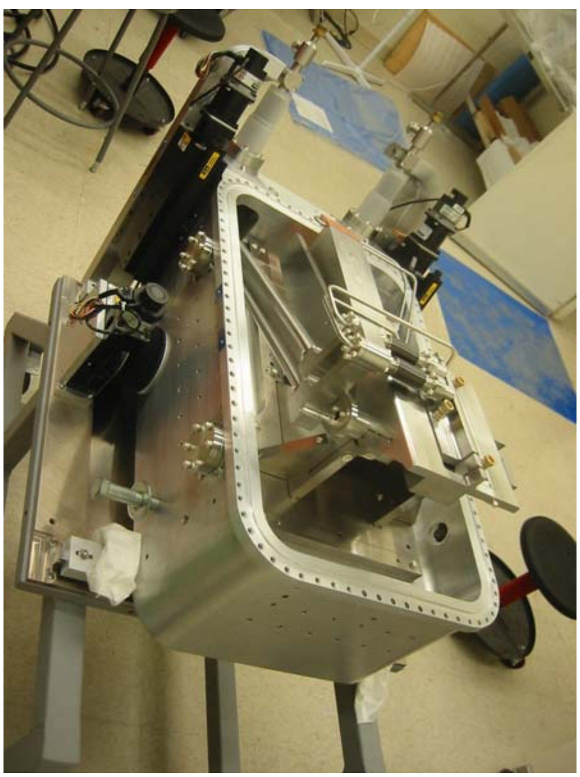
3. Control System and Actuation

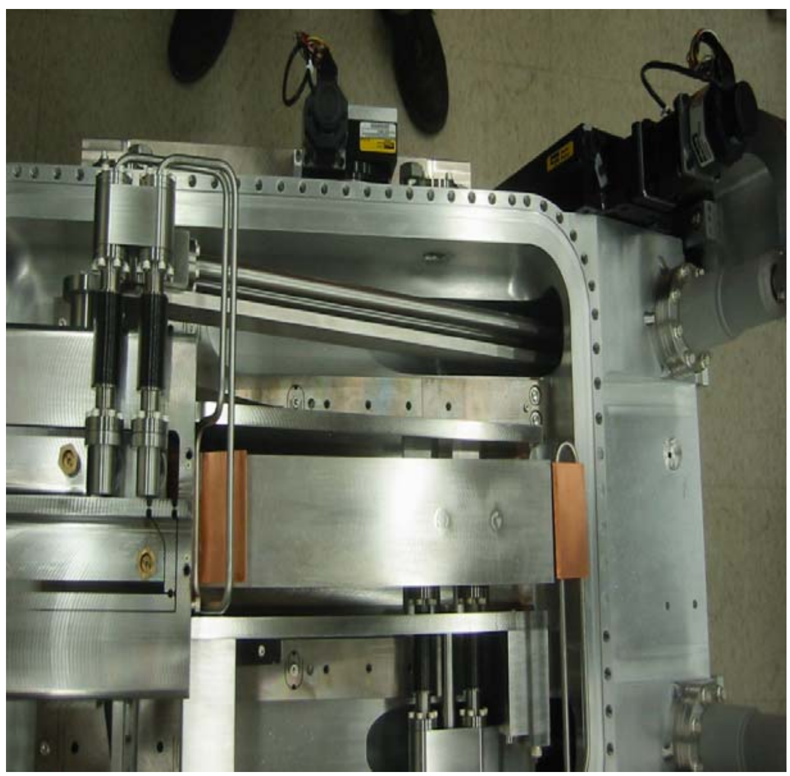
All (three) motors are Parker Model OS21A-DNFL-YRE Size 23 stepper motors with rotary encoders. They require a two phase stepper motor control system with microstep capability, rated for 75VDC, up to 3A output. The stages are equipped with end of travel electrical switches and mechanical hard stops, which preclude mirror-to-grating or optic-cradle-to-mono-body touch.

The customer will need to make fine adjustments of protective stops after final optic installation and angle to stepper motor calibration, which also depends on the stepper motor control system choice.
Two optical LF 481 150mm scales from Heidenhain equipped with IBV 650 digitizing unit will be provided for linear measurement of angular travel of mirror and grating. An additional 5VDC power source for digitizing unit and I/O unit to count TTL pulses could be supplied to complete the mono control system.

The protective equipment could include calibrated water flow switches, vacuum controller and stand alone bakeout system. JUV can supply a complete control system with software for further integration with beam line control system, or individual components for start-up testing and compliance verification test upon special request.

4. Photo Gallery





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