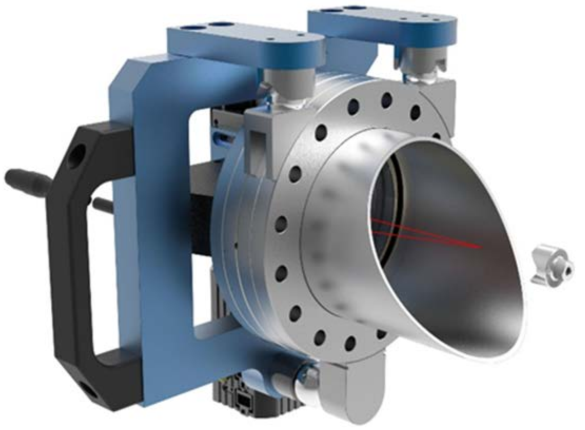
A PRECISION 2-D LASER SCANNER FOR MEASUREMENT OF THERMAL SHIFT IN SUPERCONDUCTING DEVICES



William G. Jansma,
Joel D. Fuerst, Kurt A. Goetze

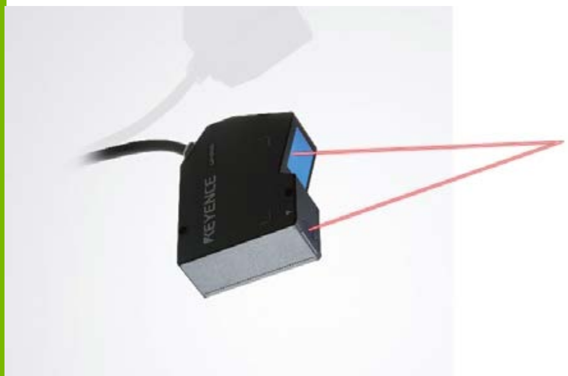
Argonne National Laboratory

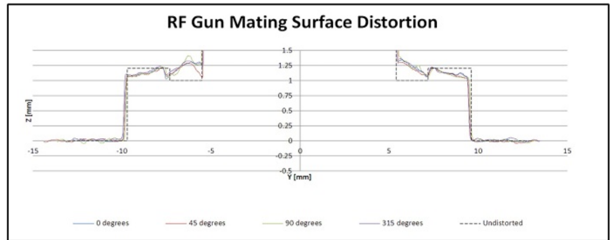
IWAA 2018 8-12 October 2018 Fermilab, Batavia, Illinois, USA

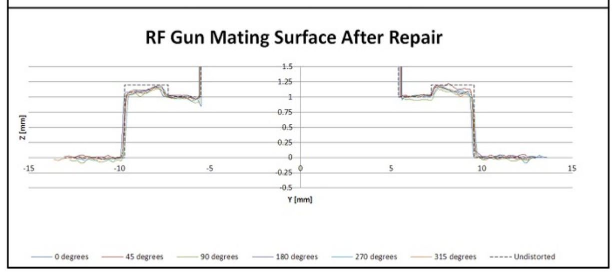
ARGONNE NATIONAL LABORATORY

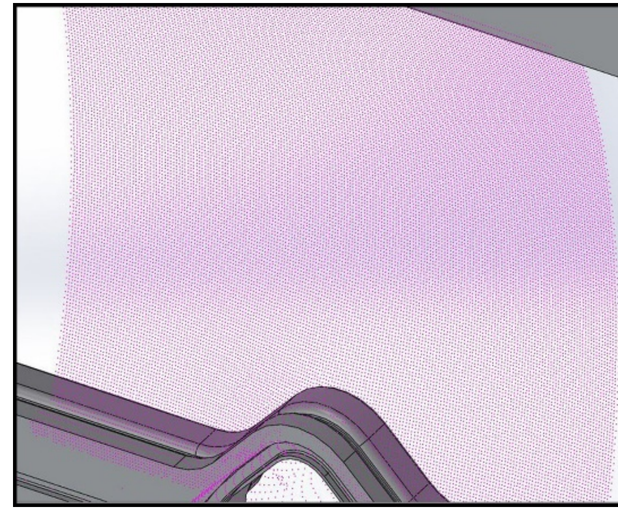
- First US National Laboratory – Established 1946
- Multi-disciplinary facility operated by UC-Argonne, LLC for the U.S. Department of Energy.
- Focus on basic science research, energy storage and renewable energy, environmental sustainability, and national security.

BASIC 2-D SCANNING



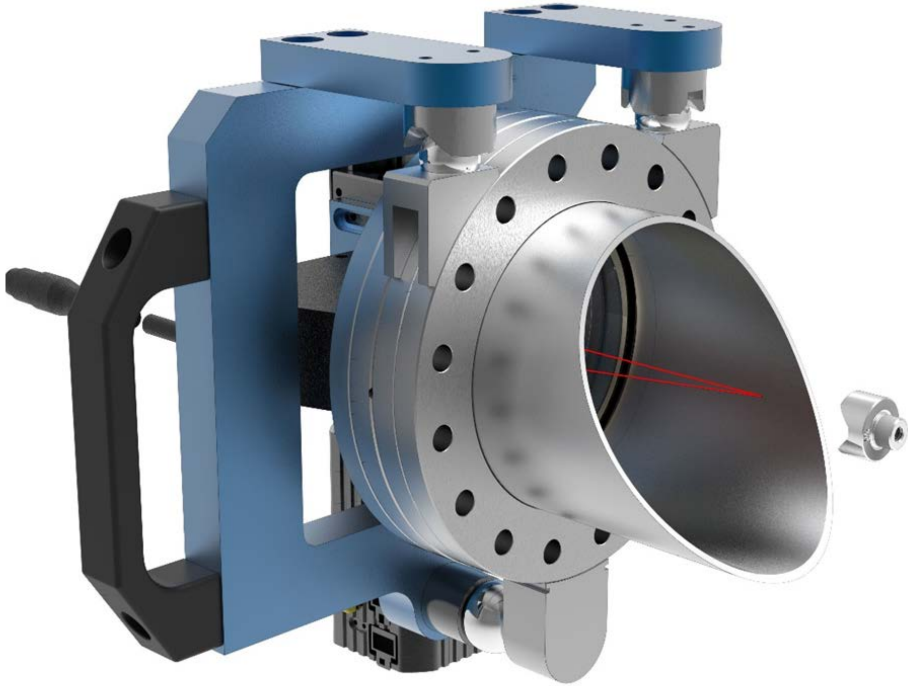




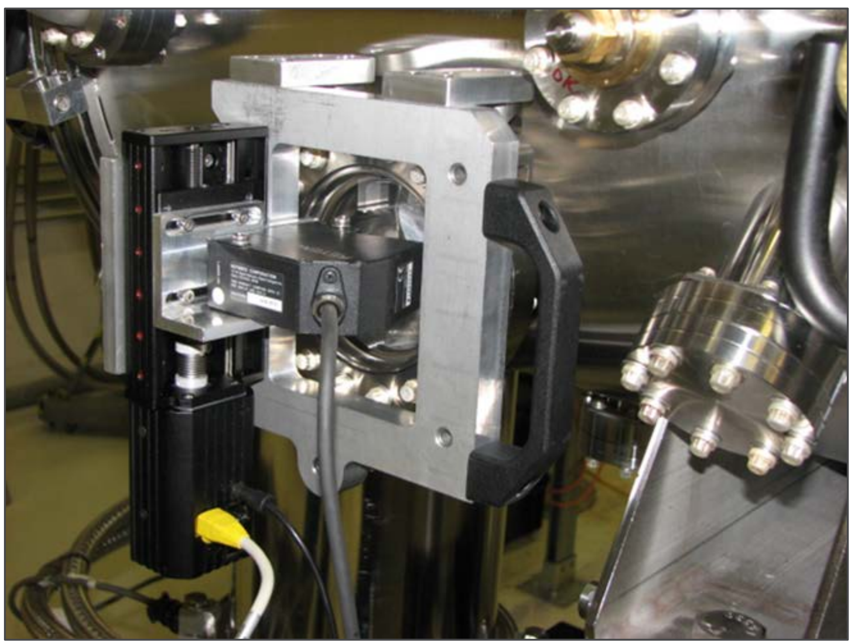


- 2D laser scanning method developed at the Advanced Photon Source (APS) – first application in 2010
- Low-cost, simple design
- Laser displacement sensor (LDS) mounted to a motorized linear translation stage.
- LDS translated in a move-stop-read routine; LDS displacement measurements (X), and position along translation (Y); combine to produce 2-D coordinates (X, Y)
- 3D measurement accomplished by adding second orthogonal translation stage
- <5 μm resolution has been achieved

CRYOSCANNER



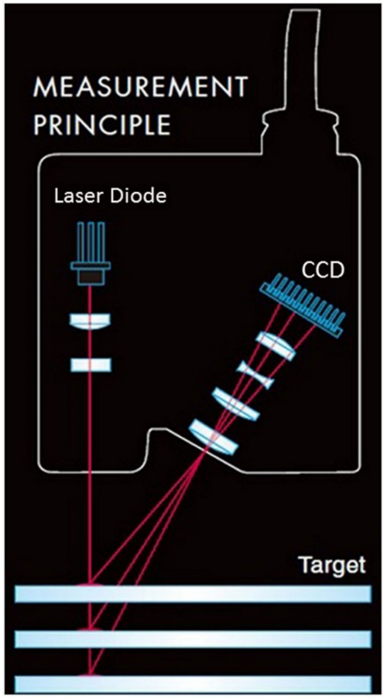
- Compact, portable 2-D CMM to measure thermal shift in SC devices
- Measures relative displacement of components inside a cryostat vacuum vessel through glass viewports.

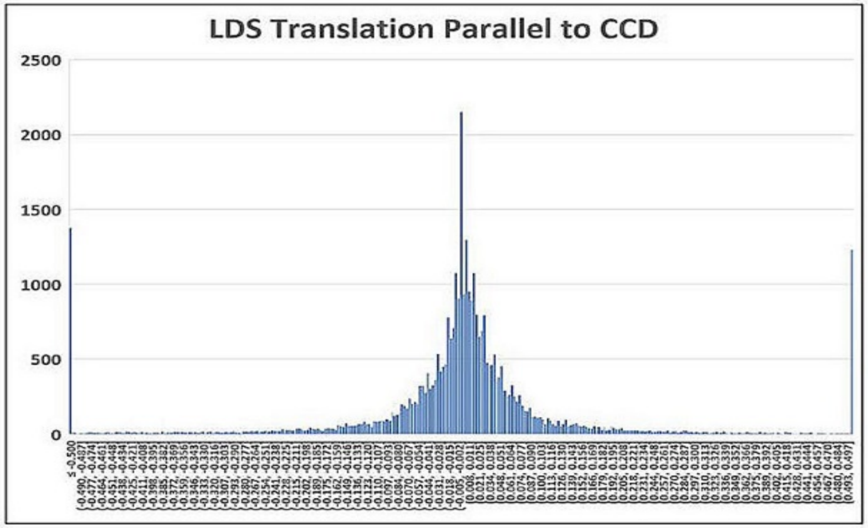


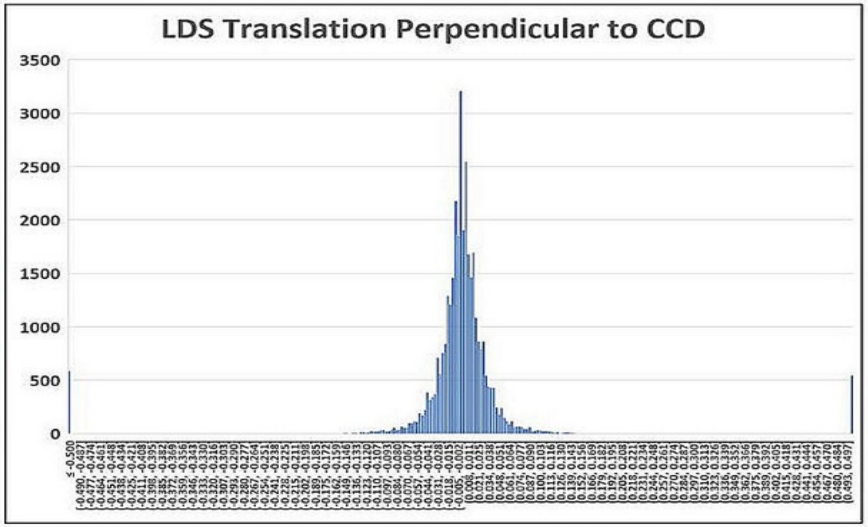
- Acquires 2-D coordinates from several locations – displacement information in up to six DOF.
- Laser tracker measurements record the 3-D coordinates of each instrument and target location with respect to the vessel.

LASER DISPLACEMENT SENSORS

- Keyence LK-G series LDS
- Various ranges, resolutions, settings
- Diffuse or specular surface reflectivity
- Measures through glass
- Measures transparent object surfaces
- Displacement information, not absolute measurement
- Translation is perpendicular to CCD axis; Parallel translation physically moves CCD in direction of pickup axis
- Histograms compare distribution across >35,000 samples for different LDS orientations

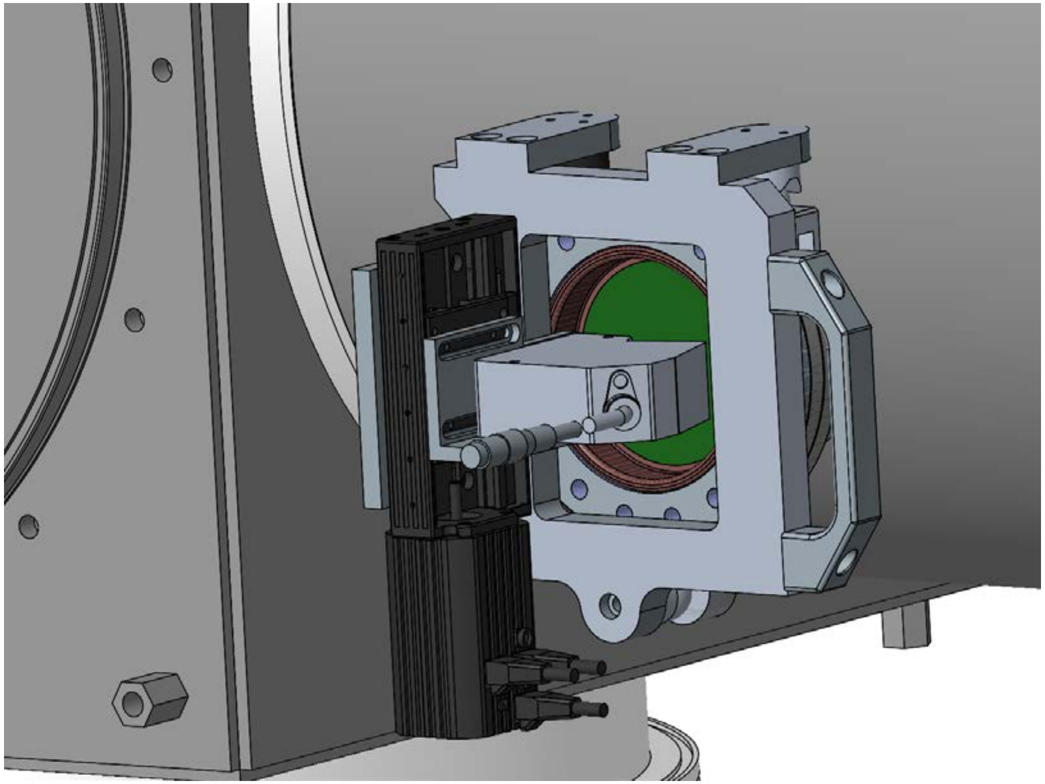




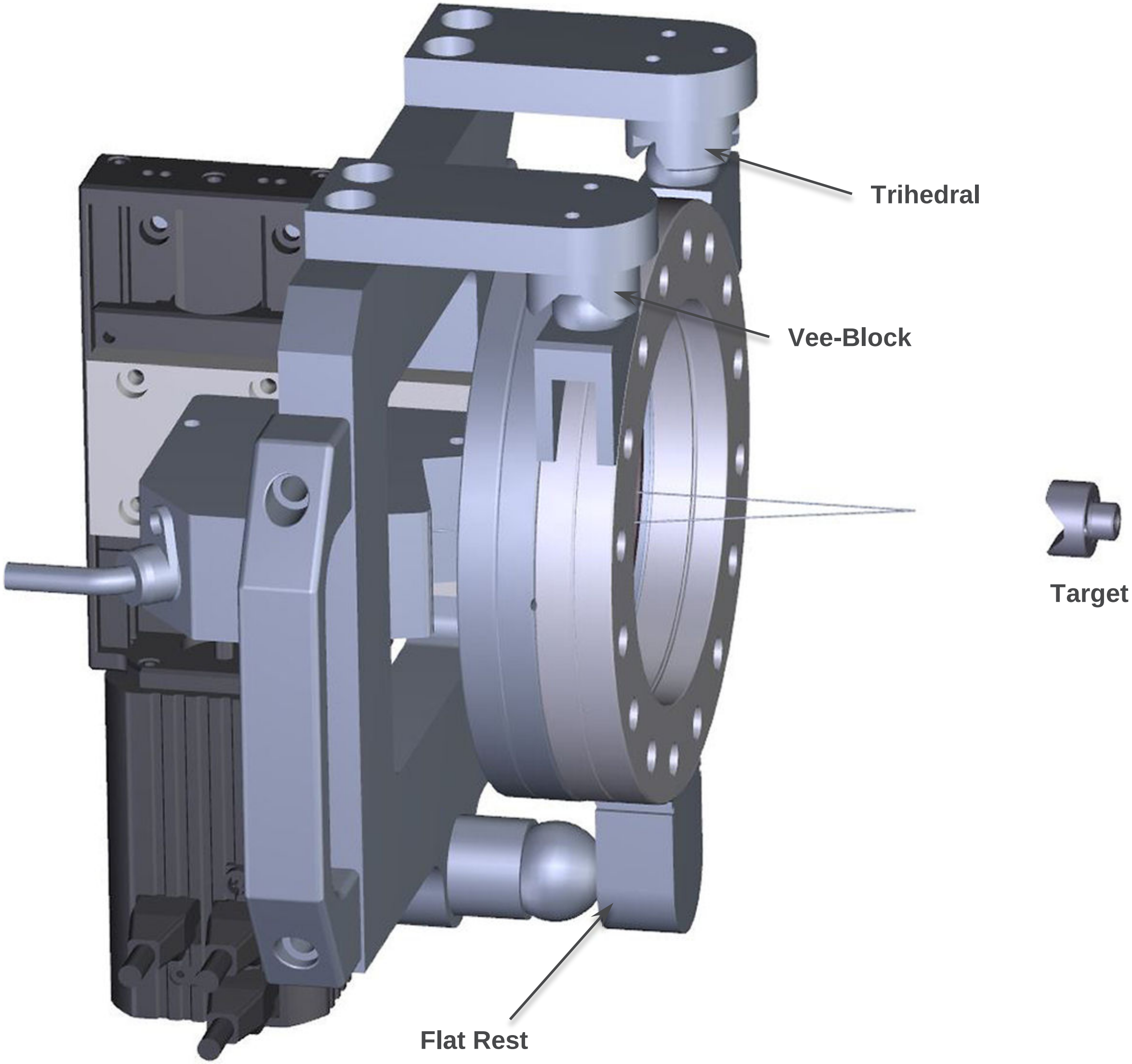


TRANSLATION STAGES

- Motorized translation
- Linear encoders record vertical position of the LDS.
- Straightness affects transverse accuracy <10 μm per meter
- Unidirectional linear encoder repeatability <1 μm
- LDS translated in only one direction to avoid backlash error



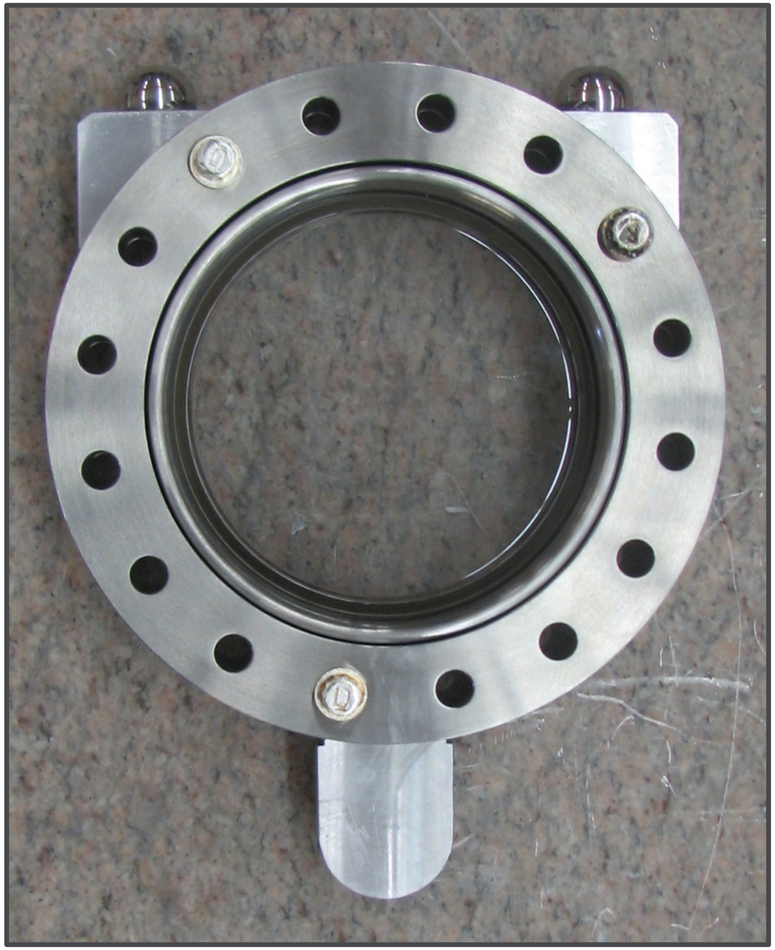
KINEMATIC COUPLE

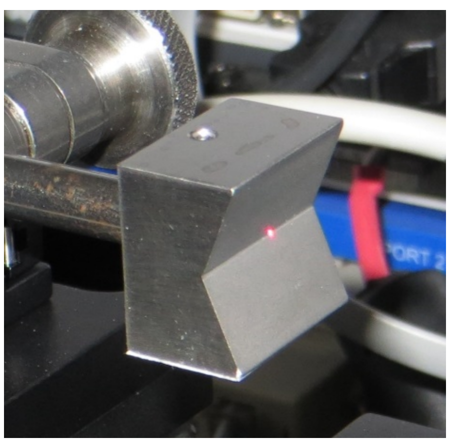


- Deterministic, highly repeatable positioning system
- Exactly constrains six DOF
- Kelvin kinematic couple interfaces *Cryoscanner* device with cryostat vessel for repeatability at multiple measurement locations.
- Modification of a standard 6” diameter con-flat vacuum flange.

VACUUM VIEWPORTS

- Different approach to dealing with refraction effects
- Kinematic couple precisely locates instrument with respect to viewport
- LDS compensates for transparent medium
- Refraction effects constant
- Coplanar optical flat compared to low-cost borosilicate glass showed virtually no difference in quality.
- Specifying borosilicate windows resulted in lower overall cost - optical grade windows not necessary.
- Vacuum pressure differential forces negligible





TARGETS

- Target material and surface finish affects quality
- First targets were simple vee-grooves machined into aluminum plate. Rough finish produced noise.
- Precision-ground stainless steel vee-block target enhanced can quality.
- Lapped SS vee-block had adequate quality
- Satin Titanium finish produced superior results
- Custom satin Ti targets to be used in future devices; vee angle is 120 degrees
- Other target geometries possible

Target Finish	Line Fit Deviation (rms)	Maximum Deviation
Machined Aluminum	>25 μm	>50 μm
Lapped Stainless Steel	<10 μm	<20 μm
Satin Titanium	<5 μm	<10 μm

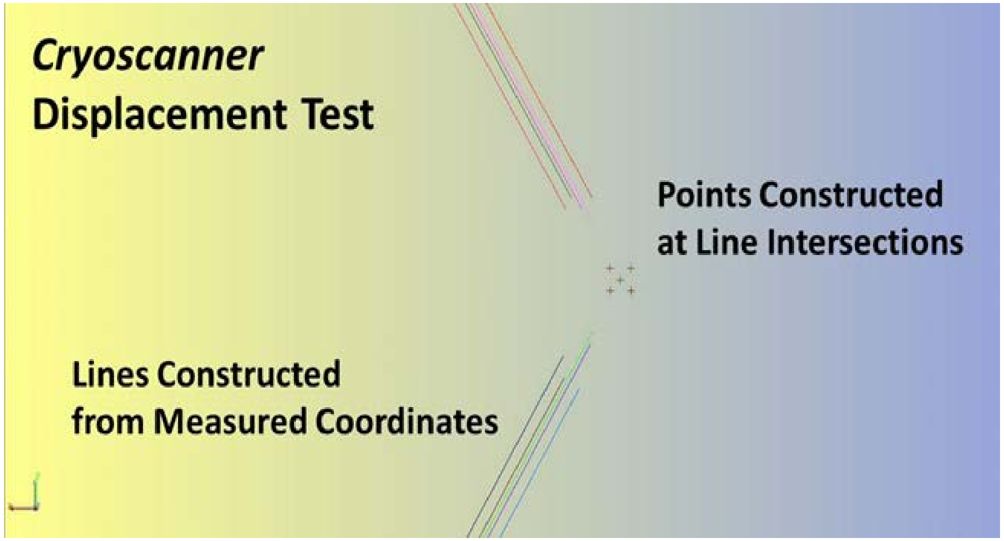
CONTROLS AND DATA ACQUISITION

- Custom Experimental Physics and Industrial Control System (EPICS) application
- Windows laptop serves as both I/O controller and graphical user interface through single USB connection

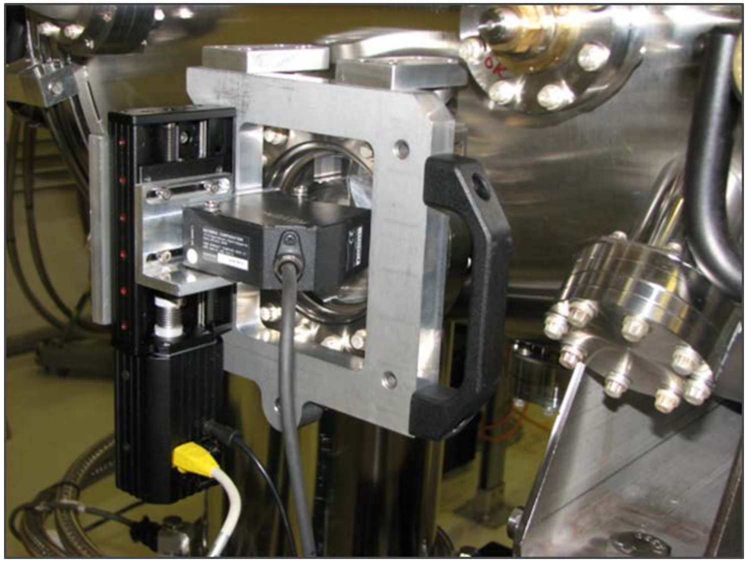
Argonne NATIONAL LABORATORY

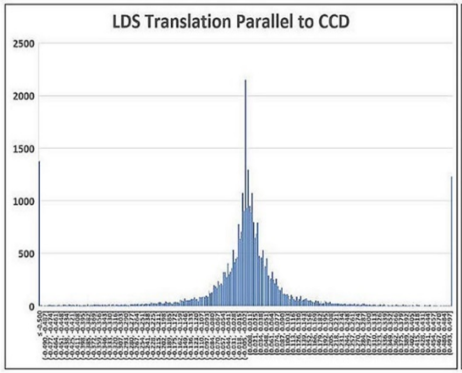
MEASUREMENT & DATA PROCESSING

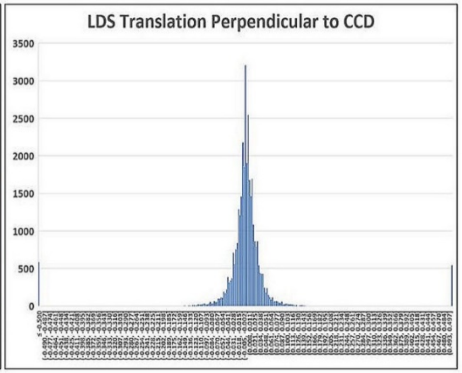
- Coordinates output as 3D ASCII file; Z value is hand-entered
- Scans reduced to a single, discreet point
- Lines fitted through scanned coordinates
- Points constructed at line intersections



- ➢ Spreadsheets
- ➢ Spatial Analyzer
- ➢ CAD

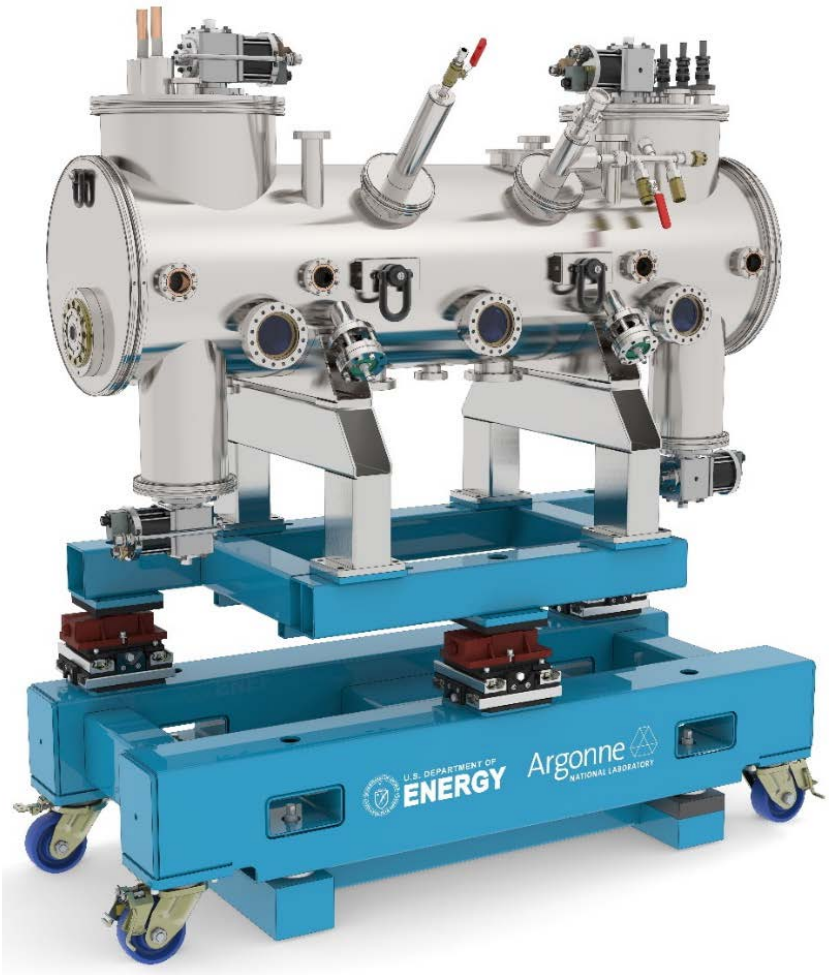






HELICAL SUPERCONDUCTING UNDULATOR

- First SC device to employ the *Cryoscanner*
- Imparts circular polarization by oscillating an accelerated electron beam to produce intense X-ray energy
- 2-D profiles from four positions quantify thermal shift in five DOF



HELICAL SUPERCONDUCTING UNDULATOR

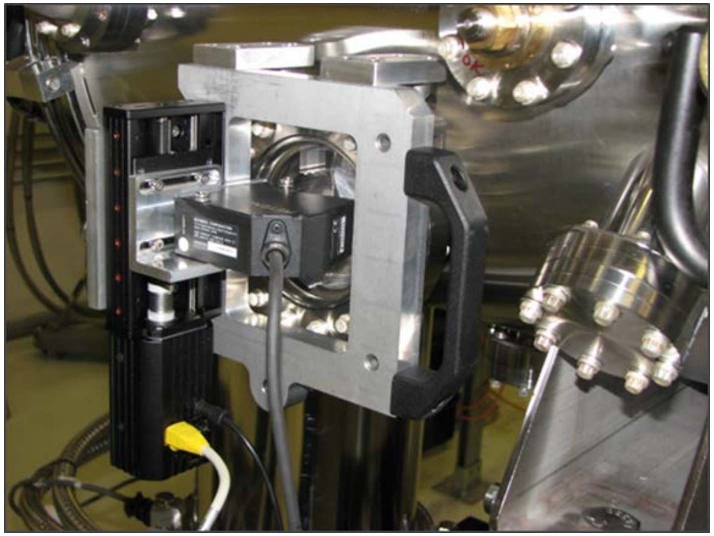
Thermal Shift Results

- Initial warm vertical alignment set to -75 μm to compensate for expected thermal shift
- Asymmetric cold mass shift is likely caused by uneven loading of the 4-point vertical adjustment system and a constraint at the inboard helium fill connection.

RMS Standard Deviation [mm]			Standard Uncertainty [mm]	
	X [mm]	Y [mm]	X [mm]	Y [mm]
Overall	0.005	0.006	0.0005	0.0006
A only	0.003	0.006	0.0007	0.0011
B only	0.005	0.007	0.0011	0.0015
C only	0.007	0.008	0.0015	0.0016
D only	0.004	0.004	0.0008	0.0008

Cryoscanner measurement quality for HSCU measurements over 96 individual scans

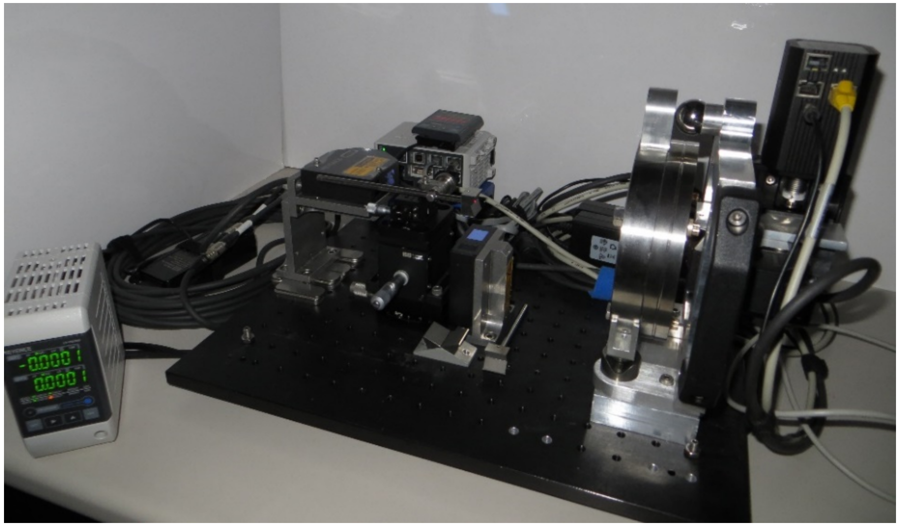
Ordinate	Initial W [mm]	W to C [mm]	C to W [mm]	W to C [mm]	C to W [mm]	W to C [mm]	Final C [mm]
	19-Oct	27-Oct	27-Nov	1-Dec	12-Dec	9-Jan	
X US	0	-0.059	0.059	-0.059	0.094	-0.082	**-0.047**
X DS	0	-0.065	0.065	-0.086	0.120	-0.109	**-0.075**
Y US	-0.075	0.100	-0.100	0.093	-0.097	0.150	**0.071**
Y DS	-0.075	0.164	-0.164	0.160	-0.183	0.174	**0.077**

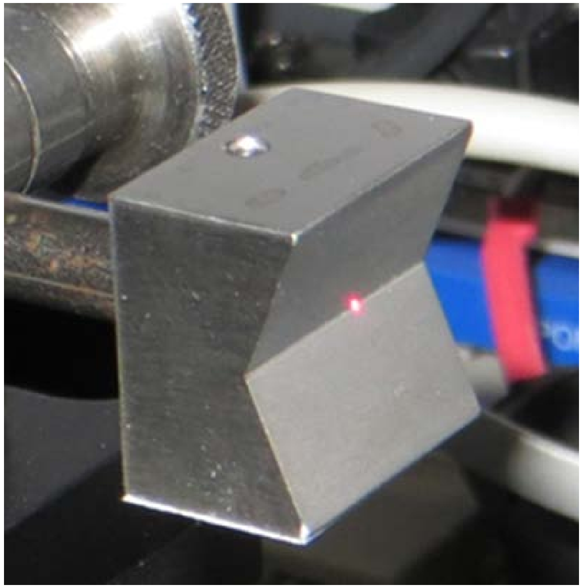


HSCU cold mass thermal shift results over three cool down cycles

RECENT PROGRESS

- Tests to determine measurement quality for a modified satin Ti target design
- Precise 2D displacements applied within a 1 mm^2 area to compare against Cryoscanner measured values (Maximum observed displacement in the HSCU device was <200 μm)
- Displacements applied using two Keyence LK-G37 LDS's with 0.05 μm resolution as a reference.
- Metrics analysed include fit statistics for lines constructed through the measured coordinates, point to point distance comparisons and best-fit transformations for all points in a measurement set.





RECENT PROGRESS

- Line fits through 70 to 80 points show a maximum deviation of <10 μm, and an RMS standard deviation of <5 μm
- Point to point distances are in agreement to <5 μm.
- Analysis of the measurement sets indicate the device is capable of repeatable, reproducible 2-D coordinate measurement at a resolution of <5 μm RMS.

LINE DEVIATION STATS

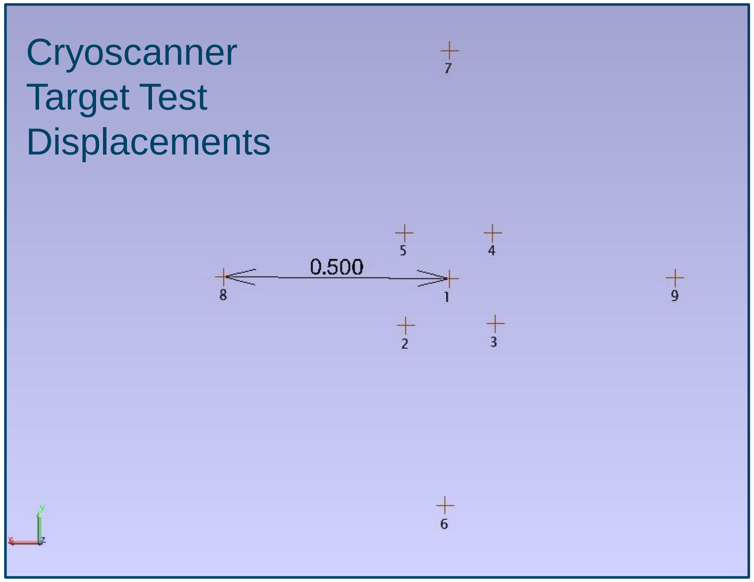
Mean = 0.002784 **RMS** = 0.003402 (mm)

Magnitude

|Max| = 0.007467 |Min| = 0.000038 (mm)

Total Number: 80 points

80 Points Used



Least Squares Best Fit

Results	X [mm]	Y [mm]	Z [mm]	Mag.
Count	10	10	10	10
Max Error	0.0038	0.0055	0	0.0067
RMS Error	0.0019	0.0028	0	0.0034
StdDev Error	0.0020	0.0030	0	0.0036
Unknowns	6			
Equations	30			

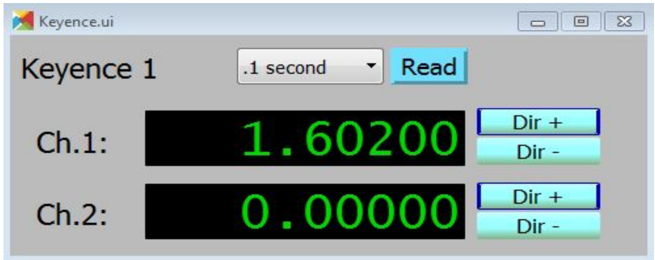
Point	dX [mm]	dY [mm]	dZ [mm]	dMag
1	0.0009	-0.0018	0	0.0020
2	-0.0038	-0.0055	0	0.0067
3	-0.0020	0.0007	0	0.0021
4	0.0002	0.0008	0	0.0008
5	0.0011	-0.0004	0	0.0012
6	0.0026	-0.0038	0	0.0046
7	0.0015	0.0044	0	0.0046
8	0.0013	0.0032	0	0.0035
9	-0.0020	0.0014	0	0.0024
10	0.0002	0.0010	0	0.0010

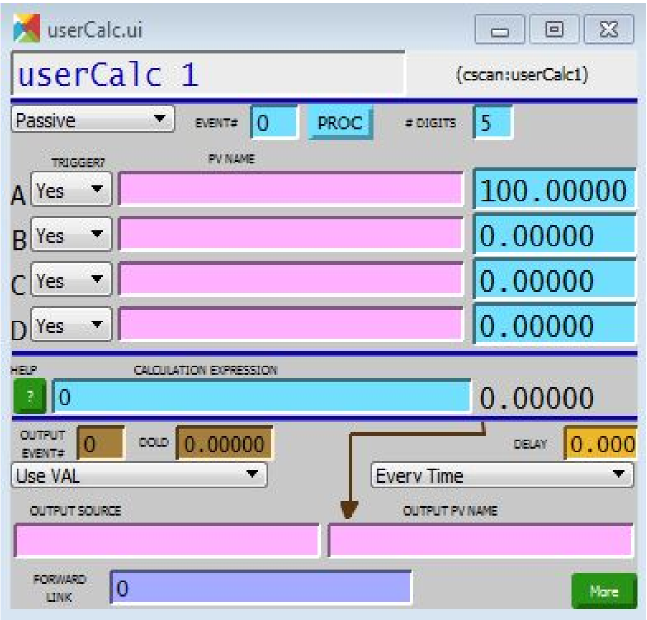
RECENT PROGRESS

Advances have also been made to streamline data collection and post-processing:

- X direction sense (+ or -) of the LDS output now toggled within EPICS
- Z coordinate may now be entered to generate 3D coordinate file output from EPICS
- Filter application re-orders the ASCII output format for import to Spatial Analyzer.

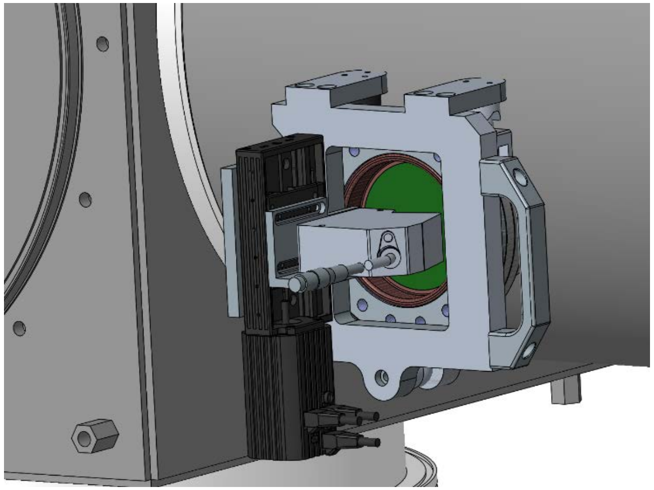
Significant time savings have been realized as a result of the improvements.

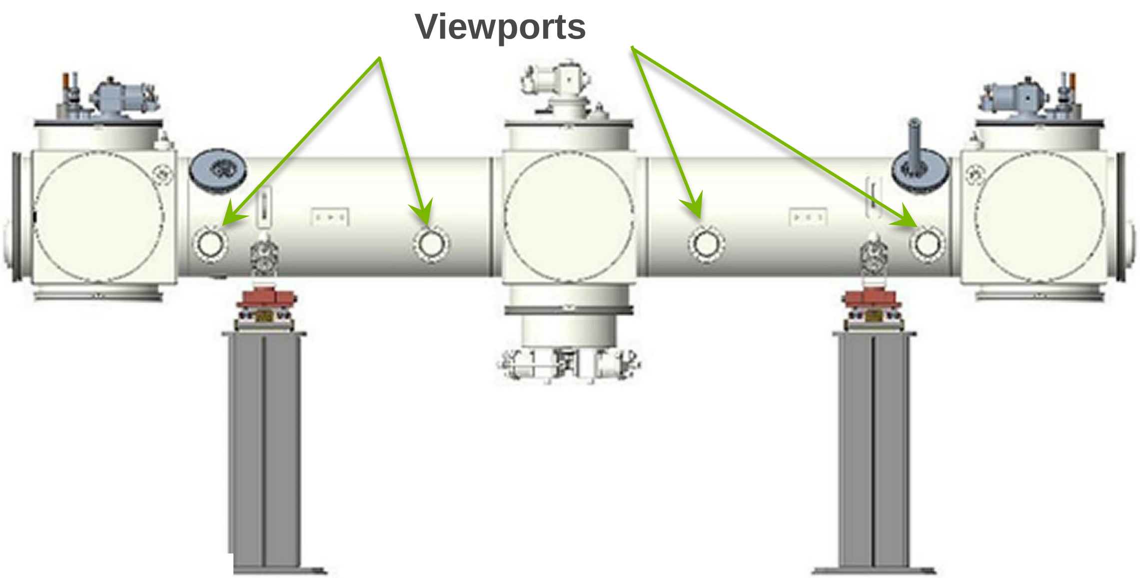


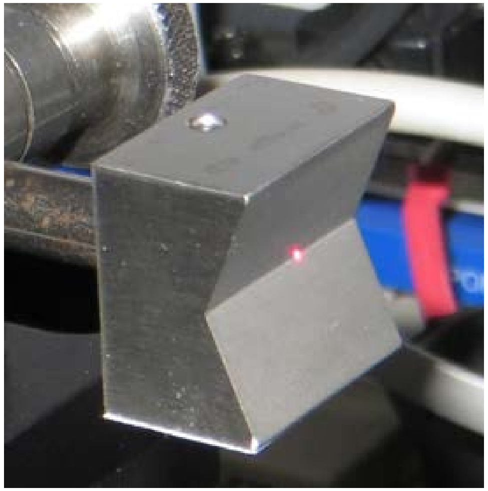


APS UPGRADE SCU

- Double-length Planar SCU under development
- 5 meter cryostat vessel length
- Eight measurement viewports specified for APS-U SCU – four for each planar structure
- New satin Ti targets to be employed
- We look forward to presenting the results in the future







CONCLUSION

A new method for ascertaining displacements in SC devices due to thermal shift has been successfully implemented at Argonne National Laboratory. The HSCU is only the first SC device to employ this instrument. We plan to use the portable Cryoscanner to ascertain thermal shifts in future SC devices, refining and improving the technique as we gain experience.

ACKNOWLEDGEMENTS

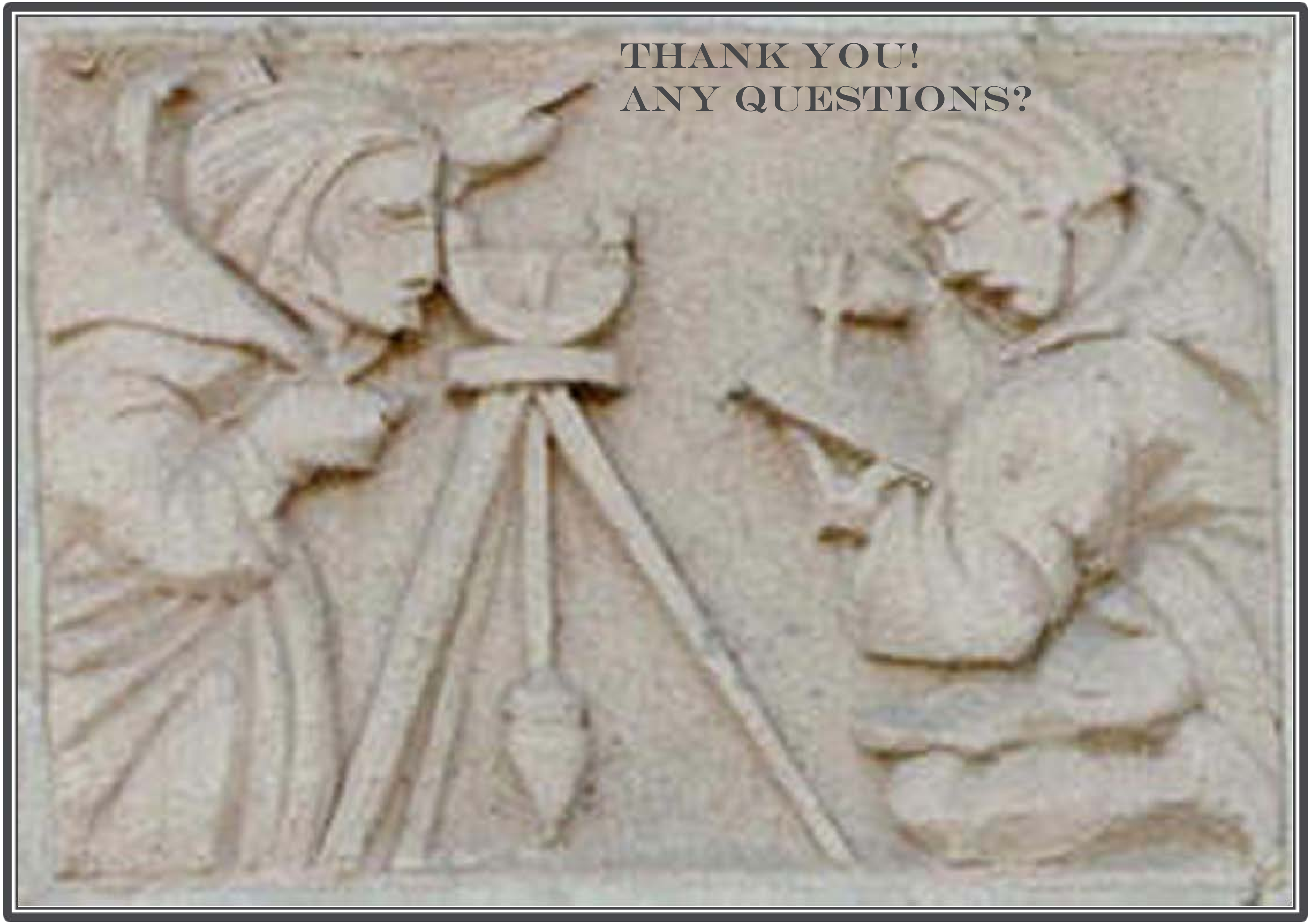
- The author expresses sincere gratitude to the following individuals for their long-term, continued support in this endeavor: Patric DenHartog, Efim Gluskin, Yuri Ivanyushenkov, Jaromir Penicka, *and* Geoffrey Pile

- Thanks to Oliver Schmidt of the APS MED Group for providing photo-realistic renderings of the HSCU and the *Cryoscanner*.

- Thanks to Joe Gleason at Micro Surface Engineering, Inc. in Los Angeles, CA, for technical assistance in the selection of target surface finishes.

- The diagram in figure 1 appears courtesy of the Keyence Corporation of America, Itasca, Illinois, 60143

- This work has been supported by the U.S. Department of Energy, Office of Science, under contract number DE-AC02-06CH11357



THANK YOU!
ANY QUESTIONS?

MEASUREMENT SYSTEM