Argonne NATIONAL LABORATORY

An Improvised Two-Dimensional Laser Surface Scanner for Diagnosis of Rf Thermionic Electron Gun Problems

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Advanced Photon Source

Argonne National Laboratory

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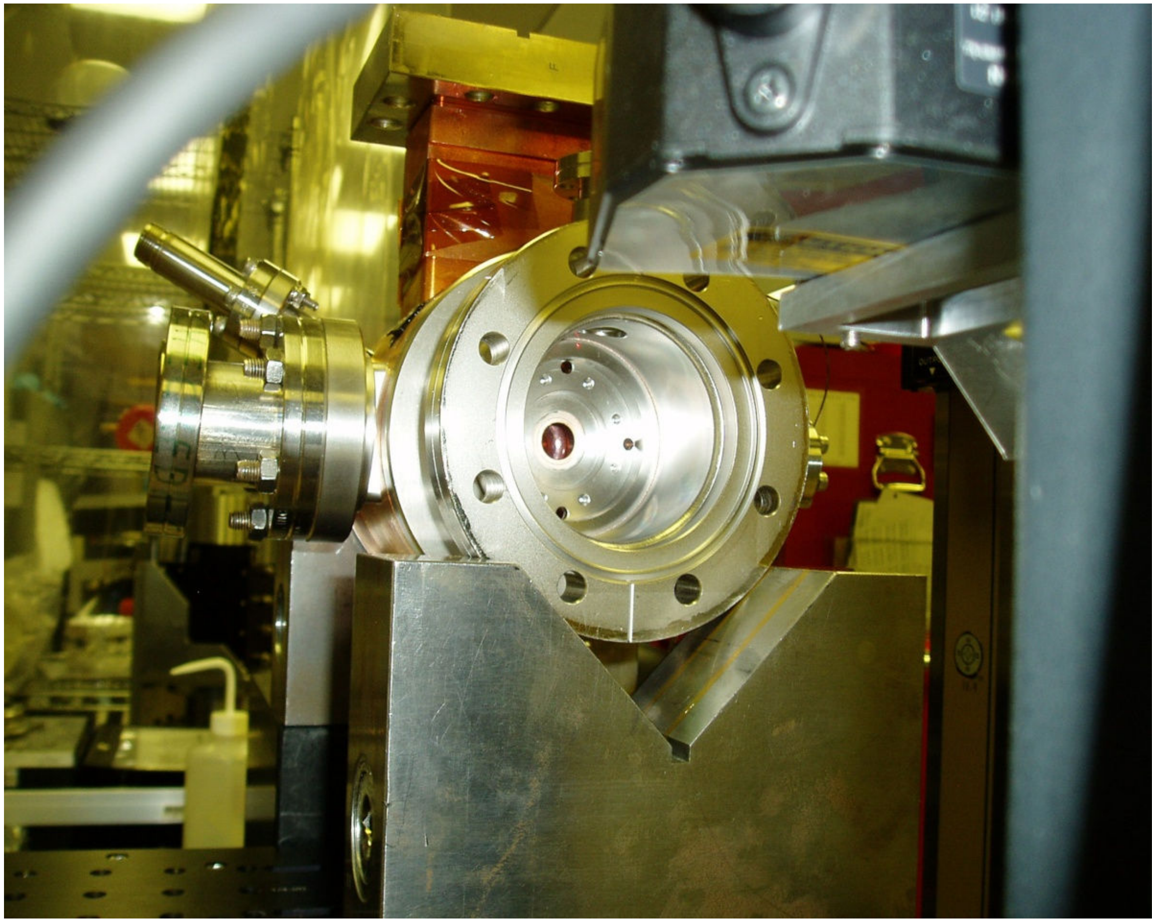
U.S. DEPARTMENT OF ENERGY

WELCOME!
Thank You For Attending This Morning

- ARGONNE NATIONAL LABORATORY
- ADVANCED PHOTON SOURCE
- BACKGROUND
- PROBLEMS ARISE
- MEASUREMENT
- IMPROVISED 2-D LASER SURFACE SCANNER
- DISTORTION REVEALED
- ALTERNATIVES
- REPAIR OF THE RF GUNS
- CONCLUSION
- ACKNOWLEDGMENTS

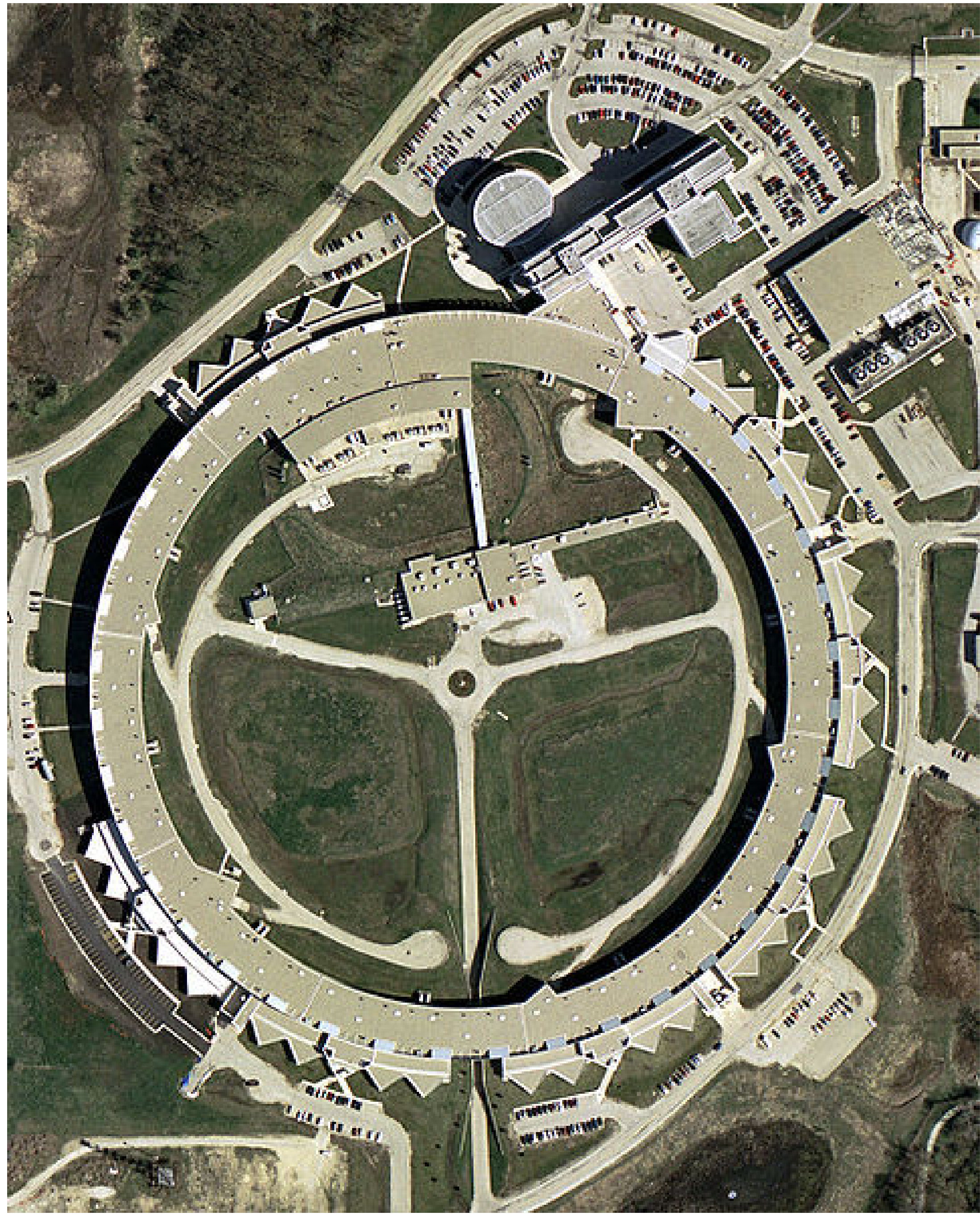


Argonne NATIONAL LABORATORY

- First National Laboratory in the United States, chartered July 1, 1946
- Argonne National Laboratory is a direct descendant of the University of Chicago's Metallurgical Laboratory, where, on Dec. 2, 1942, Enrico Fermi and his band of about 50 colleagues created the world's first controlled nuclear chain reaction. The U of C Metallurgical Lab was part of the Manhattan Project.
- A multi-disciplinary facility operated by UC-Argonne, LLC for the U.S. Department of Energy, the laboratory's current R&D programs focus on basic science research, energy storage and renewable energy, environmental sustainability, and national security.

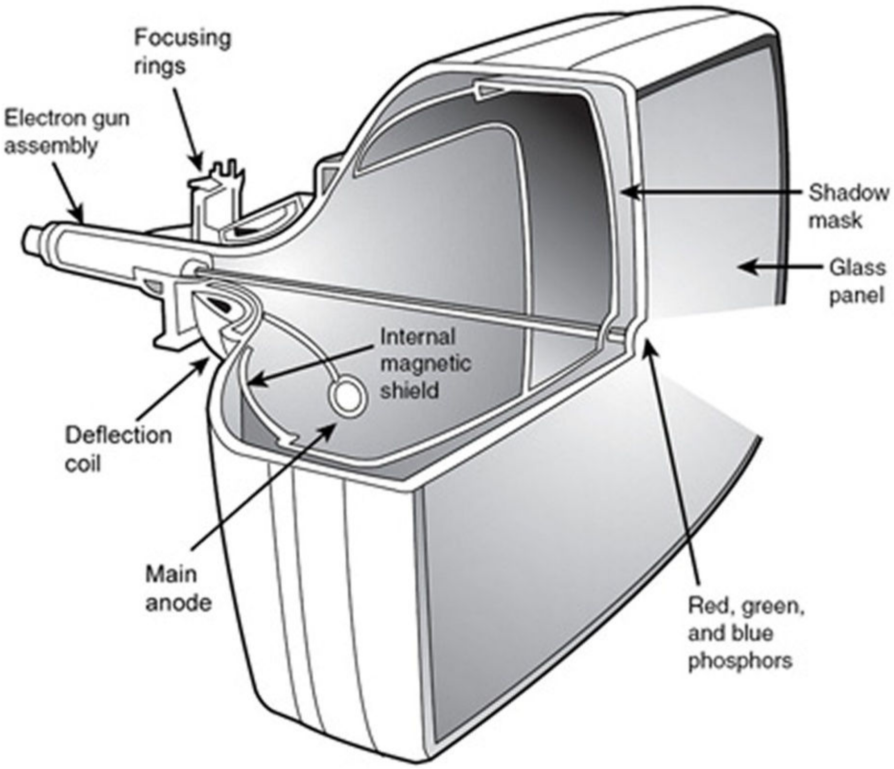
Advanced Photon Source (APS)

- Third-Generation Synchrotron X-ray Source
- Premier National User Facility in the Western Hemisphere hosting ~3,500 Scientists Per Year
- Multi-Disciplinary Laboratory:
  - Accelerator and X-ray R&D
  - Biological Science
  - Materials Science
  - Chemical Science
  - Geoscience
  - Environmental Science
  - Nanoscience (Center for Nanoscale Materials)
  - Pharmaceutical Research
  - Atomic, Molecular and Optical Physics

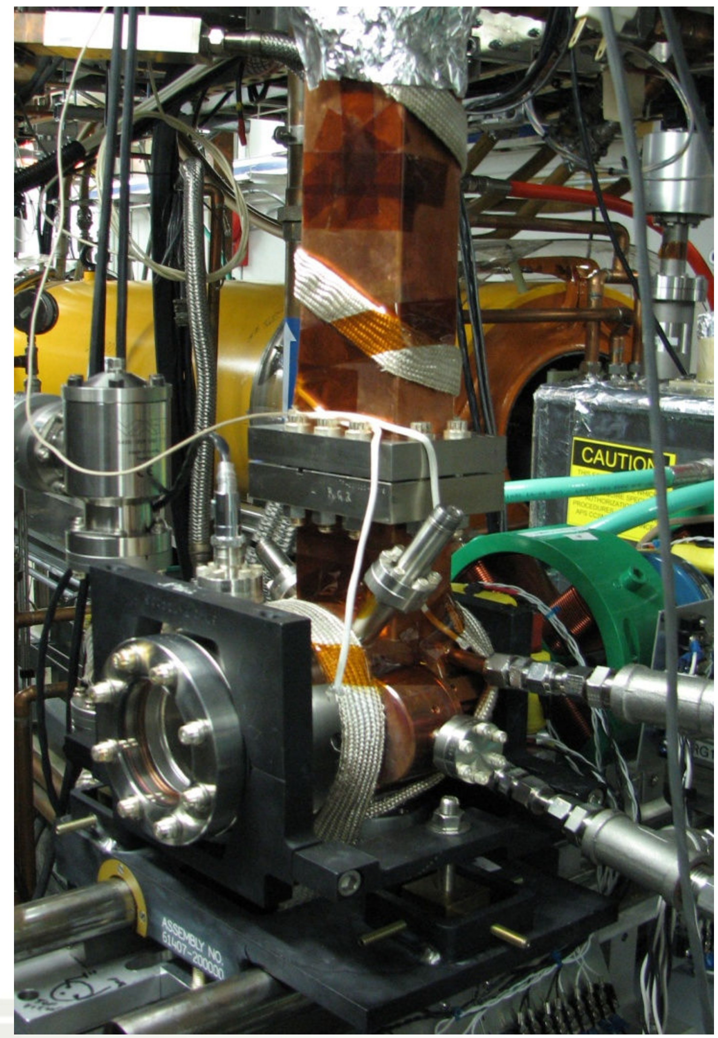


BACKGROUND

- Electron guns are devices that produce, accelerate and emit electrons. The most common type of electron guns are found in the cathode ray tubes (CRT) of older televisions and computer monitors. Other types of electron guns are used as sources for electron microscopes, particle accelerators and electron beam welders.

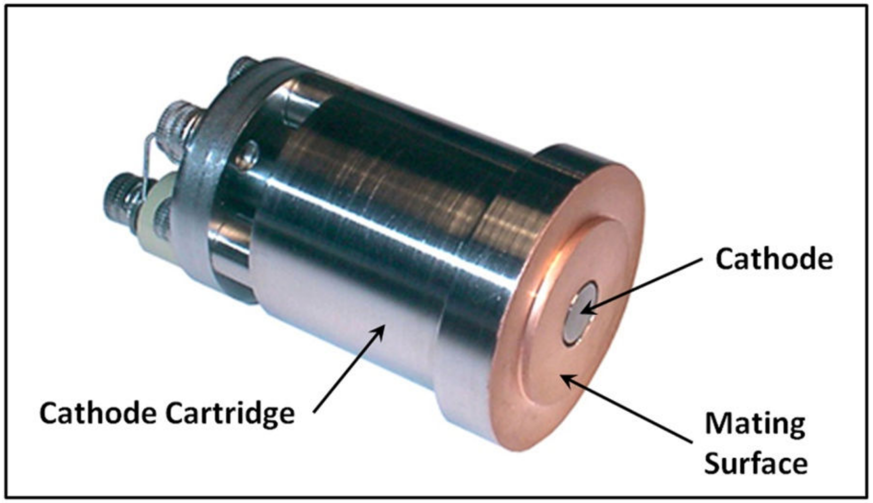


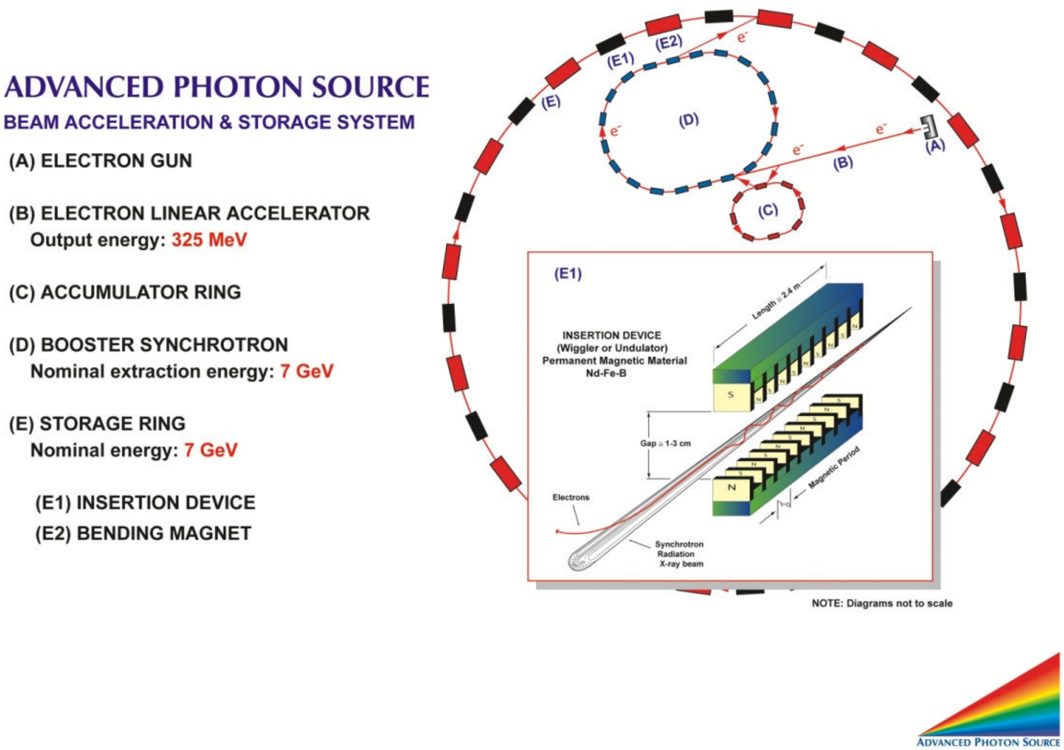
- Radio frequency (rf) thermionic electron guns were developed at SLAC National Accelerator Laboratory in the late 1980s and early 1990s. Various generations of these guns have been used to inject electrons into the APS accelerator system since 1996.



BACKGROUND

- Electrons are produced in rf electron guns by heating a tungsten alloy cathode to 800^{o} C to 1200^{o} C, boiling off electrons directly into an rf cavity energized by microwaves with a frequency of 2856 MHz and a 10 cm wavelength. The electrons are accelerated by the microwaves, analogous to the way a surfer is pushed along by waves in the ocean.





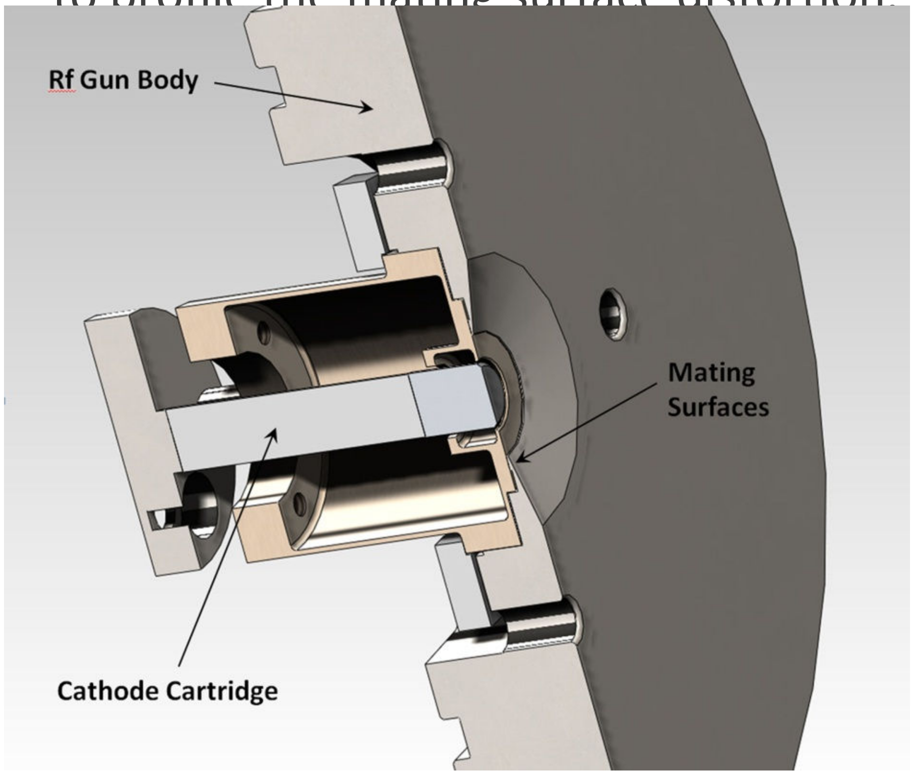
- Electrons emitted from the rf guns are injected into the APS accelerator system, forming a beam of high energy electrons that is further accelerated to velocities approaching the speed of light. When the beam is deflected by magnets in the accelerator system x-rays are emitted. With the bright, penetrating high energy x-rays scientific instruments can see deep into the atomic structure of matter, allowing scientists to carry out cutting-edge research that positively impacts our lives.

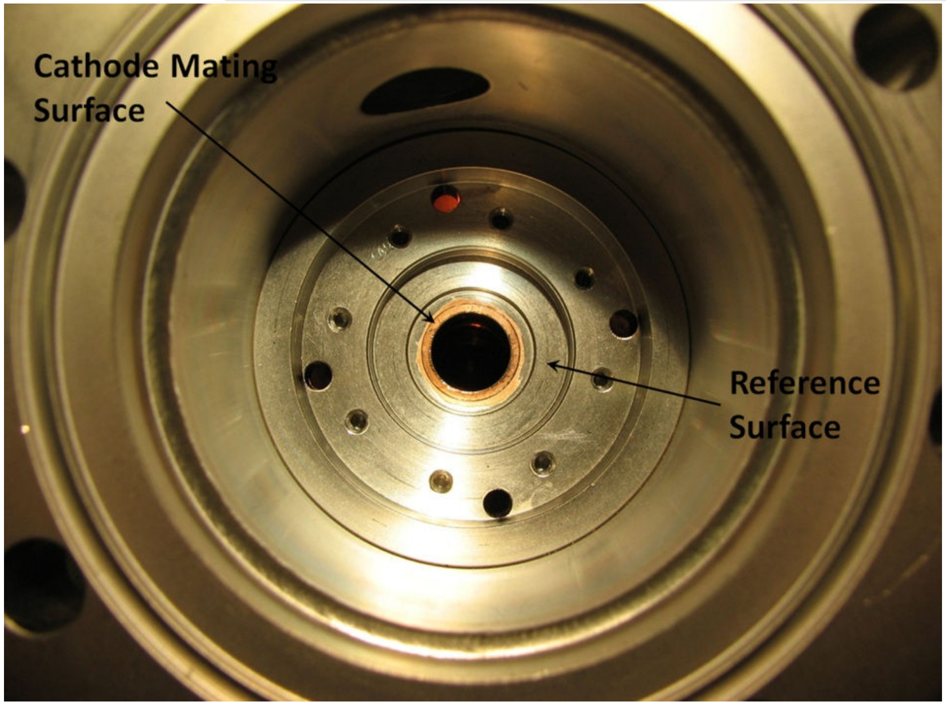
Problems Arise

- In 2001 three new rf thermionic electron guns were purchased for the APS.
- In 2009, after 8 years of operation, the ageing cathodes were replaced. Problems arose immediately after the cathodes were changed out.
- More heater power (25 W, as opposed to the normal 15 W) was required, and excess reflected power was observed. Abnormally high reflected power levels subject the cathode surface to excess back bombardment, with too many of the electrons being accelerated in the reverse direction.
- Two rf guns failed in mid 2010 due to excess reflected power. Spare guns were installed, however there was much concern that another rf gun failure could limit the capabilities of the machine and, in the worst case, shut down APS operations altogether.
- An investigation was initiated to discover the cause of the problems observed in the rf guns. Inspection revealed distortion of the cathode cartridges, leading to suspicion that the mating surfaces within the gun bodies were also distorted.
- The APS Survey and Alignment section was asked to assist in the diagnosis and measure the mating surfaces of the gun bodies to identify and characterize the suspected distortions.

Measurement

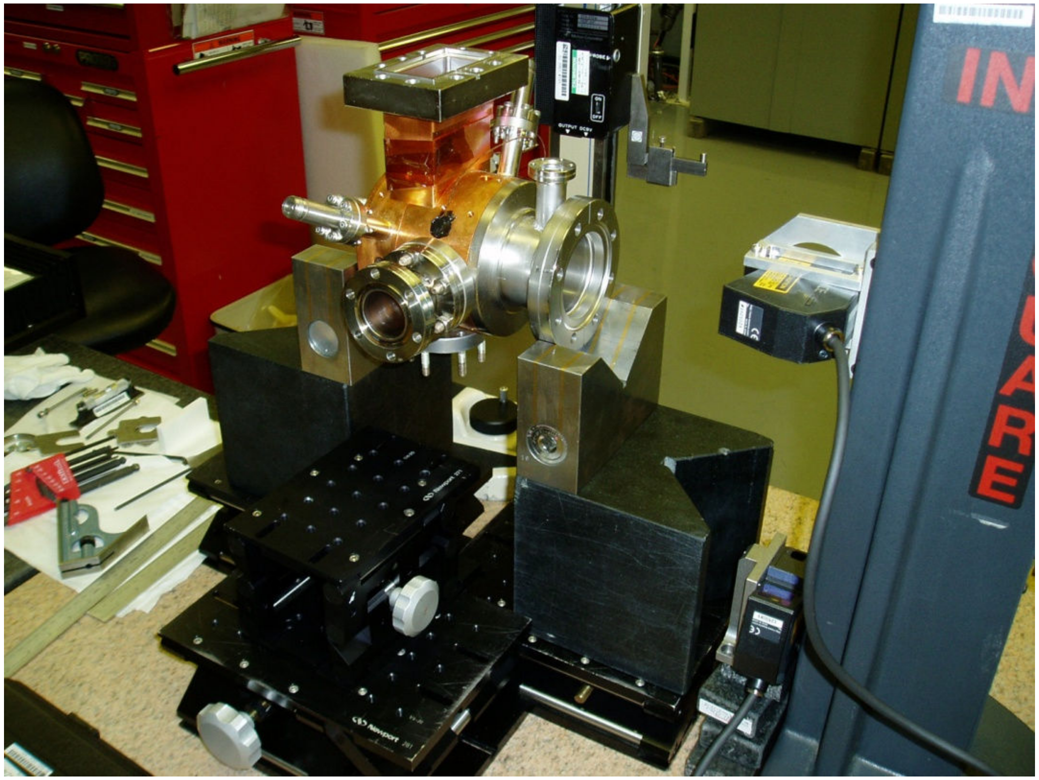
- Cathode mating surface difficult to reach located at a depth of 75-mm within a 60-mm dia. vacuum chamber section
- Initial measurement attempt using a Faro arm provided useful data for larger features, but resolution was insufficient to profile the mating surface distortion.





- APS did not have an instrument capable of profiling the surface at the needed resolution.
- Several types of profiling instruments were available, both contact and optical; none ideal for this problem, expensive....$20K plus.
- Improvised measurement system devised after much thought.

IMPROVISED 2-D LASER SURFACE SCANNER



Improvised two-dimensional laser surface scanner set up to measure an rf gun body

- System employs two Keyence LK-G series CCD laser displacement sensors configured to measure two orthogonal axes.
- Scanning sensor is mounted to an Indi Square device for vertical translation.
- Synchronous data output from both sensor heads allowing coordinates to be ascertained by combining the data in a spreadsheet.
- Keyence LK-G sensors emit a laser signal that is reflected from any surface back on to an integrated CCD array that registers displacement along the beam axis.

Laser Displacement Sensors

- LK-G 152 and LK-G 157 sensors were used for the improvised scanner. Range is 150 mm +/- 40 mm at 0.5 micron resolution.
- Sensors were connected to a single controller unit integrated with a PC or laptop. Measurement data recorded using Keyence LK-Navigator freeware.
- Calibration was verified by measuring several gage block lengths over the range of the sensor heads.
- Sensors may be configured for diffuse or specular surface reflectivity and are capable of measuring through a transparent medium such as glass.

Vertical Translation

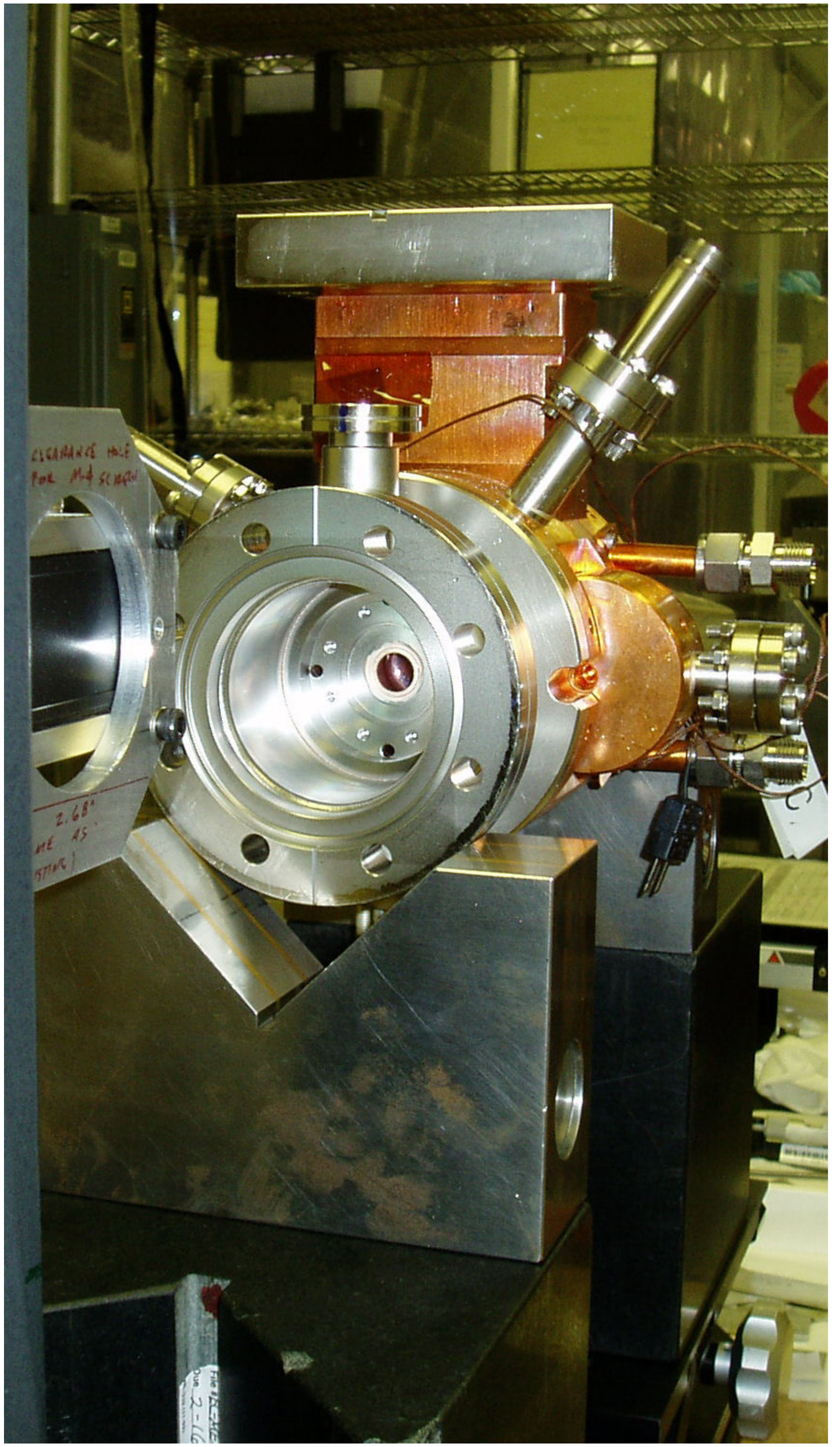
- Sensor head mounted to an Indi-Square model 18 for vertical translation.
- Translation accuracy is 0.0025 mm over 500 mm of travel.
- Designed to accept a typical dial indicator head.
- Sensor head weighs 290 grams, not including aluminum mount bracket. Counterweight was needed to balance system.
- Translation by hand not satisfactory. Crank-wheel height gage used to translate sensor head.
- Despite added weight and unorthodox translation method, the setup was smooth and precise.

COMPONENT INTEGRATION

- Initially a LK-G157 sensor head was mounted vertically to the translation, but the return signal was blocked when the laser spot was transitioned over steps in the surface. The problem was solved by horizontally mounting the sensor head to the translation.
- The LK-G 157 sensor head projects a 1.7-mm-wide laser spot, recording an average profile over the width of the laser spot. To improve accuracy a LK-G 152 sensor head that projects a 120 micron diameter laser spot was mounted to the translation, allowing a much thinner measurement "slice" to be recorded.

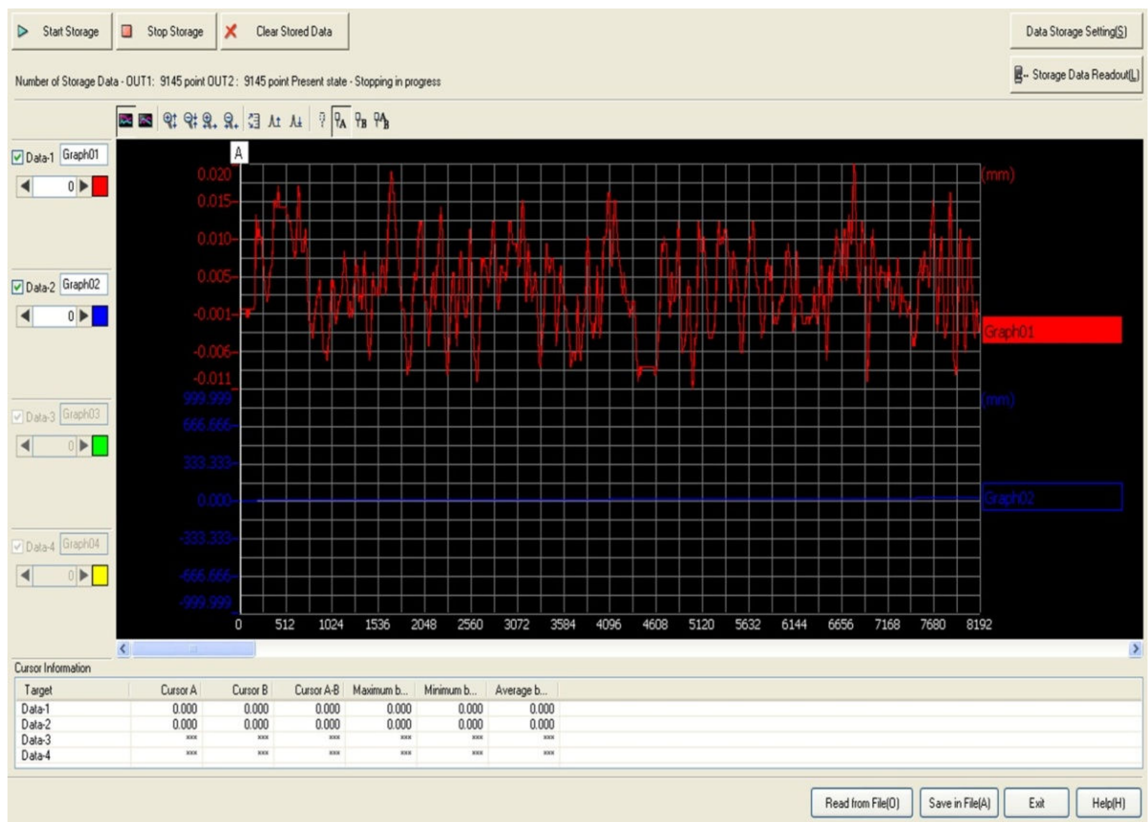
ORIENTATION & MEASUREMENT

- Rf gun bodies were rested on v-blocks that in turn rested on precision lab jacks.
- Primary surface to be scanned was placed at the optimum distance, 150 mm, from the sensor head.
- Gun bodies were set parallel to the translation by adjusting the pitch angle of the gun until the sensor display indicated equal values within +/- 10 μm when translated across a reference plane surface within the gun.
- To obtain limited 3-D information scans were taken across azimuth angles of 0, 45, 90, and 315 degrees.
- Common reference was plane was used to allow scans across different angles to overlay each other



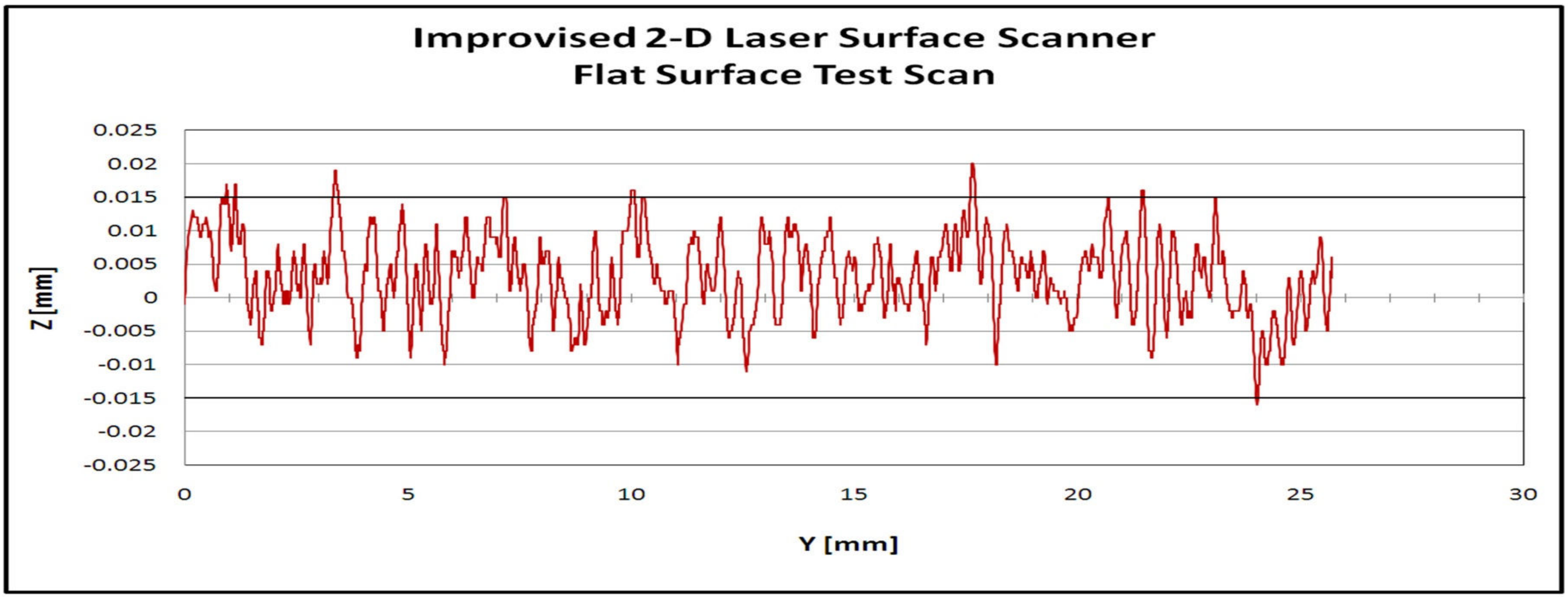
DATA COLLECTION & PROCESSING

- Data collection was accomplished using the LK-G3001 controller and laptop with LK-Navigator freeware.
- Data was saved as a .csv text file that opens as a single column in a spreadsheet that is cut and pasted into a coordinate worksheet.
- Synchronous controller output allowed the columns to be pasted side by side in the worksheet forming coordinates.
- Coordinates for each azimuth scan were adjusted to fit a common centerline and plotted over each other to produce an abstract 3-D view in a 2-D graph.

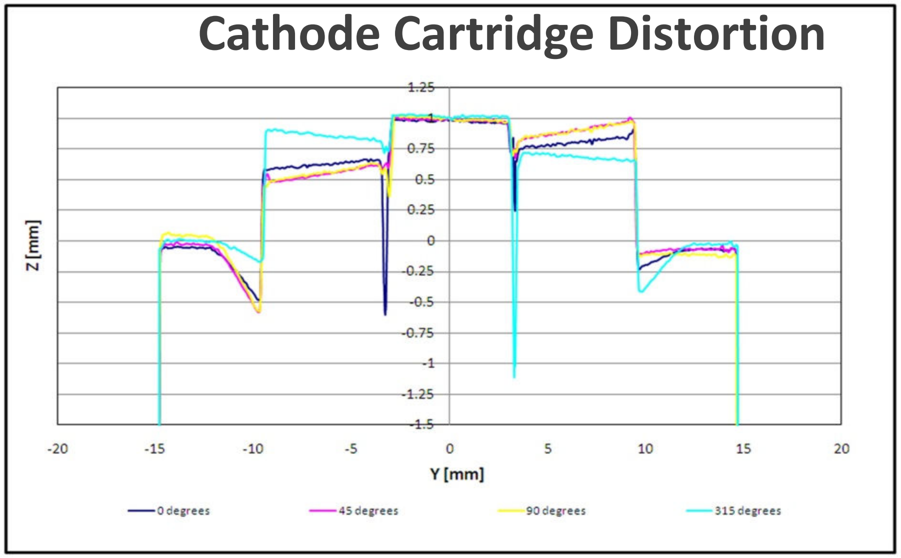


ERROR ANALYSIS

- Accuracy initially estimated to be +/- 5 microns, taking into account the sensor resolution of 0.5 microns, translation accuracy of 2.5 microns over 500 mm, and the typical scan translation of only 25 mm.
- Further analysis indicates the accuracy of measurements taken with the improvised system to be closer to +/- 15 microns.
- Decrease from the initial estimate is attributed to noise produced by the motion of the sensor head during translation.
- Accuracy might be improved through refinements in motion control for the translation.

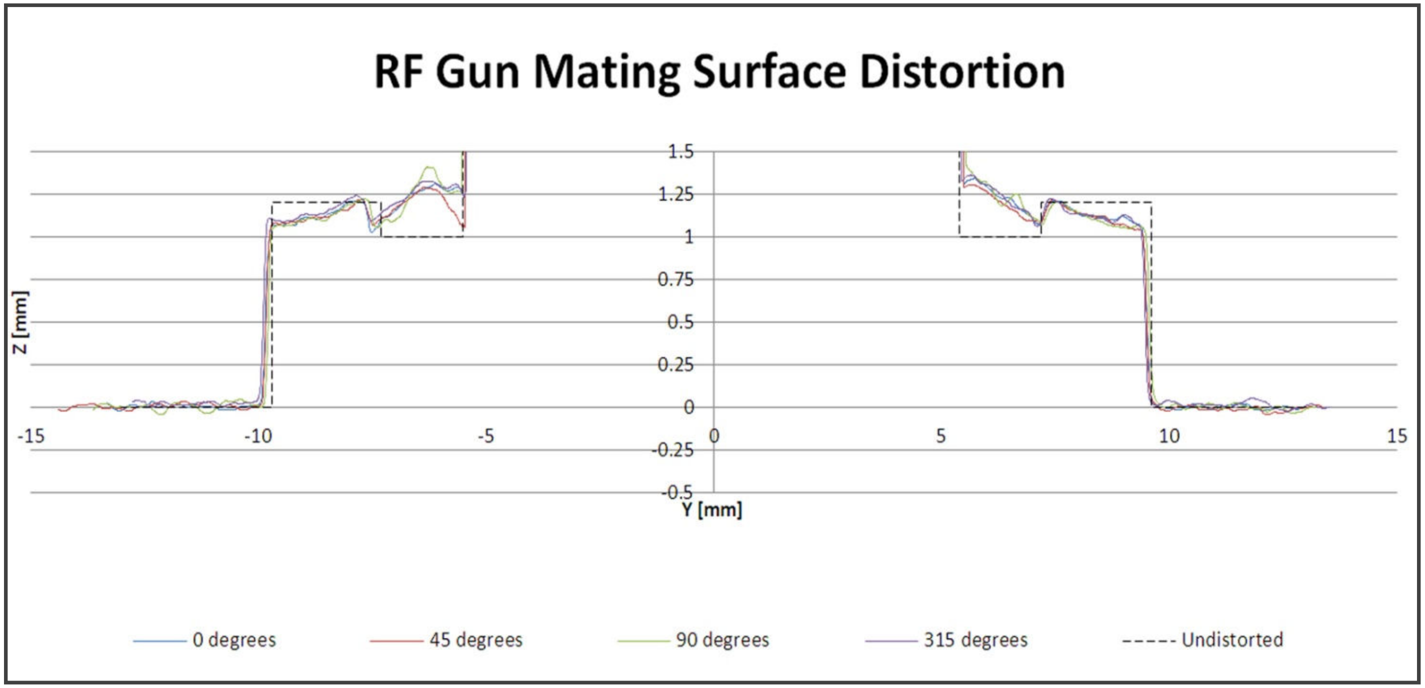


DISTORTION REVEALED



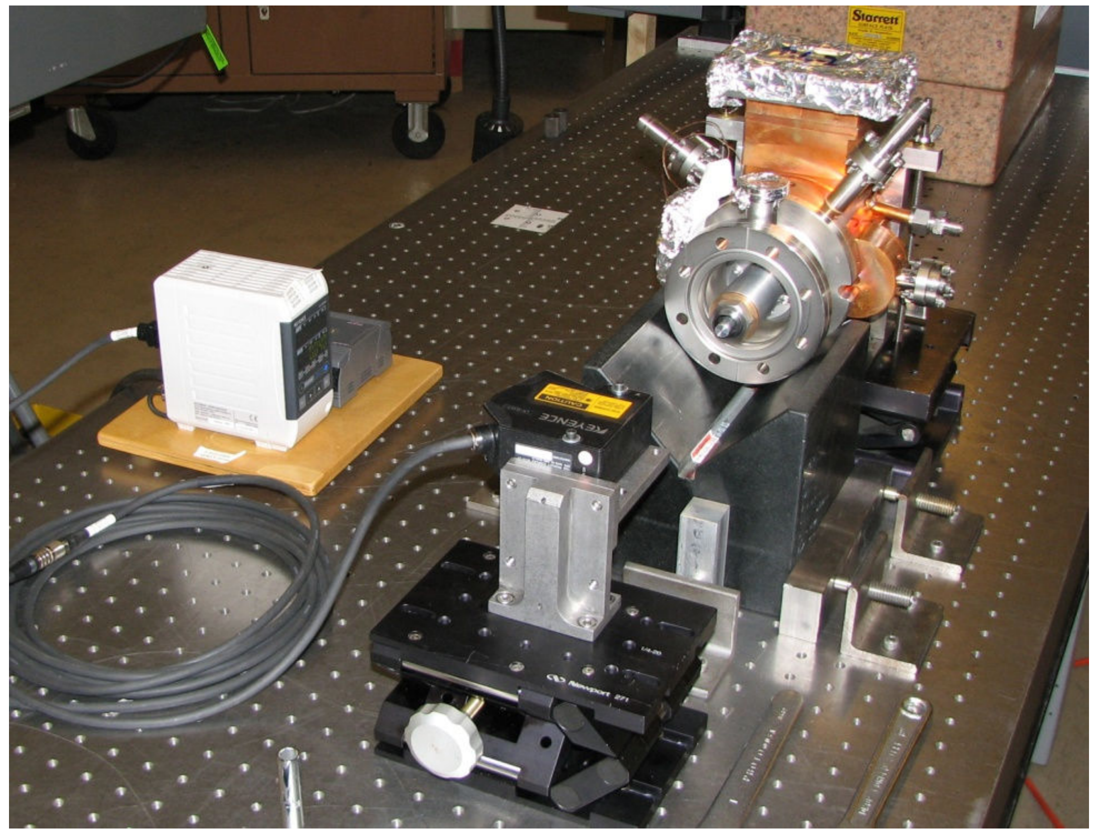
- Plots of the profile scans taken with the improvised 2-D laser scanner revealed distortion of the mating surfaces of both the cathode cartridges and the rf gun bodies.
- The flat, planar mating surface is intended to seal the rf cavity from leakage and act as a thermal conductor. Arcing can result from rf energy leakage, and improper heat transfer affects thermal stability.

- Distortion was caused by over-tightening of eight #4-40 screws that secure the cartridge within the gun body. Damage was inadvertent, as no drawings or procedure were available.
- Source of problem was discovered, but what now?



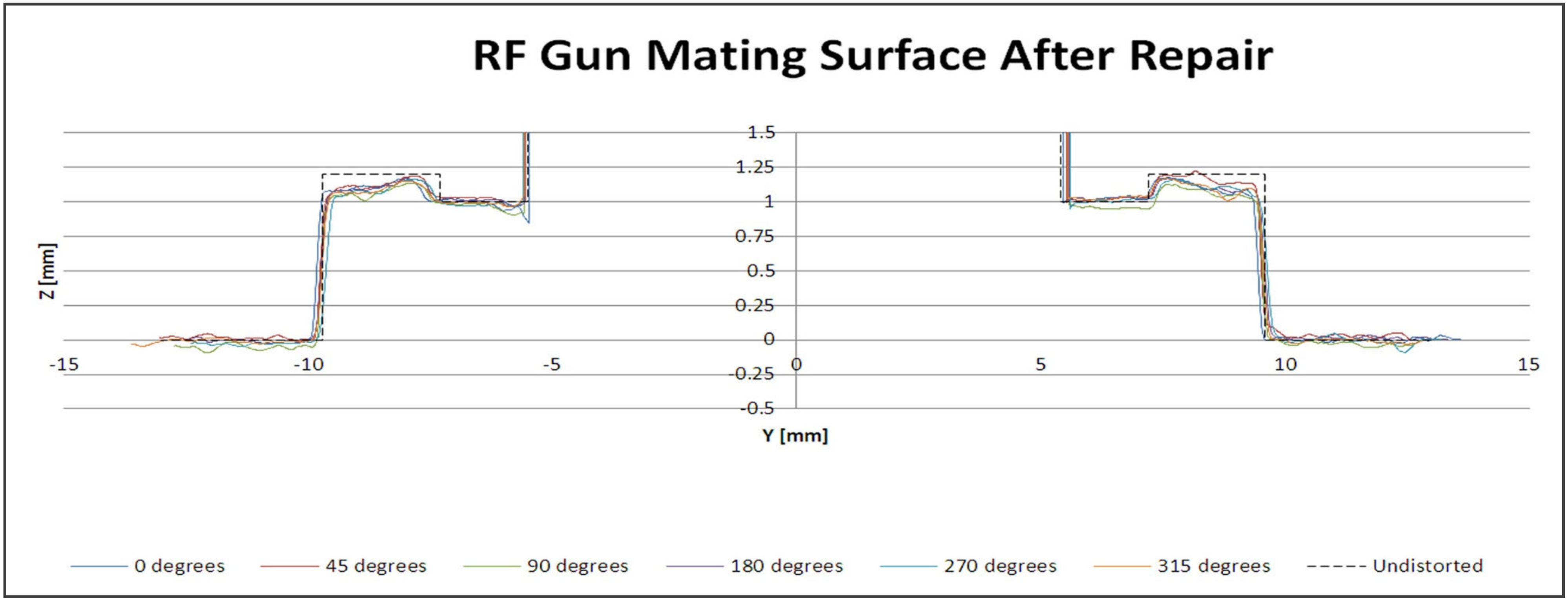
REPAIR OF THE RF GUNS

- Several alternatives were explored in the effort to solve the problem of the damaged rf guns including replacement, modification, and repair.
- Replacement cost is $70,000, and modification would be costly as well.
- Decision was made to attempt to repair the damaged guns.
- Special retraction tool was designed and tested successfully on a mockup.
- Repair was performed, using the improvised 2-D scanner to monitor the progress of the repair effort.
- Gun body was ultrasonically cleaned, and a new cathode cartridge was installed using a modified retaining system suggested by the author.
- The repaired rf gun was placed in the APS injector test stand, activated, and rigorously tested. In March 2011 it was installed in one of the APS injector stations and has been functioning normally.



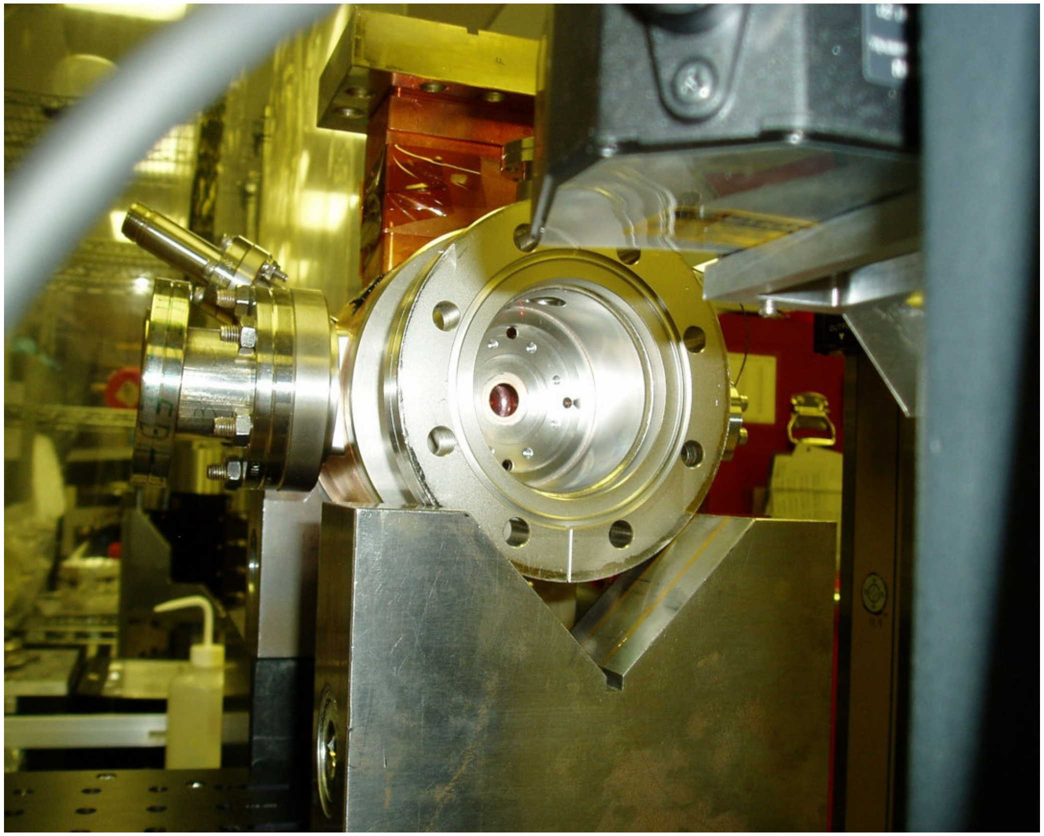
REPAIR OF THE RF GUNS

- In April 2011 the second rf gun was successfully repaired using the same process and was installed into the other APS injector station in July.
- The successful repair of two rf thermionic electron guns resulted in significant savings of both time and money for the APS. The expense of re-engineering the gun / cathode assembly was spared, and the purchase of a replacement rf gun was rendered unnecessary. In addition, by improvising a measurement system using equipment on hand, the cost of purchasing a new instrument to identify and characterize the rf gun distortions was saved.



CONCLUSION

The improvised 2-D laser surface scanner proved to be a valuable instrument, helping to both identify and repair damage in two rf thermionic electron guns. Although the instrument is not a revolutionary development, it shows that problems can occasionally be solved by using imagination and applying the tools on hand in seeking a solution. In this case an improvised application of coordinate metrology tools and methods were used to revive two damaged rf thermionic electron guns, resulting in substantial cost savings for the APS.



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