NIST gets new angle on X-ray measurements

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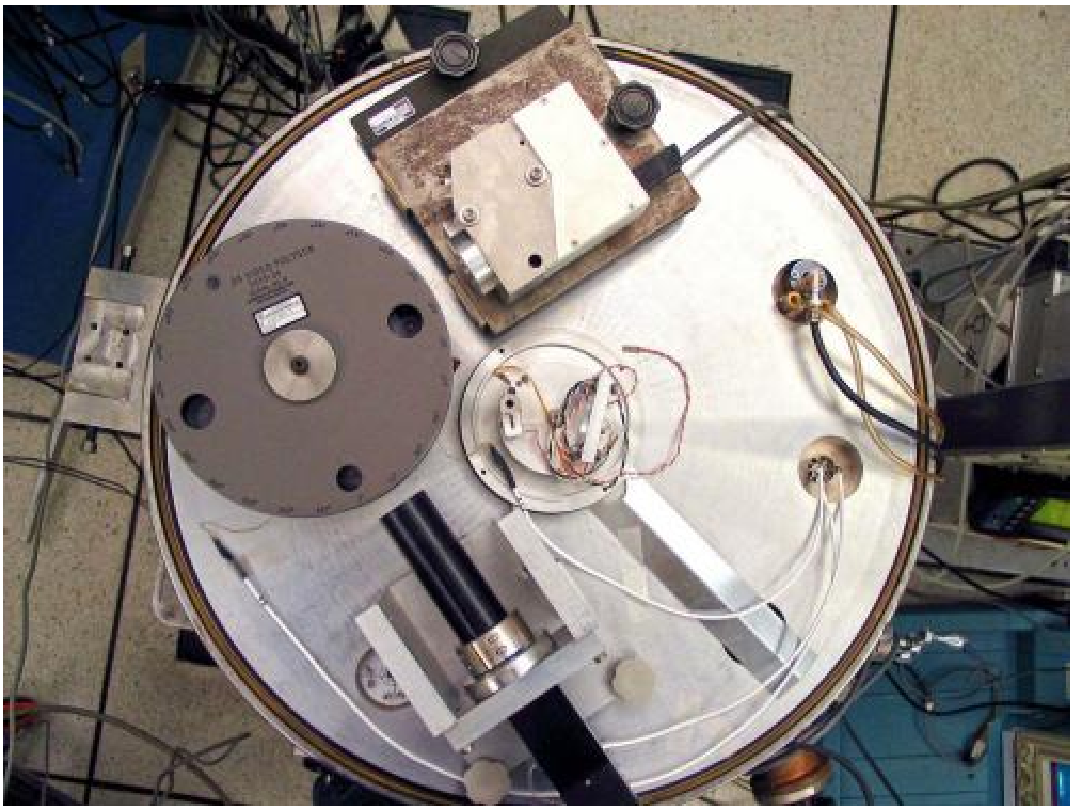

A laser from the NIST-designed autocollimator (square device at top) is beamed at the mirrored polygon in the gray circle at left, and its reflection allows the angle of the polygon's faces to be precisely determined while the polygon rotates. The black device at bottom takes measurements that minimizes the wobbling the polygon experiences while spinning. Credit: Hudson/NIST

Criminal justice, cosmology and computer manufacturing may not look to have much in common, but these and many other disparate fields all depend on sensitive measurements of X-rays. Scientists at the National

Institute of Standards and Technology (NIST) have developed a new method to reduce uncertainty in X-ray wavelength measurement that could provide improvements awaited for decades.

Accurate measurement of X-ray wavelengths depends critically on the ability to measure angles very precisely and with very little margin for error. NIST's new approach is the first major advance since the 1970s in reducing certain sources of error common in X-ray angle measurement.

Many of us associate X-rays with a doctor's office, but the uses for these energetic beams go far beyond revealing our skeletons. The ability to sense X-rays at precise wavelengths allows law enforcement to detect and identify trace explosives, or astrophysicists to better understand cosmic phenomena. It all comes down to looking very closely at the X-ray spectrum and measuring the precise position of lines within it. Those lines represent specific wavelengths—which are associated with specific energies—of X-rays that are emitted by the subject being studied. Each material has its own, unique X-ray "fingerprint."

But a slight error in angle measurement can skew the results, with consequences for quantum theories, research and manufacturing. "While many fields need good X-ray reference data, many of the measurements that presently fill standard reference databases are not great—most data were taken in the 1970s and are often imprecise," says NIST's Larry Hudson.

X-ray wavelengths are measured by passing the beam through special crystals and very carefully measuring the angle that exiting rays make with the original beam. While the physics is different, the technique is analogous to the way a prism will split white light into different colors coming out at different angles.

The crystal is typically mounted on a rotating device that spins the crystal to two different positions where a spectral line is observed. The angle between the two is measured—this is a neat geometry trick that determines the line's position more precisely than a single measurement would, while also cancelling out some potential errors. One inevitable limit is the accuracy of the digital encoder, the device that translates the rotation of the crystal to an angle measurement.

Hudson and his co-authors have found a way to dramatically reduce the error in that measurement. Their new approach uses laser beams bouncing off a mirrored polygon that is rotated on the same shaft that would carry the crystal. The approach allows the team to use additional mathematical shortcuts to their advantage. With new NIST sensing instrumentation and analysis, X-ray angles can now be measured routinely with an uncertainty of 0.06 arcseconds—an accuracy more than three times better than the uncalibrated encoder.

Hudson describes this reduction as significant enough to set world records in X-ray wavelength measurement. "If a giant windshield wiper stretched from Washington D.C. to New York City (364 kilometers) and were to sweep out the angle of one of these errors, its tip would move less than the width of a DVD," he says.

What do these improvements mean for the fields that depend on X-ray sensing? For one thing, calibrating measurement devices to greater precision will provide better understanding of a host of newly designed materials, which often have complicated crystal structures that give rise to unusual effects such as high-temperature superconductivity. The team's efforts will permit better understanding of the relationship between the structures and properties of novel materials.

More information: M.N. Kinnane, L.T. Hudson, A. Henins and M.H. Mendenhall. A simple method for high-precision calibration of long-range errors in an angle encoder using an electronic nulling autocollimator. *Metrologia*, 52 238. Posted online March 9, 2015. DOI: 10.1088/0026-1394/52/2/238

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