Visualizing strong magnetic fields with neutrons

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The device for determining the orientation of the magnetic field functions like a compass. If you hold it against a magnet (here, silver-grey), the blue-red pin rotates so that its red end points in the direction of the north pole. Credit: Paul Scherrer Institute/Mahir Dzambegovic

Researchers at the Paul Scherrer Institute PSI have developed a new method with which strong magnetic fields can be precisely measured. They use neutrons obtained from the SINQ spallation source. In the future, it will therefore be possible to measure the fields of magnets that are already installed in devices and thus are inaccessible by other probing techniques. The researchers have now published their results in the journal *Nature Communications*.

Neutrons are, as their name suggests, electrically neutral and are the building blocks of almost all atomic nuclei. Neutrons interact with magnetic fields due to their so-called spin. Researchers at the Paul Scherrer Institute PSI have now shown that this property can be used to visualize magnetic fields. They used polarized neutrons, which means that all of the neutrons have the same spin orientation.

If beams of polarized neutrons pass through a magnetic field, a refraction of the neutron beam can be detected behind this field. From the refraction pattern, the magnetic field and in particular the differences in field strengths can be reconstructed. For the first time this method, also known as polarized neutron grating interferometry (pnGI), has been used to measure magnetic fields.

One million times stronger than Earth's magnetic field

pnGI can be used to measure very strong magnetic fields with a so-called gradient strength in the order of 1 Tesla per centimeter. "This allows us to move in orders of magnitude about one million times stronger than Earth's magnetic field," says Christian Grünzweig, a neutron researcher at the Paul Scherrer Institute PSI. Until now, neutrons could only be used to measure significantly weaker magnetic fields.

Christian Grünzweig (left) and Jacopo Valsecchi look at a magnet similar to those used, for example, in magnetic stickers for refrigerator doors. With the device Grünzweig is holding, the orientation of the magnetic field can be determined. Credit: Paul Scherrer Institute/Mahir Dzambegovic

From alternators to MRI systems

Numerous applications are conceivable for the new method, above all because neutrons penetrate most materials non-destructively. "We can also probe magnetic fields that are difficult to access because they are already built into an apparatus," explains Jacopo Valsecchi, first author of the study and a doctoral candidate working at PSI. "Applications range from alternators in car engines to many components of the energy supply system to magnetic fields from magnetic resonance tomography systems used in medicine."

The researchers proved that their method works by using computer models to simulate the expected results of the measurement. They then checked whether comparable results could actually be achieved with a real measurement. "The results from the simulations and the actual measurement results agree very well," says Grünzweig.

With the new method, fluctuations in the magnetic field can also be detected. For example, even permanent magnets, such as those familiar from magnetic stickers for refrigerator doors, do not have a homogeneous magnetic field. "We can now detect possible gradients, even if the magnetic field is very strong," says physicist Valsecchi.

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More information: Visualization and quantification of inhomogeneous and anisotropic magnetic fields by polarized neutron grating interferometry, Jacopo Valsecchi, Ralph P. Harti, Marc Raventós, Muriel D. Siegwart, Manuel Morgano, Pierre Boillat, Markus Strobl, Patrick Hautle, Lothar Holitzner, Uwe Filges, Wolfgang Treimer, Florian M. Piegsa, and Christian Grünzweig, *Nature Communications*, 22 August 2019, DOI: 10.1038/s41467-019-11590-2

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