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# A Tunable Permanent Magnet Quadrupole with Openable Design for In-Situ Installation

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We present a novel tunable permanent magnet quadrupole specifically suited for low-energy beam transport lines in ion source systems. These front-end sections often operate under tight spatial constraints and limited access, making conventional electromagnets or complex cooling systems impractical. Our design addresses these challenges by combining wide field tunability, mechanical openness, and zero power consumption.
The magnet consists of two concentric, independently rotatable Halbach rings made of NdFeB permanent magnets. Their relative rotation enables continuous tuning of the field gradient—including polarity reversal—allowing precise matching of ion beams to downstream optics without active power or cooling. Simulations predict a tunable integrated gradient of 0.8 to 4.5 T (depending on aperture size), corresponding to field gradients of ~10 to 70 T/m—well-suited for focusing and matching in the low-energy sections following an ion source. A prototype with a 54 mm aperture was constructed and tested, demonstrating a measured tuning range of 7.75–17.75 T/m and an estimated integrated gradient of 0.36–1.01 T.
A key innovation is the openable, split-yoke mechanical design, enabling installation directly around existing beamlines without disassembly—ideal for integration into operational ion source facilities, especially where frequent maintenance, diagnostics, or vacuum bake-outs are required. The design also ensures low hysteresis (<1%) and suppresses unwanted multipole components by more than three orders of magnitude.

This scalable, modular quadrupole concept supports high-performance, maintenance-free ion optics in beamlines where power availability, space, and accessibility are constrained—making it a compelling tool for modern ion source front ends.

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