Tunable, unmountable, permanent-magnet-based accelerator magnet

HUN REN Centre for Energy Research

G. Anda[1], D. Barna[2]

[1]*HUN-REN Centre for Energy Research, Budapest, Hungary*

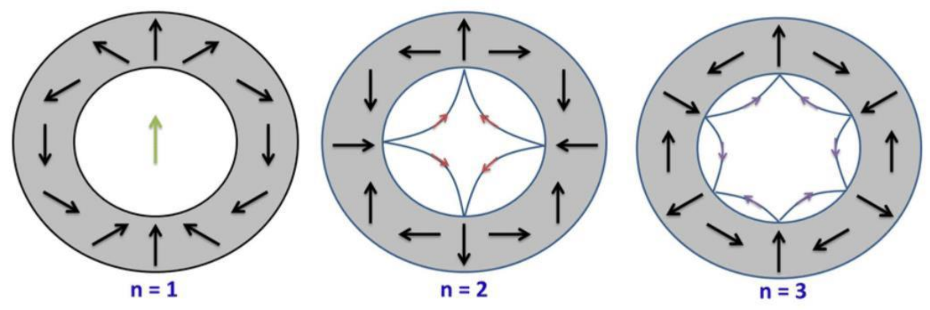
[2]*HUN-REN Wigner Research Centre for Physics, Budapest, Hungary*

Wigner

Electro- vs permanent magnets

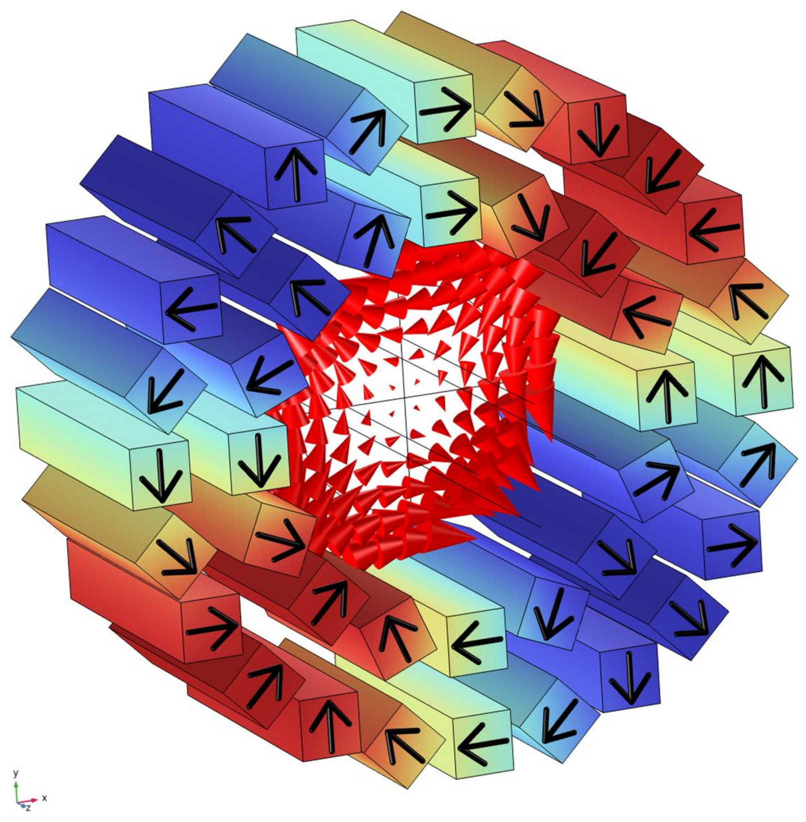
- High → zero **power consumption**
- High/complex → no **cooling**
- normal-conducting electromagnets **magnitude** is limited to ~2 T (iorn yoke saturation). Superconducting magnets can exceed this limit, but they require expensive cryogenic cooling → **magnitude** is limited to ~1 T
- **Tuneable** → see below how it can be solved with permanent magnets, as well.

Tuning – the Halbach concept



- Minimal stray field outside the ring
- Natural geometry for rotation
- Same concept to create dipole, quadrupole, etc fields.

Tuning solution: two nested, rotatable Halbach rings.



Dipole: combined X/Y corrector (steerer) in a single unit.

Quadrupole: focusing + optional X/Y coupling.

At every Halbach layout (2 nested rings):

- the direction (deflection/direction of focus planes) is freely adjustable, including polarity reversal
- magnitude (the degree of deflection/strength of the focusing) can be varied between the extreme values determined by the rings.

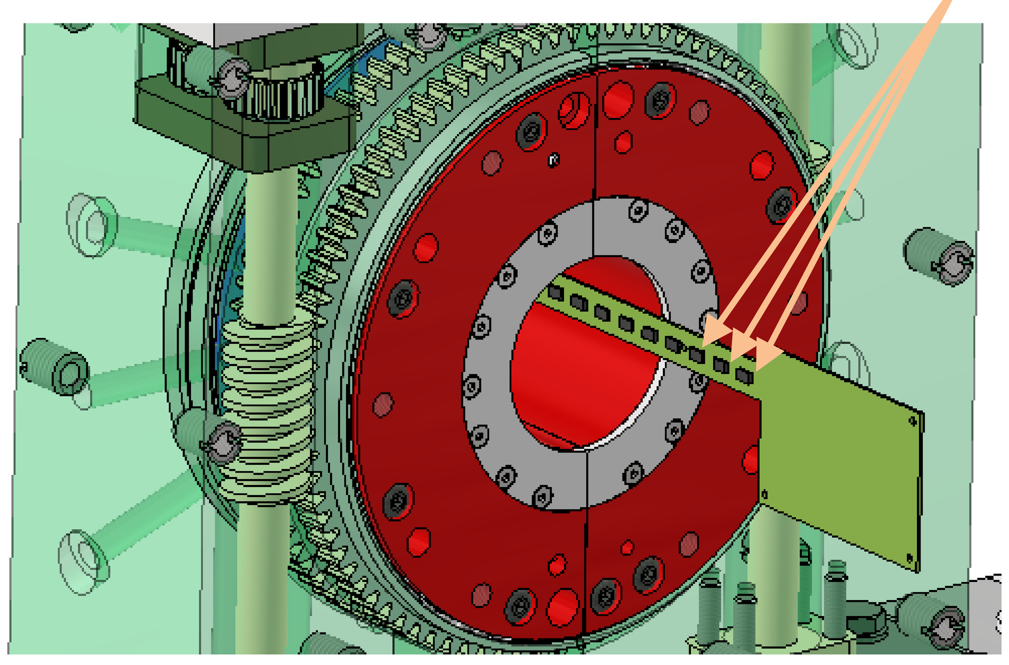
Hysteresis

It is only ~1% or less over the entire tuning range (140–320 mTat the sampling radius). This is caused by the negligible stray field outside of the Halbach rings.

In situ calibration

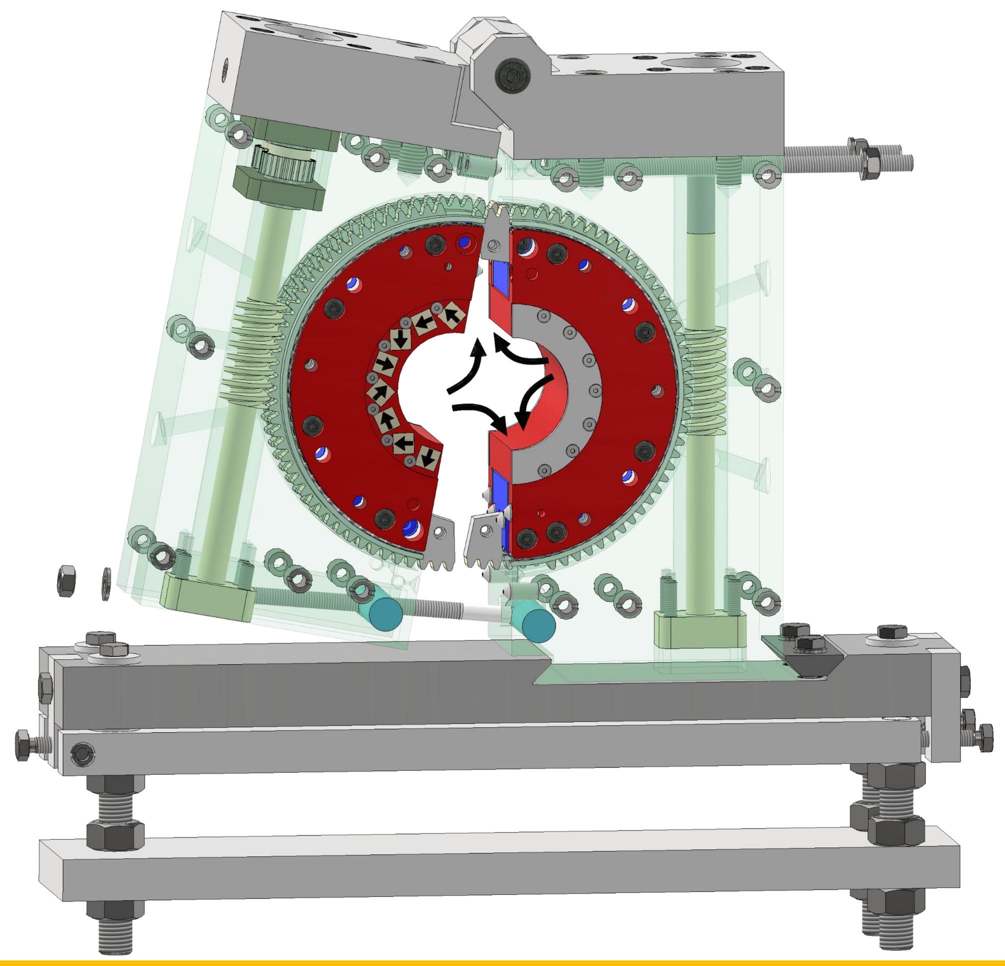
Hall probe array is developed to measure the magnetic field:

- 16 Hall probes, 10mm between each, positioned axially between the flight tube and the magnet
- Temperature stabilized



Prototype – quadrupole layout

Zero energy consumption

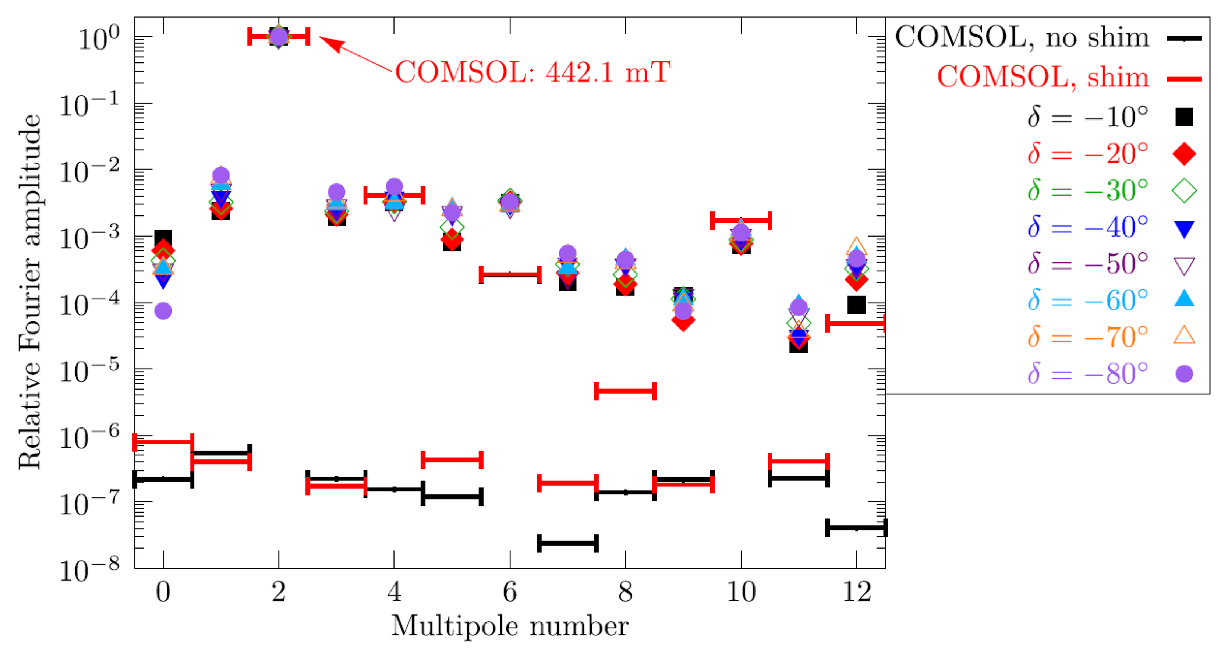


Patent pending

Can be installed around/removed from existing beampipe.

Prototype – field quality

Standard way: rotating coil method. The present construction offers to invert this approach and rotate the magnet around a fixed measurement coil (or in our case, a Hall sensor, placed at about 2/3 of the aperture).



All unwanted multipoles are suppressed at least by 2 orders of magnitude. The measurement precision was limited by the Hall probe. More accurate measurements show even better suppression, by a factor of 3. This result is reached without sorting of the magnets (by strength, inaccuracy, etc.)

Ultimate tuning range

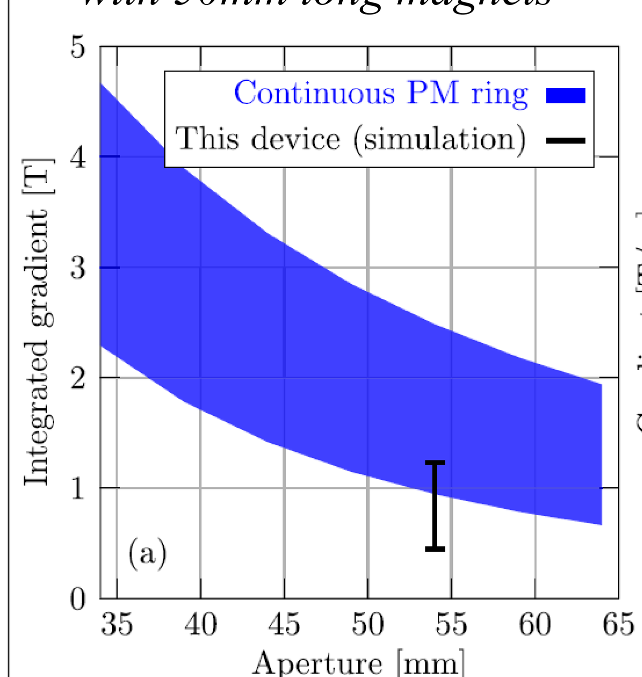
Filling factor can be increased by wedge shaped magnets. In order to define the ultimate limit, 100% filling factor was taken into account, i.e. two continuous ring with a continuous magnetization of

$B_x = -\sin[(m+1)\vartheta]$

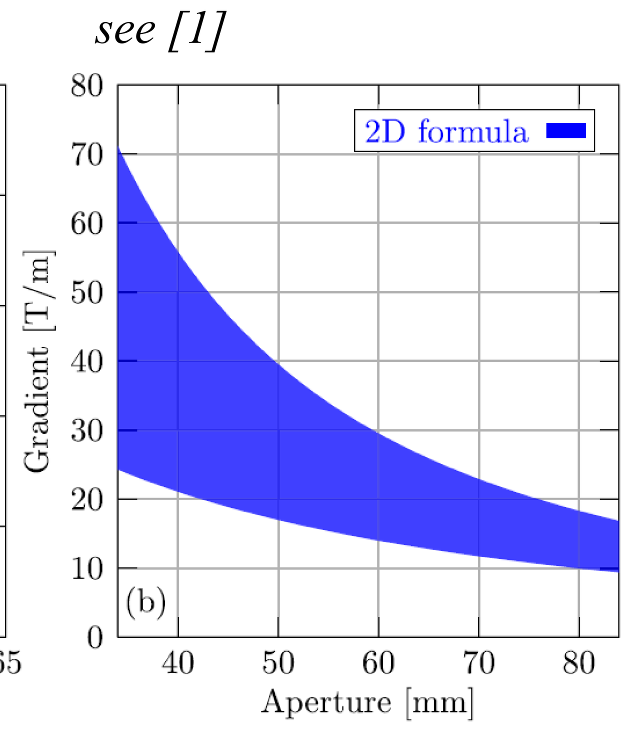
$B_y = \cos[(m+1)\vartheta]$

In case of quadrupole field, m=2.

3D COMSOL simulation, with 50mm long magnets



2D COMSOL simulation, see [1]



Reference

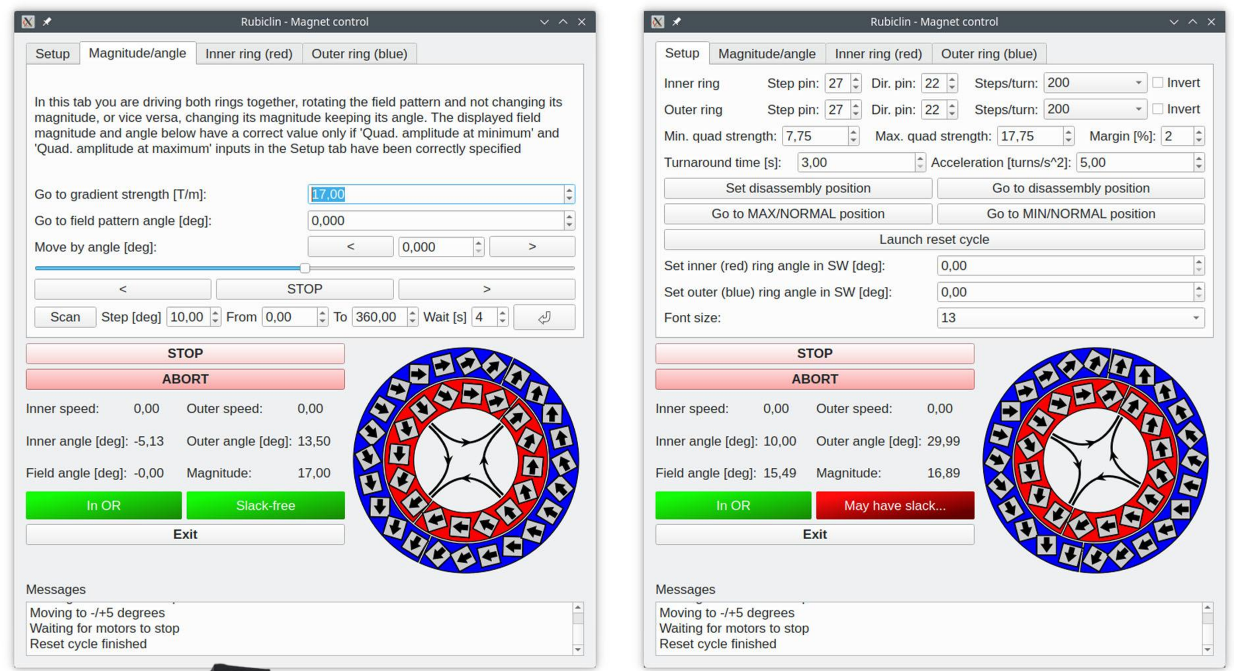
Tunable, unmountable, permanent-magnet-based accelerator magnet, Phys. Rev. Accel. Beams 28, 072401

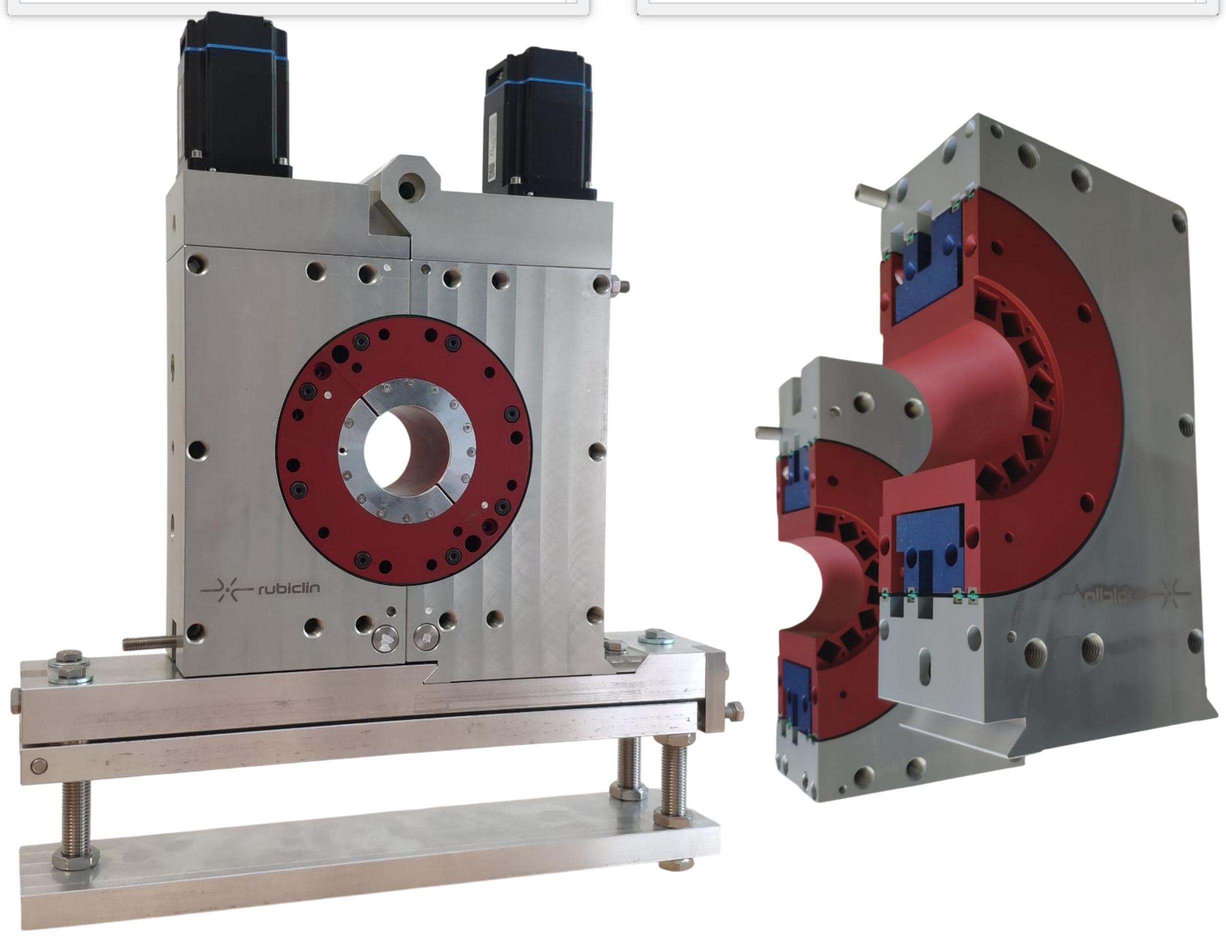
Prototype parameters

- Aperture: 54 mm
- Device length: 80 mm
- Number of magnets, inner/outer ring: 16/24 pieces (10 x 10 x 50 mm)
- Permanent magnet grade: NdFeB N52, B_r ~1.47 T
- Gradient (device centre): 7.75-17-75 T/m
- Integrated gradient (simulation): 0.36 – 1.01 T
- 2 stepper motors (for each ring)
- Openable (split rings)
- Stackable axially (wo gap)
- Adjustable base plate: high repositioning accuracy without realignment
- Quadrupole layout
- Tunability minimum: 0.01T (play-free driving mechanism)
- Switching time between min – max position ~1 s.
- Can be calibrated in situ (using a hall probe array)
- B_r degradation (due to radiation):
  - By tuning, if homogeneous
  - By reshuffling the magnets if non-homogeneous + tuning
- Can be converted between dipole, quadrupole or higher multipole by exchanging just one component

Control

Control of the unit is done via a software specifically developed for this purpose (by Rubiclin Ltd).





Summary

Prototype (made by Rubiclin Ltd, https://www.rubiclin.com) has been tested:

- robust, massive design, play-free driving mechanism
- **field quality is similar to standard electromagnets** wo additional efforts (sorting of magnets), unwanted multipoles are suppressed by at least 2 orders of magnitude.
- Realignment causing negligible change in the field pattern/magnitude
- Hysteresis is negligible
- Polarity reverse in ~1 s
- In situ magnetic field calibration (with hall probes)
- **installed/removed without opening the beampipe, large flexibility in varying the optics**