TECHNICAL ARTICLE · MAGNET SYSTEMS & MICROTECHNOLOGY

SEKELS

Magnetic Particle Mover: Contactless Control of Magnetizable Nanoparticles in 2D and 3D

How a patented Halbach magnet system makes contactless manipulation of smallest particles reproducible for life sciences, diagnostics and microrobotics.

The Challenge at the Micro- and Nanoscale

The controlled, contactless motion of ferromagnetic nanoparticles is becoming increasingly important across numerous fields of research and applications – from life sciences and biomedicine through laboratory processes to micro- and nanorobotics. Wherever smallest particles need to be moved precisely, reproducibly and without contact, new possibilities open up.

Traditional mechanical handling, however, quickly reaches its limits at the micro- and nanoscale: dominant surface forces, limited installation space for actuators and the demanding, reproducible positioning of smallest objects make precise processes difficult. Contactless methods are therefore of great interest, particularly when handling sensitive samples or controlling many particles in parallel.

This is precisely where the **Magnetic Particle Mover** from SEKELS GmbH comes in. The system enables precise and reproducible control of motion and positioning sequences in two or three dimensions – contactless and based on precisely generated magnetic fields and field gradients.

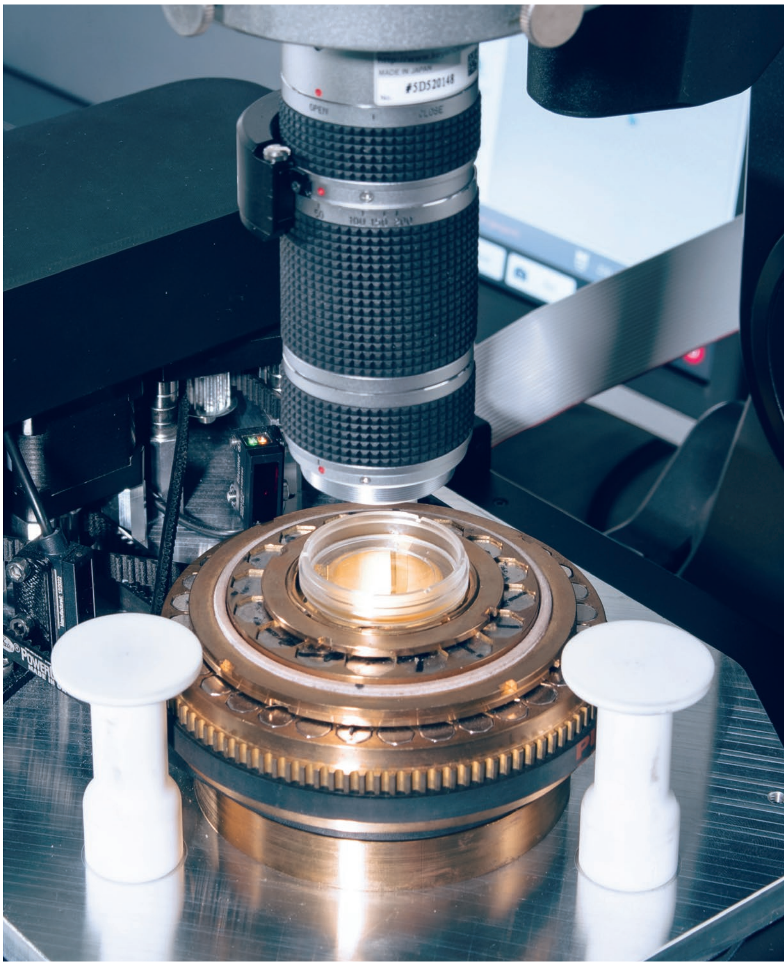


Fig. 1: The Magnetic Particle Mover under a digital microscope – the Petri dish sits centrally within the ring-shaped Halbach magnet system.

The Operating Principle: Halbach Dipole and Quadrupole

The technical principle is both clear and powerful. The system generates superimposed magnetic fields and field gradients by combining Halbach dipole and Halbach quadrupole arrangements of ring-shaped magnetic subsystems. A dipole ring provides a homogeneous magnetization field, while two rotatable quadrupole rings generate the field gradient.

When the two quadrupole rings are in a compensating position, the field remains homogeneous and no net force acts on the particles. When both rings are oriented in the same direction, the maximum field gradient is created – and with it the maximal magnetic force on the magnetized particles. The amplitude and direction of the gradient can thus be precisely adjusted, allowing particles to be moved in a controlled manner and positioned exactly.

The cross-sectional view of the magnet system illustrates the arrangement: two dipole segments enclose the two quadrupole rings, at the center of which the Petri dish with the sample is positioned. Particle motion can be visualized, observed and documented in real time using a digital microscope.

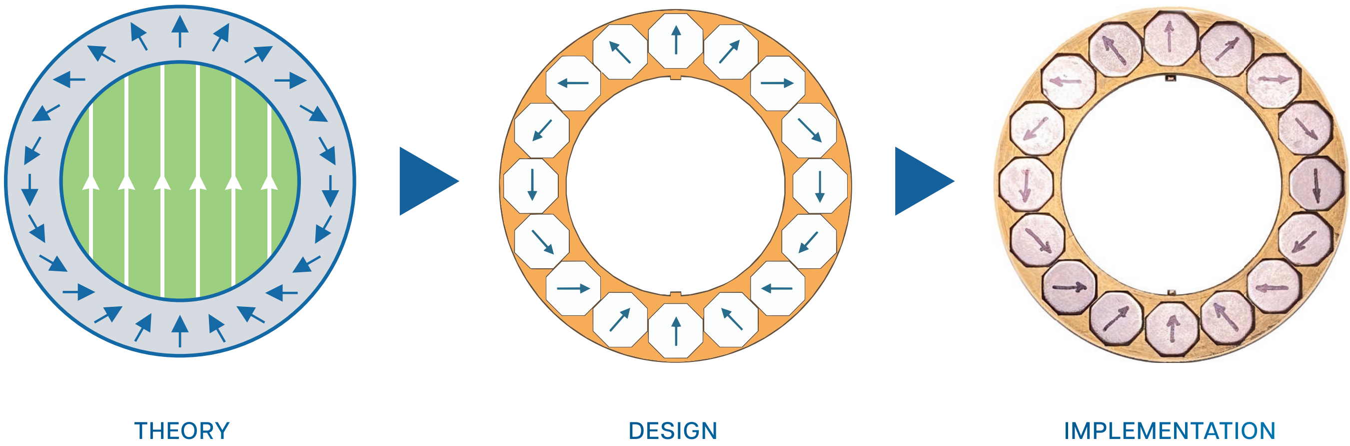
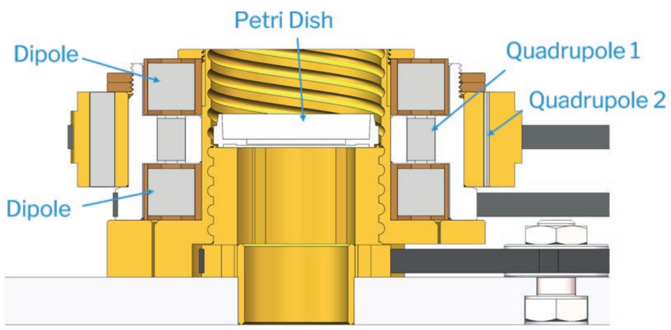


Fig. 2: From principle to component – theory of Halbach magnetization (left), constructive implementation with segmented magnets (center) and the realized magnet ring (right).



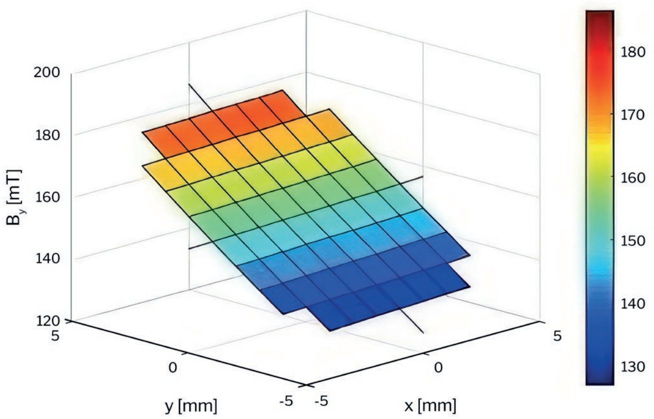


Fig. 3: Cross-section of the magnet system with dipole, two quadrupole rings and the centrally placed Petri dish.

Fig. 4: Measured distribution of the magnetic field component across the sample chamber.

Design and Technical Implementation

The implemented 2D system consists of the ring-shaped magnet system and the driving actuators. The quadrupole rings are driven by stepper motors via toothed belts; a compact control unit connects the device to a PC via USB. The low overall height makes it ideal for use on laboratory benches or for in-vitro experiments.

Control and Operation

The supplied software handles real-time control. Users can approach individual target positions via coordinates or program entire motion sequences as macros – with definable angles, rotation and holding times, and repetitions. This allows particle trajectories to be defined exactly, experimental conditions to be fine-tuned and processes to be automated reproducibly.

Technical Data of the 2D System

Designation	Magnetic Particle Mover (2D)
Field strength	0.15 T
Field gradient	6 T/m
Sample chamber diameter	Ø 35 mm
Interface	1× USB A 2.0
Power supply	230 V, 60 W
System requirement	Windows 10 or newer
Dimensions	250 mm × 180 mm × 60 mm
Mass	3.9 kg (4.7 kg incl. controller)

Fig. 5: Final device with housing and control box.

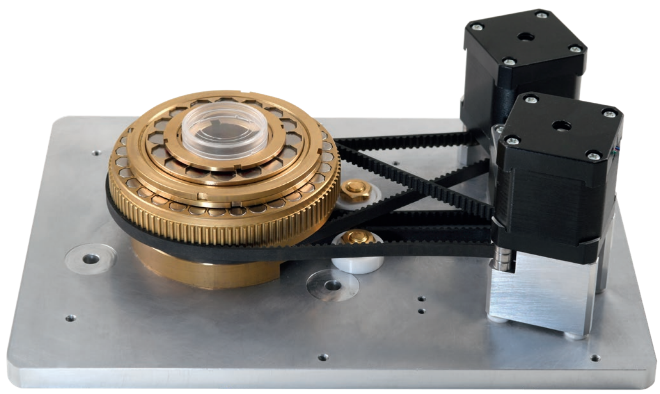


Fig. 6: Magnet system (left) and stepper-motor actuators (right) on the base plate.

From the 2D Manipulator to the 3D Guider

While the Magnetic Particle Mover as a 2D manipulator enables precise and repeatable movement of magnetizable particles in a plane, the 3D Guider extends contactless control into three-dimensional space. The prototype presented has an inner diameter of 100 mm, is designed as a portable assembly with a total mass below 5 kg, and was manufactured using 3D printing.

For future development stages, a doubling of the inner diameter to 200 mm in an aluminium-and-brass construction is planned, complemented by a controllable sample stage. Further scaling of the system is possible.

Fig. 7: 3D Guider prototype (inner diameter 100 mm) – a portable, 3D-printed assembly for three-dimensional particle control.

Fields of Application

When assessing the possible uses, a distinction must be drawn between functions that are already available today and a potential that reaches beyond them. The following description therefore separates the applications demonstrated with the current system from the visionary applications that are still being developed.

Applications Available and Demonstrated Today

The delivered 2D system is operational and, combined with a digital microscope, ready for use. Specifically, the following functions are available today:

- **Contactless 2D particle control:** precise and repeatable movement and positioning of magnetizable nanoparticles as well as micro- and macro-magnetic objects in a plane – demonstrated on particles in the single-digit micrometer range.
- **Programmable trajectories:** definition of target positions and complete motion sequences (macros) via the supplied software, including adjustable angles, rotation and holding times, and repetitions.
- **Real-time observation:** visualization, observation and documentation of particle motion in real time under a digital microscope (e. g. Keyence VHX with Z20 and Z100 lenses).
- **Reproducible laboratory processes:** contactless, automatable experimental workflows as the basis for handling sensitive samples – ideal for in-vitro experiments on the laboratory bench.
- **3D functional demonstrator:** the 3D Guider prototype (inner diameter 100 mm) already shows the extension of control into three-dimensional space as a portable assembly.

Fig. 8: Microscopic image of controlled particles – the size measurement of individual particles in the micrometer range demonstrates the achieved resolution and control.

Possible Future Applications

Beyond today's functional scope, contactless magnetic particle manipulation opens up a broad spectrum of visionary applications in biology, cell technology and microtechnology. Some of these are in research and development and indicate the direction of future development stages:

- **Microfluidics & lab-on-chip:** DNA/RNA extraction using functionalized nanoparticles, automated separation in microchannels, and point-of-care biosensing and pathogen detection from the smallest sample volumes.
- **Cell biology & diagnostics:** cell separation with antibody-coated particles, isolation of circulating tumour cells (liquid biopsy), and targeted drug delivery for precise drug application.
- **3D cell culture & organoids:** magnetic levitation for scaffold-free spheroid formation, organoid assembly, tissue engineering and drug screening on physiologically relevant 3D models.
- **Microrobotics:** magnetically actuated microrobots, soft microgrippers and helical swimmers for minimally invasive procedures and stem-cell transplantation.
- **Magnetic navigation:** actively steerable capsule endoscopes for human and veterinary medicine as an alternative to purely passive, peristaltic locomotion.

Conclusion and Outlook

For universities, research institutions and technology-oriented companies, the system creates new freedom: it supports addressing new research questions, enables more precise and reproducible experiments, and opens up perspectives for innovative product and process development. With its patented Halbach architecture, real-time software and the step from a 2D to a 3D system, SEKELS positions the Magnetic Particle Mover as a versatile tool for contactless manipulation at the micro- and nanoscale.

The next development step is marked by the planned enlargement of the 3D system: with an inner diameter of 200 mm in a robust aluminium-and-brass construction, a controllable sample stage and the fundamental scalability of the architecture, contactless manipulation is to be opened up for more demanding samples and larger working spaces. The Magnetic Particle Mover thus grows from a tool for basic research into a platform for reproducible, automatable processes in diagnostics, cell technology and microtechnology.

Available today	**Future potential**
Contactless 2D particle control at the micrometer scale	DNA/RNA extraction and biosensing in lab-on-chip systems
Programmable trajectories and macros via software	Cell separation, liquid biopsy and targeted drug delivery
Real-time observation under the digital microscope	3D cell culture, organoids and tissue engineering
Reproducible in-vitro laboratory processes	Microrobotics for minimally invasive procedures
3D Guider functional demonstrator (Ø 100 mm)	Scaled 3D system (Ø 200 mm) and magnetic navigation

The overview above summarizes what the system already delivers today and where development is heading

About SEKELS GmbH

SEKELS GmbH (Ober-Mörlen, Germany) is a specialist in magnetic fields, materials, magnet systems and magnetic shielding. With around 25 employees – roughly half of them physicists and engineers – the DIN EN ISO 9001-certified company serves more than 600 customers worldwide, from consulting through to the series delivery of finished systems.

Contact

Dr. Stefan Hiebel
+49 6002 9379-46
shiebel@sekels.de

particlemover.com