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HUMAN-LIKE ROBO HANDS WITH SEPARATELY CONTROLLABLE FINGERS

## High-Performance Robotics



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Precise drive system delivers digitized images of the very highest quality.



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Brushless DC motors  
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- Ultra-compact  
Penny geared motors  
Series 1307/1309 ... BH



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### Pinpoint Accuracy

Installation of a new assembly plant at the Schönaich site



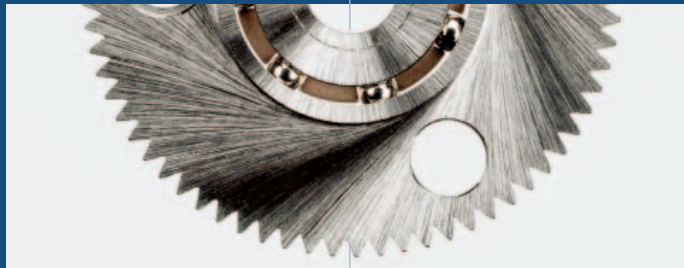
DECADES OF EXPERIENCE IN "STATE-OF-THE-ART" MICROTECHNOLOGY PAYS OFF:

# High-precision bearings and actuators for micromechanics

Micromechanics and microengineering are synonymous with advanced technology geared to the future. Today, miniature components manufactured and put together to form complex micro-assemblies appear to capture the

As early as the 1930s, the Swiss company RMB – which changed its name to MPS (Micro Precision Systems AG) in January 2003 – was producing miniature ball bearings for clocks, watches and the measuring instrument industry. In the 1940s, the Swiss-based specialist unveiled

provide a very long service life and feature minimum friction. Furthermore, bearings deployed within this area should be lifetime-lubricated. These requirements also apply to all other sectors of micromechanics. Introduction of the 4-point ball bearing represented a milestone in micro-



essence of pioneering research and production. And yet, this technology is not quite as new as is often thought. Even in the high-tech sector of microengineering, there are companies that have been dealing with these miniature components for several decades. The wealth of experience gathered in this area is a significant advantage, not just when it comes to selecting state-of-the-art materials but also in the production processes.

Components of the miniature 4-point bearing



its miniature 4-point ball bearings. The company, which today operates within the FAULHABER Group, then went on to supply components for the Apollo Moon missions, thus establishing a strong foundation for its future as leading manufacturer of miniature bearings and actuators. The company's expertise is translated into cutting-edge solutions as part of three product lines: 4-point contact bearings and miniature balls, linear bearings and high-precision recirculating ball screws, besides all-embracing customized systems based on brushless miniature DC motors, including control modules.

**Precision mounts ...**

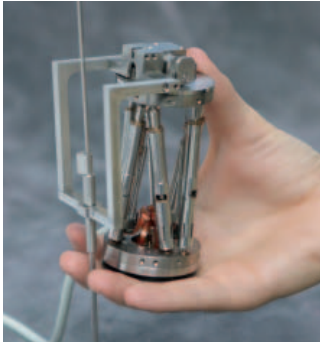
All microengineering has its origins in the clock and watch industry. Initially, the MPS product portfolio of precision bearings was tailored to the requirements of this industry. The bearings used in clocks and watches have to be extremely accurate,

bearing technology. Based on their design, these bearings are maintenance-free, feature low backlash and are able to absorb both radial and axial forces. Consequently, the clock and watch industry used them for self-winding mechanisms on automatic watches. This type of bearing quickly found its way into other functional areas, such as adjusting wheels and mounts for Tourbillon cages on high-precision mechanical clocks and watches.

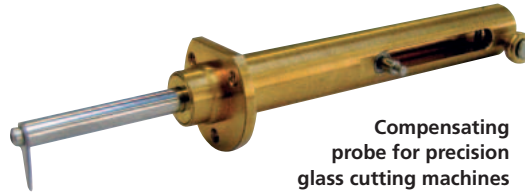
The ability to absorb axial and radial forces is a major advantage in modern actuators. It means that the bearing assembly requires only two identical bearings on motors and gear mechanisms. For extreme applications and in the case of medical implant engineering, MPS manufactures the ball bearings from titanium with balls made of ceramic zirconium oxide. These bearings are biocompatible and feature no lubricants. The titanium bearings are available with an inside



Body-implantable peristaltic pump



Hexapod auxiliary robot for spinal column operations



Compensating probe for precision glass cutting machines

standard. The spherical deviation is less than  $0.08\ \mu\text{m}$ , with a diameter deviation of  $1.3\ \mu\text{m}$  per batch. The hardness of 760 HV in the case of steel and 1150 HV in the case of zirconium oxide provides major wear resistance.

### ... with perfect guidance

The bearings of the microlinea® range allow linear movements with low friction. Linear bearings, ball cages and recirculating ball screws ensure that the applications "keep on the straight and narrow". The linear bearings with a shaft diameter of 2 to 6 mm, an outer

systems, analysis instruments, robotics, precision tools and scanners.

Body-implantable, miniature peristaltic pumps and even dosing micro-pumps for implantation in the eye socket have already been developed in this sector.

The portfolio also includes mechanical "aids", such as hexapod robots for orthopaedic surgery on the spinal column or compensating probes for optical glass cutting machines. One of the key aspects is maximum precision in each phase of the production process. For this purpose, the individual components with a small cross-section are sorted in pairs into



diameter of 1 and 1.5 mm, with outside diameters of 4 and 5.5 mm and an overall height of only 1.2 or 2 mm. The standard versions of the bearings made of stainless steel are even smaller. They have an inside diameter of 1.2 mm, with an outside diameter of 1.6 mm and an overall height of 0.4 mm. The axial play of this tiny component is only  $6\ \mu\text{m}$ . Of course, the bearing balls are also available individually. The standard range for steel balls is 0.02 to 1.5 mm, while zirconium oxide balls are supplied from 0.7 and 1 mm as

diameter of 4 to 12 mm and an overall length of 5 to 18 mm, have a load-bearing capacity of 10 to 245 N. With their ultra-compact dimensions, linear bearing cages provide perfect solutions. The range also includes bearings with an inside diameter of 3 to 12 mm. The third linear assembly is the linear recirculating ball screw, suitable for use as a miniature actuator. With its ball nut diameter of between 10 and 28 mm and a shaft diameter of 4.25 to 13.6 mm, it allows precise traverse distances between 70 and 260 mm.

$2\ \mu\text{m}$  classes so as to ensure an optimum press-fit. The bearing play is also monitored 100% and limited to a maximum tolerance of only  $8\ \mu\text{m}$ . Among other solutions, MPS deploys company-developed measuring instruments, which are also available for use by customers and suppliers, allowing them to guarantee first-class quality at all times. Decades of experience in development and series production of precision micro-parts pays off, with state-of-the-art materials. Proprietary measuring systems and special-purpose manufacturing equipment and processes ensure MPS's technological lead, while also guaranteeing superior product quality. In turn, the high-quality products made possible in this way allow users to take innovative new approaches and provide a source of reliable components.

Miniature linear recirculating ball screw with high positioning accuracy



### All-in customized systems

The third main pillar of micro-production relates to all-in solutions manufactured precisely to customer specifications. The main fields of activity are prosthetics, implants and medical devices, miniature pumps, positioning actuators and servo-actuators for optical

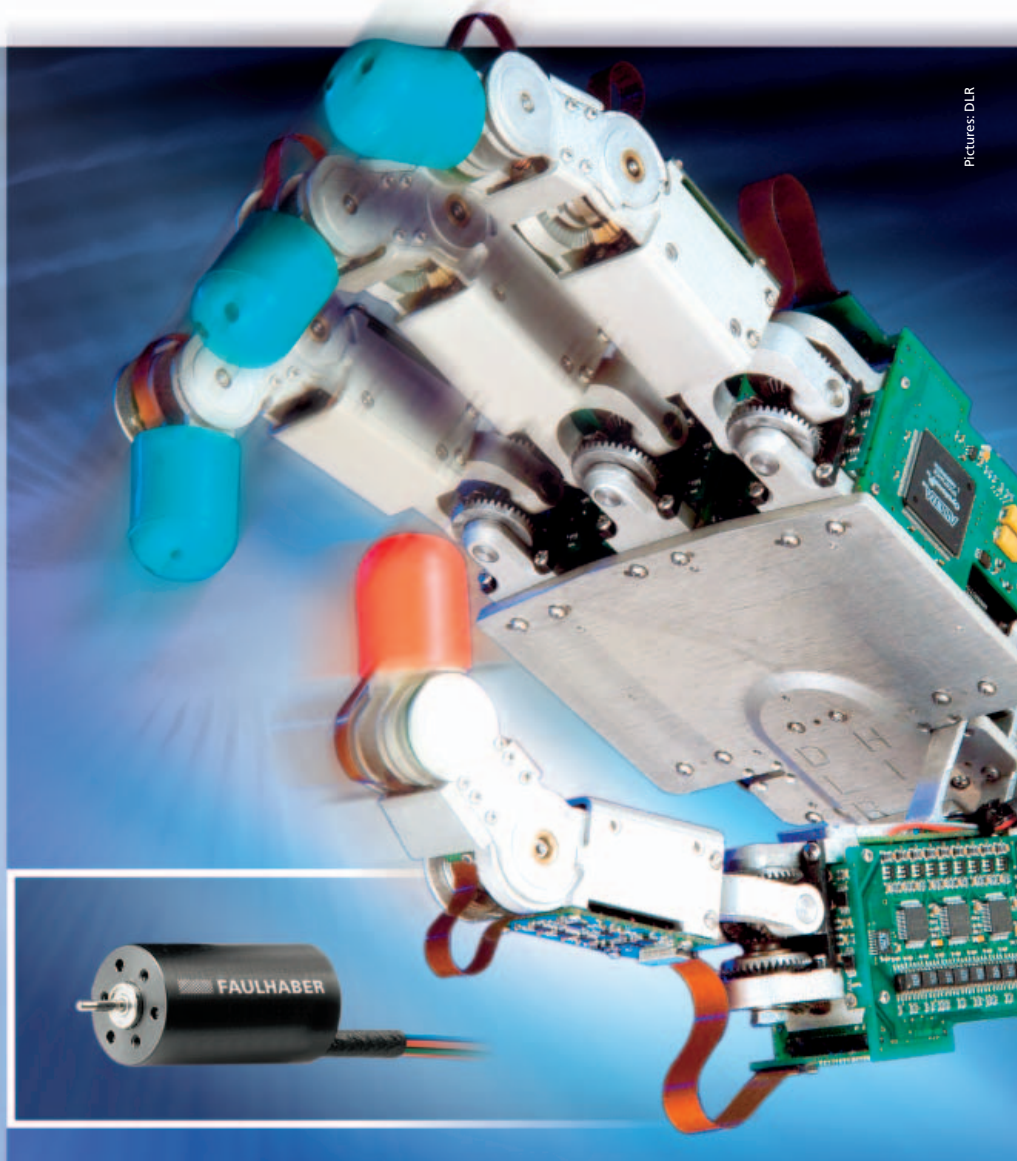
**weblinks**  
[www.mpsag.com](http://www.mpsag.com)

# Micro-actuators move sensitive 4-finger hand

## SYNERGY OF MICRO-ELECTRONICS AND MICROENGINEERING

To date, use of robotic hands in industrial production has been restricted to rugged two- and three-finger grippers. They are being used for the purpose of executing relatively simple movements. Robotic hands for more delicate tasks have proved unsuccessful due to the lack of technical capabilities available.

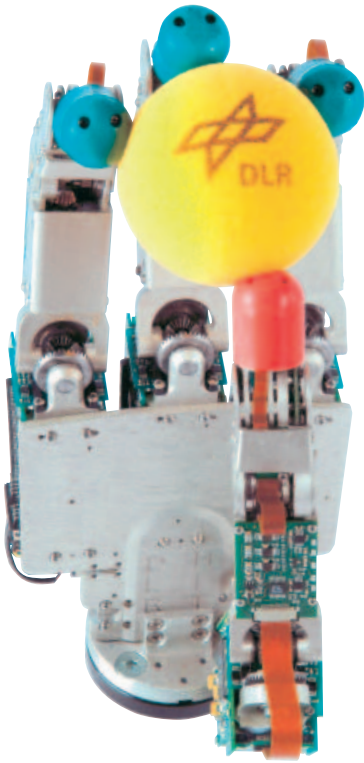
Positive interaction of micro-electronics and micromechanics has now produced the much sought-after breakthrough. Indeed, technological advance within this field is continuously growing. Thus, robotic hands with separately controllable fingers and joints based on human hands are no longer fiction and will probably soon be available on a day-to-day basis within the industrial sector.



Pictures DLR

The human hand is one of the most universal tools in nature. No wonder that researchers are eager to apply the advantages of this evolutionary design to a new generation of robotic hands. The German Aerospace Centre (DLR), in

cooperation with the Harbin Institute of Technology (HIT), has already developed a robotic hand similar to a human hand – with the aid of miniature actuators and high-performance bus technology.



Twelve Faulhaber motors ensure complex and delicate movements of the robotic hand with a firm grip

Constructing a robotic hand with the capabilities and dexterity of a human hand requires at least four fingers: three fingers to allow the robotic hand to grip conical parts, and a thumb used as a support. Consequently, the new robotic hand consists of three fingers, each with four joints in three degrees of freedom. The fourth finger, designed as a thumb, has four degrees of freedom. It goes without saying that the diverse movements made possible by this solution have to be controlled and monitored in a practical manner. Within this context, high-performance information channels are essential.

### Bus technologies for the “nerves”

In the past, robotic fingers were moved using cable pulls. In contrast, modern-day microengineering allows the motor to be fitted directly in the finger. In this case, supplying the control processor with the requisite position and operating data. This is an integral part of the overall operation – and the only way of allowing the actuator to use its strengths to the fullest.

Each finger joint features a company-designed contactless angle sensor as well as a torque sensor. Since both sensors require an extremely high resolution, a bus is used

to transfer the wealth of data required. Rapid feedback for comparison of setpoint and actual value is crucial to the function of the control system, particularly when performing intricate tasks. Therefore, alongside high-volume processing, time is of the essence.

The real time-capable 25 Mbps high-speed bus incorporated in the robotic hand itself and developed specifically for this application is based on FPGAs (Field Programmable Gate Arrays). Only three leads are required for the external serial connection from hand to control processor.

The actual control system, a signal processor on a plug-in PCI card, is integrated in a standard PC. An operator-friendly interface allows the “hand” to be controlled from the computer. All sensor data can be displayed on the monitor.

Data display, control and the connection of hand to computer were designed, from the outset, with a view to future use in industrial environments.

Besides the “nerves” and the “brain”, a functioning hand also requires “muscles to give it strength”.

### Miniature actuators replace muscle power

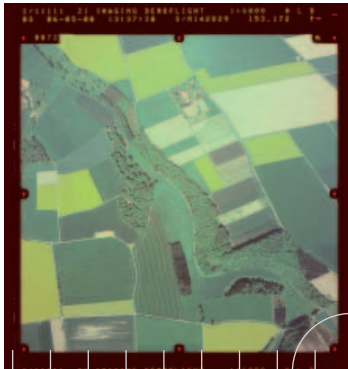
The tremendous complexity of the new robotic hand has its price. Each finger requires several separately controllable actuators. In this particular case, there are twelve electronically commutated DC motors (EC motors), including analogue Hall sensors, per hand. The team of engineers opted for actuators developed by miniature motor specialist FAULHABER since they covered the full range of specifications required. They are low-cost, commercially available, performance-packed products with an extremely small footprint. Brushless DC servo-motors with a diameter of 16 mm were selected for the four-finger robotic hand. They can be connected with gear systems of the same diameter to form one integrated unit. The motors are available as 12 V versions and

24 V versions and feature an output of 11 W with a maximum continuous torque of up to 2.6 mNm. A good dynamic response, even when subject to changes in direction of rotation, and pre-stressed ball bearings ensure precise response behaviour to control commands. The analogue Hall sensors fitted as standard signal the exact position to the control and deliver the requisite feedback information with a resolution of at least 8 bits. The Hall sensors and motor form a compact unit with a length of only 28 mm and an outer diameter of 16 mm – with a weight of a mere 31 g.

The motors idle at 29,900 rpm. The actuators are combined with all-metal planetary gearheads. These standard FAULHABER products reduce the high rotational speeds for use in the “hand” and, at the same time, enhance torque. A broad selection is available with ratios from 3.7:1 to 5647:1. The ratio used in this application is 159:1. The permitted torque thus increases to a maximum value of 450 mNm. The gearhead itself weighs a mere 33 g, with an overall length of 29.4 mm.

The new HIT-DLR robotic hand can be controlled very delicately and precisely thanks to the compact actuator technology with feedback and fast data forwarding by bus. In this way, microengineering and microelectronics complement each other perfectly. “Armed” with standard components and a good concept, engineers can now manufacture products that would have been inconceivable several years ago, even with the most expensive customized components.

[weblinks](http://www.robotic.dlr.de)  
www.robotic.dlr.de



The copper graphite-commutated DC micromotor runs extremely uniformly and positions precisely even at low speeds of rotation

## Micrometer accuracy



Photogrammetry is a method for "measuring in pictures". It is used in many sectors: for instance cadastral surveying, agriculture, cartography and environmental impact studies.

Pictures: INTERGRAPH

### GEO-SCANNER MAKES EXTREME DEMANDS ON SYNCHRONOUS MOTORS

There can be no doubt that the successful advance of digital photography will continue well into the future. But cameras with films are still required for special fields of application in photography, for example making aerial photographs for surveying purposes. These special-purpose devices, frequently weighing two hundred pounds, are far too valuable to be replaced by digital technology. Today the films are digitized with the help of high-quality scanners. Such applications call for accuracy and resolution levels in the range of micrometers. At the same time, it is necessary to accelerate large volumes – some of the rolls have a length of up to 150 m and weigh around 5 kg. This not only makes enormous demands on the optical systems, but the actuators deployed within this area also need to come up with a spectacular performance.

The individual image sections are taken from various directions with a generous overlap in order to produce three-dimensionality from two-dimensional photographs. The series of images are transformed to a common coordinate system for processing.



The scanner was developed specifically for processing photogrammetric photographs. It achieves resolutions up to 7  $\mu\text{m}$ .

A special program then computes the 3-D coordinates of the specified elevation points. The individual photographs have to be scanned with maximum geometrical and radiometric accuracy in order to produce correct images as part of the superimposition process. Therefore, high-performance scanners are essential.

PhotoScan by INTERGRAPH was developed specifically for scanning photogrammetric images. It achieves resolutions up to 7  $\mu\text{m}$ . The images are each scanned with the required resolution, meaning that losses in quality owing to resampling are a thing of the past. The unit is suitable for scanning standard 236 x 236 mm<sup>2</sup> films through roll films with a length of 150 m. The negative carrier is stationary. The mobile, 40 mm-wide CCD sensor scans the image line by line. This process achieves a geometrical accuracy of better than 2  $\mu\text{m}$  RMS per axis.

### Actuators for constant speed

Klaus Neumann, Project Manager at INTERGRAPH, is aware that far more than just a high-resolution CCD sensor is required: "A high radiometric accuracy of the sensor is of no particular benefit if the actuator is not able to provide at least the same mechanical resolution. Therefore, one of the key requirements was that the actuator had to provide a resolution accurate to the micrometer". The high-performance scanner is equipped with several actuators developed by FAULHABER, the micromotor specialist. As Neumann continues: "We have been working together with FAULHABER for many years now and have nothing but praise for their actuator technology. Besides this, we have always received good support when developing new products".

An actuator moves the CCD sensor at constant speed in x direction. As Neumann emphasizes: "Even a small jolt is noticeable with these resolutions. So it is important for the actuator to operate at constant speed. Otherwise the image is subject to signal noise. We use a copper graphite-commutated DC micromotor. It features extreme synchronism even at low speeds and operates very precisely." The bell-type armature motor displays no signs of cogging thanks to an ironless rotor coil, thus ensuring high speed constancy without "torque ripple". This allows the rotational speed and the position to be controlled precisely using the tachogenerator mounted on the motor, together with a pulse generator. The analogue tachogenerator supplies information on velocity extremely quickly, while the pulse generator supplies precise position information.

### High precision

When the sensor has scanned one line, the actuator moves it back in the x direction. At the same time, another actuator moves the sensor in the y direction precisely through its width. The next scanned line continues seamlessly from the previous one. However, owing to the design, the

x axis and the y axis of the scanner are never exactly at right-angles. Even minimal angle offset may have devastating consequences with a required resolution of 1  $\mu\text{m}$ . For this reason, the second actuator not only has to position the sensor next to the last scanned line, but also position it accurately to the micrometer. During traverse in x direction, the actuator must also compensate for the positional error of the axis so that the scanned line follows the previous one precisely. The perfect solution: a DC bell-type armature motor with an attached pulse generator or encoder, which, as the active element of a control loop with incorporated electronic circuitry, is able to respond in an extremely short time very precisely and without overshoot.

### Small, compact and powerful

The photo-scanner achieves very high scanning speeds. Seven minutes to scan a standard 236 x 236 mm<sup>2</sup> film with a pixel size of 14  $\mu\text{m}$  is an exceptional performance. But when scanning an entire film with up to 550 images, it is important that the process can be performed independently, for instance overnight. The meter-long films are fed automatically via a roll-film attachment. Once again, DC bell-type armature motors play a pivotal role. In this case, it is important for the actuators to provide high torque levels, while at the same time being compact and energy-efficient. Absolute accuracy is not necessarily required in such cases. The film simply has to be positioned accurately to a few millimeters. The scanner itself determines its precise start point by conducting a comparison with a frame mask present on the film.

The interplay of high-resolution optics and high-performance, compact actuator technology delivers picture-perfect results.

**weblinks**  
www.ziimaging.de

## Even better



Scale 1:1

### The new 1525/3153 ... BRC Series

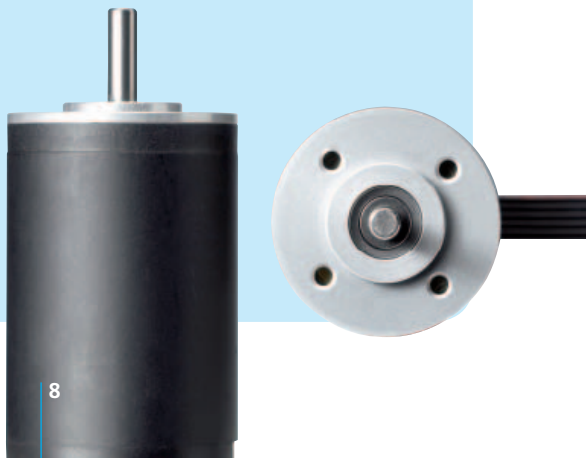
Thanks to an optimised design and extended scope of functionality, the time-proven brushless DC motors with integrated electronic circuitry have been enhanced even further. The FAULHABER actuators with high-quality neodymium magnets now achieve continuous torques of up to 1.8 mNm in the 1525 BRC Series and up to 28 mNm in the 3153 BRC Series.

One interesting new aspect of these two lines is their integrated speed control function. The speed can be controlled independently of the torque via a separate setpoint input with an applied voltage of 0...10 V.

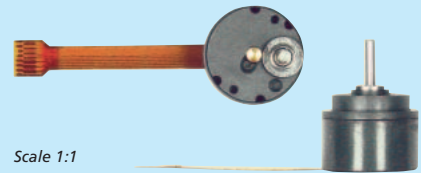
The motors are available in versions for voltages from 9 to 24 V. Owing to electronic commutation, their service life is basically limited only by the bearings and the electronic components used. Their long service life and synchronised operating temperature range mean that they are particularly suitable for endurance applications, e.g. as actuators for pumps, fans or scanners.

**weblinks**

[www.faulhaber-group.com](http://www.faulhaber-group.com)



## Ultra-compact



Scale 1:1

### The new 1307/1309 ... BH Series

The FAULHABER Group has also extended its product portfolio within the area of "penny motor" technology. The Group recently launched two series of geared motors with ratios of 6:1 to 1.830:1 on the basis of these ultra-slim actuators.

The motors owe their extremely compact design, identical for all ratios, to their self-supporting coil that is produced photolithographically (i.e. printed) rather than being wound mechanically as on other motors. This allows precise, synchronous operation without cogging.

Without doubt, one of the most noteworthy performance features of the 1307/1309 ... BH Series is the torque of up to 10 mNm, which is particularly impressive when one considers its size of 13 mm outer diameter and 7 or 9 mm length. This dynamic performance is achieved by the use of high-quality neodymium (NdFeB) magnets. The brushless structure with electronic commutation ensures the long service life typical of this motor design.

The two series of ultra-compact actuators provide the perfect platform for a vast range of innovative product applications.

**weblinks**

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# New Products Folder 2005

The latest drive and actuator highlights of the FAULHABER Group



When it comes to developing new products, we continually incorporate the data obtained from projects associated with the implementation of numerous drive and actuator solutions. Committed to excellence, the FAULHABER Group is thus able to extend its range of products at the very highest level both technically and in terms of quality.

A special information pack has been produced for the full range of new drive and actuator products, including technical specifications. The pack also contains a Catalogue CD with technical information on the entire range of products developed within the FAULHABER Group.

**Request your free copy now:**

Fax +49 (0) 70 31/638-333  
or on the Internet at  
[www.faulhaber-group.com](http://www.faulhaber-group.com)



## penny-motor Flyer

Micro-motors combine unusual design with outstanding performance. Hot off the press: learn about all the key facts in the new penny-motor flyer – technology, technical data and possible applications of the ultra-slim, brushless actuators.

Ask for your free copy now:  
Fax +49 (0) 70 31/638-333 or on the Internet at  
[www.faulhaber-group.com](http://www.faulhaber-group.com)



## penny-motor Starter Kit

Discover the impressive performance of the ultra-slim brushless motors for yourself – with the penny-motor Starter Kit. It contains a fully fledged actuator system, consisting of a penny motor and control unit, allowing all operating modes to be demonstrated easily and conveniently.

The starter kit is available at a price of EUR 189,– plus VAT from the Express48 Shop at  
[www.faulhaber-group.com](http://www.faulhaber-group.com).

# Pinpoint Accuracy



After the unit had been assembled and tested by the manufacturer, a team from Scholpp Kran & Transport in Stuttgart took on the task of transporting it to the installation site.

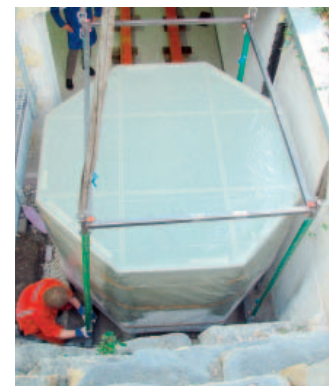
While long and narrow components as well as small parts posed no particular problems – they were transported easily via standard entrances and a goods lift – handling of the assembly cells was a very intricate procedure.

The only access point for the nine modules, each with a unit weight of around 4 metric tons, was an approx. 2.4-meter-wide shaft. The challenge related to the size of the assembly cells rather than their weight. In view of the module width of 2.30 m, there was a space of only a few centimeters at the right and left for positioning the cells safely in the building.

The Scholpp team did an amazing job: the entire installation work was completed in only one day, and the new unit was able to be integrated in the existing FAULHABER consignment and Kanban logistics system.

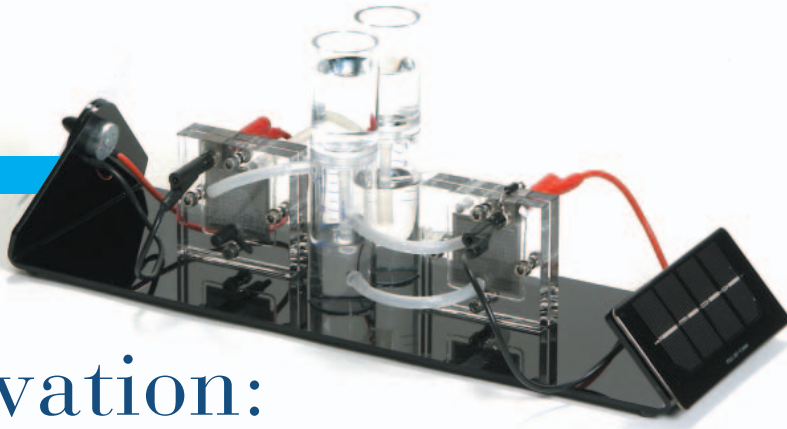
## INSTALLATION OF A NEW ASSEMBLY UNIT

FAULHABER's company motto "maximum performance in the smallest package" also applied when it came to installing a new fully automatic assembly unit in Schönaich/Germany back in May 2005. The system, destined for series production of a specially developed, customised drive unit, consists of seven assembly turntables and two test chambers with 6-axis robots, taking up total floorspace of approximately 23 x 14 m.



The nine assembly cells were inserted through a narrow shaft.

## TRENDS



# Innovation: »Fuel-cell drive«

Regenerative energy is used to produce hydrogen by electrolysis. This hydrogen is buffered and converted back to electrical energy by means of a fuel cell so as to drive an electric motor. This technology is clearly geared to the future, and its commercialization – also within the area of micro-drive engineering. It promises to unlock tremendous opportunities, particularly for use in portable equipment.

Teaching and demonstration models provide a glimpse into the fascinating future of fuel-cell drive technology. For the purposes of “experimental visualisation”, motors featuring a low starting voltage, high efficiency and operation without dwell torque are essential. The

bell-type armature motors developed by FAULHABER have the best credentials. Experience the fascination of fuel-cell drive technology live at one of the FAULHABER trade fair presentations. Dates, facts and figures on the relevant trade fairs can be found overleaf.

## ENVIRONMENT CORNER

## Spick & Span

FAULHABER has installed a new system for cleaning and degreasing workpieces at its Schönaich site.

Within the framework of the company’s environment policy, FAULHABER ensured that the new system would allow the use of modified alcohol instead of PER (perchloroethylene), used to date as the cleaning agent. All tests conducted within this area were extremely promising. Thus, FAULHABER has taken another giant step forward in terms of reaching its goal of completely replacing the old perchloroethylene cleaning system currently in use and converting to a more environmentally acceptable cleaning agent at the same time.



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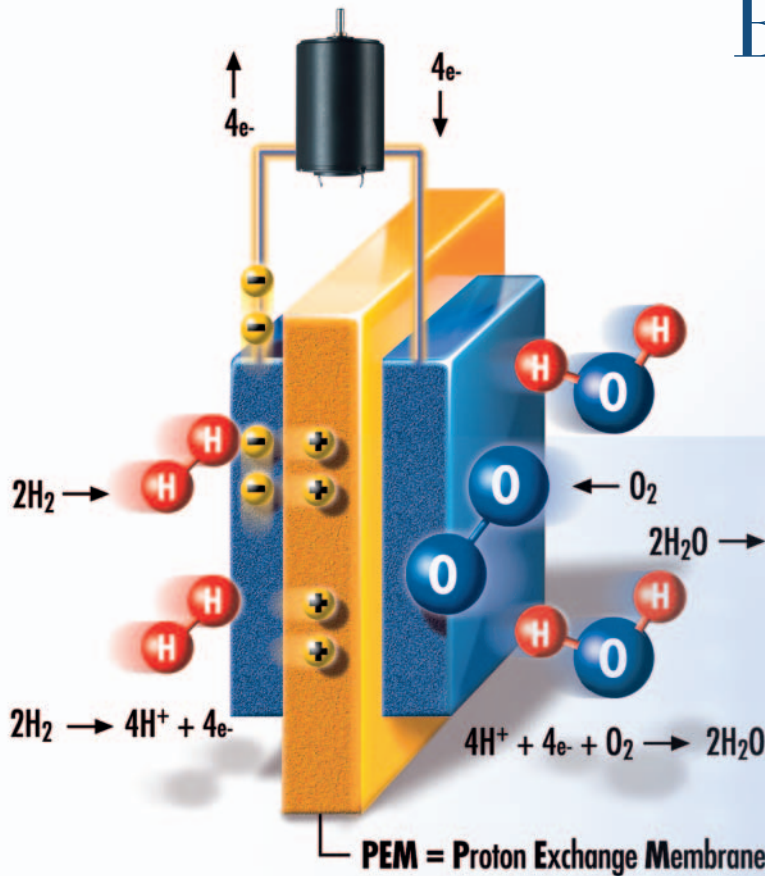
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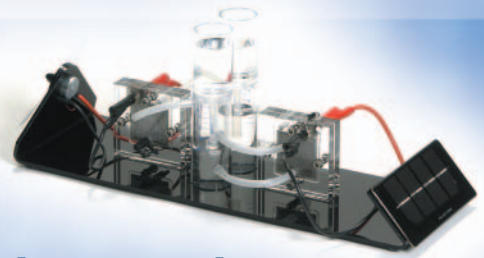
**COMPETITION**



# Be there ... and win

Find out about the FAULHABER Group's current technology highlights and experience the fascination of fuel-cell drive technology live at one of the trade fairs below.

- Productronica · Munich · November 15 – 18, 2005  
Hall B5 · Stand 437
- SPS/IPC/DRIVES · Nuremberg · November 22 – 24, 2005  
Hall 1 · Stand 127



## Time to Win

With a little luck you could win an original "Fuel-Cell Drive Technology" demonstration model.

Simply complete this page and fax it to us on: +49 (0) 70 31/638-333.

**More information? No problem!**



- FAULHABER Drive and Actuator Systems Catalogue
- Micro-Systems Folder
- ARSAPE Stepper Motors Folder
- FTB Thin Profile Motors
- MPS Folder
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