FAULHABER

motion

01.2022

THE MAGAZINE WITH DRIVE

Being able to walk again – not just a dream

75 YEARS OF MOTION

Dear Readers,

The first edition of our magazine traditionally appears in spring. This time of year is also a labor-intensive period in agriculture. For example, the crops sown before winter must be fertilized – a process that today is becoming ever more automated. In the new AERO fertilizer spreaders from the agricultural machinery manufacturer RAUCH, FAULHABER drives ensure precise dispersion and therefore the optimum supply of nutrients. This is sustainable environmental protection because only the amount of fertilizer that can actually be absorbed by the crops is spread, which in turn prevents the groundwater from being unnecessarily contaminated with nitrates.

2022 is a special year for us. 75 years ago my grandfather founded Dr. Fritz Faulhaber Feinmechanische Werkstätten and in doing so paved the way for the internationally successful group of companies that we know today. His invention, the ironless, self-supporting skew winding, contributed significantly to the miniaturization of drive technology and brought with it a huge boost in innovation in many different applications. This creative energy and the pioneering spirit continue to shape and influence us today and I'm proud of what we together with our employees and partners have achieved over the years. Courage breeds success: this is also demonstrated in the decision in 1962 to expand into other European countries. This is why I am particularly pleased that this year, apart from our 75th anniversary, we will also be celebrating 60 years of FAULHABER in Switzerland.

And, in the future, our aim is to continue delivering the perfect drive solution for every life-enhancing innovation. For example, we have developed an innovative all-in-one component motor with torque sensor for the "Autonomyo" exoskeleton. Six micromotors deliver additional power to enable people with certain neuromuscular conditions to fulfill their dream of walking without crutches. The active walking aid supports the weakened muscles and enables an intuitive sequence of movements that mimics the natural sequence.

Read more about these and other exciting topics in this issue of FAULHABER motion – the magazine with drive.

Sincerely,

Karl Faulhaber
Managing Director

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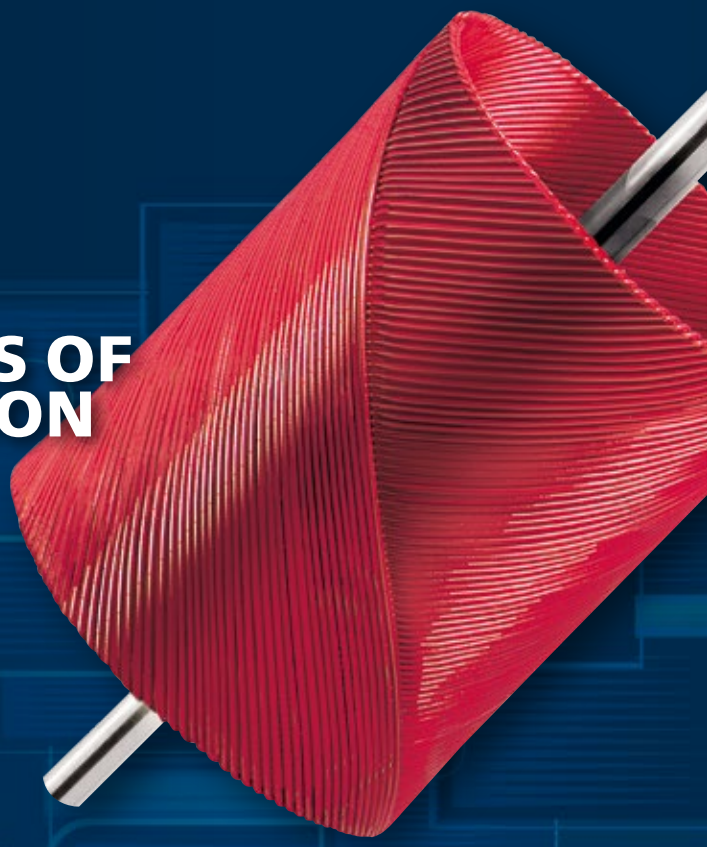
75 YEARS OF MOTION



Every beginning needs drive

Our success story began in the late 1940s. In 1947, the young engineer Dr. Fritz Faulhaber founded "Feinmechanische Werkstätten" (Precision Mechanical Workshops), his first company. His customers included the renowned camera manufacturer Voigtländer, for whom he developed the "Vitessa" in the early 1950s. The "Vitessa" camera could be operated with revolutionary simplicity: The camera could be triggered and the film advanced simply by pressing two buttons one after the other. At that time, he was already playing with the idea of using an electric motor to advance the film. The problem was that with the existing technology, it was not possible to build motors small enough for the installation space available. Giving up was not an option for the passionate tinkerer, so in the mid-1950s, he once again sat down at his desk and pondered what an electric motor would have to look like for it to not only fit in the camera in front of him, but also be efficient and powerful enough to advance the film using battery power. He then had an ingenious idea and quickly used the ironless, self-supporting, skew-wound design to develop an innovative drive technology that would solve his camera problem, but also form the basis for the future of miniaturization in many application areas worldwide.

A trendsetter who moved with the times

When he applied for a patent for his invention in 1958 and began series production, he would probably never have dreamt that in doing so he would provide application developers then and now with a very important drive. But that's exactly what made his invention so successful in the long run – although not overnight, because the potential customers needed time to incorporate the ideas it inspired into practical applications. But the world had been waiting for an invention like this one: An invention that could give the global trend toward progressive miniaturization new momentum. Even now, this momentum continues and, as market leaders, we at FAULHABER have been the driving force behind it for 75 years. The creative yet equally pragmatic spirit of our founding father shapes our company to this day. We think in the long term. We monitor the market carefully and take a proactive approach – or as Dr. Fritz Faulhaber Junior, son of the founder, once modestly said: "It is our philosophy to always be technologically ahead by a nose length – but the nose shouldn't be a meter long".

Pioneering spirit requires freedom

For 75 years, FAULHABER has been a traditional, family-run company. This independence gives us the freedom to make far-reaching decisions relating to the company without having to consider the interests of third parties such as investors. This is especially important because we invest substantial resources in fundamental research,thereby enabling us to stay true to our founder's philosophy of having new drive technologies ready for the trends of tomorrow long before our customers start asking for them! Our ability to identify potential new application areas for innovative drive systems at an early stage is one of the reasons for our continued success.

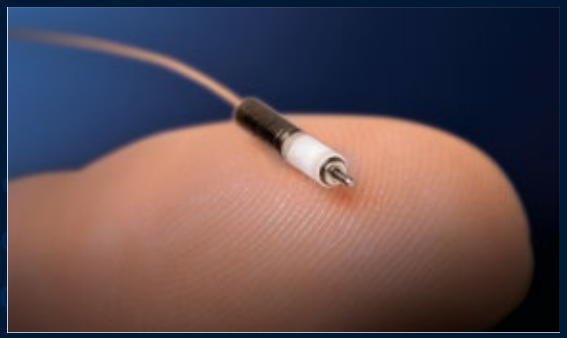
We are celebrating our family

75 years of FAULHABER – we have come a long way, but we haven't traveled this distance alone. FAULHABER is now more than just a family-run company; FAULHABER has grown into a company family with many members all over the world. There are strong connections between us and we share our passion for precision when it comes to both the development of our products and synchronized production across locations. We are proud to be able to celebrate this anniversary together because everyone has played an important part in our success in Switzerland. The foundation of Minimotor S.A. in 1962 marked an important strategic step for FAULHABER, giving us a presence in the traditional Mecca of precision mechanics. Today, we are celebrating not only our 75th anniversary, but also, together with our Swiss colleagues, 60 years of FAULHABER in Switzerland.

We want to make a difference to people's lives

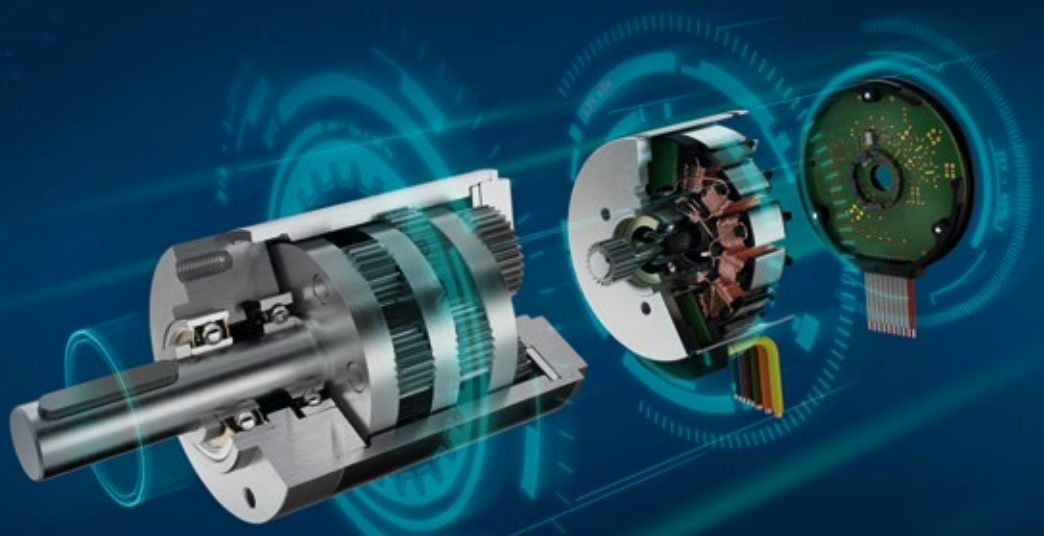
We have always claimed that for every technological innovation that can help to improve people's lives, FAULHABER always has the appropriate drive solution. Therefore, in 1998, through our efforts to continuously expand the limits of what is technologically possible, we succeeded in building the world's smallest DC micromotor – its diameter: just 1.9 mm. The ability to miniaturize our drive technology to such microscopic dimensions and even at this size to produce a usable torque became the foundation for brand-new applications in the medical sector. Just one year later, developers using this technology began working on a motor-operated, minimally invasive cardiac pump to help save lives during heart operations and convalescence.

The smallest, series-produced DC-micromotor with planetary gearhead measures just 1.9 mm in diameter.



In the Philae lander, 14 FAULHABER drive systems successfully defied the harsh conditions of its 10-year journey through the vacuum and extremely low temperatures of space.

Where have we come from and where are we headed? This is a question that we naturally ask ourselves in our anniversary year, but also one that humanity has been considering for thousands of years. Finding out the answer was the focus of the Rosetta mission when the space probe visited the comet 67P/Churyumov-Gerasimenko in 2014, but also of our team of developers, when the scientists of the ESA entrusted them with an unprecedented task: The development of a drive system that would anchor the Philae lander module to the comet surface with a harpoon during landing. The challenge was to find a way to guarantee precise operation after a 10-year flight through space. We wouldn't want to claim that we saw this task coming – but we were well prepared for it.



The solution lies in the system

We are technological leaders in the field of miniature and micro drive technology thanks to our reputation for working on the solutions of tomorrow and of the future well beyond that. In doing so, we consider what ought to be possible using FAULHABER microdrives in the future, but we also take a holistic look at all system components. In this way, over the last 75 years, we have repeatedly succeeded in using innovative products to develop new system solutions for a wide range of customers in a variety of different markets. Our customers' trust in our ability to reliably find customer-specific solutions to complex new problems is the distinguishing feature of our customer relationships. This ability is based on our willingness to form close partnerships with our customers, and on the innovative power of diversity that we draw from our international cooperative network.

The future is waiting

After these exciting 75 years, we could take this moment to pause and look back on our success with pride. And we will do just that. But only for the time needed to take one quick, deep breath. Because our past has taught us how important it is to keep our eye on the future – so that we will be ready in good time whenever a developer needs an appropriate drive solution for an innovation that has the potential to make all our lives a little better.

75.faulhaber.com

20 years of FAULHABER motion

Exciting stories from the world
The next chapter

This year we are celebrating 75 years of FAULHABER and 60 years of our location in Switzerland. But that's not all – Our customer magazine "motion" is also looking back on 20 years and 40 issues. First released as FAULHABER info at the Hannover Messe trade fair in 2002, the company magazine is now beginning a new chapter: in future, motion will also be available as an online magazine. We look back, while also looking forward to the future.

First released just in time for the Hannover Messe trade fair in 2002: FAULHABER info was a customer magazine designed to offer more. The magazine was professionally researched and offered reports on exciting customer projects from all over the world, as well as the presentation of innovative ideas, background information and glimpses beyond the horizon. The magazine also provided news and new products from FAULHABER presented in an appealing way. A total of 21 editions were published in the 11 years from 2002 to 2013. Traditionally, info was released just in time for the big trade fairs, the Hannover Messe in the spring and SPS in the autumn.

Getting under the skin

Innovation thrives on the willingness to make changes and to break new ground. This also applies to our customer magazine FAULHABER info. Now and then, it is simply time for a relaunch that gives a medium a new, fresher look or even a complete rebranding. Since the issue 02/2013, our customer magazine has therefore been released under the name FAULHABER motion – the magazine with drive – with even more emotive images and a modern design. Exciting reports about the drive technology that we create in collaboration with our customers remain a key feature.

You could say that the first issue of the new motion got under the skin. Under the heading "Technology that gets under your skin," we reported on handy devices that are used for tattoos and permanent make-up, and in which DC-Micromotors from Schönaich are a particularly crucial component due to how smoothly they operate.

of drives.


motion
FAULHABER
ZUVERLÄSSIG
FREI KLETTERN mit SICHERHEIT
ROBOTICS | THE NEXT EVOLUTION IN THE OPERATING ROOM
SURGICAL ROBOT
ZELLANALYSE MIT PRÄZISION

An international audience

From the beginning, FAULHABER info was released in German and English, with French added from 2008 and Chinese from 2010. Since then, these languages have been joined by Dutch, Italian and Polish, demonstrating the growing strength of our global presence.

The reports, which are bursting with interesting details and rounded off by high-quality images, go one step further. We can say with full justification that motion is out of this world! After all, we have already reported on the various projects in which FAULHABER drive systems have conquered space, whether as a digital assistant on board the ISS or as part of a Mars mission. In the future, we will continue to present you with an exciting, varied mix of topics that covers both traditional industry applications and also brand-new innovations.

When FAULHABER info was first released in 2002, mobile end devices were nowhere near as widespread as they are now. It wasn't until 10 years later in 2012 that these devices first accounted for a significant proportion (10 percent) of data traffic on the internet worldwide. That has now changed completely. More than 55 percent of all page call-ups in 2021 took place via mobile-end devices, and in 2019 the internet was rated higher than television as the top medium.

Mobile, modern, multimedia

We are taking this trend into account by relaunching our FAULHABER website www.faulhaber.com in our anniversary year and further optimizing it for display on all end devices.

The new website has a modern, contemporary design and the navigation has been overhauled to offer users more opportunities to obtain more in-depth information on selected topics via links. It is still simple to contact us and access the chat function from all pages. The new know-how area offers new, informative content such as how-to videos, application notes, tutorials and our webinar library.

Our calculation and selection tool, FAULHABER Drive Calculator, is in a more prominent position on the website and can now be accessed on all pages. The powerful comprehensive tool assists with the calculation and design of drive systems comprising motors, gearheads, encoders and other components, and helps users to quickly find the appropriate solution for their application. Click "Start Drive Calculator" and see for yourself!

związane z napędem

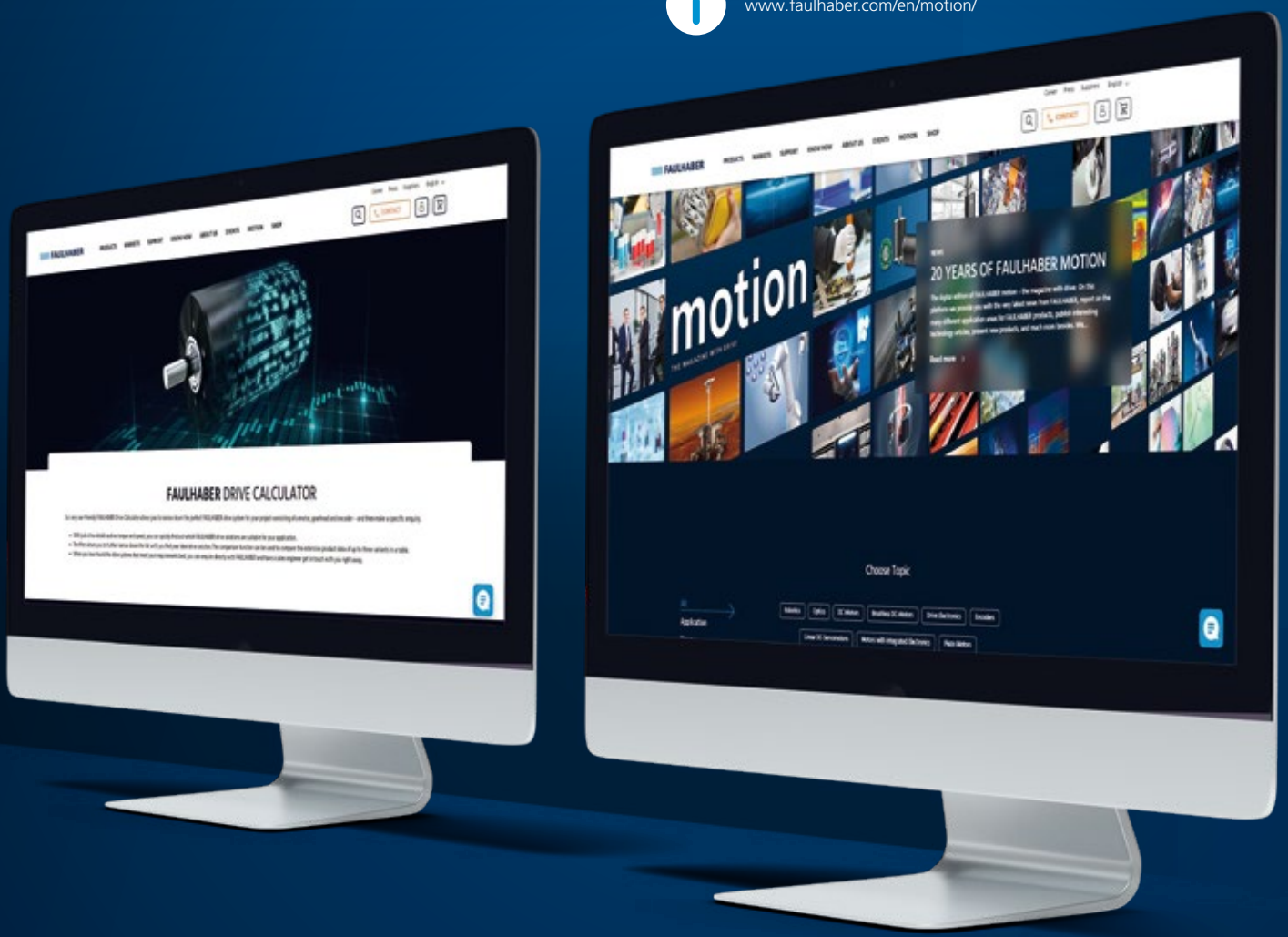
VERHALEN

ie di guida

FAULHABER motion is going digital

With the launch of the new website, our popular customer magazine is also being expanded with a digital offering. In future, under the menu item "motion", you will be able to find an online copy of the magazine, which will be regularly supplemented by new, exciting features such as application examples, product news, interviews, technical articles and background information. Using the filter functions, you can adjust the content to suit your interests and thus create a personalized version of motion – helping you keep up to date with the topics that are particularly important to you. The print edition will continue to be released twice a year and combine the most exciting articles in printed form.

www.faulhaber.com/en/motion/



"Smart farming" is an important part of the answer to this existential question: Extremely high efficiency in food production through the targeted use of the latest technology, computer-supported and – where possible – fully automatic. Seeds are individually and precisely placed; fruits carefully picked by mechanical grippers; fertilizers and plant protection products applied in small doses and in a targeted manner. These operations require a large number of small electric motors that are both robust and powerful.

Quantum computers, space tourism or hydrogen technology – the latest technological hype focuses on constantly changing topics. Curiously, the most important sector is often overlooked: agriculture. Even though it has thus far reliably fed an exponentially growing human population. The agricultural revolution, which began in the 18th century, allowed yields to increase enormously. It is based on the increasing use of high-yielding varieties, mineral fertilizers and chemical pesticides, and on mechanization and large-scale artificial irrigation. These interventions into the ecology are not without unwanted side effects, however; all well-founded population forecasts predict that the human population will grow to be between nine and ten billion people by the end of this century. The earth offers the potential to supply even this large number of people with sufficient food. Agriculture faces an enormous challenge here, however; crop cultivation and livestock farming must produce more without endangering the life-sustaining resources like fertile soil and groundwater, where it clearly does not

belong. Fertile soil, clean groundwater and an intact natural world are our most valuable "resources." They must be protected at all costs.

Focus on the plant instead of the field

Until now, many important work steps in crop cultivation, such as planting, fertilizing and plant protection measures have been based on land area. When spreading seed or pesticide, one calculates the quantity per acre or hectare and the machine distributes the material with the appropriate flow rate. Instead of strengthening the plants, however, a portion of the nitrogen fertilizer, for example, reaches the groundwater, where it clearly does not belong.

Tasks such as the pruning of fruit trees or the harvesting of delicate fruit and vegetable varieties require costly manual labor, while more and more enterprises suffer from a personnel shortage.

Smart farming uses modern technologies to increase the efficiency of agriculture in order to use all of the resources more sparingly to relieve people from monotonous work, while producing higher yields. In this context, one also speaks of precision farming, digital farming or e-farming. Using computer supported and networked processes, in addition to machine learning and customized robot functions, the focus can be placed on the individual plants instead of the field as a whole.

The more directly the measures are targeted at the plants, the more economically and efficiently these measures can be used. For example, the use of herbicides can be significantly reduced if applied to the individual plants in a more targeted manner. Fruits and vegetables could also be harvested by robots in continuous passes to always allow optimum ripeness.

Lightweight, autonomous field robots also provide an opportunity to protect the ground. Today's large agricultural machines weigh up to ten metric tons. With such weight, every pass results in dramatic soil compaction. This greatly limits the ability of the affected layer of soil to absorb water and air, thus strongly impacting soil life. The growth and health of the crop plants in the areas near travel paths are also impacted. Smart farming can help contribute to healthier soil and increased biodiversity.

Targeted use of fertilizers and herbicides reduces soil contamination

Automation in agriculture and horticulture

For now, many applications exist only as studies or prototypes. But smart farming is already being put to practical use, such as in precision planting. This was originally developed for research and seed breeding. These machines can plant the individual seeds at precisely defined intervals. Each plant receives enough space to grow, and the acreage is optimally utilized. At the same time, the valuable seeds are used extremely efficiently.
The most modern machines use one separation module with electric drive per row. A motor drives a slotted or toothed disk that transports the individual seeds to the outlet. Using an intelligent controller, it is possible to precisely set the optimum spacing for each type of seed; when traveling around corners, the different radii of the individual rows can be compensated for. The feeding of the seeds to the disks is controlled using closures that are also motorized.

Always perfectly ripened products through continuous automated harvesting

With vegetable and flower cultivation in greenhouses, many plants are first sprouted in small pots and later replanted in larger pots or in beds. In modern horticultural enterprises, machines perform the sorting and handling of plants and pots. Their machinery is very similar to that used in industrial production and logistics. There are conveyor belts and roller conveyors on which trays with products in various stages are transported, sorted and repotted. The grippers used here differ from those used in similar devices in other industries only in the shape of their "fingers." Driven by micromotors, they perform the automatic handling of the individual pots and root balls.
Self-driving harvesting machines for fruits and vegetables have not yet reached series maturity for general use, but the direction of the technical development is already apparent: camera-assisted sensors detect the degree of ripeness of strawberries or peppers on the basis of color and shape and record their exact position. The on-board computer uses this data to control a robot arm, which is equipped with a type of shears and a collection device. The prototypes of this technology are full of electric motors, from the single-wheel drive and the robot arm to the cutting apparatus and the collection system for the harvested produce.

Key technologies: electrical system and electronics

"In conventional agricultural machinery, mechanical gear transmissions and pneumatic drives are very common," explains Kevin Moser, who, as Business

Modern machinery takes over the sorting and handling of crops

The Development Manager is responsible for applications in this sector at FAULHABER. "For smaller-scale systems in smart farming, these are often too heavy, too bulky, too mechanically complex and too energy inefficient. We therefore see an increasing number of electric micromotors in use here that supply the power for specific work steps. The drives in an agricultural environment must, however, usually meet very high requirements."

Unlike the traditional large devices, the machines and components used in smart farming are generally more compact and lighter. This means that there is often little space available for the motors. Nevertheless, as drives of sowing disks, flaps, grippers, robot arms or shears, they must supply sufficient power to reliably perform the respective task over countless cycles. At the same time, they should operate extremely efficiently, as the autonomous units usually draw their energy from batteries with limited power reserve. It must also be possible to integrate the drive electronics in networked structures and make intelligent control possible.

"These are typical requirements placed on drive systems of the highest class; the right answers are always standard issue at FAULHABER," says Kevin Moser. "Moreover, the drives used in agricultural environments must also be extremely robust so that they themselves function reliably and for the long term under the most demanding conditions. Large temperature fluctuations and strong mechanical loads are the norm in agriculture and horticulture. And, in spite of all of this, the costs must remain reasonable.

We at FAULHABER can offer multiple series of devices that manage this balancing act."

Moser is referring to the maintenance-free brushless and especially compact flat DC-micromotors of the BXT series as well as the exceptionally robust and cost-efficient copper-graphite motors of the CXR line. The gearheads of the new GPT series are very well suited for high load transmission under harsh conditions. Extremely efficient, they are also very robust and, thus, ideal for agricultural applications. Optional incremental encoders enable highly precise positioning. Various controllers, e.g., with CANopen interface, are available for the networking of the drive systems. "Drives from FAULHABER are already being used in smart farming," reports Kevin Moser. "They will continue to play an important role for demanding applications in this area."

www.faulhaber.com/en/markets/industry-automation/

Drives used in agricultural environments must operate reliably under harsh conditions

Not too much & not too little Fertilization

Plants need nitrogen. Unfortunately, they can only absorb this omnipresent element in the form of soluble nitrate compounds. Excess nitrogen fertilizers can thus easily find their way into the groundwater where it is very much unwanted. Applying no more fertilizer than the plants can actually absorb is, therefore, practical environmental protection. The new Aero fertilizer spreaders from agricultural machinery manufacturer RAUCH put the mineral fertilizer exactly where it is needed and in just the right quantity. Motors from FAULHABER assist with the precision dosing.

In addition to light, water and trace elements, plants need just six nutrients: phosphorus, potassium, magnesium, calcium, sulfur and nitrogen. The last of these, denoted with the chemical symbol N, is the most important in terms of quantity. It is needed for, among other purposes, the formation of protein compounds and chlorophyll as well as for the growth of shoots and leaves.

Nitrogen is the main constituent of the earth's atmosphere. It is present there in abundance in its elementary gaseous form (N2). Unfortunately, most plants are not able to do anything with it in this state. They can only absorb nitrogen from the soil through their roots and need it in the form of ammonium (NH^{4+}) or as nitrate (NO^{3-}).

Nitrate compounds make up the majority of the fertilizers with which modern agriculture achieves high yields. Applied at the right time and in the right quantity, they can be absorbed nearly completely by the plants and converted into food and biomass. Subsequent problems only arise if too much nitrate lands in the fields. Sooner or later, excess nitrate seeps into the groundwater with the rain.

Refining the spreading pattern

The conventional method for spreading mineral fertilizers on a field uses so-called twin disk spreaders: The fertilizer falls out of the reservoir container behind the tractor onto two horizontally rotating disks. Their rotary movement ejects the grains up to 25 meters to the left and right as the machine drives over the field. While this allows

large areas to be fertilized in a short amount of time, the distribution is performed at a fixed rate and is calculated on the basis of the total area. The "spreading pattern" is imprecise; in the case of irregular field shapes, in curves and along the edges of roads, there are inevitably strips that receive too little or too much fertilizer. Moreover, ejecting the fertilizer through centrifugal force only functions reliably with fertilizer grains that are of uniform size and quality.

"We are able to avoid all of these drawbacks with our precise fertilizer spreaders of the Aero series," says Maximilian Zimmer. He is the team leader for electronics development at RAUCH Landmaschinenfabrik in Sinzheim (Baden-Wuerttemberg, Germany). "Here, the granulate is not ejected over a large area but instead lands on the field through a system of tubes in the correct quantity and finely dispersed. During this process, the machine can block out specific areas that require no fertilizer."

Dosing system with switchable sections

The basis for such precision fertilization is the MultiRate dosing system which, according to the manufacturer, is "the world's first dosing and distribution system for granulated fertilizer for small-scale and precise plant nutrition" for pneumatic fertilizer spreaders. It allows thirty spreading sections to be switched on and off individually. At the same time, the applied quantity can be controlled individually for each section.

This allows a reduction in fertilizer usage per unit area of up to 23 percent as well as a significant increase in yield.
The fertilizer granulate lands on the field through thirty individual tubes, precisely dosed in strips of 1 to 1.2 meters in width. Each individual infeed uses sophisticated technology: The fertilizer is guided through multiple funnels to six metering shafts with five segments each.

Motor speed controls fertilizer quantity

Each cam wheel segment is moved by a FAULHABER brushless flat motor of the 4221…BXT series with a special customer-specific gearhead and can be individually actuated. "The speed of the motor controls the quantity of the fertilizer applied," explains Maximilian Zimmer. "The machine can thereby ensure, e.g., that the quantity per unit area is always the same in a curve formation even though each outlet travels a different radius.

30 dispenser nozzles over 36 m

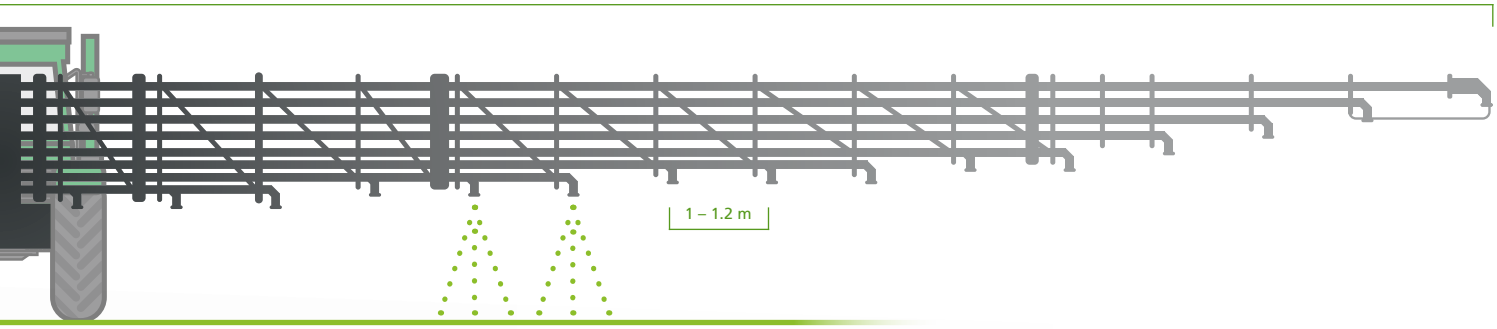
These are CAN-bus-controlled and are equipped with cam wheels that divide the granulate into small portions. The granulate is then accelerated by a stream of air and transported to the outlet.

If, in the case of non-rectangular field geometries, rows overlap or the machine encounters the side of a path, the individual outlets can be automatically switched off and then switched back on again later. Here, the dynamics of the motor are essential. It must reach the precisely specified speed with practically no time delay and deliver a high torque."

This power comes from an extremely compact drive with a diameter of just 42 millimeters and length of 49 millimeters including gearhead, all fitted in robust steel and aluminum housings. The unit can thus withstand the unavoidable mechanical vibrations that occur in agriculture. They can even handle weather extremes without problem: The temperature range spans from minus 10 to plus 60 degrees Celsius.

In addition to the fertilizer, the Aero fertilizer spreaders can also be used to plant intercrops, such as rapeseed or mustard grass. These bind nutrients, protect the soil and contribute to its improvement. The quality of the fertilizer granulate plays a less significant role than with disk spreaders: The machine can dose precisely and can accurately apply the fertilizer even if there is a high percentage of breakage and dust.

The Aero fertilizer spreader was awarded the Environmental Technology Prize (Umwelttechnikpreis) in the category of Measurement and Control Technology, Industry 4.0, by the State of Baden-Wuerttemberg in November 2021.



Taking variable soil quality into consideration

The MultiRate dosing system driven by the FAULHABER motor enables "precision farming" in the true sense of the word. The tracks – i.e., the marks left by the tractor wheels – are excluded from fertilization as are small biotopes or other non-agricultural areas that may be located in the middle of fields. Furthermore, the fertilizer quantity can also be precisely adapted to different soils within a field. "The soil quality is recorded in detail in digital application maps," explains Maximilian Zimmer. "Using such maps and GPS data, the machine control can adapt fertilizer application to the circumstances fully automatically."

Maximilian Zimmer summarizes: "This precision technology not only protects the environment and – in particular – the groundwater, it also lowers costs. The farm has a higher yield with less fertilizer. And, with a lower granulate quality, the cost of the fertilizer may be significantly lower."

FAULHABER BXT
BRUSHLESS FLAT MOTORS

www.faulhaber.com/en/markets/industry-automation/
www.rauch.de/duengerstreuer/aero-gt-60-1.html

Being able to walk again

Walking without crutches – this is something that people with certain neuromuscular disorders dream of. With the exoskeleton "Autonomyo", this dream can now be made a reality. The active walking aid supports the weakened muscles and enables an intuitive sequence of movements that mimics the natural sequence. The additional power is supplied by six micromotors. To facilitate a harmonious interaction between the exoskeleton and its user, FAULHABER developed an innovative all-in-one component motor with a torque sensor.

– not just a dream

Medical science distinguishes between more than 800 different neuromuscular disorders. As the name suggests, they affect both the nerves and the muscles. Some have an impact on the whole body, while others only affect it in certain areas. Fortunately, however, the majority of these disorders are relatively rare. Many of the affected patients suffer from severely restricted mobility. This is because, even though these disorders have many different causes and develop in many different ways, they all have one thing in common: muscle weakness (muscular dystrophy), which is progressive in many cases.

"If the muscle weakness occurs in the legs, walking becomes increasingly difficult, and eventually it becomes impossible without something to lean on," explains Mohamed Bouri, Leader of the research group for Rehabilitation and Assistive Robotics (REHA Assist) at the Swiss technical university of Lausanne (EPFL). "The muscles are still functional but they cannot muster enough strength for the patients to stand stably or move their legs independently. As you would expect, this has an enormous impact on the patient's range of movement and quality of life. The effects are similar to those of hemiplegia after a stroke. Our aim was to overcome these limitations as much as possible using motorized support — therefore, still taking advantage of the patient's contribution to his own movements."

Lightweight partial assistance

The group leader is referring to conventional exoskeletons already in use leaning on humanoid inspired technology. These devices enable paraplegic people to walk without a crutch, but they weigh more than 40 kilograms.

With only 25 kilograms, "Autonomyo" developed by REHA Assist is much lighter, and it works with the patient's weakened but still partially functioning musculoskeletal system.
The device is fastened with a corset around the trunk and cuffs around the legs of the user. On each side, three motors enable movement by supplying the power that the muscles are lacking. In each case, one motor is responsible for the flexion and extension of the hip and another motor does the same for the knee. The third motor supports abduction and adduction of the leg at the hip joint – in other words, the lateral movement of the leg away from the midline of the body. All together, the motors help the patient to maintain their balance and to walk upright. In a recently conducted clinical study including persons with walking impairment, Autonomyo proved to be working as intended. The exoskeleton provided support while allowing freedom of movement, following the users' intentions. The range of joint motion and gait cadence were not negatively affected.

Feedback from the magnetic measurement system

It is absolutely crucial that the device assists gait according to the user's intention. "The initial trigger to change position – that is, to start walking – is expressed as a small change in the lower limb position," explains Mohamed Bouri. "We detect it by combining the information from an inertial measurement unit, eight load sensors at the soles and the encoders of the motors that act as joint position sensors. All of this data contributes to the assistance of balance." When walking, the interaction between the device and the user is crucial. A torque sensor developed by FAULHABER is responsible to sense this interaction and thus to precisely implement the assistance strategy.

"The project of integrating a precise torque sensor in a motor started a few years ago, aiming to promote applications such as Cobotics for safe human-robot interactions," explains Frank Schwenker, Group Leader for Advanced Engineering at FAULHABER. "With Autonomyo, we are able to implement the concept in a challenging assistive technology application for the first time."

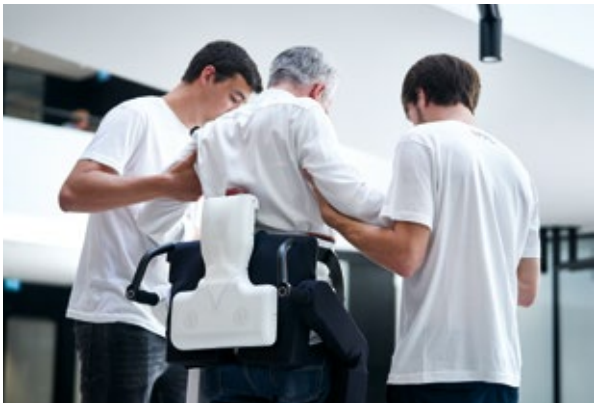
The conventional technology for torque detection uses expansion strips on components; these strips are deformed by the force exerted. The weak point of their construction is the adhesive bond with which they are attached. The developers in the Advanced Engineering group have replaced these strips with a high-resolution measurement system.

"This enables us to achieve a deviation of less than 1.5 percent in the measurement range of plus/minus 30 newton-meters," says Frank Schwenker. "The sensor therefore supplies a highly precise value for the response torque in the walking movement."
This value plays a vital role in controlling the Autonomyo exoskeleton, which is of course also supplied with numerous other values. "Adjusting the device to the individual patients requires very differentiated calibration of the entire system," explains Mohamed Bouri. "Using the various parameters and the feedback from the movement, the software calculates the control signals for the drives. The type and level of assistance from the motors are then determined based on these informations."

Drive power and development potential

The six drive units in each device are supplied by FAULHABER. Their core component is the 3274 BP4 brushless motor with a diameter of 32 millimeters. It offers the most power of any motor in its size class available on the market. Its power is transmitted by a 42 GPT planetary gearhead with a shaft produced especially for this application. A magnetic IE3 encoder supplies the position data to the controller. The torque sensor is integrated in the gearheads of the four motors for the flexion/extension movements.
The requirements on the drive units are typical for top-of-the-range micromotors. High power with the smallest possible volume and weight, plus precision, reliability and a long service life are among the most important properties for this application. "It wasn't particularly difficult to find the right supplier," recalls Mohamed Bouri. "Having defined the specifications, the choice of possible motors was already reduced to just a small number of candidates.

The astrophysics inter-faculty research group of our university already works with FAULHABER so they provided convincing recommendations, and a good relationship was already in place. In addition, FAULHABER was already in a position to be able to develop the torque sensor within a short timeframe. That was very important for our project."
For the time being, the component is not a series product and has so far been produced only for the EPFL in small quantities. However, development engineer Frank Schwenker can imagine many other areas of application: "High-resolution torque measurement can add significant value in all haptic applications. For example, for all types of robotic assistance in operating theaters where the surgeon guides the instrument and the machine controls the power and precision. The sensor can also provide a protective function and be used to limit torque. What's more, it is ideally suited to documentation processes in quality assurance in all cases where evidence of extremely precise torque values needs to be provided."



Briefing of the patient

FAULHABER BP4
BRUSHLESS DC-SERVOMOTORS

FAULHABER 42GPT
PLANETARY GEARHEADS

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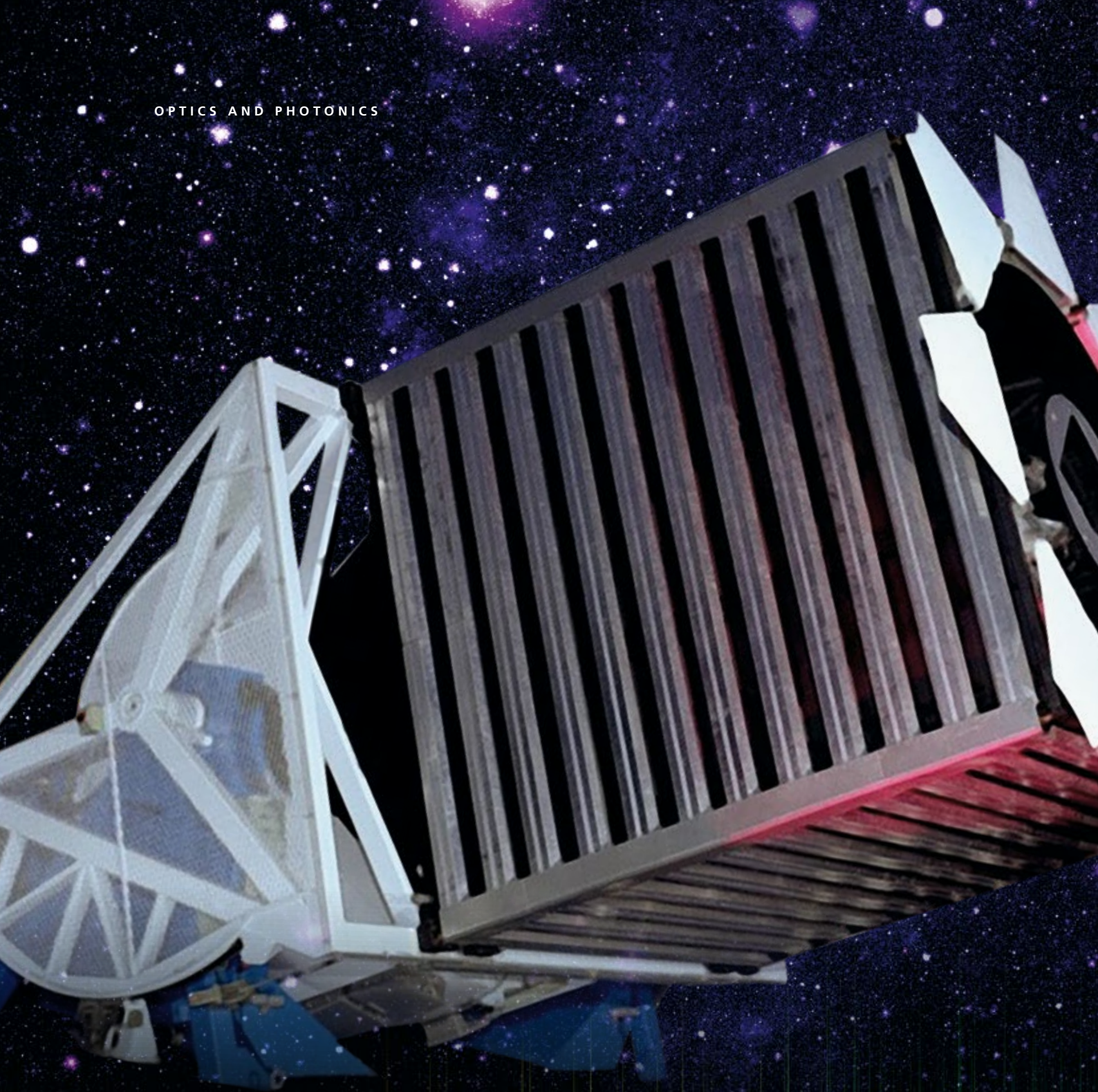


SDSS stands for "Sloan Digital Sky Survey" and is a cooperative alliance of astrophysicists from around the world. Over the past year, they have already presented the largest 3D map of the universe and thereby marked a milestone in astronomical research. Equipped with numerous telescopes and other scientific instruments, the researchers are working constantly on a wide range of projects. The latest is SDSS V, which aims to enable another qualitative leap in the understanding of the physical processes in outer space. The project will make possible the "first spectroscopic observation of the entire sky in various astronomical dimensions of time in the optical and infrared light spectrum." In total, more than six million objects are to be targeted.

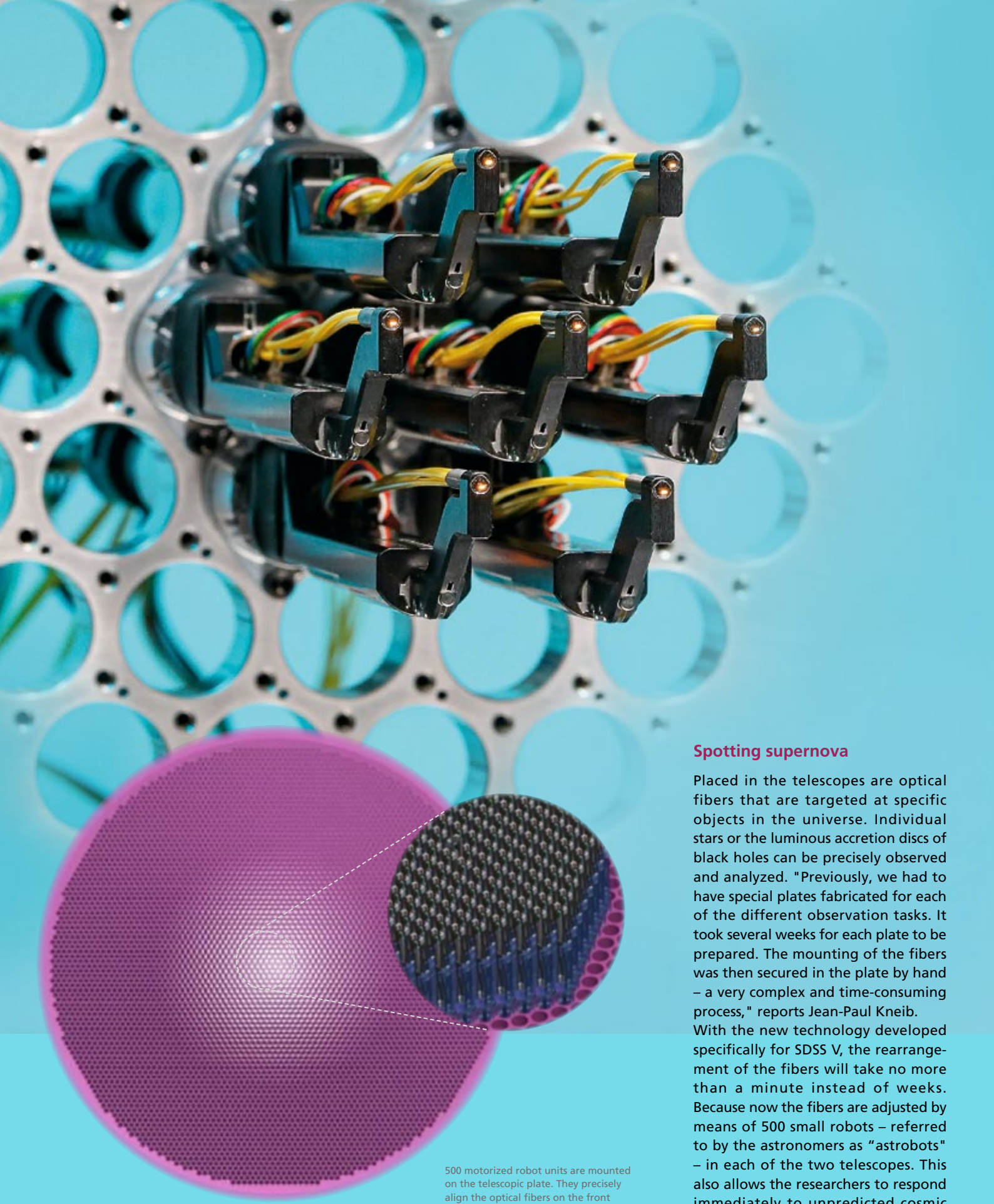
How planets are formed

Among the objectives of this endeavor is the reconstruction of the history of our home galaxy, the the Milky Way. Researchers plan to retrace the forma-

THE SECRETS OF THE UNIVERSE IN FOCUS

It's a task of galactic proportions: SDSS V aims to observe and analyze four million stars and 300,000 black holes over the next five years, as well as reconstruct cosmic evolution stories and verify the physical models of the genesis of the galaxy. 500 small robots align the optical units with great precision in each of the large telescopes.

tion of the chemical elements, decrypt the inner workings of stars, examine the formation of planets and answer many of the open questions that remain with regard to black holes. Another aspect is the mapping of the interstellar gas masses of the Milky Way – a thousand times more precisely than previously – to describe the "self-regulating mechanisms of galactic ecosystems." The data related to black holes and for the measurement of the Milky Way are to be collected by two large-scale telescopes: Apache Point in New Mexico and Las Campanas in Chile. "With the dual perspective from the northern and southern hemisphere, we can view the sky in all directions," explains Jean-Paul Kneib, professor of astrophysics at Ecole Polytechnique Fédérale de Lausanne in Switzerland. "We have also used the two telescopes in the previous SDSS projects. With SDSS V we are now making a true quantum leap with regard to the efficiency of the observation and the amount of collected data."



500 motorized robot units are mounted on the telescopic plate. They precisely align the optical fibers on the front extension with the individual objects to be observed.

Spotting supernova

Placed in the telescopes are optical fibers that are targeted at specific objects in the universe. Individual stars or the luminous accretion discs of black holes can be precisely observed and analyzed. "Previously, we had to have special plates fabricated for each of the different observation tasks. It took several weeks for each plate to be prepared. The mounting of the fibers was then secured in the plate by hand – a very complex and time-consuming process," reports Jean-Paul Kneib.
With the new technology developed specifically for SDSS V, the rearrangement of the fibers will take no more than a minute instead of weeks. Because now the fibers are adjusted by means of 500 small robots – referred to by the astronomers as "astrobots" – in each of the two telescopes. This also allows the researchers to respond immediately to unpredicted cosmic events.

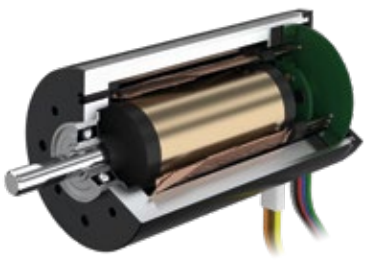
If, for example, other telescopes discover a current event such as a supernova, one of the optical elements can be aligned with it with practically no time delay. This enables a detailed analysis of the physical-chemical processes within a time span of supernova development that was not previously possible with this type of instrumentation.

With micrometer precision

Each of the astrobots consists of two slim cylinders arranged lengthwise with a curved extension at the front end. The rear, thicker cylinder is secured in the plate of the telescope. It forms the alpha unit and turns the central axis of the robot. Mounted eccentrically to the front of this is the beta unit. It likewise moves the fiber tips in the curved end in a circular path.
Through the combination of the two axial movements, the fiber tips can be freely positioned within a circular area. Each circle covered by one of the robots partially overlaps the circles of the adjacent units. In the detection range of the telescope, each point of the sky can thereby be automatically targeted.
Three optical fibers are arranged in each astrobot. One is designed for light in the visible spectrum and one for the infrared spectrum. The third is used for calibration. With its help, the fiber tips are moved into position in three steps with an accuracy of just a few micrometers: In a first rough alignment, the two motors turn until the fiber intended for the observation is directed at the target object with a deviation of, on average, 50 micrometers. A camera in the telescope that is directed at the front ends of the robots now detects the tip of the calibration fiber and measures its position. In two further positioning steps, the robot head is then moved into position with a precision of better than five micrometers.

Researching faster

"Because we save an enormous amount of time with the automatic alignment, we can observe many more objects and perform a corresponding larger number of individual measurements," explains Jean-Paul Kneib. "This effect is raised to an even higher power through the high precision. The diameter of the optical fibers is one hundred micrometers. The diameter of the light spot from an observed cosmic object that hits the telescope is just as big. The more exact these two small surfaces are aligned with one another the greater the light output we have for our measurements and the faster we obtain valid results."
The technical prerequisites for this extreme accuracy are provided by motors and gearheads from FAULHABER as well as the mechanics developed specifically for this application by FAULHABER subsidiary MPS. The two robot axes are driven by brushless DC-servomotors of the 1218 ... B series for the alpha axis and the 0620 ... B series for the beta axis. The first two digits of the type designation indicate the diameter of the microdrives: twelve and six millimeters. Their force is transferred to the robot mechanics by means of suitable planetary gearheads.



FAULHABER B
BRUSHLESS DC-SERVOMOTORS
2 POLE TECHNOLOGY

The robot mechanics used here were developed and constructed by MPS. Integrated encoders report the rotary position of the motors to the controller.

Backlash-free precision

"To achieve the required precision, we had to eliminate the backlash in the system," explains Stefane Caseiro, who was responsible for the design of the components at MPS. The engineers accomplished this by, among other things, replacing the conventional coupling between the gearhead shafts and the mechanical axes of the robot with clamp connections and by installing a compression spring to make the gearhead backlash-free. "Finding the suitable springs alone took several months," recalls the MPS engineer.
The search for the right partner for this technical development took Professor Kneib's team less time. "There are not even a handful of manufacturers in the entire world who can produce the micromotors with the required quality and durability," says the astrophysicist. "FAULHABER was, of course, on the short list of companies from whom we requested a quotation. We had already worked together successfully with MPS in a prior project. The physical proximity to these specialists is, of course, also an advantage – it is located just an hour and a half drive from the university in Lausanne to MPS in Biel. In addition to the outstanding quality and the good mutual experiences, a very decisive argument was that FAULHABER, together with its subsidiary MPS, can supply everything from a single source."

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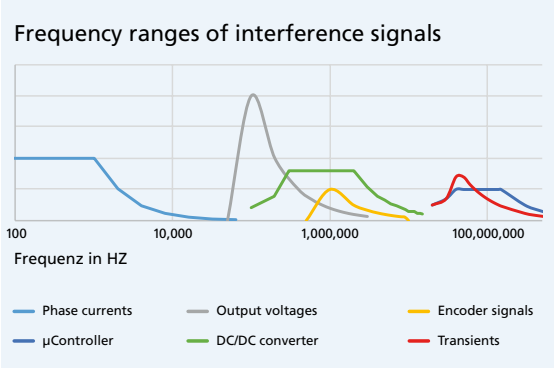
Electromagnetic compatibility (EMC) describes the ability of electrical and electronic components to function with one another without any mutual interference in a certain environment. Users must bear this in mind when working with controlled drives and address this complex topic.

ELECTROMAGNETIC COMPATIBILITY

In the 1920s, it was the conflict between the already established electric drive technology in urban traffic and the emerging telecommunications sector that led to the development of radio interference suppression, a sub-concept of EMC. Today, electric drives are usually controlled. In addition to the energy conversion, they also contain the telecommunication components required by the sensors for data transmission. Due to the interference emitted during energy conversion, it is important to ensure the necessary interference resistance of the sensors and telecommunications – often in the smallest of spaces.

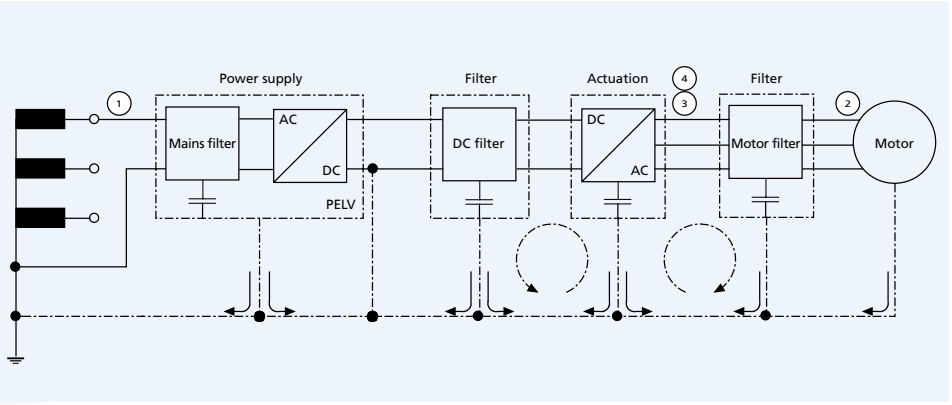
Certification in the application

The limit values for controlled electric drives for both emitted interference and for interference resistance are today defined in EN 61800-3. The standard does, however, serve only as a basis for evaluating a drive that is ready for operation. How this behaves in the end device cannot be reliably predicted. Here, the user is obliged to obtain the certification that is valid for his application.
In systems with electric miniature drives, the electrical energy is usually transformed several times. Alternating electrical quantities arise here as voltages and currents with widely varied frequencies, e.g., switching operations in the output stage, (electro-)magnetic interference fields during dynamic operation or voltage fluctuations (ripple) when the drives switch.



Frequency ranges of the different signals and interference in the vicinity of a controlled drive.
The effects are qualitatively assessed here.
Although output stages with PWM are compact, great care still needs to be taken when designing the system.

Interference paths for common-mode, differential-mode interference between various components along the path from the controlled motor to the mains network

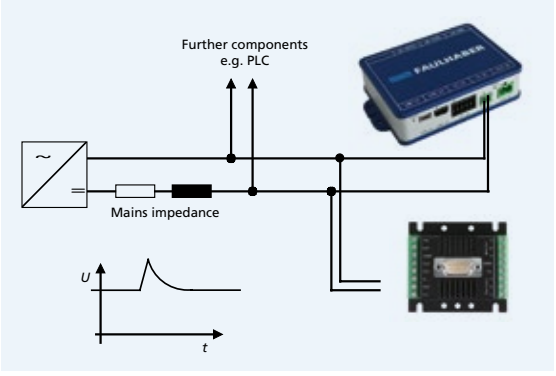


800-3

IFIED

FOR MINIATURE DRIVES

While EMC directive 2014/30/EU applies to devices in the European single market, concrete evaluation is performed based on the so-called harmonized standards. Compliance with the EMC directive as indicated by the CE marking is mandatory for devices if they are sold directly to end users. But devices that are not placed on the European single market or that are intended for industrial re-users also often require proof of compliance.



Galvanic coupling of multiple participants in the DC connection. Regenerated energy could cause critical overvoltages

Limit values for controlled drives

EN 61800-3 serves as the basis for the evaluation of an operationally ready drive consisting of motor and inverter or motion controller operated directly on mains. It also defines the rules for the measurement setup. Various quantifications apply to the types of interference here: In the frequency range from 150 kHz to 30 MHz, they are defined as interference voltage in dB(µV), in the frequency range from 30 MHz to 300 MHz as interference power in dB(pW) and in the range from 30 MHz to 6 GHz as interference field strength in dB(µV/m).

The approach assumes that low-frequency alternating quantities are observed primarily as an interference voltage superimposed on the power supply. The pulsating currents of a controlled drive could then impact, e.g., the operation of a PLC that is connected in parallel. Likewise, a voltage peak in the supply during a braking operation could cause devices that are connected in parallel to initiate a protective shutdown. The interference power and interference field strength, on the other hand, describe the non-cable-borne propagation of electromagnetic fields.

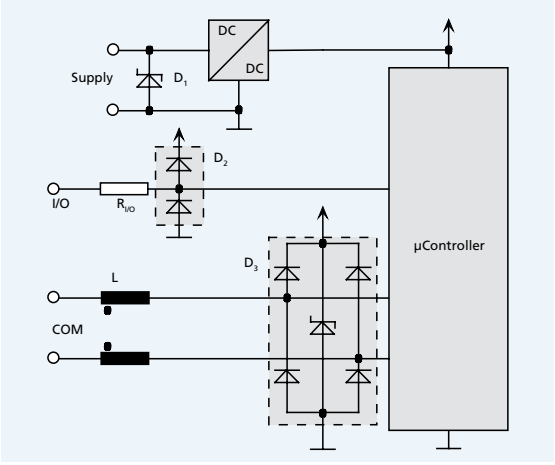
Interference field strength as a challenge

During the certification of a device with integrated miniature drive, the interference field strength is often the greater challenge. Measures that can be taken against it are, e.g., filters on the power outputs for suppressing high-frequency, capacitive interference currents. Each motor supply line must usually also be fully shielded. The same applies for the sensor cable, which is laid separately from the motor supply line.

It is also important that all conductive parts be conductively connected to so-called functional earthing using RF shield connectors. Building upon this functional earthing, both ends of the shield can then be connected flat. Pure PE protective earthing is sufficient in only a very small number of cases.
Whereas the interference field strength is effectively attenuated by the functional earthing and the shielded cables, the returning alternating current component in the base plate tends to increase as a result. If these alternating currents flow back to the switching converter via the mains supply or the power supply unit, the AC voltage component on the supply conductor inevitably increases and, thus, so too does the interference voltage. An additional filter is therefore often needed in the supply line that limits the propagation of these currents. It is left to the device manufacturer to decide whether he installs such a filter upstream of each drive – with miniature drives, typically in the 24 V or 48 V supply line – or just upstream of the power supply unit on the AC side. The latter saves costs but functions only if the drives themselves are designed in such a way that they do not mutually interfere with one another.

Interference resistance in the standard tests

For interference resistance, a wide range of electromagnetic effects are covered by the standard tests, such as interference resistance against electrostatic discharge (ESD) and against high-frequency electromagnetic fields from a neighboring emitter, interference resistance against electrical fast transients (bursts), surges, e.g., caused by lightning, or against RF common-mode interference on longer sensor and communication lines. Additional tests for shorter voltage dips are defined primarily for drives operated directly on the mains network. The typical voltage fluctuations of multiple dynamic drives on a DC system, on the other hand, are not actually detected. For miniature drives, additional interference suppression measures here include using the shortest possible cables or using protective diodes on the supply side. Also possible are ferrite filters, such as are common on analog PC monitor cables or communication cables.
With compact drives, encoders pose the primary challenge for the interference resistance of the components. They must likewise be housed in minimum installation space. Even in small encoders, however, sufficient basic protection against ESD can be achieved through compact protective elements. The field strengths specified for the interference resistance do not generally pose a problem in either the RF frequency range or in the mains frequency range. Interference resistance against bursts, or fast transients, requires filters on both the supply connections as well as on the signal cables.



Typical protective measures for increasing the interference resistance of supply, signal and communications inputs.

This does, however, pose a problem on the supply connections because the power supply is typically directly connected to the circuits integrated in the encoder. Effective protection is only possible here in the complete device. Full protection directly in the encoders against standard interference is not generally necessary. If needed, however, a protective diode can be installed, e.g., in an adapter board.
The test signal for conducted RF disturbances acc. to IEC 61000-4-6 is larger than the useful signal of typical encoders. Common mode filters in an encoder for motor diameters of just 20 to 22 mm are not feasible. Here, an evaluation must be performed at device level to determine what interference is to be expected. If necessary, the interference resistance can be improved with externally attached ferrites. Voltage dips in the power supply of the drive system can cause the system to shut down. Depending on the buffer of the encoder power supply in the motion controller, the encoder may then likewise be undersupplied in the event of voltage dips. Incremental encoders lose the absolute position information in this case and must be re-referenced.

EMC-compliant design and documentation

EMC for miniature drives is, therefore, anything but trivial for users. This is why the drive specialists at FAULHABER have explored this complex topic in great detail. All motion controllers of the broad range of products comply with current EMC regulations. Not only has the hardware been appropriately optimized, but the documentation has also been redesigned to provide users with the best possible support during the certification of their own devices.

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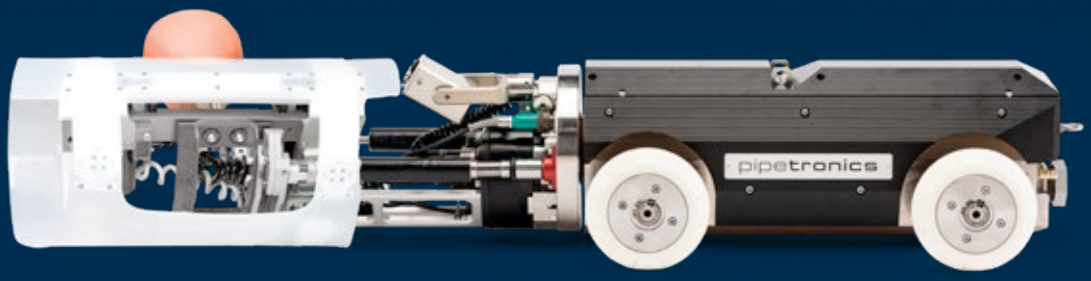
SUBTERRANEAN CHAMPION OF PIPE REHABILITATION



Germany alone has piping systems measuring a total length of almost 600,000 kilometers. These systems need to be maintained, cleaned and, if necessary, repaired. Previously this meant digging up the street – a costly and laborious undertaking resulting in week or month-long construction sites. Nowadays, intelligent pipe rehabilitation robots do this while life on the street above goes on as usual. In an interview in the next edition of motion, Pipetronics Managing Director, Markus Lämmerhirt, explains how the combination of FAULHABER drives and pipe rehabilitation robots ensures that sewer systems are kept clean.

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