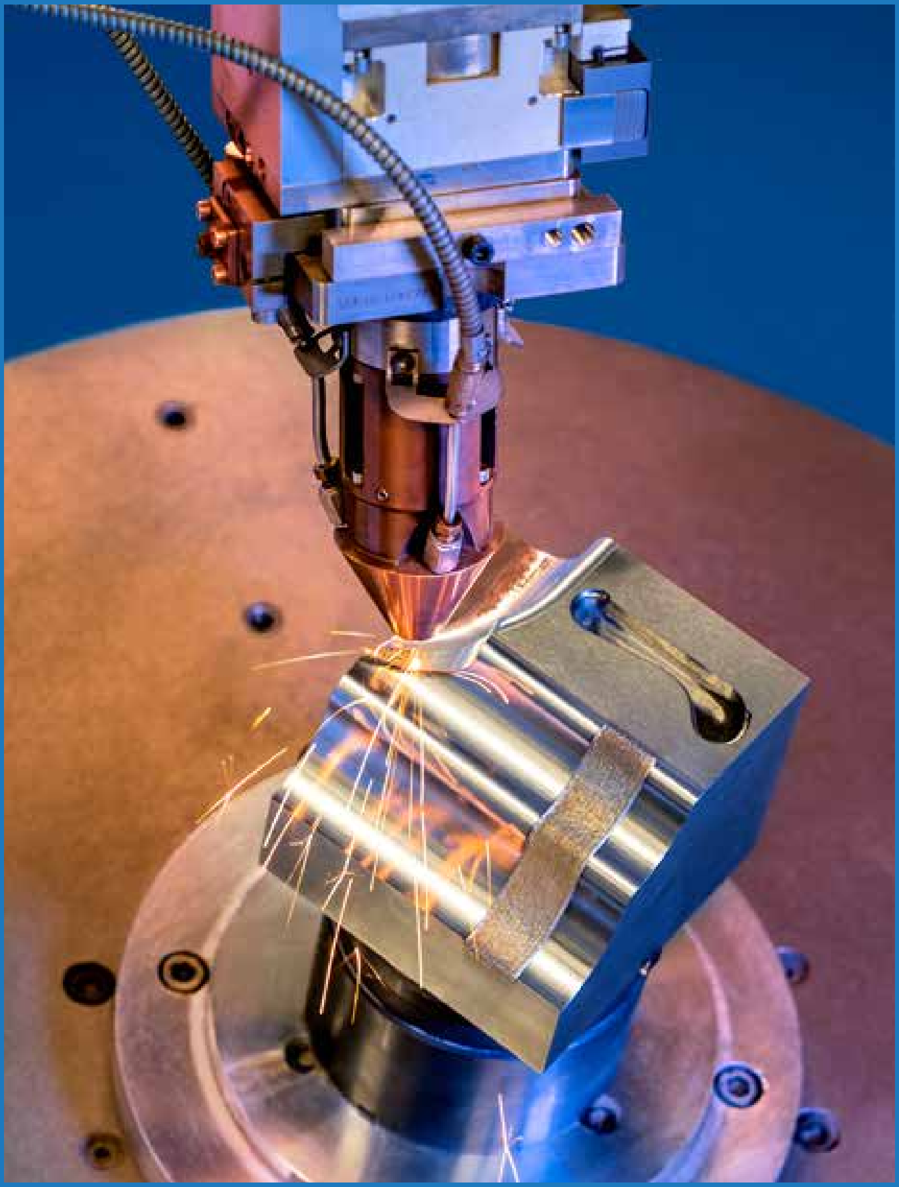
THE MAGAZINE OF THE **PRODUCTION TECHNOLOGY CENTER BERLIN**

futur

VISION | INNOVATION | REALIZATION



From Smart to Heart

A new Fraunhofer lighthouse project is investigating how production systems can become more resilient through cooperative behavior. Empathy plays a crucial role in this.

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Better Than New

By combining Scangineering and additive repair technologies, tools or components can be repaired automatically.

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How flushing channels in electrical discharge machining help to increase productivity

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Precision Is Key

Machine tools still set the tone in terms of accuracy. But industrial robots are catching up more and more – thanks to AI, among other things.

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MANUFACTURING

Fraunhofer IPK

INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY

INSTITUTE MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN

**Diamonds are
an engineer's best friend ...**

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Production Technology Center (PTZ) Berlin

PROFILE The Production Technology Center (PTZ) Berlin houses two research institutes: the Institute for Machine Tools and Factory Management IWF of the TU Berlin and the Fraunhofer Institute for Production Systems and Design Technology IPK. As production-related research and development partners with a distinctive IT competence, both institutes are in international demand. Their close cooperation in the PTZ puts them in the unique position of being able to completely cover the scientific innovation chain from fundamental research to application-oriented expertise and readiness for use.

We provide comprehensive support to companies along the entire process of value creation: Together with industrial customers and public-sector clients, we develop system solutions, individual technologies and services for the process chain of manufacturing companies – from product development, planning and control of machines and systems, including technologies for parts manufacturing, to comprehensive automation and management of factory operations. We also transfer production engineering solutions to areas of application outside industry, such as traffic and safety.

DEAR READERS,

when people talk about »innovation in production« today, they usually have a big picture in mind. Digitally integrated production in the sense of Industry 4.0 networks entire factories. Activities aimed at resource efficiency focus on complete manufacturing systems. And resilience measures are designed at the supply chain level.

In this context, one thing is often overlooked: The linchpins for all these initiatives are the individual machines. After all, networking is not possible without interfaces at the machine level. And data that is used to optimize complex processes are essentially generated in singular systems. In this issue of FUTUR, we therefore present current research and development activities in which our researchers are sticking their heads deep into the individual machines.

Our project teams are investigating, for example, how controlling the temperature of motor spindles can reduce warm-up times and increase machining accuracy, or how flushing channels in electrical discharge machining can increase the productivity of the process. They are approaching the »old« problem of burr formation during machining by using new types of cutting materials and innovative tool guidance, but also targeted post-processing concepts.

Machines that work ever more precisely and are ever easier to operate also promote resource efficiency – Bernfried Fleiner from the machine tool manufacturer exeron and our own Professor Julian Polte discuss this correlation in our expert panel. The topic of artificial intelligence is not neglected in this issue either: With its help, we upgrade industrial robots to become a competitive alternative to machine tools and modernize older machines to ensure their future viability.

Speaking of future viability: In the recently launched Fraunhofer EMOTION lighthouse project, we are thinking ahead about the roles of humans, machines, robots and other resources in manufacturing systems. We want to enable the individual players to recognize and respond empathically not only to their own condition, but also to that of surrounding players. This is only possible with fundamental work on the individual machine.

Last but not least, we would like to introduce you to two new machines in our institute, with which we are equipped for the next research assignments at the machine level. A cold spray system acquired in cooperation with the Werner-von-Siemens Centre for Industry and Science e. V. enables us to look into coating by means of thermal energy. The machining center Moore Nanotech 650 FG addresses minute structures: The latest-generation ultra-precision machine allows for the production of highly precise surfaces by turning and milling.

We hope you enjoy reading this issue.

Yours sincerely

Eckart Uhlmann

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Responding to change in an anticipatory and flexible manner is a basic prerequisite for economic success today.

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Cutting tools made of diamonds are extremely accurate

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Burrs are a tiresome issue in machining

↳ More on page 44

»Using hydrogen to generate energy is not a novel idea. Hydrogen-based fuel cells, however, have been dismissed in contrast to fossil fuels and renewable energies. Their production was deemed too costly and, moreover, only possible in small quantities.«

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AI supports industrial robots in precise positioning

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SHORT CUTS

WELL SAID


© Verena Müller / BG ETEM

»Our overriding goal is to help shape an economy that, like nature, functions according to a cycle principle. The contribution we can make as a machine tool manufacturer is to enable ›first time right‹ in every manufacturing process. In other words, our machines should produce a correct product right from the start.«

Bernfried Fleiner, Managing Director of exeron GmbH

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NUMBER OF THE ISSUE

1.100°C

is the temperatur reached by the carrier gas during cold spraying in the new cold spray facility at the Werner-von-Siemens Centre for Industry and Science e. V.

↳ **Learn more about this high-tech process** on page 20.


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RETHINKING PRODUCTION: PRODUCTION AS A DRIVER FOR AN INDUSTRIAL SOCIETY IN TRANSITION

The Production Technology Colloquium is back! At the 17th edition of the tradition-steeped event at the Production Technology Center Berlin on September 14 and 15, 2023, everything will revolve around the major challenges facing Germany as an industrial location: digitization and sustainability. Experts and executives from business and science will present successful approaches and strategies for CO_2-neutral production as well as current Industry 4.0 solutions.

↳ **Register now at**
www.ptk.berlin

NEW TECHNOLOGIES FOR PRODUCING MRNA-BASED PHARMACEUTICALS

mRNA technology was originally developed for cancer therapy and can be used to treat many diseases. Together with partners from science and industry, Fraunhofer IPK is now researching how mRNA therapeutics and other medication can be better produced and more effectively applied.

↳ **Further information at**
www.ipk.fraunhofer.de/mrna-en

IN DETAIL

What is this gun pointed at? Find out

↳ on page 21.

ENEFFNET – DIGITAL NETWORKING PLATFORM FOR EFFICIENCY SOLUTIONS

ÖKOTEC and Fraunhofer IPK, in cooperation with Mercedes Benz AG at the Berlin site and Daimler Truck AG at the Mannheim site, are developing and testing a digital networking platform for all relevant operating data within the new »EnEffNet« research and development project, thus enabling end-to-end management. In addition to applications for optimizing efficiency, the networking platform opens up numerous possibilities for a future-oriented use of energy-, machine- and systems-related data in the sense of an Industry 4.0 approach. Areas of application may be found for example in predictive maintenance, intelligent quality assurance or optimizing controlling processes.

↳ **More about the new platform at**
www.ipk.fraunhofer.de/eneffnet-en

From Smart to ❤

A new Fraunhofer lighthouse project is investigating how production systems can become more resilient through cooperative behavior. Empathy plays a crucial role in this.

Political aggression, supply chain risks, accelerated energy transition – the global framework conditions for manufacturing companies have changed massively. This is a turning point: Today, more than ever, their ability to react in an agile way to abrupt changes is in demand. The keyword here is resilience. When acute events hit insufficiently resilient value chains, the consequences can be dramatic. Or, to put it another way: Responding to change in an anticipatory and flexible manner is a basic prerequisite for economic success today.

This is where EMOTION comes in. The new Fraunhofer lighthouse project aims to show how resilient value chains can be created through more efficient cooperation between all those involved in production. The key to this is empathy. Together, Fraunhofer IPK and six other Fraunhofer institutes will develop solutions for human-technology collaboration to support production systems in becoming responsive, adaptive and able to learn.

The researchers' assumption: It is essential for a resilient production system that all its elements – people, intelligent machines and products, as well as IT and OT systems – work together in a way that complements their expertise. This cooperation only works, if the players have a »mutual understanding« of each other. That is, if they are able to understand not only their own (production-related) state, but also the state and intentions of the other actors. The ability to build up such a mutual understanding is representative of the term »empathy«.

COPIED FROM HUMANS

In the context of the project, this term is used in the production domain for the first time. In psychology, empathy describes the ability to put oneself in the position of others and to take on their perspective. Empathy makes it easier to get in touch with other people, anticipate their behavior and respond adequately to their needs. In the workplace, empathy strengthens cohesion – especially in heterogeneous teams.

But how can these properties be applied to technology? The researchers have developed the concept of an »empathic technical system«. This could be, for example, a mobile robot that is able to take on the perspective of other robots. It knows their goals, control variables and can proactively support them if necessary. To do this, it »slips« into another role and independently adapts the scope of its tasks. Another example could be a machine tool that is capable of understanding the urgency of production orders: It knows its setup status, the production specification and the expected delivery date, and autonomously coordinates workflows with other machines as well as production planning and control.

A completely empathic production system ultimately consists of networked units of such cooperative, digitally sovereign actors. Analogous to empathy in humans, empathy in production thus enables better cooperation, more predictability and, as a result, faster recognition of internal and external disturbances as well as more dynamic countermeasures.

> In the workplace, empathy strengthens cohesion – especially in heterogeneous teams.

ON TO THE NEXT LEVEL!

In the vision of the lighthouse project, empathic production systems embody the next technological evolutionary stage. Currently, we are at the stage of so-called cognitive production systems: By being connected to sensors and actuators and using data and AI technologies, actors are already capable of sensing their own state, interpreting ongoing processes and events, and making decisions. This includes, for example, intelligent assistance, robotics, machine and au-

tomation systems. However, in order to effectively communicate with other actors, they would require a form of information processing that includes the complete system: Mutual understanding is not possible in cognitive production systems. The great challenge is therefore to further develop cognitive systems in such a way that they are able to map cooperative behavior.

The interdisciplinary competencies of the participating Fraunhofer Institutes in the areas of production technology, smart maintenance, machine learning and Industry 4.0 offer optimal conditions for this. A decentralized system architecture that ensures the high-frequency and secure exchange of heterogeneous data volumes is elementary for the mutual interaction of the production actors. Accordingly, the project team is designing a reference model that is scalable and can be derived

> The great challenge is to further develop cognitive systems in such a way that they are able to map cooperative behavior.

for a wide variety of production types. Based on this, the individual institutes will develop combined hardware and software solutions, which will then be brought together in a comprehensive platform. Finally, the added value of empathic technical systems is to be demonstrated through industry-oriented testing in three areas: assistance systems, maintenance, and production planning and control.

EMPATHIC ASSISTANTS

Specifically, the first area of application involves cognitive and physical assistance systems that are being expanded into empathic assistance systems. These include an empathically acting exoskeleton, which recognizes – situationally and individually, depending on the physical constitution – whether an employee can perform a task such as lifting a component on his own or whether they need adaptively controlled support. The empathic-cognitive assistance system, on the other hand, automatically detects whether an employee is cognitively overloaded – for example, due to a complex assembly task under high time pressure – and then offers them specially prepared information via AR glasses, cell phone or audio assistance. If the system recognizes that the worker is returning to a productive state, it also retracts the assistance. Another example is automated guided vehicles (AGVs) for logistics and assembly, which identify transport orders on their own initiative by communicating with other actors and coordinate their activities among themselves independently.

EMPATHY AS A CLOCK GENERATOR

In the area of maintenance, anticipation is the primary feature of empathy: Since an empathic production system permanently analyzes the condition of all machines, it can act proactively. The system recognizes which machine is in danger of failing soon and also has a plan ready for which actor will take over the tasks in the short term. Since all players are aware at all times of what the most urgent goal is at the moment, they can also work together towards this goal in terms of machine utilization and wear. For example, if the on-time completion for an important customer is of supreme importance, the machines are »aware« of the urgency and adjust their control parameters accordingly. A bottleneck machine, in this case, will configure itself to avoid maximum utilization in order to prevent the risk of downtime. If a breakdown nevertheless occurs, it can take precautions together with other machines at an early stage to schedule an alternative sequence of production orders. This means that production and maintenance are no longer separate areas, but are closely networked.

EMPATHIC, TRANSPARENT AND RESPONSIVE

Linking formerly separate factory areas also affects the third area of application, production planning and control. Here, the empathic cooperation of digitally networked actors leads to a dissolution of hierarchical structures: Virtual real-time feedback from the shop floor to the planning level enables even the smallest deviations, such as a longer setup process, the delayed provision of materials, or a minimal change to the product, to be immediately detected and appropriate countermeasures to be initiated. By integrating all means of production into the digital infrastructure of production planning, a completely transparent production is created that organizes and optimizes itself independently with the help of intelligent algorithms.

These are just a few practical examples, but they already show how empathic production leads to seamless interaction between all stakeholders – and makes companies more resilient to disruptive change. ◆

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Bernfried Fleiner

is Managing Director of exeron GmbH. exeron manufactures machine tools for high-end EDM and high-speed milling, which are precisely tailored to the user's needs. As one of two managing directors, Mr. Fleiner is responsible for innovations and services at exeron. At PTK 2023, held on September 14 and 15 at the Production Technology Center Berlin, he will give a presentation on the »Zero Defect Approach as a Contribution to Sustainability«. *(right image)*

Prof. Dr.-Ing. Julian Polte

holds the chair of Machines and Technologies for Additive Precision Manufacturing of Metallic Components at the Technische Universität Berlin and is head of the Manufacturing Technologies as well as Production Machines and System Management departments at Fraunhofer IPK. With his teams at both institutes, he is working to make machine tools and manufacturing processes more efficient, precise and sustainable. *(left image)*

Right to the Point

Our two interview partners jointly develop solutions for manufacturing with the highest precision. In the FUTUR expert panel, they discuss the variable »precision« as a key to sustainable production.

| futur | **Mr. Fleiner, exeron machines stand for the highest manufacturing precision with high process reliability. What motivates this demand for quality?**

/ FLEINER / Our overriding goal is to help shape an economy that, like nature, functions according to a cycle principle. The contribution we can make as a machine tool manufacturer is to enable »first time right« in every manufacturing process. In other words, our machines should produce a correct product right from the start. That is a high goal, and we want it for two reasons. Firstly, because of resource efficiency: We reduce scrap and thus minimize energy and material consumption. In addition, we achieve machine longevity by reducing wear. This massively reduces the ecological footprint of production. Second, it improves employee health. If a part is produced incorrectly, trouble ensues, which causes stress – with enormous effects on the people in production and thus on the productivity of a company. If employees can approach manufacturing processes with composure because they know the machine will work as planned, that's a powerful tool for keeping the staff healthy.

| futur | **Professor Polte, why does a machine tool have to work with maximum precision to enable zero waste?**

/ POLTE / Demands on component accuracy have increased enormously for many workpieces. A few years ago, the technological spearhead was a few micrometers of accuracy. Today, many can do that, and at the same time, more and more components have very high precision requirements. This is not least due to the fact that components are constantly becoming smaller and more compact, and power density is increasing. Plus: More and more machines are being set up in non-specified environmental conditions, yet, the highest demands are being placed on accuracy and reliability. Therefore the market demands innovations in the area of component quality, but also in the accuracy and reliability of machine tools.

/ FLEINER / The extent to which requirements for workpiece accuracy have increased is also mirrored in the fact that we now conduct systematic product acceptance processes with dedicated acceptance workpieces. These workpieces are always manufactured in the same way for each machine acceptance procedure to see how reliably a process is running. We did not do anything like that in the past, but today it is a matter of course. And it always provides us with new data on process reliability that flows into further development.

Images:
1
Bernfried Fleiner at the exeron site in Oberndorf, Baden-Württemberg
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2
exeron Milling machine HSC MP7 with workpiece and electrode handling AWEX 100
© exeron GmbH

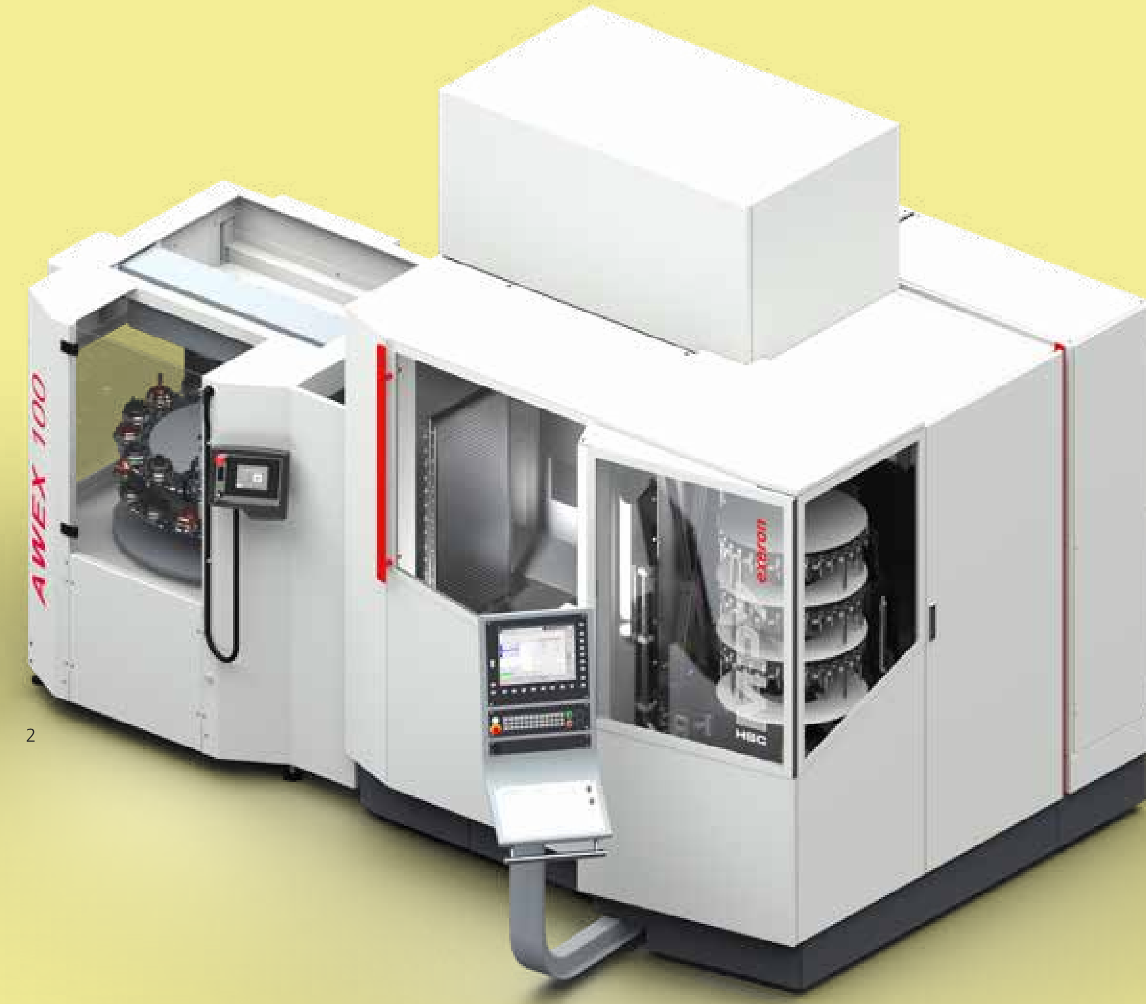
1

| futur | **Mr. Fleiner, in retrospect, what would you consider a milestone in the development of exeron machines where components have decisively improved accuracy and component quality?**

/ FLEINER / With our cool-base concept, we address internal and external heat sources simultaneously. In doing so, we use fast heat transfer into the applied cooling medium and a braked heat transfer from external interference sources. From a cooling logic point of view, we rely on complementary systems: a power cooling circuit as a basis, a precision cooling circuit and, in selected areas, a maximum precision cooling circuit with a maximum deviation of ± 0.1 Kelvin. Our high-precision measurement technology is then built on this basis, enabling output data for discrete volumetric and rotational compensation mechanisms where necessary. In addition, our decision to form a coherent logical bridge between the acceptance criteria according to DIN ISO 230 via the milling strategy and milling tool-neutral 5-axis measurement to the already mentioned acceptance workpiece was an important step in customer communication. We presented the concept at the Berliner Runde 2019 at the PTZ.

| futur | **And what topics are driving the next development steps in machine tools?**

/ POLTE / If we look at the machine tool as it is today and as it might have to look tomorrow, we see numerous aspects that have to be considered. In my opinion, two are standing out in particular: In the past, highly qualified personnel were needed to operate it, and there are fewer and fewer of them available. So, with improvements in operability, we are meeting the challenges of demographic change and a shortage of skilled workers. In addition, we had to painfully learn over the last two years how important the issue of resilience is. The question is: What can a machine tool do to improve the resilience of production companies – and how can a machine manufacturer enable enterprises to become more resilient?



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| futur | **Then let's take a look at these topics. What can a machine tool manufacturer do to counter the shortage of skilled workers? For example, how can you deal with the situation when there are no people with specialized training to operate a machine, and yet high precision and repeatability must be achieved?**

/ FLEINER / We already started automating our machine tools a good while ago. This takes normal operating tasks off of skilled personnel and allows them to take care of processes for which a skilled person is indispensable. In addition, our user interfaces enable comparatively fast learning – which makes it easy to become familiar with new machines or new processes.

/ POLTE / I find exeron's approach to the first point fascinating. The company produces mini manufacturing cells in which, for example, the workpiece changing unit is symbiotically integrated into the machine tool. This is particularly interesting for SMEs that do not have fully automated process chains, but still want to automate processes on an individual machine to some extent.

| futur | **Could you please explain what this means?**

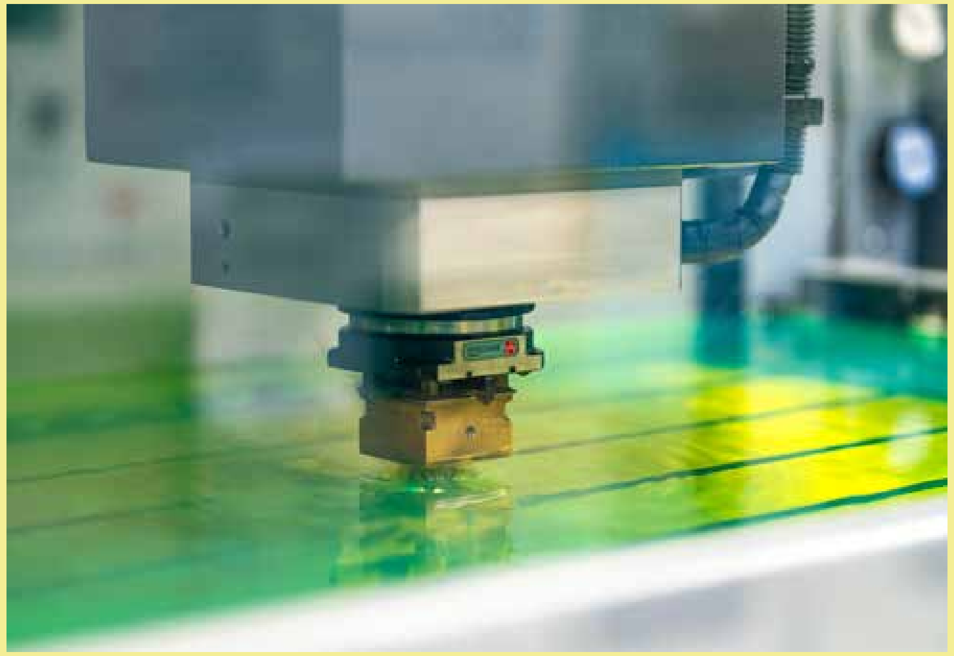
/ FLEINER / Well, most customers who purchase such a system from us used to have someone standing at the machine all the way through, routing the production orders. Now, in the most extreme expansion stage, they have a job management system that keeps track of the entire process. Raw material goes into this process and is first checked for completeness and measured to see, if it fits together. Then an electrode is produced on a milling machine, followed by erosion on an EDM machine. And if, for example, a milling cutter breaks during electrode production, the system reacts flexibly. Ideally, the process runs autonomously to an extent that loading takes place on Friday evening, the process is finished on Monday, and no intervention is required in between. This way, I can make a relatively large amount of production available with comparatively few people. In the popular sense, it is like »sowing on Friday and reaping on Monday«.

/ POLTE / So if you were called a machine manufacturer, your service would be inadequately described. Your claim is rather to offer holistic solutions to customer problems.

/ FLEINER / Yes, and there is hardly any other way, because reproducibly producing high-precision components requires the machine manufacturer to be accessible to the user. Apart from that, we also have to give our customers a helping hand, because it takes some re-learning to deal with more automated processes – starting from the fact that the distance to the process is greater.

/ POLTE / Of course, this is a nice template for us, because at Fraunhofer IPK we are working on the next level of service, so to speak. We want to use context-sensitive assistance to enable machine tools to provide operators with the best possible support for various processes. The operators are guided through the process with edge devices such as tablets, smartphones or smartwatches depending on their experience level. These may be manufacturing processes, such as support with workpiece setup or preparation processes in the area of component programming, but of course also service and repair.

1



2

Images:
1
View into the tool magazine of the HSC 600 in the PTZ test area
2
EDM machine EDM 313 Hochgenau at the Application Center for Microproduction Technology – AMP
3
Professor Julian Polte at the HSC 600

/ FLEINER / This is definitely a topic where it makes sense for a medium-sized company like us to make use of research support. Because if I want to assist the operator, for example, in intervening in a process that is not running smoothly, I first have to analyze: What is the status of this process? And I must be able to recognize warning signals. Sensors in the machine and the recording of status data via these sensors and, above all, the interpretation of this data play a major role. Starting all this from scratch is a challenge.

/ POLTE / Incidentally, you don't even necessarily need additional sensor technology for condition monitoring. We are also working on the question of whether such monitoring could be based entirely on internal machine data, for example by going directly to the CNC control. Research in this area focuses mainly on understanding interrelationships. How are certain signals to be interpreted and how can conclusions be drawn about the condition of a machine when combining all available signals?

| futur | **And where does that lead? Or, to put it another way: By what means will the machine tool of the future push the boundaries of what is possible today?**

/ FLEINER / If I let Prof. Polte's thoughts sink in for a moment, I would say: We will use intelligent software solutions to reduce the entry barriers for operating machines that guarantee high process reliability and very high manufacturing accuracy for an even wider range of people. In addition to sensors, intelligent measurement technology will also play a role, and human-machine interaction will continue to improve.

/ POLTE / And it will not stop there. Current research projects are already focusing on cognitive production processes. The idea is that resources involved in production – machines, transport vehicles, and so on – can independently perceive their status and, for example, make themselves available for orders or request maintenance. With the EMOTION lighthouse project, we even want to go one step further and create empathic production systems – in other words, system networks in which the resources involved can recognize that another resource in the process is under- or overstretched and respond accordingly. We are convinced that the success of production depends on the efficiency with which the stakeholders within a manufacturing system work together. And to get there, it is essential to go to the machine level and enable a machine tool to actively cooperate in such a context. And this brings us to the topic of resilience: If technical resources actively react to unforeseen situations, they help to increase the resilience of a manufacturing system. ◆

COOPERATION BETWEEN EXERON AND FRAUNHOFER IPK

exeron aims to ensure reproducible component quality at the highest quality level with guaranteed machine availability. With its vibration-decoupled foundations and climate stability, Fraunhofer IPK's Application Center for Microproduction Technology – AMP offers excellent conditions for the further development of such properties. Furthermore, exeron has found a partner in Fraunhofer IPK that is attuned to the company's challenges and implements suitable solutions in a targeted manner to efficiently cover peaks in development requirements.
By now, three exeron machines are in use at Fraunhofer IPK:
- a milling machine HSC MP7/5, which is used for development work in tool and mold making, energy and medical technology, the watchmaking industry, and the mobility sector
- an EDM 313 high-precision EDM machine, for joint developments to optimize processes and increase efficiency
- an HSC 600 milling machine in the »dip« application lab, for research work on small-batch production of customizable fuel cells for niche markets as well as empathic production systems in the EMOTION lighthouse project (see p. 10)

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Cold Spray: Additive Manufacturing by Means of Kinetic Energy

Cold spray is considered one of the most modern processes in the field of thermal spraying. A research cooperation has recently equipped Fraunhofer IPK and IWF of TU Berlin with access to a state-of-the-art cold spray manufacturing system.

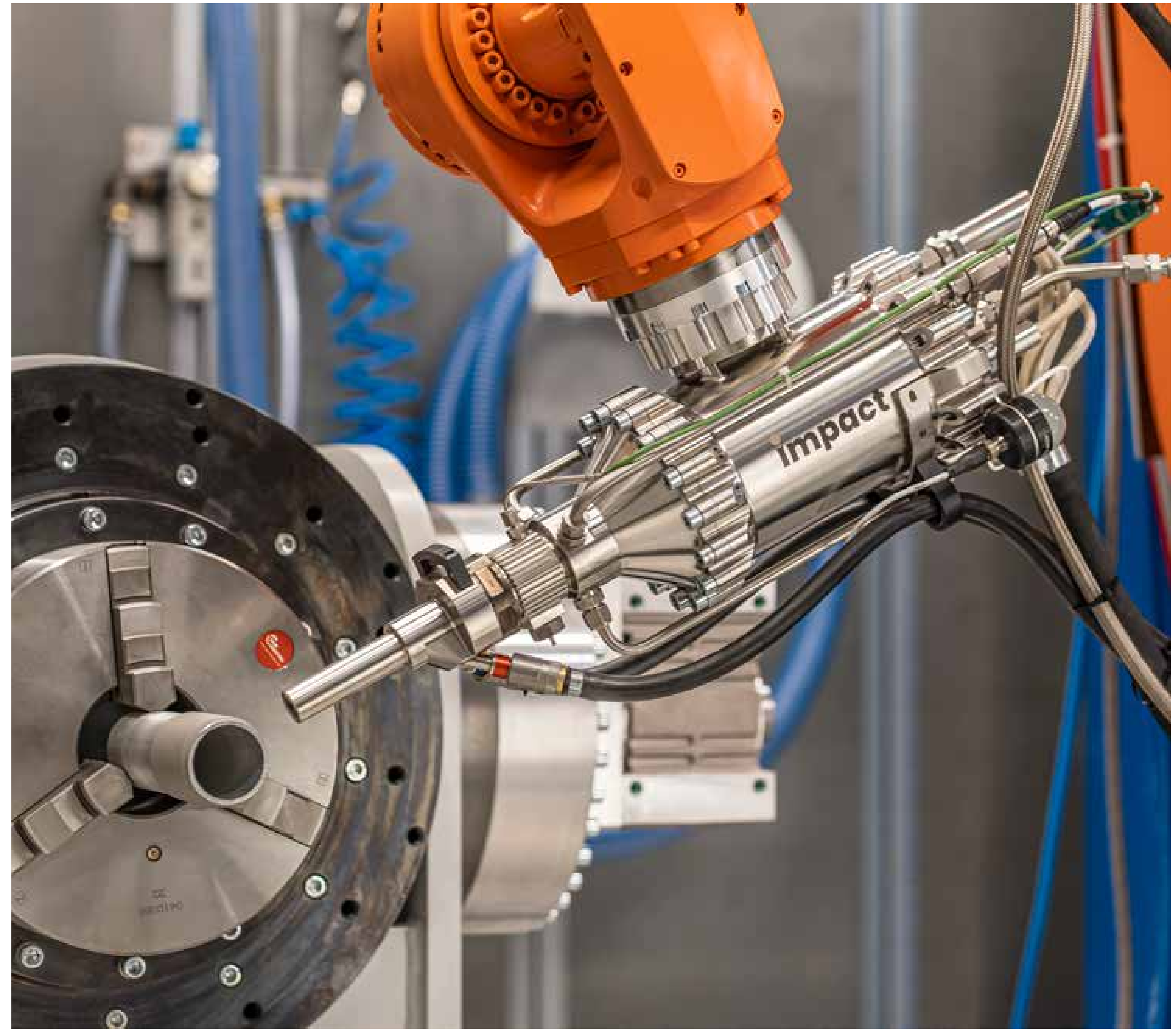
Anyone who wants to manufacture large components with complex geometries, for example for use in the automotive sector, faces a challenge: The heat input of most coating processes harbors the risk of impairing the component shape – the danger of distortion due to residual stresses ensues. Here, the so-called cold spray process offers an innovative solution: A powder material is blasted at high speed onto the surface to be coated. Due to the high velocity, the particles form a solid and resistant layer on impact. Since the powder has a relatively low temperature below the melting temperature during processing, there is no melting and resolidification in the material. Thus, shape deviations due to thermally induced residual stresses can be largely avoided.

As a result of a joint investment with the Werner-von-Siemens Centre for Industry and Science e. V. (WvSC), the TU Berlin's IWF and Fraunhofer IPK have a state-of-the-art manufacturing system for cold gas spraying at their disposal since spring 2023. They aim to use the system for pushing the boundaries of what has been possible to date with additive manufacturing processes.

HIGH PERFORMANCE MANUFACTURING SYSTEM

Cold spray is a coating technology, or more precisely thermal spraying process. In this process, a usually metallic material powder is injected into a carrier gas stream and passed through a Laval nozzle. The fluid mechanics acting in the nozzle accelerate the gas flow to up to three times the speed of sound, causing the material particles to absorb high kinetic energy. When the particles strike a substrate surface, this energy causes them to form a firm deposit.

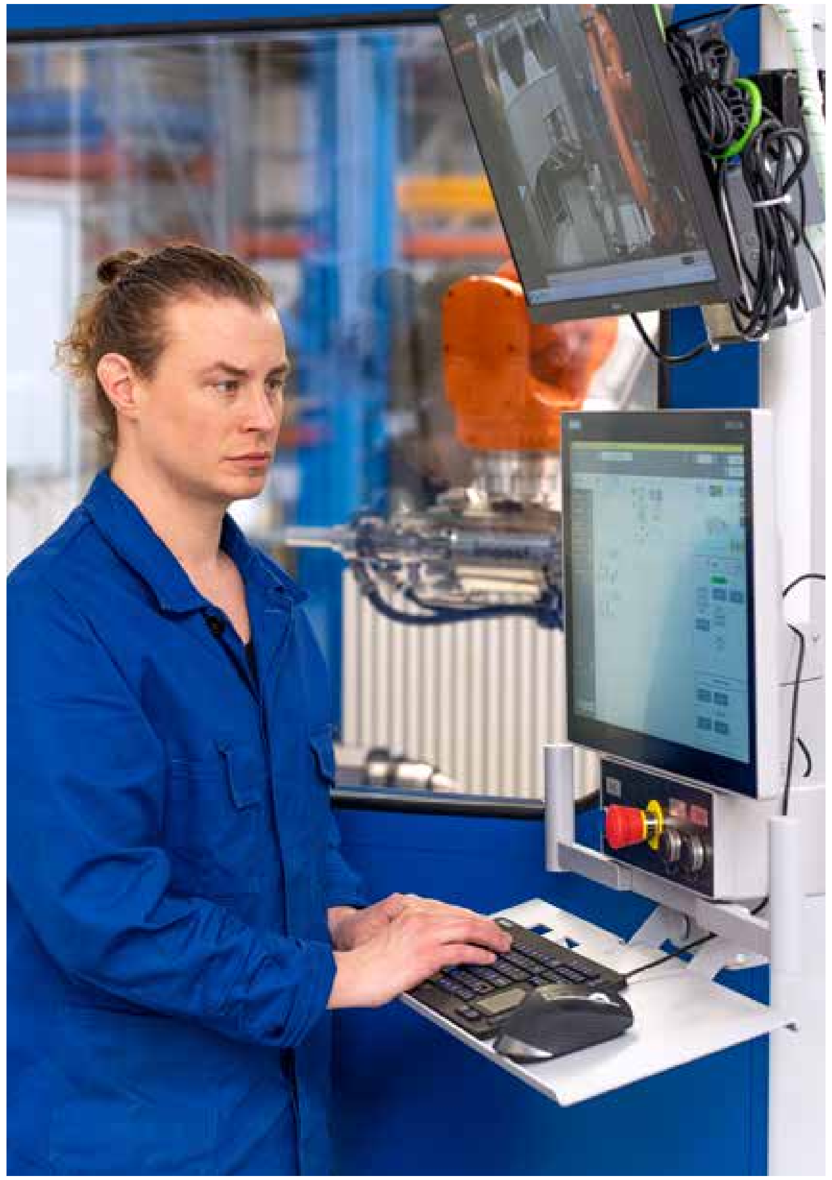
One can imagine the principle as when a snowball hits a hard surface with a lot of momentum: On impact, the side facing the surface is flattened, and the snowball sticks. If not just one snowball hit the surface, but thousands, the result would be a layered structure similar to that produced by cold spraying. High component densities and excellent material properties are achieved. These include high mechanical load-bearing capacity and thermal or electrical conductivity, which can be specifically adjusted by suitable process parameters. Moreover, material combinations that were previously not possible in the field of additive manufacturing can be realized through a material feed that can be adjusted either serially or in parallel.



The core component of the manufacturing system at WvSC is a spray head by manufacturer Impact Innovations GmbH, which accelerates the carrier gas through a pressure of up to 60 bar and a gas temperature of 1100 degrees. A latest-generation Kuka robot brings the spray head into relative motion with the workpiece to be manufactured. This movement defines at which point of the component geometry material is to be applied. The robot's reach enables component dimensions of more than two meters. The highly performant control system, which can also control additional axes aside from the six robot axes, enables the production of component designs with complex geometries.

RESEARCH ON INNOVATIVE TECHNOLOGIES

Current research projects underline the high degree of innovation of cold spray processes. The research project »Electric Drives 2.0«, which is being carried out in cooperation with WvSC, is dedicated to the competitive electric machine of the future. The process chain for manufacturing large electrical high-voltage machines has so far been characterized by the use of conventional manufacturing technologies. Additive manufacturing processes offer the possibility of breaking through geometric limitations in the production of stator windings as well as permanent magnets and thus achieving higher power densities.



1

2

Images:
1
An engineer controls and monitors a running cold gas process
2
Coating process of a rotationally symmetrical titanium component
3
Coating process of a flat copper component
4
Production system with cold gas gun on the Kuka KR120 robot system in the coating booth

3

Co-funded by
the European Union

Process gas temperature:
100°C – 1100°C

Heating capacity, max.:
40 kW

Process gas pressure, max.:
60 bar

Process gas stream, max.:
190 m^3/h N_2

Handling system:
Kuka KR 120

Part size is defined by the robotics reach of
2701 mm

Line of freedom:
6 + 2
robot axes and linked rotation axes for complex part geometries

4

In the »AddGleis« cooperation project from the Additive Manufacturing Berlin Brandenburg (AMBER) funding program of the state of Berlin, the cold spray system is being used for additive manufacturing of topology-optimized lightweight components. A powerful imaging sensor system in combination with AI-based monitoring of the process result will contribute to the additional further development of process control. ◆

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COOPERATION WITH WERNER-VON-SIEMENS CENTRE FOR INDUSTRY AND SCIENCE E. V.

Werner-von-Siemens Centre for Industry and Science e. V. is a research cooperation of numerous partners from science and industry in Berlin. Research is looking into innovative technologies for transforming production technology in order to rethink production and the products of tomorrow. In addition, other WvSC projects are investigating new and innovative technologies in the future topics of mobility or energy transformation. Scientific work currently focuses on the areas of digitalization, additive manufacturing, new materials and sustainability. It is accompanied by the application of new forms of work, collaboration in a co-working space and educational offers. In this way, the projects and the participating institutions and companies are closely interlinked and the employees regularly gain access to the place of production for their research and development activities.

Heat Pump for Machines

It can heat as well as cool – a new thermoelectric system enables temperature control of motorized spindles as needed, thus increasing the precision of machine tools.

Whether it is glass lenses for cameras, mirrors for the aerospace industry or gear wheels for watches – in precision manufacturing, the highest level of accuracy is essential. Even the smallest errors or uneven surfaces can impair the functionality of components. For this reason, the parts must be milled or ground to micrometer precision. The need for components machined in this way in the fields of optics, metrology, automotive engineering, and information and communications technology is growing steadily. In order to be able to meet the demand in the future, highly productive precision manufacturing is necessary.

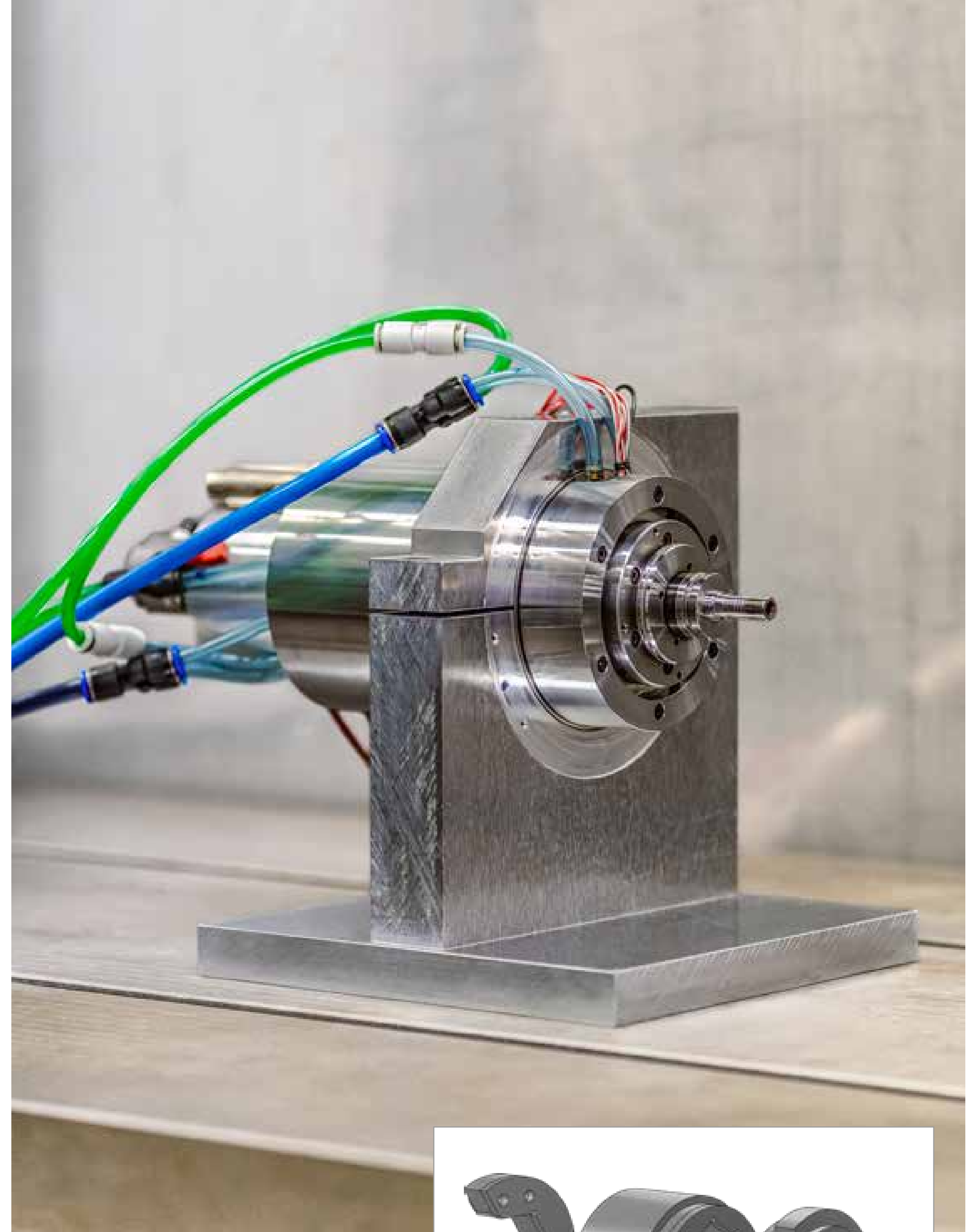
The problem: Machine tools currently used for this purpose have a long warm-up time, which limits productivity. The necessary warm-up times result from the high requirements placed on working accuracy in precision manufacturing, which requires a steady state of thermally induced displacements. Up to 75 percent of geometric component errors can be traced back to thermally induced displacements.

Motorized spindles, in which, for example, a milling tool is clamped are the critical component of a machine tool: Due to their proximity to the tool center point, they have a significant influence on the working accuracy. Drives and bearings of motorized spindles are significant heat sources. Electrical as well as mechanical power losses cause the spindle housing and shaft to heat up. As a result, these components expand and cause a shift of the tool center point.

To reduce this effect, state-of-the-art fluid cooling systems are used in motorized spindles to dissipate a large part of the induced heat flows. Conventional fluid cooling systems, however, do not respond to changes in heat flows caused, for example, by a variation in rotational speed due to tool changes. Even a short downtime of a motorized spindle in the course of a tool or workpiece change leads to a thermal disturbance, which requires a new warm-up time. This is a waste of energy that must be avoided not only for reasons of productivity, but also for climate protection.

In order to improve the thermoelastic behavior of motorized spindles and, in particular, to reduce the warm-up time after a spindle downtime, researchers at IWF of TU Berlin together with the German manufacturer of motorized spindles Alfred Jäger have developed a thermoelectrically tempered motorized milling spindle. Core components of the temperature control system are so-called Peltier modules: tiny cubes made of the semiconductor material bismuth telluride, connected electrically in series and arranged between two ceramic plates. When a voltage is applied, the semiconductors transport heat from one side to the other. In total, a heat flux density of up to 15 watts per square centimeter can be achieved. For the developed motorized spindle, this means that theoretically a heat flow of up to 2.5 kilowatts is available – this is comparable to the cooling capacity of an air conditioning system for a larger room. For a conventional spindle cooled with water, in contrast, it is not possible to determine how much heat is dissipated.

Installing the Peltier modules, therefore allows operators to control the heat flow and adjust the temperature of the spindle



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Images:
1
Test setup for the operation of the thermoelectrically tempered motorized milling spindle
2
Sectional view of the thermoelectrically tempered motorized milling spindle

as required. For example, a temperature of 25 degrees Celsius can be set at the front bearing and this can be maintained regardless of changes in rotational speed. By reversing the applied current direction, the spindle can also be preheated to reduce unproductive warm-up times. Think of it like a heat pump for machine tools: by reversing the direction, both cooling and heating become possible.

To test the potential of the thermoelectric temperature control system, comparative measurements were carried out between the prototype and a commercially available reference spindle. Both motorized spindles were operated in a test rig at a speed of 55,000 revolutions per minute and stopped for a downtime of 300 seconds, which was intended to simulate a workpiece change. The measurements show: A controlled heat supply significantly reduces the shaft displacement during standstill as well as the warm-up time of the prototype. This opens up considerable potential for increasing productivity in precision manufacturing. Bottom line: Thermoelectrically tempered motorized milling spindles can not only reduce the risk of component defects, but also have a positive effect on the energy efficiency of machine tools in use. ◆

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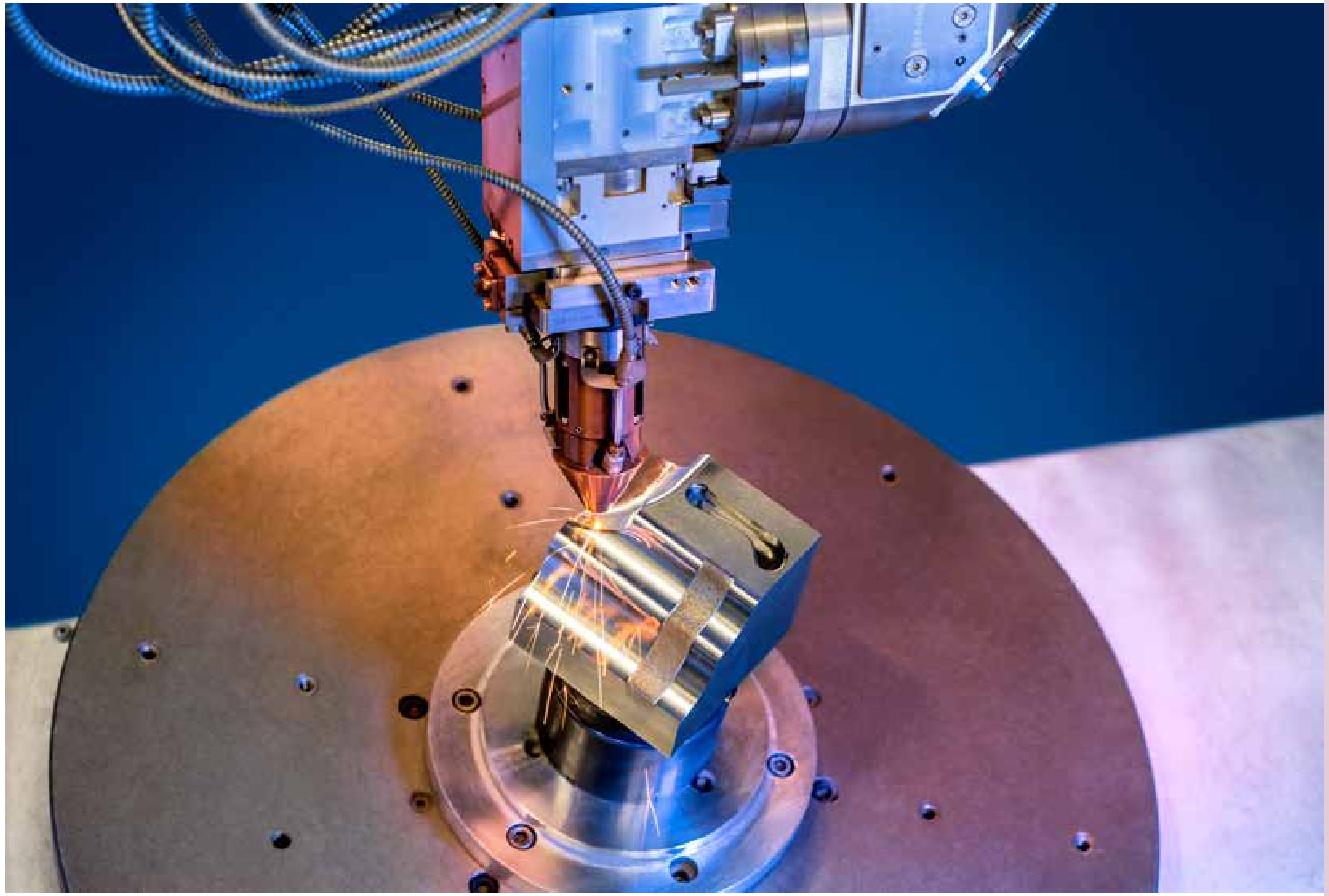

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Better Than New

By combining Scangineering and additive repair technologies, tools or components can be repaired automatically – an exciting field of application for the reverse engineering technology made by Fraunhofer IPK.

Where massive forces are at play, even the hardest component eventually gives way. When in use, turbine blades develop cracks, shafts develop dents and punching tools start showing signs of deformation at the edges. Modern additive processes are used to efficiently repair such damage and make the worn component ready for use again.

Laser Powder Directed Energy Deposition (LP-DED) in particular has become an efficient process of choice for these kinds of repair tasks. A laser beam is used to create a weld pool into which a nozzle conveys a powdery, usually metallic filler material. This melts in the weld bath, and movements of the nozzle or the component produce weld beads, two-dimensional coatings and more complex 3D structures layer by layer. In this way, LP-DED can be used to repair a wide range of components by local welding. For simple geometries such as running or sealing surfaces of shafts, the process is established and widely used in industry.

But repairing localized damage using DED can also be worthwhile for expensive components such as stamping or molding tools, like those used in automotive engineering. However, complex geometries and individual damage patterns, as in indentations, edge chipping or deformation, make it significantly harder to use the process efficiently in such scenarios.

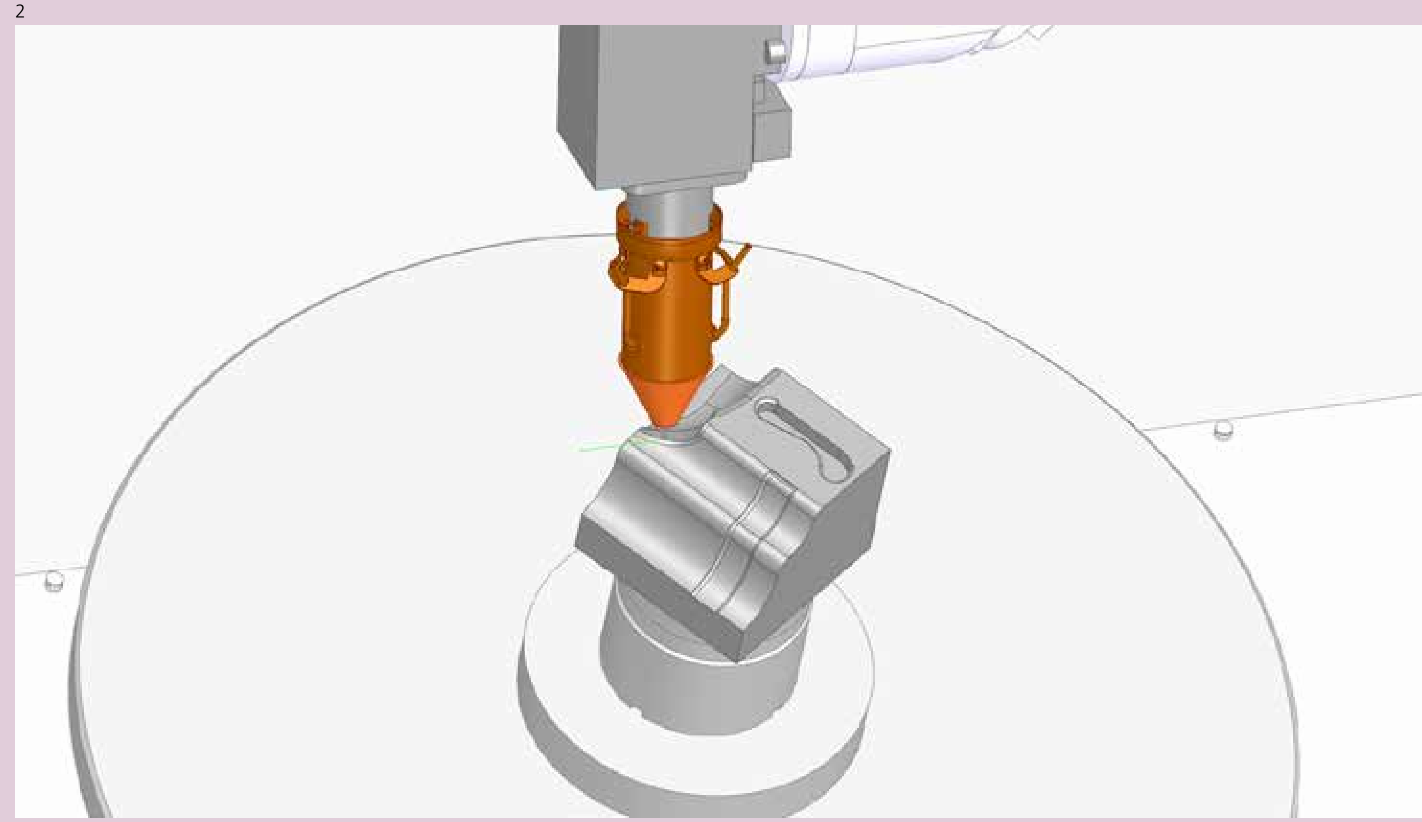
THE REPAIR PROCESS CHAIN

For such repair tasks, a process chain like the following is usually run through:

1. The defective component is 3D scanned, including its damaged area.
2. The component is prepared for repair (for example by grinding or milling out the damaged area).
3. The prepared component is 3D scanned again.
4. The 3D scan data thus generated is processed, detecting the defective areas and generating a difference volume that distinguishes the nominal and actual states.
5. An additive LP-DED repair process is planned in a CAM program.
6. The repair process is carried out.
7. The repaired part is heat treated and reworked.

Images:
1
Repair welding using LP-DED
2
Generation and job simulation of toolpaths in the CAM software

2



In this chain, steps 4 and 5 in particular pose challenges. A weld path cannot be derived easily from a simple 3D scan. It is true that the capture and measurement of geometries by laser scanning or photogrammetry is standard for many applications today. But the resulting large data volumes are often only used for visualization or measurement purposes. To use them for repair processes, the scan data must be processed, aligned and converted into parameterized 3D models. Only with these models can path planning for the repair process be carried out in a CAM program. This process of converting 3D images into CAD models is called reverse engineering. It is still carried out manually to a large extent, which requires trained specialists and a great deal of time. For highly individualized components, the repair effort is therefore often very high.

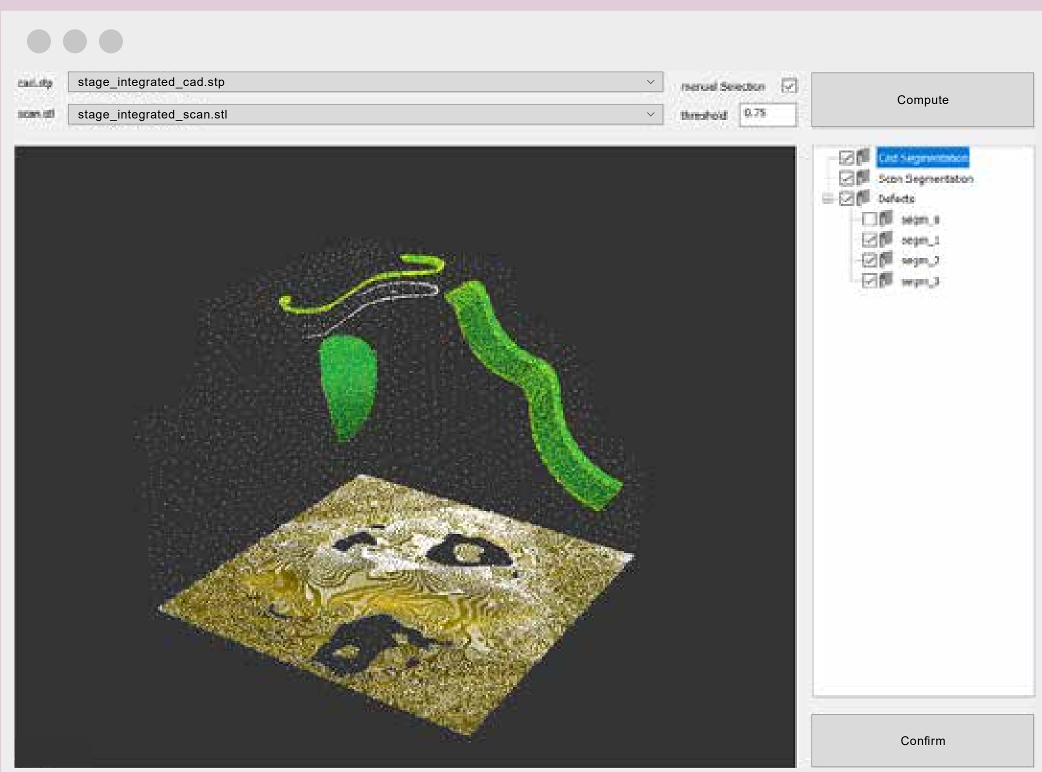
As if that were not enough, the actual repair process is complicated by welding and material challenges. Forming tools are often made of cold-work or hot-work steels with relatively high carbon contents. While the carbon content contributes to good hardenability, it also reduces the weldability of the material, which is problematic for repair welds. This is all the more true since the repaired areas must meet the requirements for resistance and hardness in the same way as the original component did as a whole.

Researchers at Fraunhofer IPK are addressing these challenges with an end-to-end automated repair solution. Thanks to Scangineering with automated component recognition and geometry-based modeling as well as modern AM processes, defective components can be made ready for use again with little technical effort.

3D SCANNING AND REVERSE ENGINEERING RESULTS IN SCANGINEERING

The reverse engineering process known as »Scangineering« is an in-house development of Fraunhofer IPK. In this process, intelligent algorithms are used to preprocess, align and parameterize 3D scan data of components. This means that a geometry-based and thus modifiable 3D model is generated from the point clouds of a laser scan, which, for example, can be loaded into a CAD program.

Users can intervene in the conversion process at any point as input providers and analysts. At the same time, they are relieved of manual and repetitive steps. By means of Scangineering, complex components, but also other objects such as machines or even buildings can be turned into virtual models quickly and easily.



More information:
www.ipk.fraunhofer.de/automated-reverse-engineering

Image:
Scangineering software as a tool for the additive repair process chain

The combination of »Scangineering« and modern AM processes makes defective components ready for use again with little technical effort.

CAM PLANNING: CALCULATING TOOLPATHS

For automated component repair, in the next process step the additive repair processes are planned on the basis of the models. The detected geometric defects are used to calculate the tool paths and welding commands for the additive building process.

Mathematically determined volumes, surfaces and curves reduce the need for additional auxiliary geometries to be created, thus simplifying and accelerating the programming process: Coating surfaces are clearly defined and can be selected, complete difference volumes can be programmed by building them up layer by layer and complex curves can be used as support curves for the alignment of tool paths. By simulating build-up and checking traverse paths, the tool paths can be verified and any collision points can be detected and eliminated in advance.

ADDITIVE REPAIR PROCESS AND FINISHING

The final step comprises the design of the process parameters and the actual component repair. This phase requires materials engineering know-how to ensure a metallurgically high-quality and durable repair: Material-specific properties must be considered. The high carbon content in tool steels, for example, favors high hardness values – desirable to increase service life. However, in conventional repair welding, such as arc processes, the high heat input in combination with the carbon content and other alloying elements can lead to cracks in the component. Laser-based processes such as LP-DED can be advantageous here: The high energy density and the resulting low heat input reduce the cracking tendency, the size of the heat-affected zone, the influence on the base material as well as the degree of base and filler material mixing. Additionally, the selection of the filler material is not limited to the alloy of the base material. ◆

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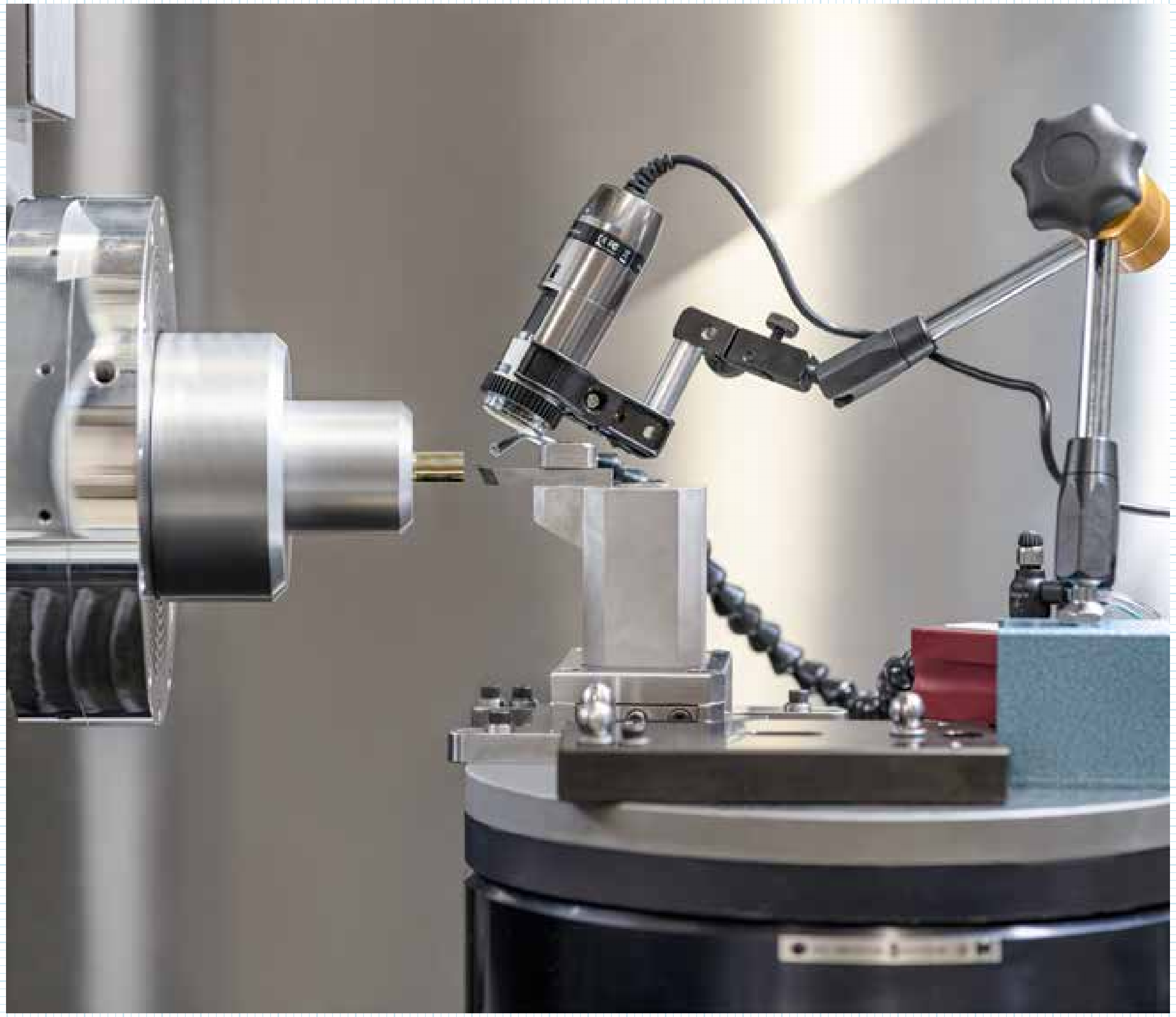

Diamond Insights

Ultra-precision machining is the ultimate in manufacturing technology – it hardly gets any more accurate than this.

Camera lenses, mirrors, eyeglasses – in optics, highest precision is essential. Extremely hard cutting tools made of diamond are used to remove material in processes lasting several hours until the desired geometry is achieved. Ultra-precision machining is the name of the manufacturing process in which materials such as metal, ceramics or glass are machined by cutting in the range of a few micrometers down to the submicrometer range. In addition to optical applications, the method is also used in tool and mold making and microsystems technology.

Image:
Moore Nanotech 650 FG at the Application Center for Microproduction Technology – AMP

TOOLS AND PROCESS PARAMETERS DETERMINE THE RESULT

The accuracy of the result in ultra-precision machining depends on various factors. First of all, there is the cutting tool. Cutting tools made of diamond ensure long tool life and high precision. Due to its atomic lattice structure, the material can be precisely ground down to the nanometer range. This is important in order to obtain a sharp edge, which can later be used to produce precision-fit injection molds for camera lenses, for example.

Another important aspect is controlling the thermal and mechanical influences on the workpiece. Even the slightest deviations can reduce quality. This is fatal if, for example, the focal length is not correct and an intraocular lens implanted in the cornea does not produce the desired vision correction or the camera lens does not focus over the entire image field. Machine tools for ultra-precision machining are therefore equipped with extremely precise linear and rotary axes as well as high-resolution position encoders – a kind of mini-GPS – in order to implement the smallest possible machining steps in a process-safe manner.

Last but not least, processing machines for the ultra-precision range place high demands on the climatic conditions of the installation site: The temperature must be constant, for example 21 degrees Celsius. Precise temperature regulation is not trivial, because machines and lighting produce waste heat, and people entering and leaving the room also heat it up. However, special air-conditioning systems make it possible to limit fluctuations to about 0.1 degrees Celsius. In addition to air conditioning of the room, precise and fast-acting temperature control of the machine and turning and milling spindles is required to prevent thermal expansion of the system during machining.

ULTRA-PRECISION TURNING RESEARCH

One process variant receiving special attention at Fraunhofer IPK is ultra-precision turning. This highly complex machining technology has made enormous progress in recent years and now makes it possible to produce components with very tight tolerances of less than one micrometer. To take advantage of the process, the machined materials must have high strength and low ductility, meaning they have to be rather brittle. The choice of lubricant in the machining zone is also crucial, because it plays an important role in reducing friction and tool wear.

Using coupled movement of the turning spindle, tool stroke axis and feed axis, even non-rotationally symmetrical workpieces can be produced via a turning operation. The so-called slow slide process realizes the tool stroke by moving the entire machine axis. This means that the tool is fed to different depths depending on the component rotation. In this way, contours and free-form shapes can be produced. With the aid of an additional fast tool servo – a component that only moves the tool instead of an entire machine axis – a lower mass is created, which increases the production speed and simultaneously reduces the machining time.

Image:
Facet component manufactured by slow slide turning

STATE-OF-THE-ART MACHINE TECHNOLOGY AT FRAUNHOFER IPK

The Microproduction Technologies department at Fraunhofer IPK recently acquired an ultra-precision machining center made by the US company Moore Nanotechnology Systems. The cabinet-sized Moore Nanotech 650 FG offers high accuracy and repeatability when machining surfaces up to 650 millimeters in diameter. A WEC (Workpiece Error Compensation) system – essentially a lane keeping assistant – tactilely measures the workpiece with a probe. Any shape deviations that occur can be automatically fed back to the CAM software, which then compensates the deviations by adjusting the tool path. In this process, the software compares the actual geometry with the nominal state and calculates how the tool movement must be changed so that the error does not occur again. These functions make it possible to machine a wide range of materials – including hard metals, ceramics, crystals, and glass – with maximum precision and increased efficiency.

Conventional CAM software quickly reaches its limits in ultra-precision manufacturing. The reason: The software, which is designed for coarser machining jobs such as large steel parts, divides the workpiece into segments or points and then draws a line between the points that the tool traverses. The greater the distance between the individual points, the coarser the grid. Excessive point spacing and erroneous linearization of small arc segments are the most common sources of error when applying conventional CAM software in ultra-precision machining. The necessary accuracy in tool path generation often cannot be achieved.

To close this gap and offer a machine-specific CAM solution, the machine manufacturer Moore has developed special software that can be used to manufacture optical lenses directly by specifying the required focal length or the parameters of the aspherical equation, that is, the mathematical description of the lens geometry. Precise knowledge of the lens geometry is therefore not necessary – production can be carried out directly after the beam path has been designed. This way, in the end the viewer has a full perspective through the lens. ◆

Highly complex ultra-precision turning has made enormous progress in recent years and now makes it possible to produce components with very tight tolerances of less than one micrometer.

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Clean and Efficient

How flushing channels in electrical discharge machining help to increase productivity

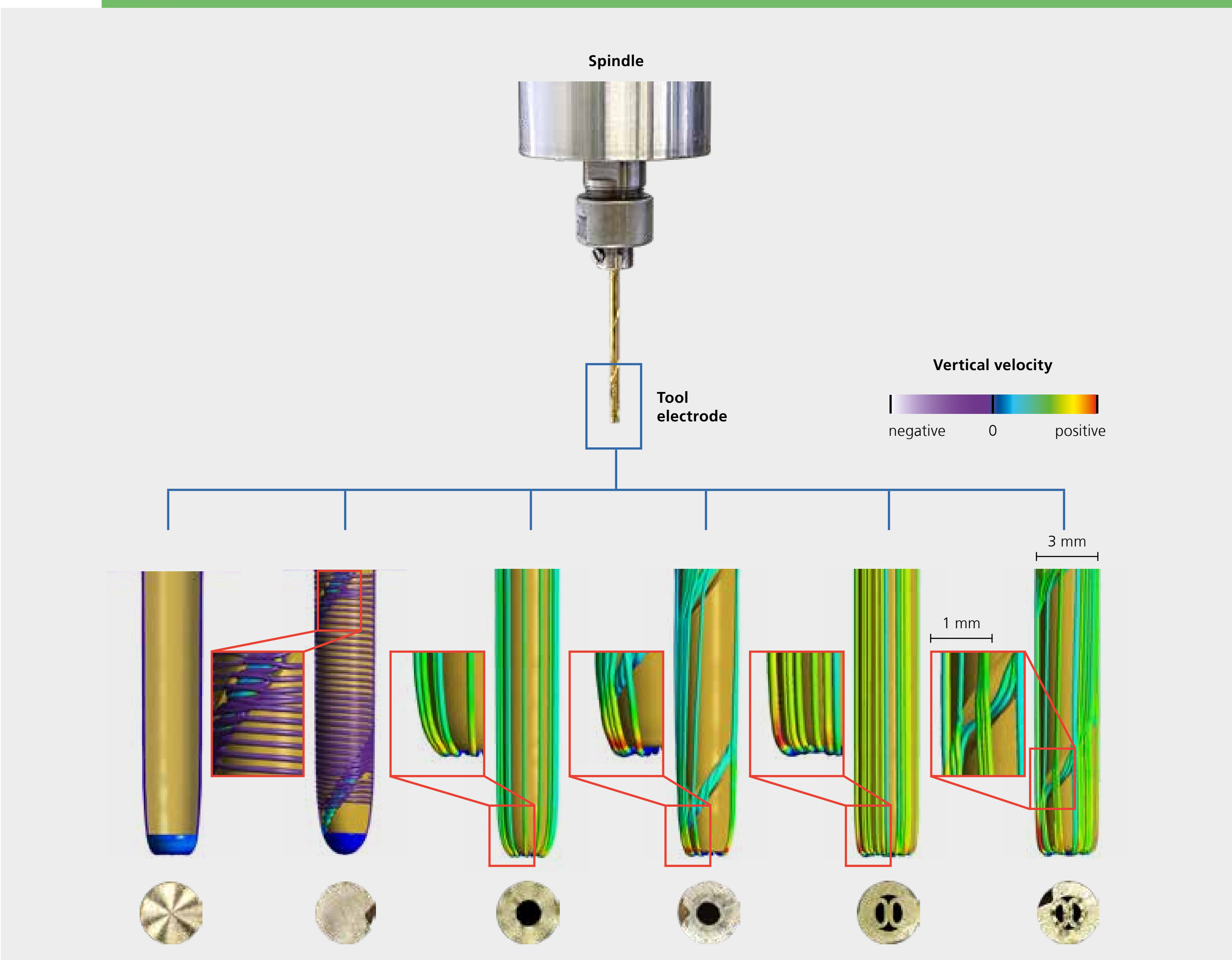

Image: Single-phase fluid simulations of six different tool electrodes

Sparks fly, lightnings flash, particles swirl around – electrical discharge machining (EDM) is probably the most spectacular manufacturing process in production technology. With the aid of a generator, a voltage is applied between two electrodes in a non-conductive liquid, a so-called dielectric. As a result, sparks are generated between two materials. The tool and workpiece electrodes do not touch each other and their distance, the so-called working gap, is just 100 micrometers. This corresponds to the width of a human hair. Such non-contact melting allows extremely fine machining of surface structures of metals.

The material removal process, which was discovered by the Soviet Lazarenko couple in 1943, is used in dentistry, among other fields. For example, electrical discharge machining is used to manufacture precision-fit abutments that are screwed into the jaw as connecting elements for implants. EDM also allows very hard materials to be precisely machined and individually adapted, which is particularly important in dental technology: If crowns do not fit, bacteria can accumulate there and cause inflammations.

While machining processes such as drilling and milling are likely to be familiar to every hobby craftsman, few are aware of the key role that material removal processes play in the manufacture of high-precision components in many industrial applications. Examples of micro-holes produced by EDM range from cooling air holes in turbine components, fuel injection systems, gas nozzles and control valves in automotive engineering to thread guides and spinning nozzles in the textile industry. In its main areas of application, tool and die making, aerospace and medical technology, electrical discharge machining is usually used as the last work step before components are cleaned.

The process poses some challenges: Each spark generates gas bubbles and particles that float around in the dielectric and pose risks of short circuits and arc discharges. These discharges not only entail additional control steps or retraction movements, but can also inflict damage on the final component surfaces due to burned spots. The dirtier the working gap, the more unstable the process becomes and the more productivity drops. Cleanliness is therefore key, even in EDM.

In order to eliminate removal products, the gap must be continuously flushed. In internal flushing, which is well established, a non-conductive liquid is forced into the working gap at high pressure. In the process, particles and gas bubbles are flushed out vertically. However, higher pressure comes with the risk of lateral discharges and instabilities within the microbores. The consequence: shape deviations and crooked bores.

To meet these highly complex and constantly growing challenges in EDM, auxiliary equipment, tool electrodes and technologies for alternative dielectrics are being developed at IWF of TU Berlin. One example is the insertion of external flushing channels into the lateral surfaces of cylindrical tool electrodes. For this purpose, a special CNC lathe was used to mill a helical groove into the tool electrode, which spirals around a brass shaft. This helical channel creates an escape route for gas bubbles and particles. If a dielectric is now forced through the gap at high pressure, the particles are no

Cleanliness is key, even in electrical discharge machining.

longer discharged vertically via the shortest path, but are guided specifically through the outer channels. This reduces the risk of lateral discharges and inaccurate drilling.

In a basic research project funded by the German Research Foundation (DFG), a fundamental understanding of the fluid dynamic processes in the working gap is to be developed. The practical research problem is that the gap measures less than 0.1 millimeters, making it extremely small and difficult to see. Detailed optical investigations of the flushing conditions are therefore hardly possible. However, within the framework of signal analyses in which process signals of voltage and current are recorded, conclusions can be drawn about the discharges – and thus about how effective the evacuation of the removal products is.

In contrast, fluid simulations provide unrestricted temporal and spatial insights into the highly complex dynamics of EDM. By means of a statistical model, it was possible to identify a fluid-mechanical operating point that defines the combination of rotational speed and flushing pressure required for optimum performance of the helical groove. This prevents the removal products from simply leaving the bore vertically due to excessive flushing pressure, regardless of the helical groove.

With the appropriate combination of rotational speed and flushing pressure, it can be demonstrated that parts of the ablation particles are pulled into the helical groove by local negative pressures, regardless of the modeled discharge location, and leave the bore in this way. The extension of the model to include gas bubbles confirms known observations that the rising gas bubbles cause the removal particles to float on their phase boundary and thus significantly affect the evacuation of the working gap.

By combining classical experimental drilling tests with sophisticated classifications of the signal characteristics and, last but not least, with the most advanced numerical models, productivity increases in the field of drilling EDM can be achieved with external flushing channels. If you flush properly, you end up with clean results. ◆

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Simulation of a single discharge

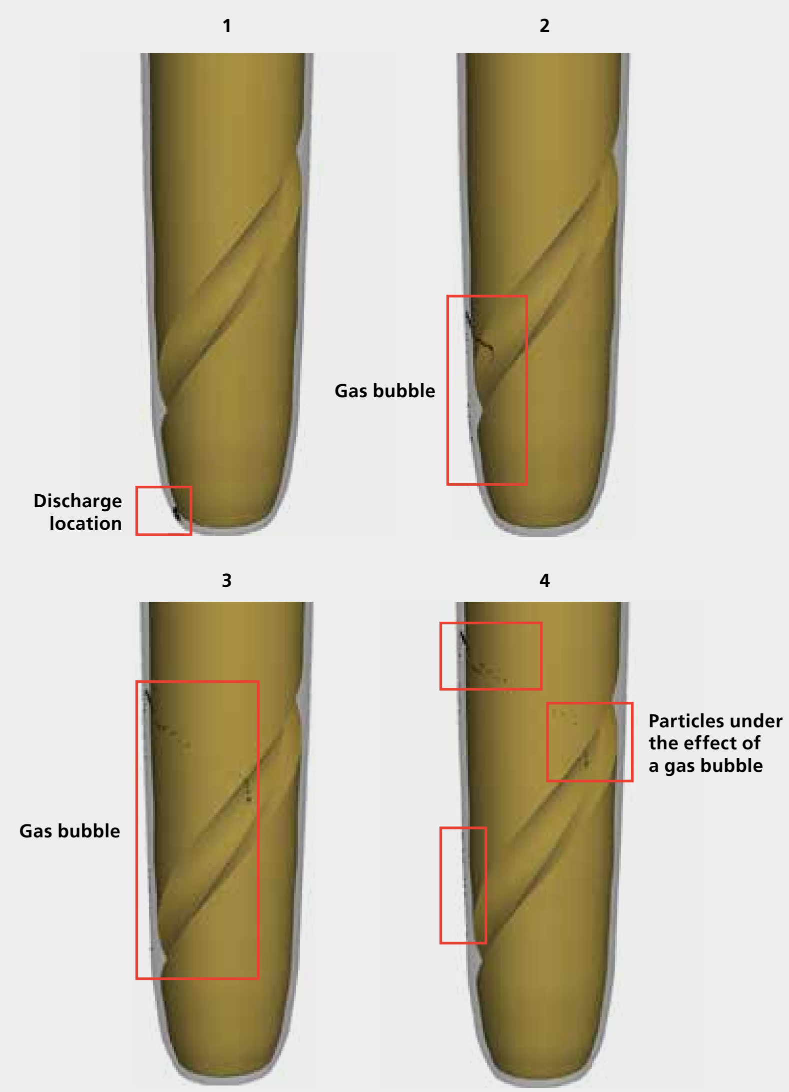

Image:
Three-phase simulation of dielectric, particles and a gas bubble: Particles rise in the working gap as an effect of the flushing pressure and a gas bubble

From Alexanderplatz to Amazônia

The cooperation between Germany and Brazil in the area of Industry 4.0 is picking up speed – with Fraunhofer IPK as a major driver.

Rarely has there ever been such an enthusiastic spirit around the German-Brazilian partnership as in the year 2023. Both the President and the Chancellor of Germany visited the South-American country in January. Only a few weeks later in March, two other high-ranking ministers, Vice-Chancellor Robert Habeck and Minister of Agriculture Cem Özdemir highlighted the countries' common interests and values during their own visit. They affirmed their intentions of building sustainable political and business relationships on equal terms with the South American »premium partner«. One of the main talking points of the German politicians was Brazil's potential in establishing sustainable, highly digitalized industrial practices.

ONE STEP AHEAD

Fortunately, the cooperation between the two countries does not have to start from scratch. There is precedence for successful collaboration in advanced manufacturing research and development. Researchers from Fraunhofer IPK have been working for over a decade with major players from Brazilian industrial research, such as the Competence Center in Manufacturing at the renowned Aeronautics Institute of Technology (CCM-ITA) as well as the National Service for Industrial Training SENAI. These partnerships have established themselves as driving forces in the joint efforts towards a digitally integrated production.

1

The Brazilian partners benefit from Fraunhofer IPK's international reputation, as well as its long-standing expertise in innovating manufacturing research and transferring results directly into industry. These competencies come into play in the »Fraunhofer IPK Project Office for Advanced Manufacturing at ITA«, in which the Berlin institute has joined forces with one of the top engineering schools in Brazil to develop innovative production technology solutions on site in São José dos Campos. Prof. Dr. Ronnie Rego, Professor at ITA and Head of Operations at the Fraunhofer IPK Project Office for Advanced Manufacturing at ITA, explains that working very closely with industry is necessary to ensure the transfer of scientific results: »Despite of all recent ad-

Images:
1
This building on the campus in São José dos Campos houses CCM-ITA
2
Multi-tool all-terrain robot for use at construction sites
© *ITA*

2

FACTS AND FIGURES ABOUT BRAZIL

12th largest economy in the world (Germany: 4th)

Annual GDP growth: 4,6 % (Germany: 2,6 %)

Share of value added by the manufacturing industry to the GDP: 9,7 % (Germany: 18,9 %)

Number of companies in Brazil with German origins: 1400

Most promising markets for joint R&D projects: aerospace, automotive, oil and gas, metalworks


1


2

Images:
1
The flight simulator built at CCM-ITA is based on a commercially available robotic arm
© ITA
2
In the interior there is a cockpit for pilot training
© ITA

vancements toward this direction in Brazil, it is still necessary to invest into efforts to deeply seed this mindset. We want to show that academic excellence and industrial application are not mutually exclusive – in fact, they are very much directly linked.«

Fraunhofer IPK researcher Gustavo Reis de Ascenção confirms the need for professionalization: »When we started working with ITA in 2017, one of the first things we did was establish a sales funnel. They already had ideas in place to acquire industry projects, and together we managed to systematize the approach.«

INGENUITY IN ACCESSIBILITY

On the other hand, Fraunhofer IPK scientists greatly appreciate the innovation potential their Brazilian partners bring to the table. One of CCM-ITA's strong suits is its transdisciplinary approach. In addition to advanced manufacturing research labs and experimental equipment, their facilities also feature a Human Factors Research Lab. With the help of tools such as EEG headsets to measure brainwaves, eye movement trackers and other physiological sensors, the scientists are researching how humans interact with industrial work environments.

Another one of CCM-ITA's priorities – and by extension also a matter of greatest importance of the Fraunhofer IPK Project Office for Advanced Manufacturing at ITA – is finding economical and scalable solutions for the Brazilian production industry. »The ingenuity of the Brazilian manufacturing research landscape lies in finding solutions that are not just more innovative, but also cheaper and easier to build and therefore more accessible«, says ITA PhD student Ivan de Souza Rehder. One very impressive example of this approach is a flight simulator built at CCM-ITA. Its hardware is based on a real pilot cabin complete with control sticks and screens, mounted on top of a robotic arm that is moving along a few meters of rails. The scientists programmed this system to move in sync with the steering movements, creating a low-investment-way to train pilots out of readily accessible industrial parts.

The complementary competencies of the binational research team, as well as their joint efforts and commitment to the partnership have made the Fraunhofer IPK Project Office for Advanced Manufacturing at ITA extraordinarily successful. Its predecessor, the FPC@ITA, surpassed its original target project volume more than threefold, reaching around 11 million euros rather than the intended 2.6 million euros. In total, they carried out 51 R&D projects, 31 of which were industry projects while the other 20 were publicly funded. If these results are anything to extrapolate from, the future of Brazilian-German R&D collaboration is looking very bright. ◆

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More about »ESCalate SENAI« in the article »Pesquisa e Desenvolvimento«:
www.ipk.fraunhofer.de/senai-en

SUCCESS STORIES

Over the years, the collaboration between Fraunhofer IPK and its partners in Brazil has resulted in several successful research projects – let us present three of them to you.

The FERA consortia project is developing additive manufacturing technologies to improve the competitiveness of Brazilian tool manufacturers in this sector. Its topics are based on needs of the local automotive and tooling industry: semi-automated additive repair of sheet metal stamping tools and additive manufacturing of tools with complex geometries, of fixtures and spare parts. »Our contribution includes automated laser metal deposition processes to repair tools for car bodies and structural components, as well as a market analysis and trainings on additive manufacturing technologies,« reports Dr.-Ing. David Domingos, Head of Operations of the Fraunhofer IPK Project Office for Advanced Manufacturing at ITA.

The aforementioned collaboration »ESCalate SENAI« has been running since 2012 and has currently been prolonged until October 2025. A team from Fraunhofer IPK has been assisting the Brazilian industry training service SENAI with establishing innovation institutes based on the Fraunhofer model. By conducting regular audits, they are also supporting the development and professionalization of said institutes, both in management and technological aspects.

The partnerships with SENAI and ITA have also spawned new collaborative projects, such as a specialization course in advanced manufacturing. The course was organized in cooperation between SENAI Minas Gerais, ITA und Fraunhofer IPK, with lectures by experts and professors from each of those institutions. It relied on two main pillars: immersion in innovation institutes (praxis-oriented approach) and technology. Around 40 representatives from Brazilian companies and entrepreneurs attended this specialization.

Clean Production for Clean Mobility

To make hydrogen drives suitable for mass production, fuel cell production must become affordable and scalable. The H2GO project is intended to contribute to this.

More about solutions for the individual and series production of fuel cells in the article »Smart Manufacturing of Fuel Cells«:
www.ipk.fraunhofer.de/dip-en

When it comes to environmental compatibility, heavy-duty road transport does not have a good reputation. Rightfully so, because until now trucks have been real climate sinners: A fully loaded forty-ton truck consumes around 30 to 40 liters of diesel per 100 kilometers. So far, there are no real alternatives on overland routes, because electrically powered trucks do not achieve the necessary ranges. But a promising technology is already waiting in the wings: hydrogen propulsion.

Using hydrogen to generate energy is not a novel idea. Nevertheless, the general public's interest in the topic has been limited, with its attention focused on fossil fuels and renewable energies such as solar and wind power. Hydrogen-based fuel cells, on the other hand, have been dismissed. Their production was too costly and, moreover, only possible in small quantities. To counter this objection, the project »H2GO – National Fuel Cell Production Action Plan« was launched. Its goal is to develop and roll out industrial technologies for the economical production of fuel cells. The overall project is being funded by the German Federal Ministry of Digital Affairs and Transport with a sum of around 80 million euros from the Automotive Industry Future Fund. The funding is coordinated by NOW GmbH, and the Project Management Jülich (PtJ) is responsible for implementation. The focus is on the question of the feasibility of mass production for road-based heavy-duty transport.

H2GO combines the expertise of 19 Fraunhofer institutes in five subgroups along the process chain of fuel cell production. Fraunhofer IPK is a member of the subgroup for the development from the half plate to the bipolar plate. The central task of our researchers is to develop a cleaning module for the automated cleaning of bipolar plates.

HIGH-TECH IN ITS PUREST FORM

The requirements for the automated cleaning of the bipolar plates quickly became clear to the scientists: It had to be climate-neutral, precise, dry, and residue-free. With these aspects in mind, the process chosen was the novel high-pressure CO_2 blasting.

To apply this technology, Fraunhofer IPK's laboratories are being expanded to include a newly designed CO_2 purification cell in which researchers can experiment and develop during and beyond the course of the project. With the help of funding of around 1.5 million euros, the cell will be equipped with state-of-the-art CO_2 purification technologies.

In high-pressure CO_2 blasting, liquid carbon dioxide is used as the blasting medium at a pressure of up to 4000 bar. The carbon dioxide jet gently cleans surfaces before and after the individual production process steps without damaging existing coatings. Contaminants can be removed precisely thanks to the variably adjustable jet diameter. This process allows the thermal influence on the sensitive bipolar plate to be kept low.

In addition to CO_2 high-pressure technology, the cell accommodates the latest snow blasting and dry ice blasting technology. For precise and automated cleaning, the cell is equipped with an industrial robot. In addition, manual guidance of the blasting equipment is possible. A quick-change system allows the robot to switch automatically between the different blasting processes. There is no shortage of potential applications for the new cleaning technology, as Fraunhofer IPK researcher Philipp Burgdorf emphasizes: »In the future, we also want to investigate the processing of composite materials such as carbon fiber-reinforced plastic. For us, this opens up a wide range of topics for further research, for example in the aerospace, automotive and wind energy sectors.« For the time being, however, Burgdorf and his team are devoting themselves to the task at hand within the framework of H2GO: making heavy goods traffic more environmentally compatible. ◆

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Smooth Edges with Lean Process Chains

They occur during drilling, milling and turning: Material residues on the edges of workpieces that are displaced, but not completely sheared off are referred to as burrs. They can be reduced by skillful process control and adaptation of the cutting conditions, or avoided completely with sharp tool cutting edges.

1

Burrs are a tiresome issue in machining: Whether in single-part or series production, they often occur as an unavoidable side effect in a wide variety of machining processes. Even in stable manufacturing processes, tool wear, fluctuating process conditions or inhomogeneities in the material can cause residual burrs on the component. In function-critical areas, these can often only be eliminated by means of time-consuming and cost-intensive quality control and manual finishing. In order to get to the heart of the problem of »burr formation«, Fraunhofer IPK is pursuing various approaches, each of which is tailored to the individual circumstances and requirements of the industrial partners.

BURR-REDUCED MACHINING

In addition to researching the use of new superhard cutting materials, the scientific staff are working on concepts for material- and process-optimized path planning for tool guidance. In particular, unfavorable edge transitions of bores with internal contours are frequently affected by burr formation. In addition to the use of spring-loaded deburring tools and contour-specific special tools, optimized contour tracking can also help to produce such molds reliably and without burrs.

At the Production Technology Center (PTZ) Berlin, the team is excellently equipped for research work in these areas. With over 22 CNC lathes and milling machines, an extensive machine park with a wide range of industrial clamping concepts is available. Moreover, the researchers can access an extensive network of machine and tool manufacturers. Thus, industry-oriented and production-ready processes can be developed and transferred to the industrial manufacturing environment, in macro as well as micro manufacturing.

TARGETED POST-PROCESSING

If it is not possible to maintain the edge or surface quality of components, efficient finishing processes are an economical alternative. A wide variety of processes and systems are available on the market for this purpose. Some of these are designed for specific components and often do not meet all the requirements of individual users. In addition to processes such as shot peening, brush peening, sliding peening and pressure flow lapping, the PTZ offers various technologies that enable development of manufacturer-independent process chains for efficient post-processing.

2

3

Images:
1
Machined series components with burr-critical component edges
2
Cross-section of a component edge with burr resulting from the drilling process
3
Effective machining processes for burr-reduced production

In the last two years, a new post-processing laboratory has been set up to address different vibratory finishing and vibratory lapping processes. It allows Fraunhofer IPK to specifically adapt various process parameters to individual component requirements of customers and partners:

- the selection of process-specific grinding and lapping media,
- the development of efficient process chains for targeted finishing of simple and complex components, and
- the design of workpiece clamping systems and their positioning in the particle and grinding wheel flow.

Furthermore, the institute offers numerical approaches for fully comprehensive process design, based on the Discrete Element Method (DEM).

OPTIMIZED CLEANING STRATEGIES

Flaking burrs and chip deposits on the component are difficult to avoid in many processes. In automated process chains, they entail a high effort for cleaning the components within the process chain. Fraunhofer IPK has been able to create sustainable solutions for component cleaning in industrial projects through targeted component-specific design of cleaning nozzles, optimized washing cycles and innovative cleaning processes, such as CO_2 snow blasting. In addition to numerical solution approaches, cleaning strategies were successfully designed, visualized and implemented in close cooperation with project partners using transparent components with complex internal structures and hole patterns that mimic the original.

In order to increase the efficiency of component production and process chains, it is important to avoid high quality control costs and manual finishing processes. This requires efficient and stable manufacturing processes, which should be designed specifically for each component and material. ◆

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Power Consumption at a Glance

Climate-neutral production is indispensable to limit global warming. To make machine tools more energy-efficient, their energy consumption has to be made transparent.

Some good news from the Federal Environment Agency in March 2023: Absolute energy consumption in Germany has fallen slightly over the past 30 years from 2631 terawatt hours in 1990 to 2407 terawatt hours most recently. Less encouraging for manufacturing companies: Industry continues to consume the most energy, namely 699 terawatts compared with the other sectors of households (670), transport (635) and trade, commerce and services (385). By far the most important energy sources in industry are gas and electricity.

Machine tools play a key role in the manufacturing industry sector, also in terms of total energy consumption. Turning, milling, EDM and other manufacturing-related machines worth around 71 billion euros were produced worldwide in 2021. They are durable capital goods and are sometimes used for more than 20 years and in multi-shift operation. The energy costs that occur from running these machines account for around 20 percent of a company's total operating costs – so it is not hard to imagine that they add up to considerable values over the entire period of use. Since the accumulation of dramatic climate catastrophes and the current energy shortage, the topic of energy consumption by machine tools in production has moved into the focus of the manufacturing industry.

ENERGY CONSUMPTION HAS MANY CAUSES

Whether a machine tool is energy efficient depends on a number of factors. Are aggregates such as cooling lubrication switched on and off sensibly? Are pumps with controlled motors in use? Is the machine well maintained? Are there standby strategies when the machine is not in use? Even today, machine tools in many companies are often not switched off even when not in use for a longer period of time – whether out of fear that temperature-related effects could have a negative impact on accuracy, that problems could arise during startup, or simply out of convenience. In addition, you cannot tell from just looking at the machine which unit is consuming how much energy. If you want to make production more energy-efficient, there are many potential levers you can use. The path to this goal is always the same: perception, understanding, prediction, control, and regulation. Fraunhofer IPK has developed an integrated solution for perception and understanding. On this basis, mechanisms for prediction, control and regulation can be developed. But first: What do »perceiving« and »understanding« mean?

PERCEIVING THE ENERGY CONSUMPTION

Fitness trackers have become an indispensable part of everyday life for many people. The aim of these little helpers is to document how fit we actually are. They use sensors to record data which is then aggregated to provide key figures, such as the number of steps we take every day. This allows us to perceive the extent of our physical activity. Energy monitoring works in a similar way: A monitoring system for machine tools records currents and voltages in order to calculate energy parameters and trace energy consumption patterns.

UNDERSTANDING INTERDEPENDENCIES

If we did not know that there is a connection between exercise and fitness, then documenting the number of steps would be a pretty pointless endeavor. However, if we relate the recorded step values to the development of our fitness, we recognize the connection. We can then deduce from our experience how our fitness will develop, if we walk more or fewer steps. If we transfer this logic to the topic of energy efficiency, documenting the energy consumption of certain production processes helps to understand whether these processes are energy efficient or not. Once these relationships are understood, measures can be derived to increase energy efficiency.

SETTING UP AN ENERGY MONITORING SYSTEM

In order to document where and in what context how much energy is consumed, Fraunhofer IPK has developed an energy monitoring solution that can be retrofitted to machines without much effort. The essential components are a power analyzer, three current transformers and a single-board computer. Built into a box, the system is connected between the machine and the mains supply. If required, however, the components can also be installed directly in the control cabinet. From the phase current and voltage curves, the power analyzer generates all the energy characteristics required by energy management systems according to ISO 50001. These are transmitted to the single-board computer via Modbus. An MQTT client installed on the single-board computer then sends the data as a so-called publisher to an MQTT broker, from where it is forwarded to any subscribers of the data, for further processing, for example by an IoT platform in the cloud. Implementing this step creates the basis for optimizing the energy efficiency of production plants. ◆

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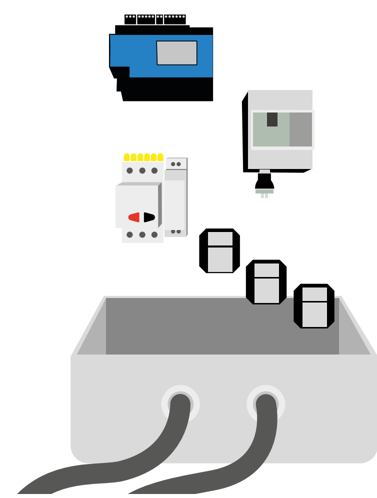
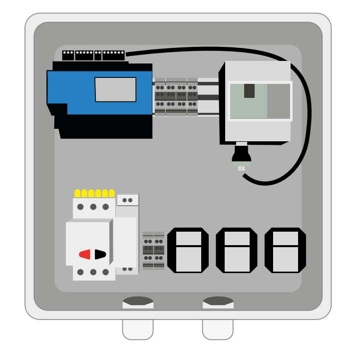
Energy Monitoring System Concept



A network analyzer (top left) detracts energy KPIs from measured current and voltage curves, a single-board computer (center right), transmits them to an MQTT broker. A power supply and three current transformers complete the system.



The components are integrated into a case – shown here without cable connections.

Distributed applications subscribe to the KPIs at the MQTT broker. An example application is a dashboard that visualizes trends in energy consumption.

Precision Is Key

Machine tools still set the tone in terms of accuracy. But industrial robots are catching up more and more – thanks to AI, among other things.

Without robots, there is no automation. Whereas industrial robots were previously used primarily for pick-and-place and assembly work, they are increasingly taking over activities from machine tools when flexible manufacturing is called for. The advantages are obvious: Improved motion axes now make it possible to reach any possible position and any orientation, and universal end effectors are compatible with all conceivable tools – be they milling cutters, drills, scanners, or saws. Industrial robots can thus perform increasingly tricky tasks and produce complex components from a variety of materials such as wood, plastics and metals. While the working range of a CNC machine is limited to a few meters, robots can also reach components that are difficult to access. This versatility is a decisive advantage when it comes to producing efficiently and cost-effectively even with small batch sizes and a high number of variants.

WEAK SPOT: LOW STIFFNESS

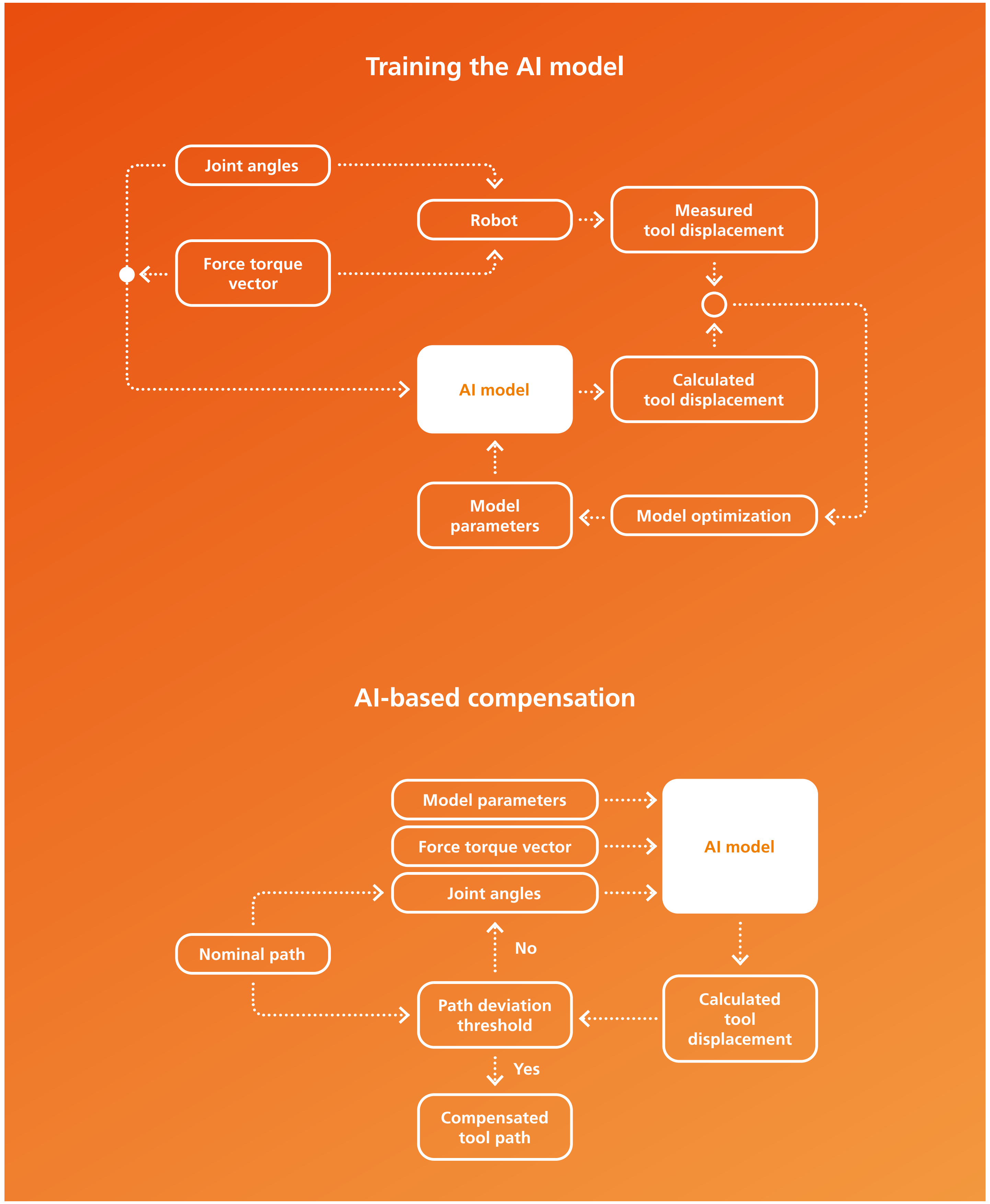
And yet, the flexible all-rounders do not come close to the high precision of a machine tool, which, for example, processes metal parts down to the micrometer range. This is because a classic industrial robot – such as the most commonly used six-axis articulated arm robot – has only a comparatively low stiffness. This is mainly due to the fact that the robot arms form a so-called open kinematic chain. During activities with high acting forces, such as milling or forming, the robot structure yields and the desired position is not approached exactly. The resulting tool displacement varies depending on the application, but almost always affects manufacturing accuracy. Accordingly, robots are predominantly used where the high accuracy of a machine tool is not required.

Improving the positioning accuracy of industrial robots – and thus expanding their area of application – has therefore been an important field of research for years. Different approaches are being pursued here, focusing either on the design, the control or the calibration of robots. However, due to the progressive networking of machines and the associated availability of large amounts of data, methods of artificial intelligence, in particular supervised machine learning, are becoming increasingly important.

PREDICTING TOOL DISPLACEMENT WITH AI

What is special about supervised learning is that the AI model learns based on a data set where the correct answers already exist. So the model receives both inputs and matching outputs. Once the algorithm detects a pattern between these, new inputs can be added, and the AI predicts the outputs.

Accordingly, an AI model for predicting tool displacement maps the robot's six joint angles and the force and moment components on the tool as input parameters to the tool displacement as output parameters. Such a trained model can be used to predict tool displacements for any task.



With the help of AI, the shape accuracy of flanges can be improved by 75 percent

SHEET METAL IN SMALL QUANTITIES AT LOW COST

To validate this training method, researchers at IWF of TU Berlin have implemented a so-called incremental hole-flanging process with an industrial robot. Hole-flanging is a tensile pressure forming process in which pre-cutted holes in the sheets are expanded to form a flange. It is part of the process chain for the production of many sheet metal components, for example in automotive engineering. The extension of conventional hole-flanging to include an incremental approach, in which the sheet is expanded step by step by a generic tool along a tool path, enables flexibility to be increased and costs to be reduced by eliminating the need for costly forming tools. The use of industrial robots further enhances this flexibility and also offers the possibility of forming flanges in hard-to-reach areas using novel processes.

HOW TO GET GOOD DATA

However, applying high forces as is required in forming causes tool displacements that have an influence on the forming accuracy of the flanges. To predict these displacements using supervised machine learning, the researchers generated a training data set for which an industrial robot was loaded with an air spring on various circular tool paths. The joint angles of the robot without load as well as under the influence of external forces were recorded at several points and each measured with a laser tracker. A total of 352 data points was determined in this way. The tool displacement results from the difference between the loaded and the unloaded position.

FORM-FITTING FLANGES

The result: The shape accuracy of the flanges improved by 75 percent, corresponding to a decrease in the maximum deviation to 0.6 mm. At the same time, differences between minimum and maximum measured flange diameters were reduced, thereby increasing the roundness of the flanges. The research team has thus impressively demonstrated how using AI compensates for positioning errors in industrial robots and significantly improves product quality. Yet, the developed method is by no means limited to hole flanging: Taking into account other factors such as dynamic parameters and temperatures, work is already underway to qualify industrial robots for any high-precision application in the future. ◆

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Smart Restart

Existing machines get a future-proof upgrade with artificial intelligence and edge computing.

Even if the goal of Industry 4.0 is networking the entire machine park: When aiming at optimizing processes, the individual machine remains a decisive starting point. A prerequisite for efficient networking in the course of highly flexible manufacturing is the smooth flow of information along the entire value chain. In this context, when it comes to the individual machine tool, its interface in particular – as the eye of the needle in networking – plays a central role: It ensures that the machine can exchange large amounts of data with other machines and machine systems, IT systems and people.

BIG DATA AS AN OPPORTUNITY

At the same time, companies are faced with the difficult task of systematically recording, storing and evaluating the ever-increasing mountains of digital data that are generated every day during production. For example, a single CNC-controlled machine tool generates a large amount of information within a second – about the efficiency and quality of production or the machine's mechanical condition. By intelligently analyzing this data, valuable insights can be gained that can serve as a basis for process optimization and important business decisions. But until now, it has been difficult or even impossible for companies to mine this treasure trove of data.

Researchers at the Production Technology Center (PTZ) Berlin have taken up this challenge and investigated how control data from machine tools can be recorded, evaluated and made usable without great effort. The exact target is to optimize existing, highly productive machines by means of new interfaces, thereby expanding their capabilities in a targeted manner.

AI AND EDGE: A POWERFUL DUO

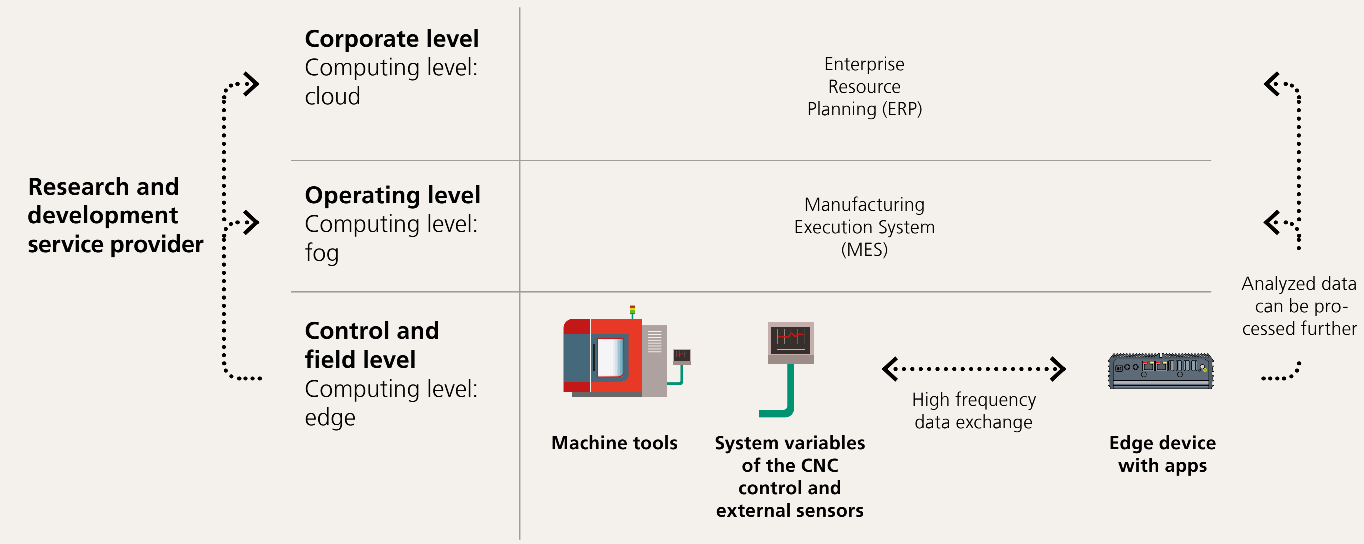
The data specialists at PTZ have implemented a digital retrofit of this kind – equipping machines with state-of-the-art sensor and communication technology – by means of an edge computing solution using artificial intelligence. In edge computing, data is collected and stored directly at the point of origin, the edge. This means that data does not have to travel long distances to central data centers, but can be processed without much delay. This is important because short response times are essential in automated production and the delay time of cloud access to local AI applications is often too high.

Since the AI models in edge computing are not executed in the cloud but on the edge device, hardware with high computing power is one of the cornerstones. The project used an industrial PC with two ethernet ports which is connected directly to the machine controller via an internal high-frequency interface.

With the help of the edge device and in conjunction with a novel edge platform, the PTZ team was able to capture around one hundred different system variables of a machine tool. This includes data relating to spindle speed, tooth feed, cutting depth, feed rate, contour deviations and indirect information on component quality. In addition, synchronously with these parameters and up to 30,000 times per second, data from external sensors such as cameras or force sensors can be read out and information about tool life and error messages can be retrieved.

The unstructured flood of raw data collected this way is systematically evaluated and transformed into meaningful insights – in other words, into economic added value –

System architecture of the edge computing platform



using AI on the edge platform: Intelligent data analysis can reveal hidden optimization potential, identify sources of error, and detect machine wear and defects at an early stage.

Other interfaces of the edge device, including Open Platform Communications Unified Architecture (OPC UA), are used to forward the data to higher-level systems such as the Manufacturing Execution System (MES) or Enterprise Resource Planning (ERP) of a company, to data lakes for storing large amounts of structured data, and to an enterprise's own servers or cloud platforms. The impact of data traffic on the machine tool CPU, on the other hand, is reduced to a minimum because the actual processing takes place on the edge device. This means that the edge device can be installed in existing machine tools without interfering with their actual control task. Furthermore, it is possible to influence the machining parameters of the machine tool via a feedback loop, or in other words: to report commands back to the machine controller. The researchers are already working on outsourcing the first parts of this process to a developed AI.

USING AI TO DETECT TOOL WEAR

Once the edge device has been successfully installed on the machine tool, apps can help to display the machine data simply and clearly. New applications or security patches can be implemented. App stores already provide applications that focus on monitoring tool condition and predicting tool wear. This allows users to make accurate decisions based on an AI model.

EDGE APPS IN USE

As service providers, the data experts at PTZ also develop customized apps for specific use cases of small and medium-sized enterprises. For example, it is conceivable to extract information from data-intensive experiments in the form of an app that is then used on a machine tool with a specially adapted edge device. Similarly, data from the tool usage history can be merged with the quality data of manufactured components and used to optimize tool geometries and materials. Intelligent online monitoring of the machine tool is also possible: Production errors, for example from pre-processes, are thus instantly detected and can be rectified immediately. ◆

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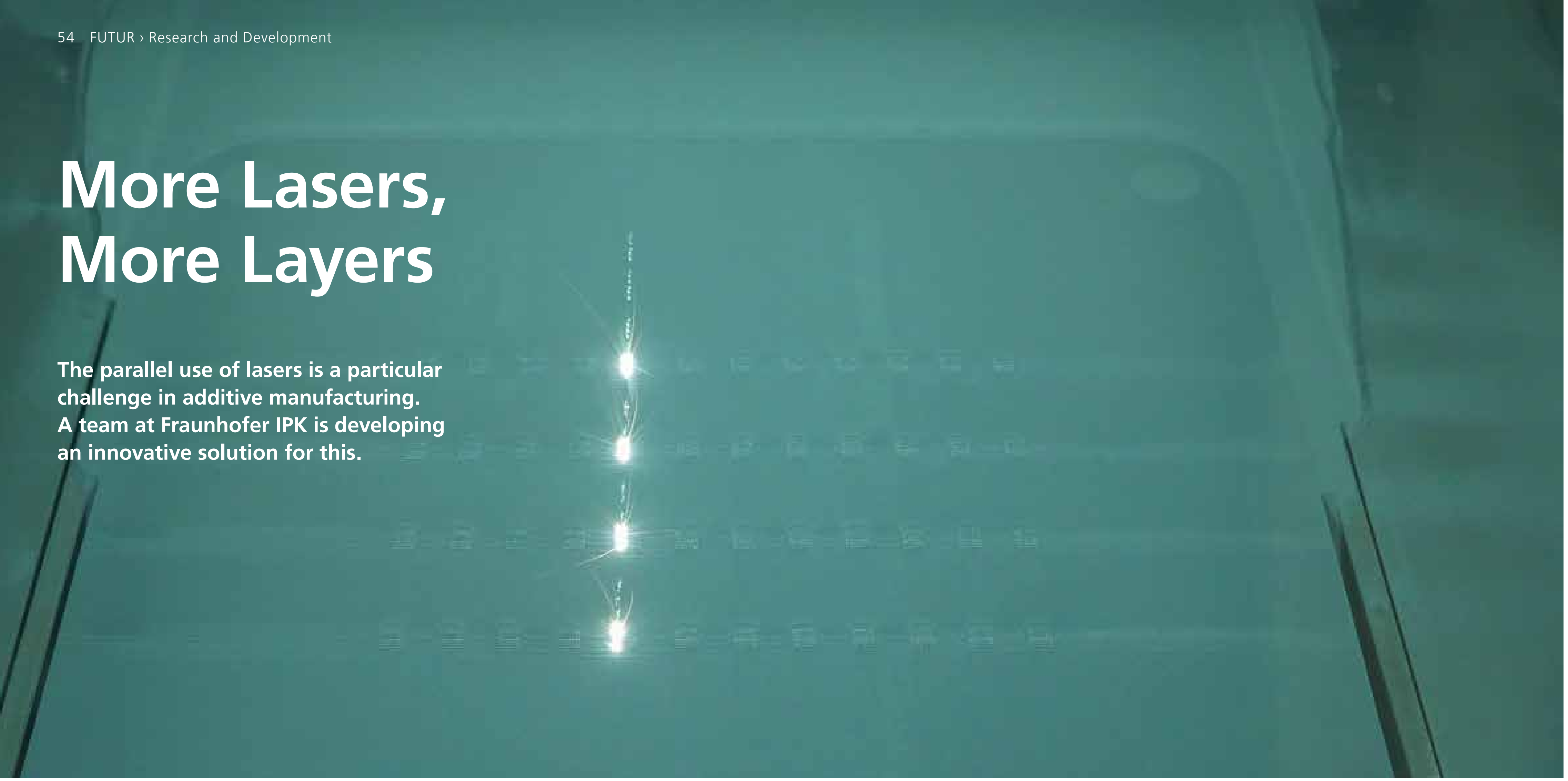
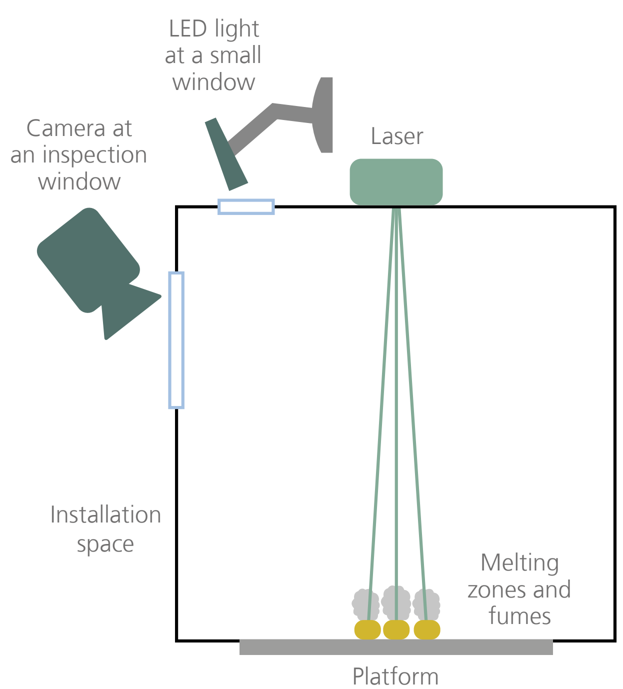


More Lasers, More Layers

The parallel use of lasers is a particular challenge in additive manufacturing. A team at Fraunhofer IPK is developing an innovative solution for this.

Powder bed-based melting of metals by means of a laser beam, PBF-LB/M for short, is the most widespread additive manufacturing process for metallic materials. This manufacturing process is used in particular for complex geometries, small series production, or customized products that cannot be made using conventional manufacturing methods. The process makes it possible to integrate functions such as internal cooling channels and lightweight structures directly into components and manufacture them in a single process step.

Although the advantages of this technology compared to conventional processes are well known, there are various challenges with regard to quality assurance and productivity when integrating it into series production. Both quality and productivity can be enhanced by increasing the number of lasers and associated laser optics. Part quality in particular can be improved with the help of innovative scanning strategies such as using pre- and post-heating lasers. However, implementation is associated with numerous challenges: During parallel exposure in adjacent areas, the laser beams with their welding by-products such as welding smoke and



spatter can influence each other, depending on the direction in which the shielding gas flow is moving. This causes fluctuations in the energy input, which destabilize the molten pool and reduce process and component quality. If several lasers are used in parallel, it is therefore important to make sure that the lasers do not get in contact with each other or their welding by-products.

A research team at Fraunhofer IPK has developed an innovative algorithm for this purpose, which can be used to control multiple lasers in parallel: Based on existing scan vectors, the algorithm adapts the scan strategy to avoid unwanted shadowing effects. To this end, it takes into account the time-dependent positions of all lasers involved in the process. Information about the geometry and direction of the welding fume trail is of particular importance in order to prevent the laser's energy from being compromised by the welding fume. Therefore, the first step was to characterize the smoke trail using visual image processing. This allows the algorithm to define »forbidden zones«, i.e. areas where no laser is allowed to enter, and to adjust the scan vectors accordingly.

In order to simplify the application of the algorithm and optimize the process, the researchers are also developing a novel welding fume monitoring system for measuring the smoke trail. The aim is to comprehensively record the smoke trail on the basis of a multi-sensor system. The scientists are currently using an optical approach: The smoke trail is monitored based on images. In addition, photodiodes are used to detect the welding smoke. Thanks to the precise knowledge of its position and size, the algorithm can automatically adapt different process parameters. To achieve high efficiency and compatibility with various software applications, the algorithm is programmed in Python. In the further development of the monitoring system, the scan vectors are to be set automatically by the algorithm so that coverage by welding fumes can be completely avoided, thus significantly improving the component quality. ◆

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