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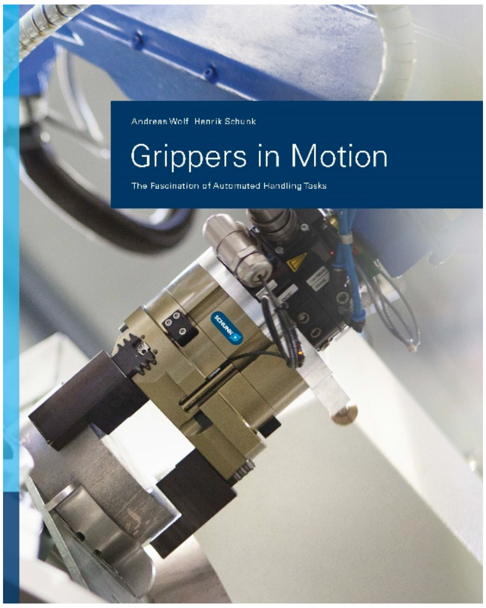

Sample Pages

Grippers in Motion

The Fascination of Automated Handling Tasks

Andreas Wolf, Henrik A. Schunk

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Preface Henrik Schunk

This update of the original work on gripping and handling technology serves to expand our series of technical books published for the automation industry. Our passion for gripping technology began with the development of the first standardized industrial grippers in 1983. The source and roots of our gripping expertize are grounded in the complex needs of our customers. The aim of this book is to offer production professionals a glimpse into the world of automation as well as to provide new insight to business leaders, purchasing agents and students who are interested in the field. This will help foster a basic understanding of the technology among a broader base, as it is becoming more and more difficult to justify purely automated self-supporting systems in production. Traversing departmental and professional boundaries has to be the focus of the future in order to plan and use technology to the fullest.
The fascination surrounding handling technology lies in its familiarity to us. Handling is a part of our everyday experience, occurring thousands of times in a variety of situations, both in our personal and professional lives. The support that technology lends to this experience is becoming increasingly important, especially in facilitating production workflows. As a medium-sized, family-owned company, we are committed to a long-term approach and sustainability. This has led us to our current focus on the Smart Factory of the future, in which humans and robots collaborate, and where intelligence, information, safety and maximized flexibility become key features in the gripping technology of tomorrow. Our mission is to create automated solutions with such high levels of efficiency and safety that our customers can achieve optimized production flows. For SCHUNK, this involves all kinds of automation, from medical laboratories and food production to the manufacturing of vehicles for which we develop and offer our components. Our customers have access to our products, replacement parts and services around the globe.

This book can only present a fraction of the myriad of possibilities that gripping systems offer. For more in-depth questions, our employees are happy to provide additional guidance and information. I would like to take this opportunity to thank all of the employees who have helped pool together information for this book. All of the companies and research institutions that have offered their support in compiling this book by contributing their experience and expertise are also owed a debt of gratitude. In addition, I would like to express my appreciation to the employees of robomotion for helping support Dr. Wolf and I with their ideas and examples.

Lauffen am Neckar, April 2018
Henrik Schunk

Foreword by Prof. Dr.-Ing. Bauernhansl

The demands placed on the production processes of tomorrow are on the rise. The future calls for high flexibility and process quality at low manufacturing costs. The reasons for this are declining lot sizes combined with expanding workpiece variety as well as increasingly shorter product life cycles. The shift in production to low-cost locations is leading to certain drawbacks such as a lack of flexibility, higher logistical costs and inadequate quality assurance. Apart from this, wages are rising even in so-called “low-wage countries”, and the precarious working conditions that occur at times are a source of concern.

The lessons learned from the Euro crisis have pushed domestic production more and more into focus. As compared to other EU countries, Germany's high share of industry of over 20% of the gross domestic product often serves as an example for nations with a lower density of production workplaces. With its abundance of innovative companies and competitive products, Germany is in the best position to counter the crisis in the Eurozone. To this extent, it has once again become the political goal of many industrialized countries around the globe to strengthen domestic manufacturing and to bring back production from low-wage countries. However, local production at high wages in an aging society requires production technology that is able to carry out efficient production flows despite high levels of workpiece variety and small lot sizes.

Robotics offer a flexible solution to meet these demands. With its origins in the automotive industry and large-scale production, it is now penetrating into a growing variety of fields and will certainly take root in the small and medium-sized enterprise sector. It is exactly this SME sector that has to intensify the fight for its workforce, ensuring that older employees in particular are not burdened with heavy physical labor. It is therefore essential to develop production concepts that can be applied to manual skills.

Innovative control systems and safety concepts make human-machine cooperation economically feasible. The costs for hardware will continue to drop. Planning tools and simulation environments will be able to handle an increasing level of detail and will make safe preparation of the application possible. Precise gripper simulation is achievable using parameters, and opening and closing behaviors.

Grippers will become more and more important as “application enablers”, or simply as “apps” for handling systems. The crucial factor here is creating a solid modular system of proven components as a basis for workpiece handling. This saves design engineers valuable development time for the entire machine. This also means that they can rely on components that have undergone long-term testing, ensuring high availability of the application. It is precisely this level of availability that is key to achieving customer satisfaction in the era of “Lean Manufacturing”. For production chains without cache and error memory, even the smallest of errors could prove fatal. That's why each and every automation component has an important role to play.

The authors of this book have succeeded in both illustrating the history of automation in handling technology as well as providing perspective on the development of technology in the years to come. The further networking of automation components, such as grippers and handling systems, is an important step forward for the future of production, or in short, “Industry 4.0”. In particular, advancements in the development of electric grippers and in gripper sensor integration have led to greater process control than in the past.

This book provides example scenarios that make it easier for the user to plan and design production facilities accordingly. It presents ideas of how new production possibilities can be developed through the introduction of innovative technologies, such as generative production methods. In the realm of research and education, this book will help provide ideas and inspiration to teachers and students alike.

The research network of the Fraunhofer-Gesellschaft has already achieved outstanding research results and infrastructural developments toward these advancements. As either users or suppliers of technology, small and medium-sized enterprises will help stimulate the development of many innovations to come in Germany. It is up to equipment and plant manufacturers to maximize this potential.

Stuttgart, April 2018
Prof. Dr.-Ing. Bauernhansl

Foreword by Dr.-Ing. Andreas Wolf

It was over ten years ago, with the founding of robomotion, that I had the privilege of working together with SCHUNK on the first “Grippers in Motion” book. Initially, it was only intended to be a summary and an overview of my lecture at the University of Stuttgart. Because of the possibilities afforded by a professional public relations department and an outstanding graphics agency, I was able to work together with the experts at SCHUNK and robomotion on a book that appropriately presented both expert knowledge and examples of automation applications for handling technology.

Today, there are many buzzwords associated with digitalizing the production of goods. I would like to demonstrate that much of this has already become a reality and that the benefits offered help drive innovation. In just over 300 pages, this book will help you gain insight into what is already being accomplished with automation production today. For those of you who are interested, Chapters 1 and 2 present an introduction to the general requirements for automation as well as the historical background of this young technology. If you are more intrigued by the implementation procedures for automation projects in your own company, you can refer to the special subsections in Chapters 3 and 4. The entire process will be systematically outlined and explained, starting with the workpiece and continuing to the gripper and fingers, and up to the robot arm. In Chapter 5, the authors have also ventured a look into the future of automation technology from today's perspective.

There isn't a book in this world that could possibly incorporate every aspect and example of automation technology. However, this book can provide an overview of the fundamental procedures involved in automation system projects, demonstrating everything from the workpiece to the gripper finger and from the gripper to the complete robot in its safety cell. “Ready to use” will soon become a familiar catchphrase for all manufacturers of automated components. That means that integrators will be capable of assembling components into a viable solution. This is already a reality for some applications, such as flexible welding robotic cells and complex, ready to use logistics software modules for connecting multiple robots. Nevertheless, without hardware for the gripper, sensors and material supply, this is not yet generally possible. A downloadable “app” for the industry will still take some time to develop. There are still too many different user requirements and tasks involved. There are too few users to justify developing hardware and software for each application. As a first step, the steadily increasing range of specific components already provides major relief for the integrator, which no longer has to take care of everything on its own. This book presents the developments that have taken place over the past ten years since the first edition was published.

I would like to thank the Schunk family and their employees for allowing me the opportunity to embark upon a new edition of this book. The discussions with Mr. Henrik Schunk and the coordination efforts regarding content were always very constructive and rewarding. I would also like to thank Mr. Ralf Steinmann and Mr. Ralf Becker for their collaborative work and idea sessions. Mr. Fellhauer provided invaluable input in the area of sensor systems. Ms. Letsch and Mr. Srouji contributed to the book with their recommendations on graphics and visual material. I would also like to express my appreciation to all of the companies that provided additional image material and granted their consent for publication. Without them, the book would have been short of some excellent examples.

I am also grateful for the attractive graphic presentation provided by REFORM DESIGN Grafik GmbH of Stuttgart. And a very special thank you goes out to Ms. Luise Marianek and Mr. Christian Kellner, who took care of preparing and modifying all of the graphics.

I would especially like to thank my father, who patiently read along and deliberated with me, time and time again. Ms. Deak and Mr. Jonas Eckstein provided exceptional support with their assistance in proofreading and compiling citations. I also owe a debt of gratitude to my family for the patience they showed their mentally absent father.

The employees and management team at robomotion have made a considerable contribution to this book, as of course many of the practical examples come from their company experience. A comparison with the first edition clearly shows that this book would not have been possible in this form without the support of these employees.

I would like to dedicate this book to Mr. Schmeer, the first employee of robomotion and an energetic colleague during its start-up phase, who tragically lost his life. Many of the applications included in this book were developed with his help.

Leinfelden, April 2018
Dr.-Ing. Andreas Wolf

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Fingers with only one effective surface can only grip workpieces that exhibit one particular geometry. Round materials are one exception here, as the gripper jaws are capable of handling various diameters. Otherwise, the aim is always to try to avoid changing the fingers or the entire gripper. Therefore, when it comes to adapting finger shapes specifically to a workpiece, the goal is to combine separate effective surfaces or multiple non-separated effective surfaces in one finger.

The advantage of a gripper with non-separated effective surfaces is that only one gripping point has to be approached even when using handling systems to handle different workpieces. This means that the robot is always able to move back into the correct position even during a faulty operation, without causing a collision.

In the case of gripper surfaces that transmit force to the workpiece using friction-fit clamping, the friction combination is critical with regard to the feasibility of force transmission. Because the coefficient of adhesive friction is a factor in the equation for gripping force, it is important to know the materials used in the friction combination as well as their surface status. The table also lists friction combinations for the lubricated status since lubricants and cutting oils are often used in production activities.

Figure 3.25 Specialized gripper fingers made of special plastic (source: SCHUNK[58])

material combinations	coefficients of adhesive friction	
	dry	lubricated
Steel on cast iron	0.2	0.15
Steel on steel	0.2	0.1
Steel on Cu-Sn alloy	0.2	0.1
Steel on Po-Sn alloy	0.15	0.1
Steel on polyamide	0.3	0.15
Steel on friction coating	0.6	0.3
Steel on special SCHUNK plastic	0.3 - 0.4	-

Table 3.12 Coefficients of adhesive friction for different surface material combinations

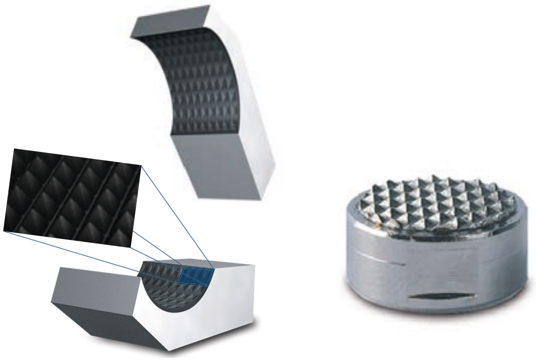

Figure 3.26 Elastomer insert (left) and carbide insert

Manufacturers of gripper fingers are always striving to introduce improved friction combination materials, with the aim of avoiding any significant increase in the grip force required while still achieving a high holding force between the gripper fingers. Coatings, coverings or special inserts for the gripper fingers are also used, such as illustrated in Figure 3.26.

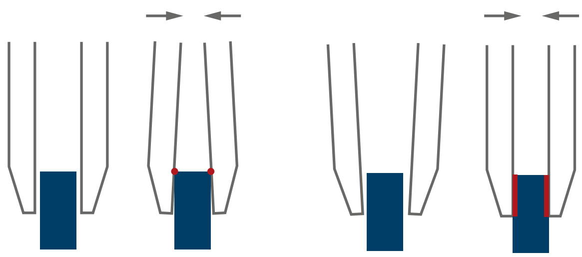

Figure 3.27 Avoiding point contact with the workpiece by gripper jaw bias

Specially formed carbide inserts can be used for non-sensitive components or components that do not impose more stringent requirements on surface quality. Thanks to micro form-fit gripping, these ensure an increased coefficient of friction especially for rough component surfaces. A secure grip is even guaranteed for cast parts with a scaly surface. These inserts can transfer gripping forces of up to 30,000 N.

The practical example of a connecting rod gripper for the automatic assembly of motor components shows the impact that gripper finger design can have on an entire automation project. Although the design of the gripper fingers took into account possible interfering edges, the sufficient gripping force and the correct material combinations, it failed to include any possible deformation of the fingers during the gripping process. Thus, the first attempt at gripping resulted in a workpiece contact surface such as that displayed to the left. The connecting rods were not held sufficiently with the point contact and proceeded to oscillate with each movement of the gripper, either making it impossible to place the workpiece in the assembly situation or resulting in too great of a time loss.

In order to gain a better understanding of the assembly situation and workpiece mounting, the complete gripper including gripped workpieces has been illustrated again in Figure 3.29.

Figure 3.28 Workpiece to be handled - single connecting rod

The solution for this problem was found in the use of fabricated angled fingers that transform into a perfectly straight shape when loaded, holding the connecting rods level. A gripper finger with a particularly slim shape was developed in order to avoid coming into contact with any interfering contours when picking. The fact that the yield point could not be exceeded had to be taken into account in the design. The illustration shows a variation of the gripper finger in the design phase in CAD.

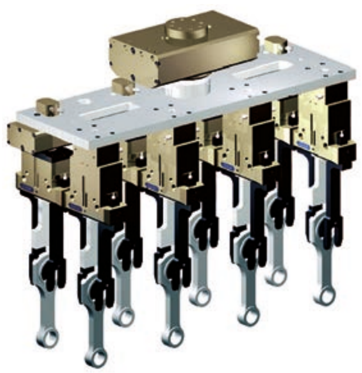

Figure 3.29 Gripper (8-sided) for the connecting rods and the long gripper fingers (source: SCHUNK[58])

These experiences have led to a tendency to introduce form-fit finger transmission behavior onto the workpiece in practice. This is met with new manufacturing processes for gripper fingers, such as additive processes, which can more easily depict complex geometries as a counter-form in the finger. This helps significantly reduce the production costs associated with geometrically adjusted fingers without losing any of the advantages in quality.

Five years ago, producing gripper fingers was still very much an expensive and time-consuming undertaking. This rang especially true for workpieces requiring form-fit gripping in three dimensions. Milling these components in aluminum was simply not always possible. Over the past several years, additive production methods have evolved into real solutions. With the materials available today, it is possible to produce gripper fingers in plastic or metal. That has resulted in more reasonable prices and the possibility of individual finger design. The SCHUNK company, with its headquarters in Lauffen am Neckar, Germany, is taking it a step further. They offer their customers an online portal (eGRIP), where fingers and gripper modules can be adjusted in minutes using a pre-loaded

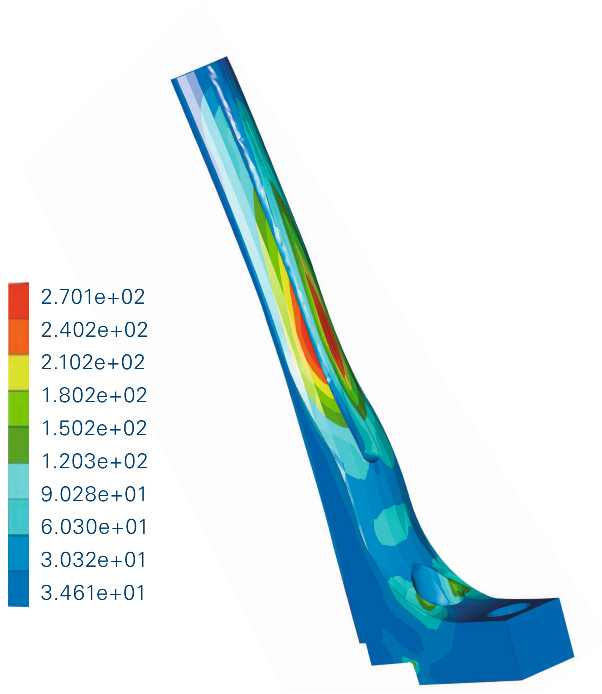

Figure 3.30 Design of the gripper fingers to the yield point (source: SCHUNK[58])

3D model of a workpiece. The model can be inspected in the 3D viewer and ordered at the touch of a button. Shipment takes place just a few days later. With advantages outweighing those of conventional clamping operations, this kind of rigid surface manufacturing will continue to grow in the coming years. Fingers suitable for small parts handling are the primary components that can be created here. For small workpieces, PA 12 plastic not only offers all the strength necessary but also sufficient wear resistance, as long as the workpieces are not too sharp along the edges. In general, this results in cost and weight advantages for small parts, as compared to using the machining method for aluminum fingers. The STL files can be downloaded and used immediately for integration into the plant construction.

As both the jaws and the gripper module are offered from one provider, the interfaces between them are no problem. The gripper jaws can be immediately adjusted to fit different gripper modules, which can be accessed from a pull-down menu. The gripper fingers are also available in a range of colors. This web-based platform for the production of gripper jaws is one of the first applications for industry components. Earlier 3D printing platforms were focused more on end consumers for activities such as producing customized mobile phone cases or jewelry. With the eGRIP platform, the manufacturer SCHUNK is taking the first step toward customized construction for components and machines, an area which had previously been reserved primarily for special purpose machine designers. The standard component gripper module can be adjusted by the customer for individual tasks.

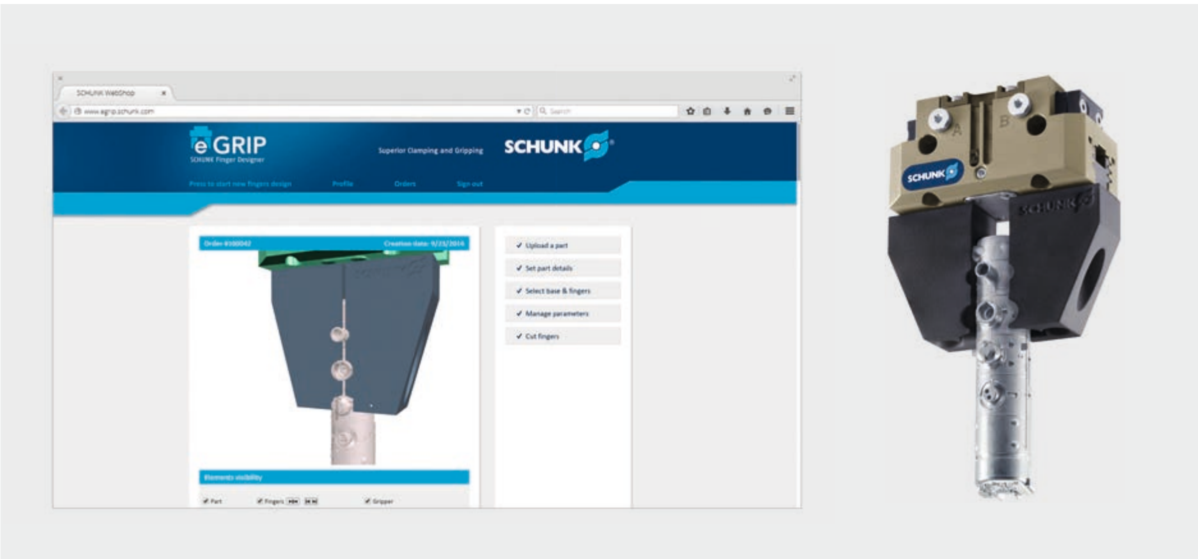

Figure 3.31 Internet portal for gripper finger design (source: SCHUNK[58])

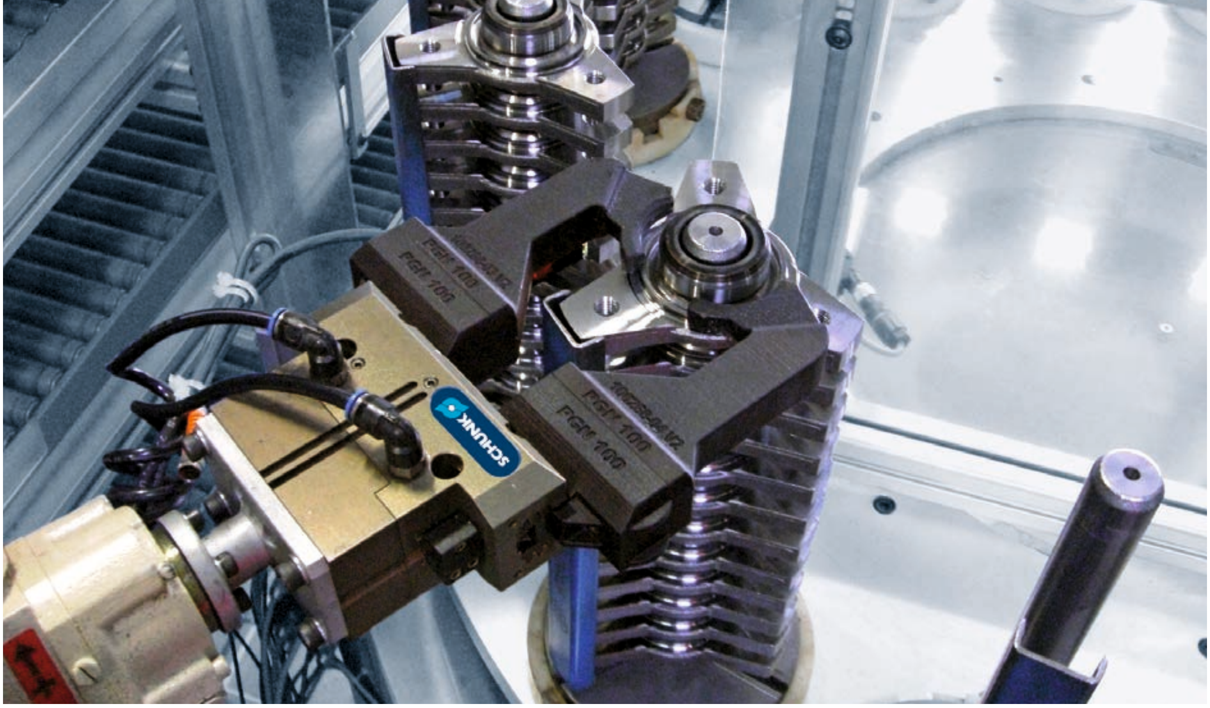

Figure 3.32 Gripper finger made of polyamide, produced in a laser sintering process (source: SCHUNK[58])

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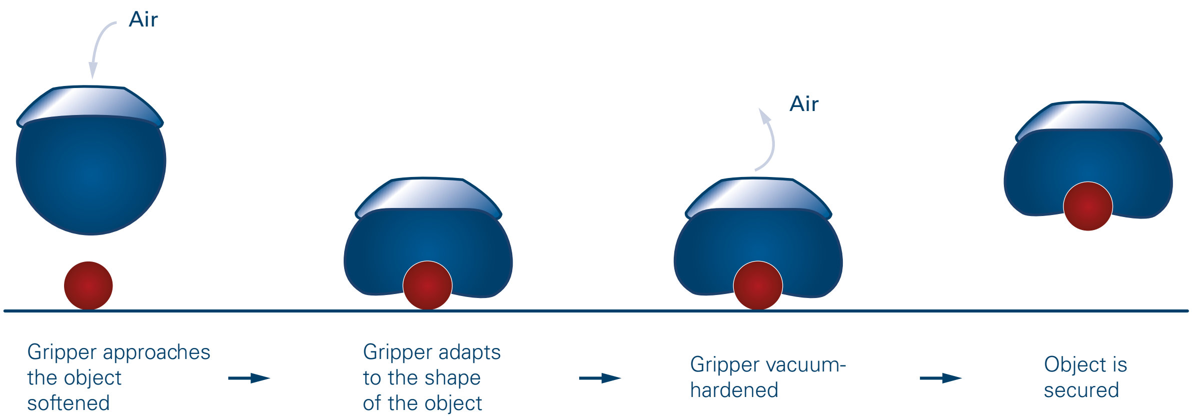

Figure 3.33 Versaball gripper in a gripping sequence (source: Empire Robotics[65])

depending on the pressure applied. The LOG I.D. gripper is an example of how laser sintering technology can also prove useful for serial productions. Producing this kind of gripper with injection molding or machining would be impossible or extremely costly.

Figure 3.34 Example of Versaball application (source: KurtwolAI[66])

Other principles also work in a similar way, where the contact surface is not filled with granulate for example, but with metal chips. The metal chips can be held or released with the use of electromagnets.

If the workpieces contain bore holes or interior contours, then the component can also be gripped on interior contact surface. In this case there are special effective surfaces that can change their diameters using compressed air. As this method makes a large surface available for force transmission, it can be used to achieve excellent holding forces. These kinds of gripper fingers can handle workpiece weights from a mere 135 grams to a maximum of 4000 grams. Up to now, this weight-to-load capacity ratio had never been achieved before in gripper technology.

The I.D. gripper works by extending contact surface 1 to the interior wall of the bore hole. The extension is accomplished via moving element 2, which can be designed differently depending on the extension stroke. The stroke is limited by the stops on base housing 3, preventing the destruction of the workpiece or the gripper. The force of the gripper can vary

Figure 3.35 I.D. gripping and functional diagram (source: SCHUNK[58])

Figure 3.36 Flexible retracting gripper finger for different toothbrush geometries (source: Zahoranskey[81]/robomotion[60])

Moving fingers are most commonly used for, e.g. balancing workpiece tolerances or different product diameters without having to change the gripper. The example in Figure 3.37 shows a gripper finger that contains multiple flexible elements. This means that a wide variety of workpiece contours can be covered, for example when grasping toothbrushes or dowels.

Flexible, adjustable gripper fingers now make it possible to grip toothbrushes with a wide range of geometries without having to change the fingers. The service life of the fingers produced by laser sintering processes has been proven to withstand millions of cycles. Depending on the gripping object, this can add up to several years of production time without having to change out the fingers. The finger shape has also been tested in combination with metal components and an electric gripper.

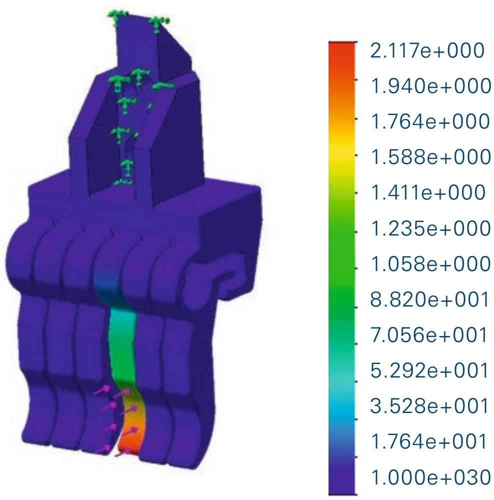

Figure 3.37 Adjustable gripper fingers for different workpiece geometries (source: robomotion[60])

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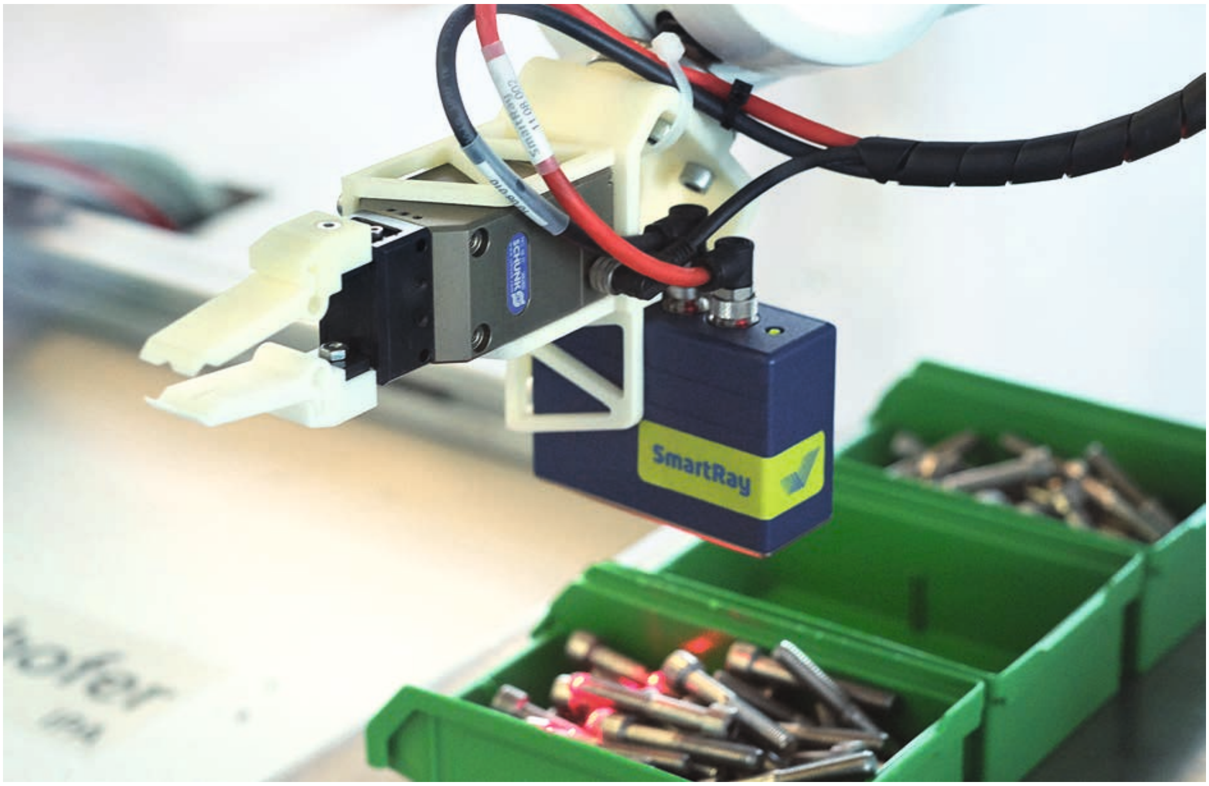


Figure 3.38 Electric gripper with laser sintered gripper fingers and scanner image (source: Fraunhofer IPA[70]/robomotion[60])

The opening width of the fingers for electric grippers can be set individually depending on the workpiece, further reducing the strain on the gripper. However, there is more wear with metallic workpieces.

For the application illustrated in Figure 3.38, containers filled with screws of different diameters had to be emptied by robots. In this case, the sensors for detecting screw length are directly integrated into the gripper brackets. This creates a highly flexible solution without any major hardware expenses.

Figure 3.39 Retracting gripper jaw design (source: SCHUNK[58])

Productions using laser sintering technology help minimize production costs for the gripper fingers for such geometrically complex components. Designing the corresponding stability and long-term tests allowed the life span of the fingers to be increased to several million gripping cycles. This means that despite some sharp-edged components, only a few fingers per year are needed as spare parts.

The principle of the elastomer gripper places the drive directly into the finger. When compressed air is applied, the finger curves into a direction defined by the shape. This kind of gripper is also suitable for extra sensitive workpieces. The force placed on a workpiece can be set using the applied pressure. This means that, e.g. fruit and vegetables can be gently gripped by the gripper, just as seen at EXPO 2015 in Milan in the Supermarket of the Future.

There are different force / pressure sequence results for the fingers depending on the design and dimensions of the fingers. The material used for the finger also plays a significant role here. PA12 or TPU are used, for example, in productions using 3D printing processes. Here, the force progression is changed via the wall thickness chosen. But today there are already printing processes that allow the use of different materials in one component, resulting in even more possibilities for producing these types of gripper fingers.

Figure 3.40 Robots in the supermarket (source: ABB[67])

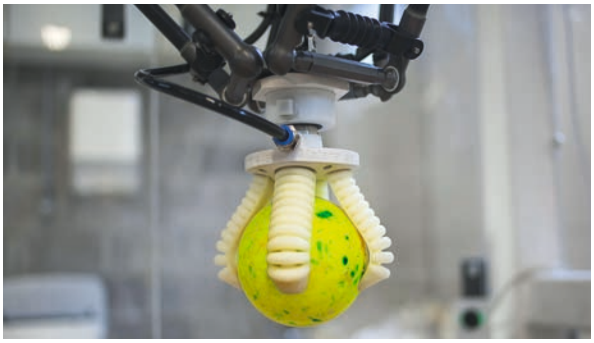


Figure 3.41 Elastomer gripper grips round workpiece (source: gripper Materialise[68])

The versatile passive gripper finger also has a flexible design. It adjusts to the shape of the workpiece and grips it very gently. This kind of finger construction allows sensitive components to be gripped gently.

With the principle of versatile passive finger design, the drive unit must close or reopen the finger using a separate cylinder. Gripper fingers with an actively driven flexible design are one step closer to replicating the human hand (see Chapter 3.3). It should also be mentioned that with flexible effective surfaces in general, the positional accuracy may not be sufficient in some cases for handling tasks or especially for assembly tasks with this finger design. The flexibility results in the workpiece not being as accurately placed in the gripper as it is with the picking position. This requirement could preclude the use of these flexible effective surfaces at times.

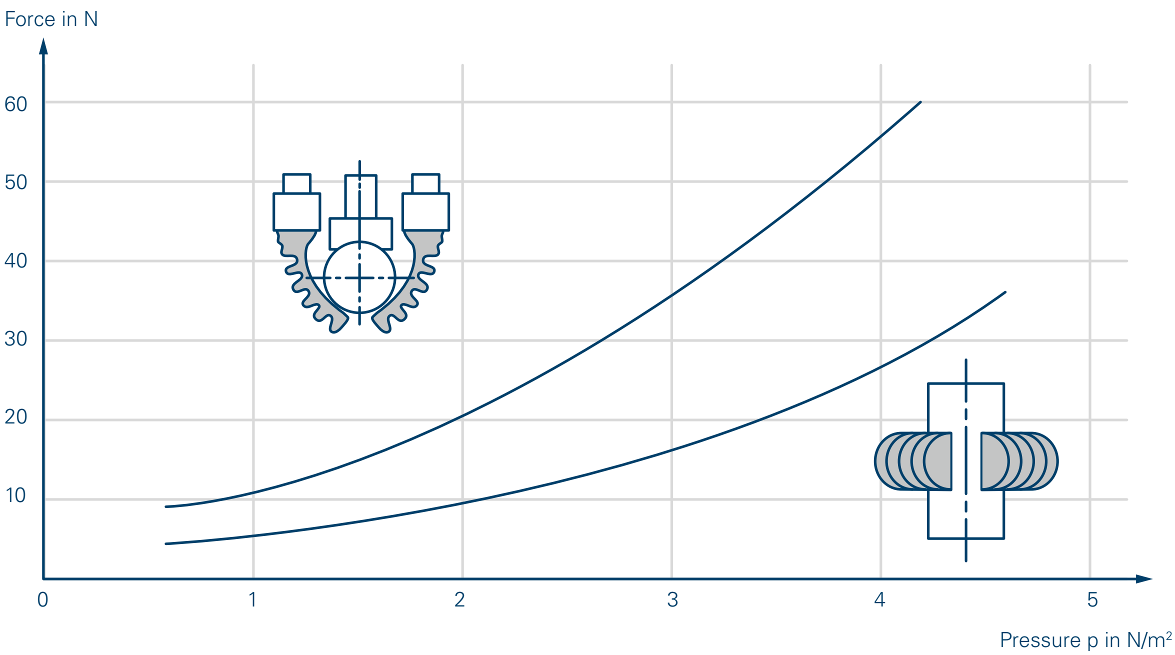
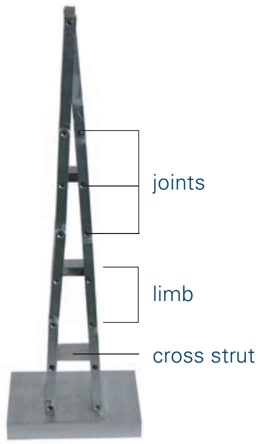


Figure 3.42 The gripping force does not have a linear relationship with the increase in pressure (source: Hesse[69])

Figure 3.43 Nail gripper (source: SCHUNK[58])

If the effective surfaces are designed to be flexible, they can be adapted to the shape of the workpiece, as seen in Figure 3.43. With this gripper design, the effective surface is pushed through the workpiece in such a way that the workpiece clamps the nails into a connecting member with two picking points. That ensures that the nails firmly adhere to the workpiece and allow them to be handled. The workpieces are placed using a contact plate that brings all of the nails back into the picking position.



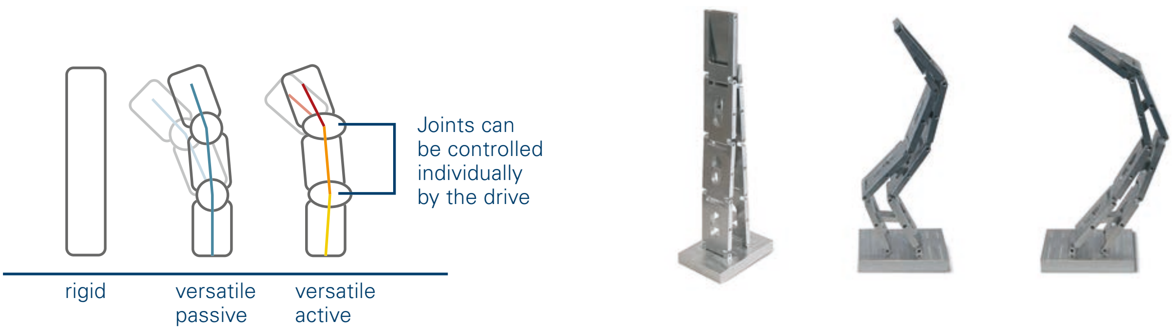


Figure 3.44 Functional principle of a moving finger (source: Fraunhofer IPA[70])

The advantages of high flexibility must be put into perspective here by also examining the disadvantages. In addition to poor product protection, the gripper is also subject to considerable wear, meaning that the service life is not suitable for high production numbers.

Also, the positioning accuracy for the nail gripper solution is not sufficient for all applications. When being picked by the gripper, it is possible for the workpiece to be shifted one nail width in one direction or the other.

Needle grippers, however, are included as standard grippers in the product ranges offered by many well-known manufacturers. They are included in the group of grippers with switch-on/switch-off surfaces. By extending the needles, a form-fit connection is established between the gripper and workpiece. The needle or needles press into the surface of the workpiece and establish a connection. Therefore, a prerequisite for gripping with needle grippers is using a material that will not be significantly damaged by the needles. The transmitted forces should not be too high, as the needles will otherwise release from the surface of the workpiece, causing damage to the workpiece. Needle grippers are used primarily for gripping textiles.

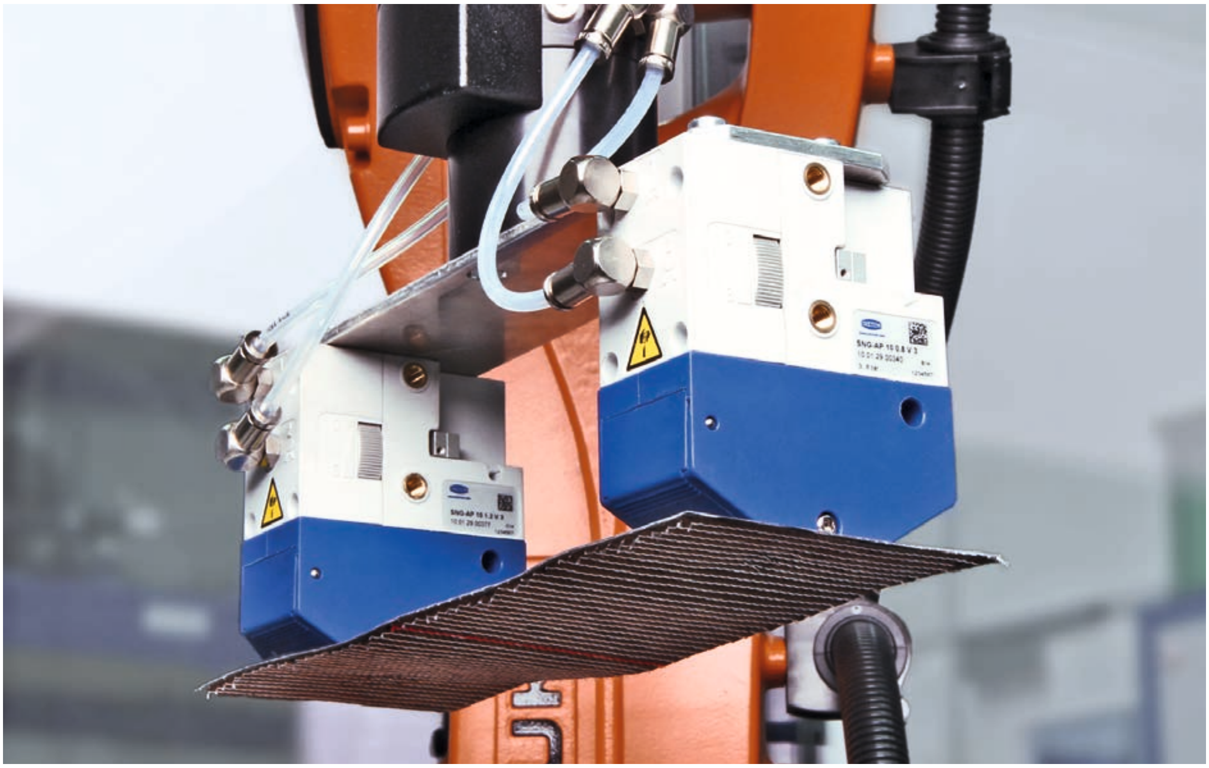


Figure 3.45 Needle gripper for textile applications (source: Schmalz[72])

Figure 3.46 Needle gripper (source: Schmalz[71])

Pressing a needle into the surface of a workpiece comes with a few considerable drawbacks, especially in terms of the careful handling of objects. Thus, the use of this gripper design or contact surface construction is severely limited.

Use in the food industry is rare due to the difficulty of cleaning such a gripper. This gripper can easily be used for mesh structures in plastics processing, e.g. for processing glass mats or carbon-fiber mats.

Another group of switch-on/switch-off surfaces are magnetic grippers. These are suitable for picking ferromagnetic workpieces. The charm of magnetic grippers is in their high holding forces and the possibility of holding complex geometrical components reliably. One major advantage that magnetic grippers enjoy is the use of electric energy as a drive medium. This means that no additional compressed air connection is required in the application.

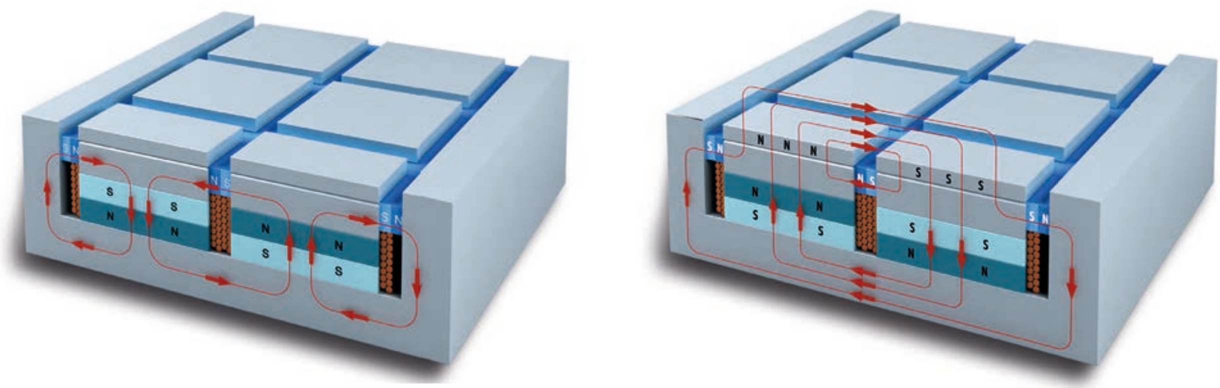


Figure 3.47 Magnetic grippers with force flow in the switch-on or switch-off status (source: SCHUNK[58])


SCHUNK

Figure 3.48 Alternative designs for magnetic grippers with permanent magnets (source: SCHUNK[58])

The illustrations in Figure 3.48 show different magnetic gripper designs. These include pneumatically switched magnetic grippers, which produce a holding force using a permanent magnet. This permanent magnet is then withdrawn when placing workpieces, allowing the component to drop. The advantage of this gripper is that workpieces remain gripped even in the event of a power outage. The electric magnetic gripper construction can be designed more compactly and used for workpieces with higher weights.

Using magnetic grippers can be an attractive option when several workpieces that must be gripped in groups and when the geometry of the individual components or groups are difficult to define. In other words, when designing an effective surface grip proves too challenging. In the example in Figure 3.49, two groups of workpieces exhibiting complex geometries are picked at the same time by the magnetic gripper before stacking them for packaging in the next step.

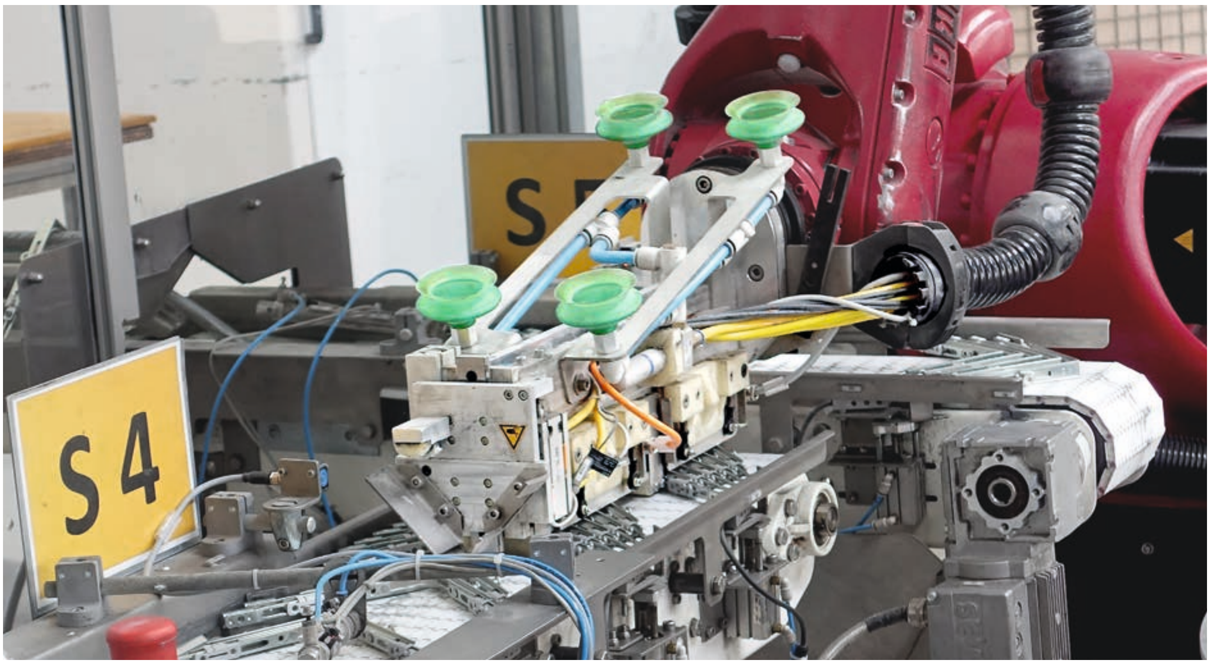


Figure 3.49 Magnetic gripper picks two product packages up simultaneously (source: Roto Frank[73]/robomotion[60])