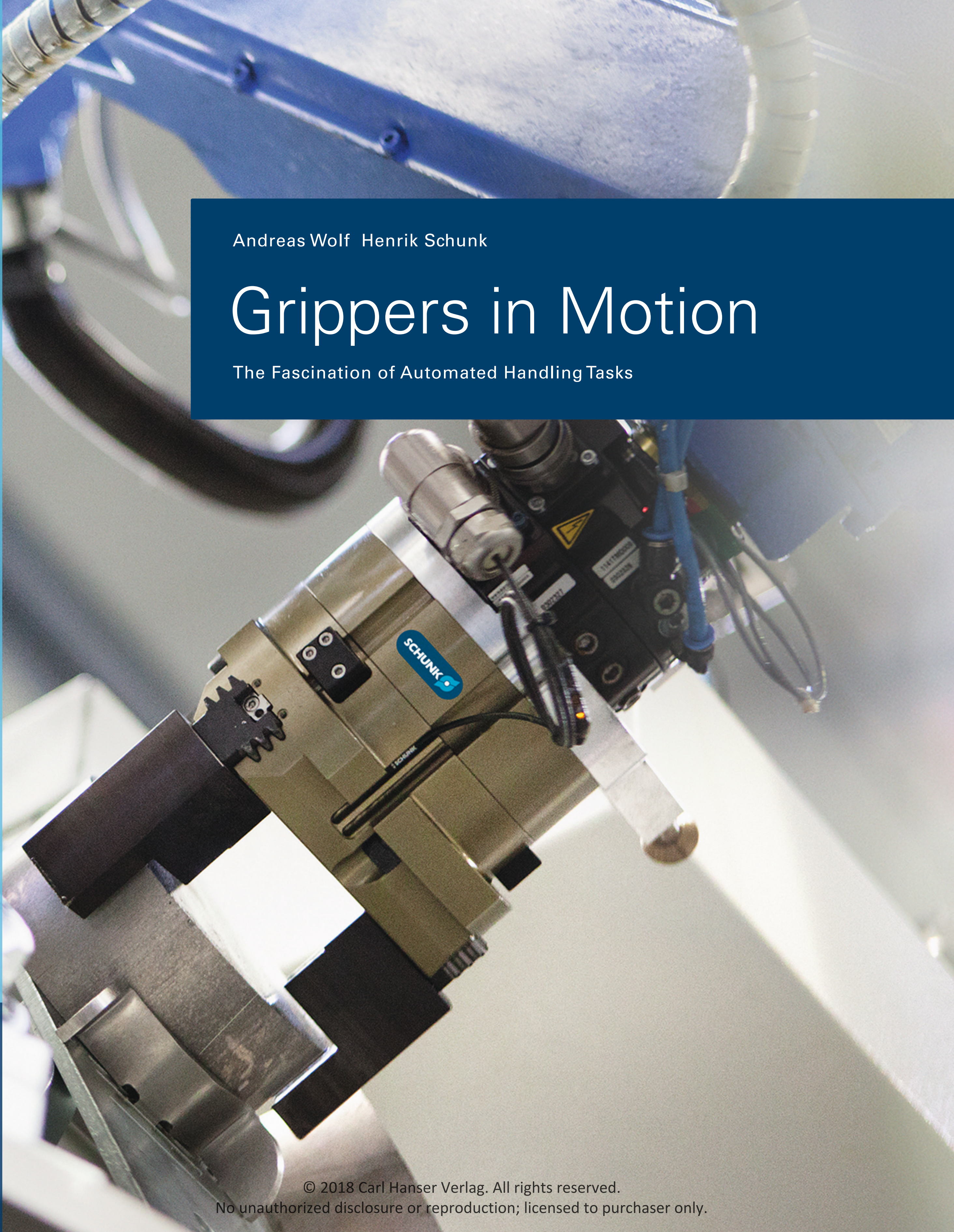
Andreas Wolf Henrik Schunk

Grippers in Motion

The Fascination of Automated Handling Tasks



Wolf / 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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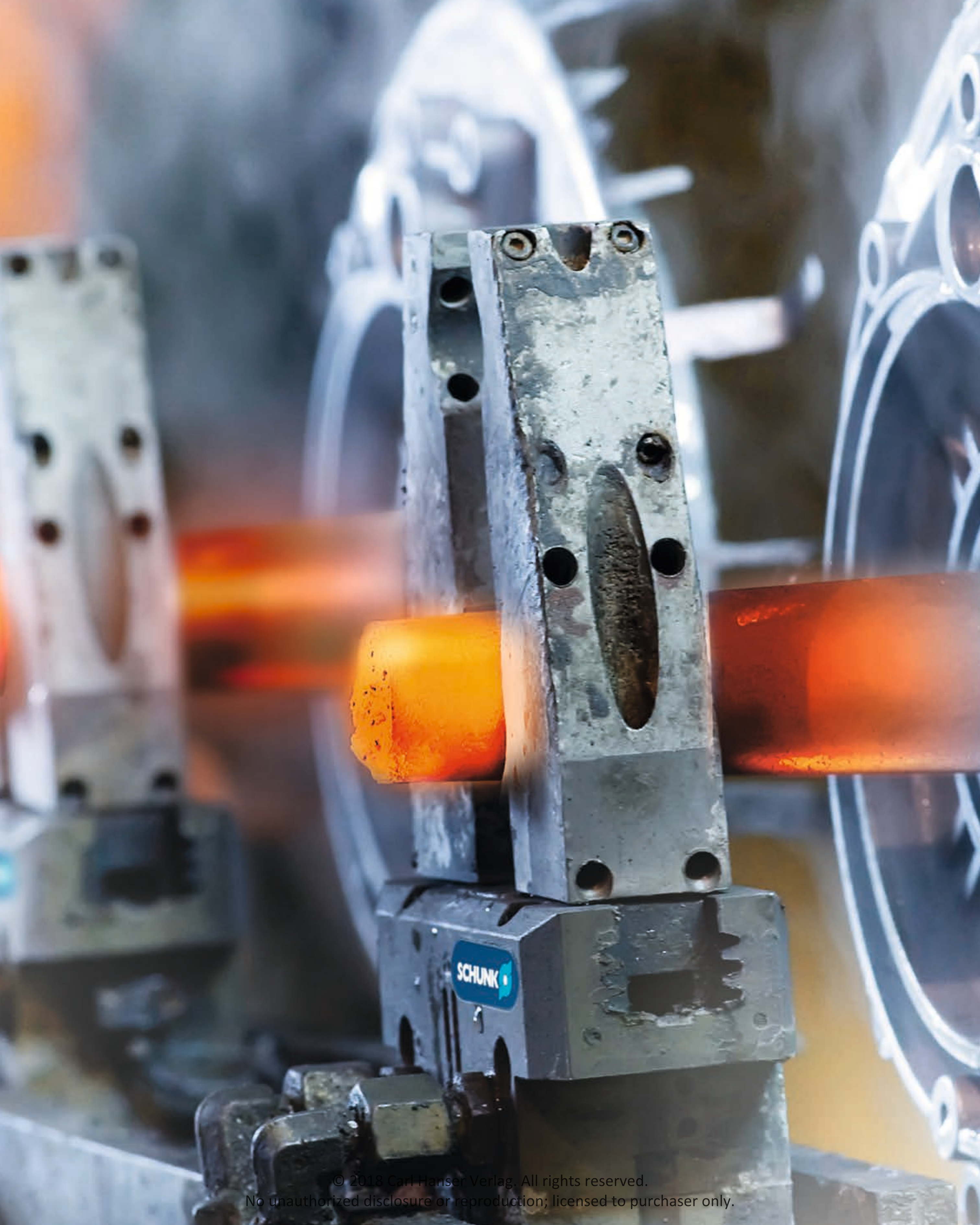
SCHUNK

1 THE HANDLING PROCESS

1

THE HANDLING PROCESS

We handle objects hundreds, perhaps thousands of times every day. This process is so deeply ingrained in our nature that we are virtually unaware of it happening.

We press the buttons on the console and move them to the switching point. We take hold of the coffee cup, bring it to our mouths and make a tilting movement. In the meantime, our eyes have also detected the location of the cup and our brains have effortlessly determined both the gripping position as well as a possible path along which the cup can be guided without colliding with other objects. Automatism, the set of behaviors that help us perform these processes, gives us the impression that these same tasks are unremarkable and even ridiculous when used in production.

But upon closer examination of even a simple example such as the "task of handling a coffee cup", it becomes clear that detecting, moving and gripping cups poses a real challenge for machines. It is not without reason that households are still not equipped with those visions of robot helpers happily doing the ironing and folding the laundry.

Not surprisingly, examples of such "useless", or as experts say "non-value added" handling processes still abound in industrial production as well. This includes processes where the component is not machined, or in other words, the form of the component is not changed. In production, handling components is necessary each time a workpiece is transported, stored, commissioned or mounted. Workpieces must be gripped and moved, and in general this requires manual labor performed by humans. In order to keep pace with rising piece numbers and wage costs, increased efforts in development and production are being directed at keeping the number of handling tasks to a minimum, and only focusing on the actual processing of the component.

Examples of this in the past include the machining centers used in machining production. Without employee intervention, these machining centers were able to process entire milling components in a single clamping. Transporting from one machining center to the next or loading each machine was no longer necessary. Workpiece quality was also improved and processing error rates dropped. Combining multiple processing operations in one machine resulted in significant gains in productivity. This came at the price of high investment costs and inflexible production planning, as production bottlenecks developed at the machining centers.

Nevertheless, for products composed of a number of different individual components, assembly still constitutes a high proportion of the production costs. In this regard, manufacturers are heading more and more toward complex component assemblies that are delivered completely assembled by "system suppliers", leaving only a few steps for the final assembly. Depending on the industry and product, this assembly process is often outsourced to low-wage countries. It was not in vain that entire factories relocated to the Far East during the economic boom of the past several decades.

Even in China, the current pressure to increase automation and take a more critical look at manual work processes is a result of higher quality standards and rapidly increasing wage costs, both of which demand higher levels of productivity in production. The automation of handling tasks is one of the design solutions available for production processes. But the product design itself, the use of additive production methods as well as factory organization are all important contributing factors that can also provide a solution, depending on the situation. A new way of

Figure 1.1 Handling a coffee cup (source: REFORM DESIGN[1])

thinking has also taken root in management consultancy firms, which in the past had concentrated solely on “lean” or “efficient” factory designs. A concept is gaining ground in which production technology that is adapted to the product range and market demands, combined with relevant organizational measures is the only truly productive method. For this reason, purely managerial consultancy teams are seeing more and more production technology experts joining their ranks, helping to generate an increase in efficiency by examining the technology used in production machines.

The common goal of all of these efforts is the prevention of waste in production by avoiding “non-value added” processes. To a large degree, all “value-added” processes (i.e. processes that are necessary for increased product value) require secondary activities. These are the focus of organizational and technical optimization measures. From an economic point of view, these organizational and technical initiatives are continually confronted with limitations.

First of all, there is a limit to how much a process can be optimized. At a certain point, technical tools are necessary in order to further increase productivity. As always, the choice of system boundaries is an important factor here. With the aim of achieving process improvements, radical jumps in optimization can hardly be expected for “sophisticated” productions if only small steps are implemented, for instance if one step of a manual process is replaced with an automatic one. This scenario requires a thorough examination of both the manufacturing process and construction of the products involved, or a thorough optimization of the system boundaries used for the production steps and processes.

This chapter provides a foundation for understanding the topics covered in this book that relate to the automation components available in contemporary handling process automation. Entering into the world of automation components begins with an introduction to handling processes in an effort to optimize.. This chapter examines the development of handling technology and addresses the driving forces that can be found in all sectors of industrial production. It will help clarify the motives behind the further development of this technology and draw conclusions for the future evolution of components. The process itself will then be defined and the terminology related to this process will be explained.

1.1. Handling – A useless Process?

In production, handling is often considered a necessary evil. Although there are some exceptions where handling actually increases the value of a product, in general handling contributes more to waste than to added value. That's why, according to Lean Production rules, the transport of workpieces from one location to another is considered[2] uneconomical and something to be avoided. This often refers to transport from machine to machine, but the aim of many on-site optimization measures also includes shortened distances or minimized handling, such as with the Kaizen method[3].

Workpiece handling as "a constant source of waste[4]" was the focus of assembly technology research already in the 60s. Back then and today, the primary concern was avoiding idle time during processing and assembling of workpieces, e.g. when loading and unloading machines.

The handling process was seen as secondary to the actual production and machining process , as handling had no "value-added" impact on the products. The time necessary for production is separated into machine time and handling time (see Figure 1.2). Machine time is the period of time during which a machine is operating, in other words when it is making changes to the workpiece itself (e.g. metal cutting, reshaping, coating, etc.). Machine time can be further separated into pre-operating time, operating time, and post-operating time. During pre- and post-operating times, drilling spindles, for example,

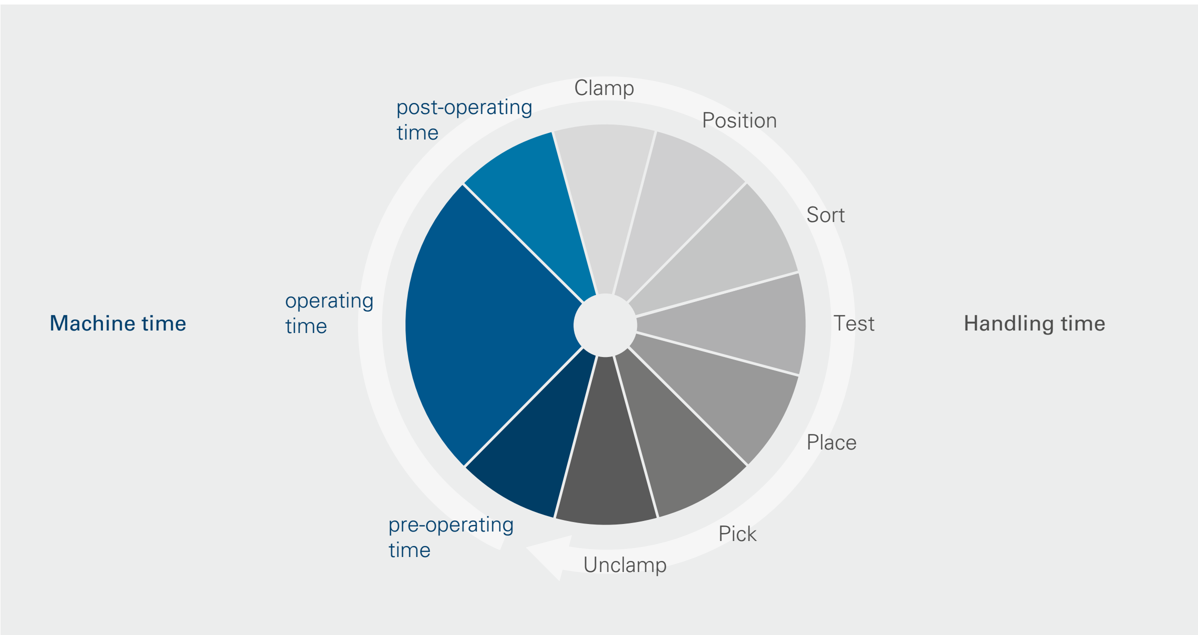

Figure 1.2 Machine time (operating time) and handling time (pre- and post-operating times)

are brought to the desired speed of rotation and positioned to the workpiece. The actual metal cutting work, e.g. drilling a hole in the metal, is conducted during the main operating time. In the past, these machine-dependent idle times were always reduced to a minimum, in order to further increase machine performance or output. But there is also a constant push to further reduce a machine's main operating times. This can be achieved, for example, by using new materials in tool manufacturing.

Idle times and handling times can be divided into the individual tasks necessary for clamping a workpiece in a stationary chuck of a machining center. In general, these tasks take place outside the machine and also include quality assurance tasks, as Figure 1.2 illustrated. Every production planner's aim is to synchronize a machine's idle times with its main operating times. This includes, for example, placing a handling device used for picking workpieces from a machine into a waiting position in front of the machine when the main processing time has completed. Non-optimized process activities result in machines having to wait for removal handling processes. If, for example, the robot performs other tasks in addition to picking objects from an injection molding machine, for example removing the sprue, this action must either have a shorter process time or the robot must be able to place the workpiece at a separate station for removal. The robot should remain on standby to pick up the next component from the machine.

Planning such processes requires an exact analysis of process times, as it neither makes sense to have the robot wait in front of the machine, nor to have the machine wait for the robot. In any case, the variation of components and their corresponding process times are to be considered for these tasks, as machines often have to work with diverse components that have different processing times.

In order to make idle times that were unavoidable more productive, automated solutions were needed that decoupled the operator from the actual machine time. Buffering materials in before and after the machine allowed humans to be decoupled from immediate cycle times. This method of buffering or retaining materials at the machine also acted as a buffer against disruptions in production lines. According to the methods of Lean Production, these kinds of buffers are not beneficial, as they prevent insight into the actual processes and any deficiencies they may occur. This means that buffers only allow waste caused by unreliable processes to be identified at a later point or perhaps not at all. Waste is the result of these unreliable processes which can only be detected when not hidden by material buffers. In this respect, it is detrimental to value chain or process chain optimization to have buffers that reduce process errors by not shutting down everything immediately.

Approaches involving continuous process chains without buffers or storage options, place increased demands on production technology and individual availabilities. In the realm of technology, this generally means that in mechanical engineering only components are used that have undergone long-term testing , in order to ensure the highest degree of process

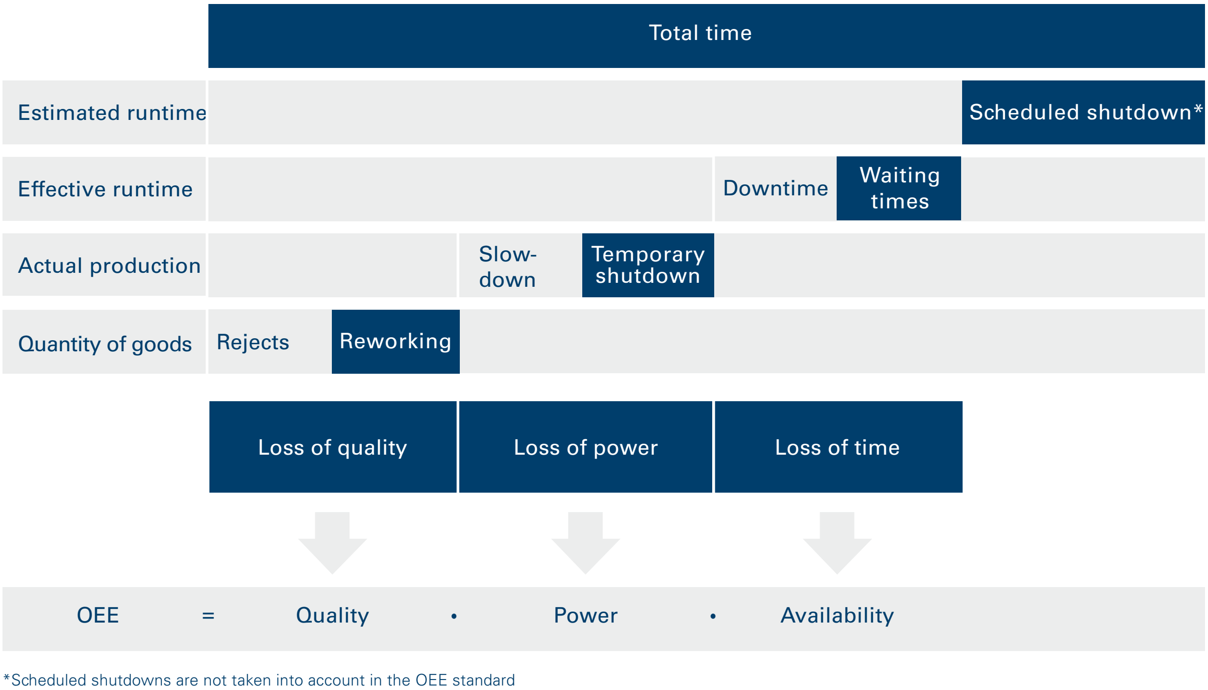

Figure 1.3 Graphic depiction of OEE value determination in production (source: fme AG[5])

reliability. This means that in a production line without buffers, the significance of the remaining handling processes increases, and high functional reliability must become more and more of a focus in automatic operations.

If, for example, a gripper component is to be installed on a robot, the executing design engineer will rely on components that guarantee high load cycles in the data sheet. Therefore, in line with the Total Cost of Ownership (TCO)[6], the price of the component is not the only factor of interest, but also its lifespan and frequency of failure. In general, in-house designs are at a disadvantage, as they cannot be nearly as sophisticated and carefully tested as standardized components that have undergone long-term testing.

In-house designs such as grippers should typically be avoided due to cost reasons as well as the fact that standardized components are generally much more economical and their development costs have less impact on the budget. This rule of thumb may not apply in the same way when dealing with higher quantities. In this case, all of the costs should be taken into consideration in the calculations, including storage costs for specific replacement parts and any long-term testing.

This shows the considerable influence the design of handling tasks has on future process reliability and Overall Equipment Effectiveness (OEE).

1

In general, the OEE value is a index number between 0 and 100%, the latter percentage representing the ideal situation. In practice, the actual values reached are partly much lower. It is important for further examination of handling processes to ensure that the handling processes impact any three contributing factors of time, performance and quality. This will allow a reliable handling process to result in a good OEE value.

The more handling processes a machine incorporates, the more important high availability of the individual processes becomes. That means that tried-and-tested components and component functions play an increasingly important role, otherwise the effective run time or performance would be reduced.

Modern handling systems allow for increasingly shorter cycle times for handling tasks due to high dynamics. As a result, machine performance can be further improved. The following table shows the acceleration and speed values of different handling systems.

Thus far, pure dynamics have been the most crucial factor in the handling process, but with a more integrated view in terms of OEE, aspects such as positioning accuracy are brought to the foreground. Even a simple packaging task with several millimeters of positioning tolerance between the product and the package, can encounter positioning errors as a result of unfavorably combined tolerance fields, which could lead to interruptions in the packaging process. A closer look at the high cycle rates in the process determined by the high dynamics (e.g. 100 pralines per minute, per robot), shows that several errors may occur in one layer even with a high quality factor.

For that reason, the handling process should not be characterized solely by the aspect of workpiece moved per unit of time. If handling tasks are to become more

Drive type	Pneumatic drive	Belt drive	Electric motor spindle drive	External drive following axis	Direct drive linear axis	Parallel kinematics
Intermediate position	only possible with additional construction	possible	possible	only possible with additional construction	possible	possible
Maximum speed	approx. 1.2 m/s	approx. 3 m/s	approx. 2.5 m/s	approx. 3 m/s	approx. 5 m/s	approx. 10 m/s
Maximum acceleration	-	approx. 10 m/s²	approx. 10 m/s²	approx. 10 m/s²	approx. 100 m/s²	approx. 120 m/s²
Positioning accuracy	to the back stop	0.1 mm/m	0.05 mm/m	-	approx. 0.05 mm/m	approx. 0.5 mm

Table 1.1 Comparison of different axis systems and their dynamic behavior

(optically and tactilely) intuitive for people with "gripping technology" and efficient "sensors", then the technical solution is at times quite complex.

In order to be able to improve the analysis of handling processes, the process can be divided into different parts. We can differentiate between three major process phases: gripping, moving and placing (see Figure 1.4).

In the gripping phase, both the workpiece and the gripping situation play a special role. On one hand, the workpiece exhibits specific features and characteristics that must be taken into account when gripping (e.g. weight, geometry, sensitivity, etc.). In addition, the gripping scenario is also to be taken into account, such as accessibility or workpiece movement.

The moving phase is defined by the handling task. The required cycle time and resulting acceleration values play a role here. Depending on the path of movement and the workpiece mass, different forces arise on the contact surface between the workpiece and gripper finger. The tendency is to keep the movement time as short as possible, in other words, to chose the maximum possible speeds and shortest possible paths for the handling system. In some cases, this is also important for reasons related to the gripping process, as there are workpieces with adhesive properties that may induce adhesive forces at the surface area between the finger and workpiece if the gripper's holding period is extended. A maximum holding period should be defined for hot workpieces, in order to avoid causing damage to the gripper due to heat exposure.

In the placing phase, similar factors come into effect as shown in the gripping phase. On one hand, the opening time of the gripper is important in order to achieve a short overall cycle time. However, it is important to note, that depending on the gripper type, the closing time can differ from the opening time for some gripper constructions. On the other hand, accessibility is again important for the selection of the respective gripping principle. Especially with short handling times, the amount of time spent on the gripping and placing phases can play a significant role as compared to the actual moving phase, such as those in parallel kinematic systems. It is critical here to accurately specify the times for the gripping and placing phases to the millisecond, as the overall cycle time could otherwise be increased unnecessarily.

In order to correctly determine the gripping and placing phases, it is first necessary to conduct an examination of the workpiece, the specific features as well as accessibility. These factors are explained in detail in Chapter 3.

For gripping, it is essential to determine the areas on which the workpiece can be gripped. However, it is also important to clarify, for example, how a robot is to be positioned in the machining area – in other words, how the gripper is able to reach the workpiece. Only then is it possible to determine how far the fingers can be opened in order to grip and how firmly they may be pressed together. The opening of the fingers may possibly be important again for placing, if, for example, the placing action must be performed in situations involving difficult accessibility. This entire process may be

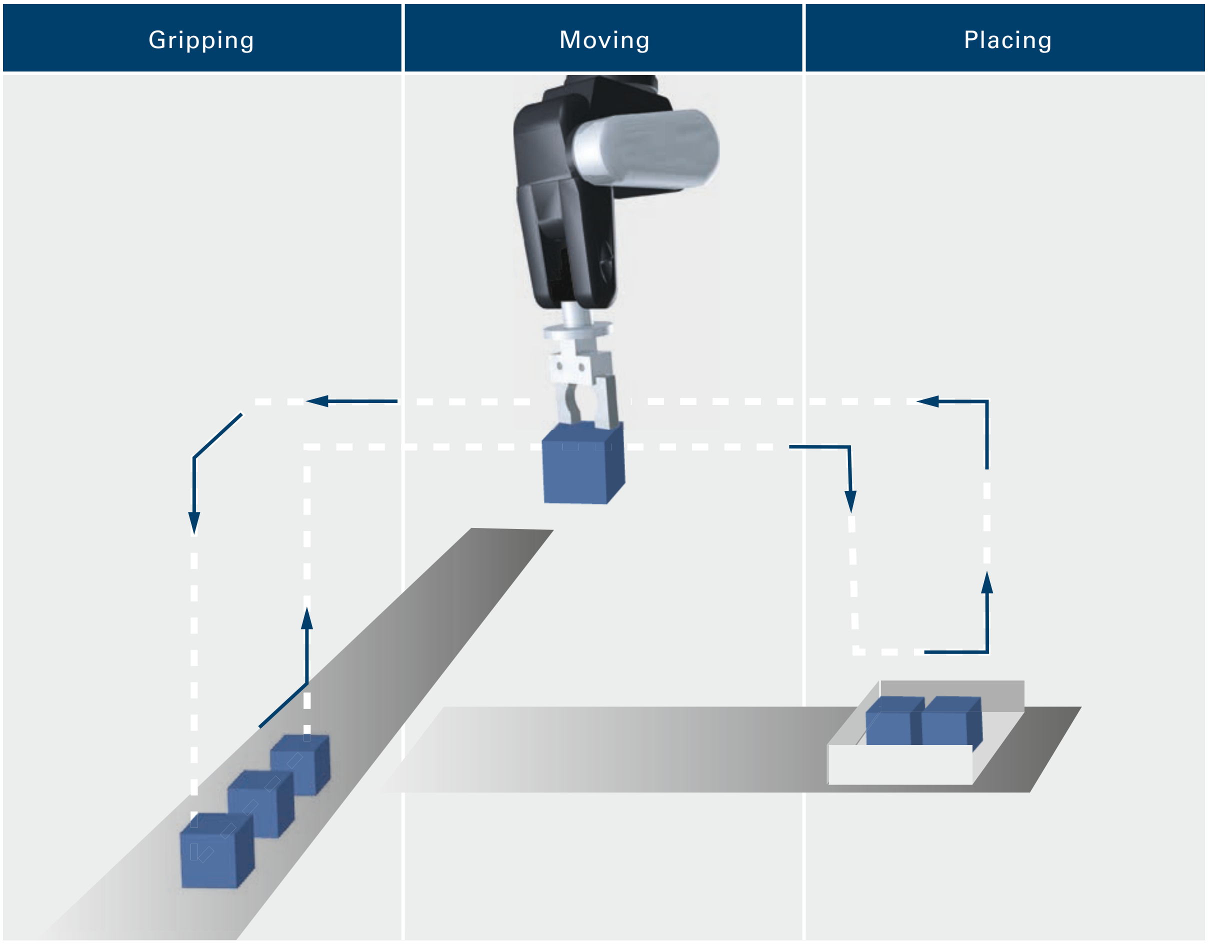

Figure 1.4 Movement sequence from picking to placing the workpieces

monitored via sensors and designed with safety-related technology for different hazardous situations.

The moving phase is to be kept short mainly for efficiency reasons. But workpiece protection is also to be taken into account with regard to product quality. With a consistent scan sequence, Figure 1.5 demonstrates the increasing distances between robot positions. These phases of acceleration as well as any necessary braking phases are critical stages in the robot's path of movement with regard to gripping force. For example, sensitive products can get damaged during periods of high acceleration. In addition, it is also possible that products have to be gripped more firmly during paths with high lateral acceleration, to avoid losing grip during the movement. That

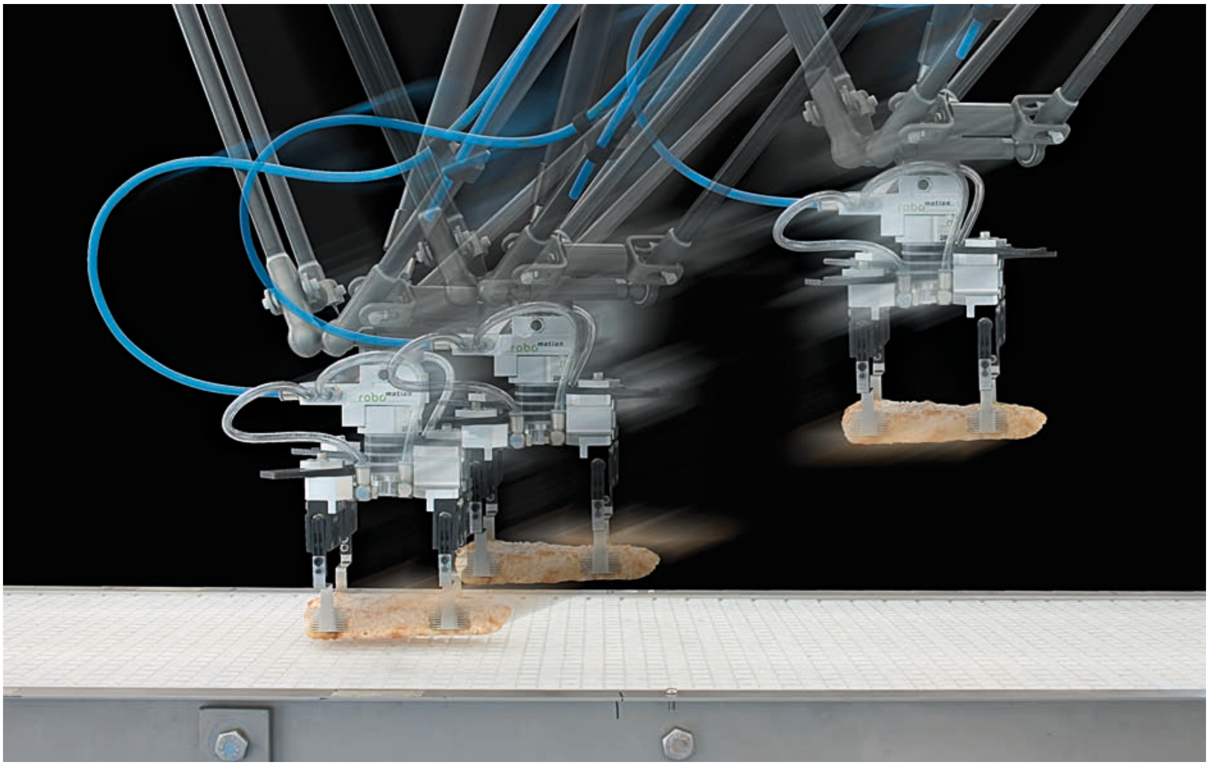

Figure 1.5 Movement phase of a gripper on a parallel kinematic (source: REFORM DESIGN[1])

could lead to damage to the products caused by the gripper itself. These factors are explained in further detail in Chapter 4.

1.2. Development of Handling Technology

The object being handled – the workpiece or the product – is always the starting point for analyzing handling technology. Often, the workpiece specifications have been pre-determined by a third party and cannot be altered. The production technology and operating equipment have the task of creating product as efficiently and economically as possible. The issue of handling-oriented product design (or assembly-oriented product design) is often not raised. The features given by the development department, design or marketing have to be met.

In many cases, this initial situation results in the automation technology or operating equipment not being ideally utilized or in the desired machine availability not being achieved.

Already in the 60s, scientific research was conducted at universities in the Federal Republic of Germany on the topic of efficient process design in handling technology. The core of these studies was mainly concerned with the mechanical automation of processes that had been accomplished manually in the past. These techniques are now collectively known as "hard automation"[7] – in other words automation that has a limited capability of working flexibly with products or product alterations.

In these cases, decoupling humans from machine cycle times was seen as significant progress in efficiency. This meant, for example, that by introducing buffers before and after the means of production, employees were able to operate multiple machines simultaneously, as the buffer allowed production to continue without the assistance of an employee after buffers being filled and emptied. Even in the case of machine malfunction, buffers helped lessen the impact of repairs, as they temporarily ensured continued production for machines that were interlinked.

By the end of the 80s, these solutions began to draw more criticism, as they essentially only made sense for mass production. However, the population was enjoying increasing prosperity and international markets were growing stronger every day, which lead to increased product variety. "Flexible automation"[8] became the new key word in technology, and robots became the primary tools or handling units. This was also the initial spark for developing automation components that could be used for anything from the construction of simple equipment to complex production systems.

Modular systems were developed for any application, starting with basic machine elements, such as extruded aluminum profiles that could be applied flexibly, to pneumatically driven grippers, or handling systems with 6 degrees of freedom – the robot. The aim was to enable equipment manufacturers in production facilities to be able to produce equipment technology themselves that could be expanded and adjusted to new products. In addition, special machine manufacturers increasingly became System Integrators, as they could rely more and more on sophisticated components available on the market.

Furthermore, the first concepts on production-oriented product design emerged at this time. More time was spent contemplating assembly-oriented or recycling-oriented product and assembly design. This branch of design theory continued its development with CAD systems. Three-dimensional illustrations greatly facilitated the planning of assembly processes. For large-scale products such as vehicle construction, other illustration enhancements such as virtual reality are used. The growing possibilities offered by additive production methods mean that models for designing test samples can now be created quickly, in order to run through different assembly process scenarios in advance.

Though the focus in the 90s was still on mechanical systems, the introduction of computers sparked the integration of more and more software-based concepts in production halls. "Mechatronics"[9] became the new buzzword and was integrated into training programs. This was the beginning of the sensor, which became widely available on the components market and which gave robots the possibility to react to changes in the environment when combined with high-level programming languages, e.g. as image processing systems. But also control technology for automation components saw quite a shift to the world of computers. By the end of the 90s, there were already good remote maintenance options for production facilities via modem connections.

Since the beginning of 2000, the internet has ushered in additional technological opportunities, endeavors that are now integrated into the concept of Industry 4.0[10]. That's why today, in addition to improved production equipment networking and production data recording, there are also new possibilities for machine operations and centralized process control as well as production options within reach. Business models in machine construction, known as "operator models" in the past,[11] have become more feasible. Intelligence can be more skillfully distributed when the complex algorithms of image processing, for example, run on the "Cloud"[12] and not directly from a computer in the production facility. On the hardware side, powerful components such as smart phones or machine vision cameras for game consoles were introduced into production environments and helped facilitate operations and service for machines.

But steadily expanding product complexity also called for a transformation especially in logistics, both inside and outside of production halls. In the 90s, the automotive industry was already pioneering new logistical methods such as "Just in Time"[13] as well as production philosophies such as "Lean Production"[14] that aimed to eliminate buffers in production processes, which were viewed as a source of waste. The focus was now on the highly dependable, "process-reliable" implementation of automated solutions.[15] The quality of individual components is becoming more and more of a decisive factor in the availability of the entire system. It was virtually impossible for robots to be sold without a statement of availability or "Mean time between failures"[16]. But even simple sensors such as light curtains were expected to be produced with a high level of quality and reliability, as high bay warehouses and logistics distribution centers essentially used several thousands of these individual components in their automated systems. Failure of one light barrier or electronic motor could bring entire truck loads of deliveries to a halt.

All of these developments have resulted in the availability of a multitude of high-quality components for handling technology automation on the market today. The introduction of these components in untapped industries will be made easier by the further differentiation of components. Today there are sensors that can withstand being placed in cold storage at temperatures as low as -40 °C, for example.

With the ever-increasing digitization of production, components are becoming information sources connected via a production network. Products are becoming more and more flexible and even lot size 1 production is becoming more economical. This vision brings new challenges and developmental possibilities for the automation components involved in handling technologies. This is explained in Chapters 3 and 4 and summarized in Chapter 5.