

Challenges and obstacles in robot-machining

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Using robots for machining, implies many advantages. By using the flexibility robots have to offer, workcells with high application versatility can be provided. Nevertheless, there are several challenges to overcome. This paper gives an overview about challenges robotic machining has already met. Besides these challenges, robot-machining still has to encounter obstacles resulting from the fact that robots have been solely handling devices so far. Furthermore, trends in robotic market are outlined by giving particular examples, emphasizing the willingness of industrial robot companies to provide robot-based machining systems.

machining, robotic workcells, CNC-programming

I. TRENDS IN AUTOMATION AND ROBOT MACHINING

Until today automation was only useful for production of large quantities. But gradually more and more tasks with lower quantities and higher mixes of work need to be automated. The fulfillment of this requirement is crucial for every country and even for every company to sustain competitiveness. Tremendous enhancement of computational power, as well as remarkable reductions of sensor and actuator costs are driving the demand for lean-manufacturing solutions forward. The main columns of desired lean-production are represented by attributes like flexibility and efficiency along with a healthy production [1]. This development in combination with the global economic crisis enforces the need for low cost but yet efficient and flexible manufacturing. The steadily growing market for lightweight constructions additionally supports the application of robot-based machining systems. Because of the weight saving of up to 60 % compared to aluminum constructions, fiber-reinforced plastics constitute a highly interesting choice of material particularly for the automotive industry [2]. Especially the automotive industry has to machine large-volume parts at high quantities. Robot-based machining systems are ideally suited for this application field. Primarily because they provide time saving by working efficiently with consistent cycle times.

Such systems are inherently more flexible and more cost effective than machining tools because of their serial kinematics. This results in a better work space-installation space-ratio as shown in Fig. 1 [3].

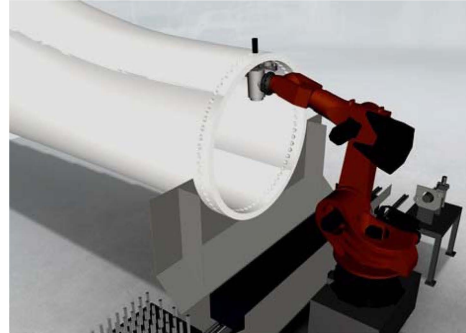


Fig. 1: robot (top) can substitute entire portal milling machines (bottom) (MAG IAS)

The figure shows exemplary a drilling operation at the root end of a blade for windmills. This operation is usually done on a portal milling machine as illustrated at the bottom. However the portal milling machine is not able to place all drill holes around the root end in one step. The root end has to be turned around several times to place all required drill holes. For this application, robotic machining represents the most suitable alternative. This is because a robots is capable of reaching all holes, as shown at the top of Fig. 1. Equipped with an external linear axis the work space can be arbitrarily enlarged and robots can even substitute whole portal milling machines.

II. PREPARING ROBOTS FOR MACHINING TASKS

To understand why robot machining is inevitable, it is helpful to look at the challenges machining tools have to meet. Most of these challenges constitute opportunities for robot-based machining systems to demonstrate their advantages and qualification. In the course of this discussion, it will also be shown, which of these challenges are already met by robot-based machining systems.

Robots have yet been used to automate machine un-/loading or other supporting measures. Therefore, the

plan of installing a robot always came with the question if there is available space on the shop floor. This space is mainly reserved for manual operations or restricted by other machines. Furthermore, robots usually require safety fences. However, a robot-based machining system will not be installed in addition to manual work stations or machining tools. It actually has the capability to replace both, the manual work station and the machining tool. This means, that the challenge of available space is even an argument in favor of robot-based machining systems. With the robot industry offering a variety of robot configurations, many space and system layout issues can be encountered. Together with changes in safety standards, robots can be installed within a compact area, simultaneously cooperating with other robots or even human workers, as shown in Fig. 2.



Fig. 2: robots cooperating (left) and interacting with humans (right) (Daimler AG)

Especially when machining fiber-reinforced plastics, an applicable chip extraction is indispensable. This second challenge is important, because usually no cooling lubricant is used for machining fiber-reinforced materials. The resulting dust can be electrically conducting and therefore damaging to every electronic device nearby. These dust particles can also be harmful to health. This makes chip extraction even more important. Many automation suppliers have recognized this challenge on machining tools before. Consequently, various chip management solutions have been developed and are already available on the market. Existing solutions for chip management on machining tools can be easily transferred and adapted on robotic workcells. One solution for chip extraction is shown on the left of Fig. 3. This is ideally adaptable for robotic workcells. The so called in-situ suction, which is shown on the right of Fig. 3, is also applicable for robot-based machining. By applying both measures for chip removal, it is possible to comply with this challenge.

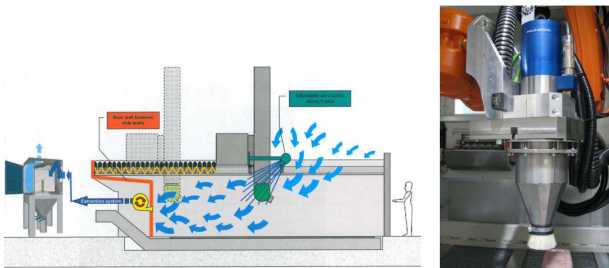


Fig. 3: left: suction in a machine (www.Handte.de); right: suction directly at the TCP (www.kraussmaffei.com)

Another challenge in automation is the recognition of parts and their orientation. This also provides the chance for robotic workcells to testify their flexibility. By using vision based technologies in cooperation with a robot, this challenge can be met with a highly flexible and low-cost solution. Parts and their orientation can be captured by the vision system, which forwards these information to the robot. Subsequently, the robot is able to pick up and handle the parts as requested [6]. The robots' ability of using a vision system and handling parts, makes noisy and expensive vibratory solutions or part channeling unnecessary. Parts can be presented in bulk or in a cage as shown in Fig. 4.



Fig. 4: separation of unsorted parts in a cage by a robot using a vision system (Fraunhofer IPA)

Looking at machining operations, certain steps are often necessary before and after machining parts. Some examples for pre- and post-operations can be setup and manual gaging of the process or deburring and other finishing steps. This challenge again constitutes an advantage of robot-based machining systems. If the system already works with a vision system, the information about location and orientation of parts for pre- and post-operations is already existing. The robot can be used to perform almost all pre- and post-operations by using different end-of-arm-tooling (EOAT) solutions. It is therefore possible to perform machining, as well as pre- and post-operations with the robot [4]. This reduces cost, space and time, because parts do not have to be transferred to a dedicated station for pre- or post-operations. By the use of lasers or other sensors, inspections in all varieties can also be done using the robot. This increases uptime of the robot-based system and again reduces costs.

Accessibility to the machine for tool changes or setup can be a further challenge in automation. As described before, a robot-based system can provide different EOAT solutions. Together with an automated tool changer, tools can be changed fast and without concern about safe access, which is needed when tools are changed manually. However, safe access can be achieved very easy by using appropriate workspace monitoring. With these features, robot-based machining systems can meet the listed challenges and provide an even better

alternative than machining tools regarding costs, flexibility and efficiency.

III. OBSTACLES AND MEASURES

Even though almost every challenge of automation can be met by robotic workcells, there are several obstacles which still have to be overcome. Robot-based machining systems have already undertaken finishing operations like chamfering and deburring [4]. But, machining harder materials e.g. steel and satisfying industrial requirements, constitutes an obstacle for robotic machining. It is the attainable accuracy that does not comply industrial tolerances. The inherent compliance resulting from gears and the serial linked kinematics causes oscillation in consequence of periodic forces due to the machining process. This leads to unacceptable surface quality.

A third obstacle for robot-based machining systems is that programming a robot for machining can be complicated. One reason for this is, that the robot programming language does not provide functions for machining tasks. So programming a robot for machining requires special trained staff.

These three identified obstacles,

1. insufficient rigidity,
2. poor accuracy and
3. complex programming,

have already been topic of numerous research projects [5][3].

Therefore, the attention will be focussed on how robotic market is trying to overcome these obstacles. It will not be an object of this study to discuss the origin of these obstacles.

A trend that points out the interest of robot manufacturers is the development of dedicated Robots for machining tasks. ABB introduced the ABB IRB 6660 with an additional parallelization of the serial kinematics for pre-machining operations, which is shown on the left of Fig. 5. In the middle of Fig. 5 the Stäubli RX170 hsm (high speed machining) robot is pictured. Its sixth axis has been substituted by a high-speed-cutting (HSC) spindle. This measure increases rigidity and precision by eliminating compliance and uncertainties due to an additional sixth axis [7]. The right of Fig. 5 illustrates the KUKA KR30 HA (high accuracy), which offers enhanced accuracy. KUKA also offers robots dedicated for machining and tooling like the KR 500-3 MT (machining tooling) with special gears to increase rigidity.



Fig. 5: Robots dedicated for machining applications (www.abb.de, www.staubli.com, www.kuka-robotics.com)

Another trend which shows the willingness to apply robots for machining operations is that CNC manufacturers as well as robot integrators are offering fully integrated robotic workcells such as the HRM 250 R workcell by MAG IAS GmbH shown in Fig. 6. This workcell is equipped with automatic tool changers, an HSC spindle and cryogenic cooling.



Fig. 6: fully integrated robotic workcell by MAG IAS GmbH (www.mag-ias.com)

Robotic workcells are more flexible than CNC milling machines and therefore a great alternative. At the same time it operates like a CNC milling machine and thus does not need special trained personnel. Basic requirement for this approach is the implementation of software, which integrates G-Code programming, trajectory-optimization and code generation for the robot control.

Such software allows to quickly generate robot-ready programs by creating trajectories from CAD/CAM information. Simplification of the complex programming is only possible, if the software also considers process- and robot-relevant factors. Robots have many parameters. For instance reach limits, joint limits and singularities. In addition collisions have to be avoided. Even if the robot is equipped with external axis. Only if all these factors have been taken into consideration, the optimization of trajectories can be expedient. The whole process can be reviewed before machining, if the software provides a simulation. If simulation shows that desired results cannot be achieved, parameters can be adapted.

There is already some software on the market providing this required functionality, for example Robotmaster, Mastercam, RobotWorx or IRBCAM.

Although robots already have a control system, it is necessary to add further Computerized-Numerical-Control (CNC). The robot control (RC) ensures the proceeding operations in the programmed order. The RC is therefore parameterized for the particular robot that it is attached to. For that reason RCs are always machine-related and the programming language is also dependent on the robot manufacturer. In contrast to that, CNCs are supposed to control the manufacturing of work pieces. Consequently they are not machine-related, because the focus is set on the contour, the work piece is supposed to have, after machining. For that reason it is important to combine the advantages of both control strategies. Fig. 7 shows such a combination. CNC runs parallel to the RC by KUKA on a separate kernel by ISG. The CNC contains functions which are needed for the machining

process. These CNC-specific functions, like tool radius compensation, are highlighted with a blue frame in Fig. 7.

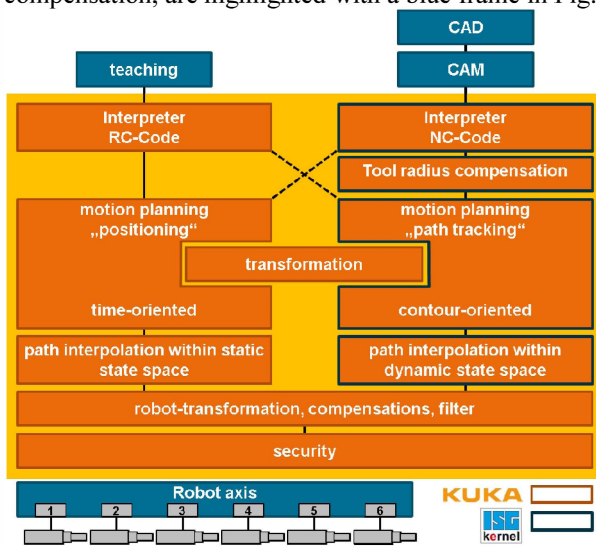


Fig. 7: combination of RC and CNC for machining operations (ISG GmbH)

Since RCs are usually given by the manufacturer, special compensation mechanisms such as elasticity-compensation are included. Furthermore RCs have optimized algorithms for robot-motion without any contour (f.e. PTP-motion). Robot-relevant parameters like singularities, reach limits and joint limits are also considered by the RC. As RCs are machine-related specialized robot-functions can be provided. Optimized transformations for the attached robot is another advantage of machine-related RC. These functionalities are important to quickly program robots for handling and automation tasks.

When machining work pieces, completely different movement strategies have to be applied. For machining tasks the contour and the surface quality are the focus and sophisticated algorithms have to ensure suitable movement. Functionalities such as correction of tool geometries, compensation of discordance, path-planning-methods (B-Splines, Akima-Splines, etc.), planning of path-dynamics or configurable contour-deviation have to be provided. The fact that robots are more compliant than machining tools makes additional functionalities necessary. These are for example minimization of oscillation and reduction of vibration excitation. All these functionalities can only be achieved by employing large numbers of fulcrums for one movement. The high quantity of fulcrums result in a high quantity of program sentences. As a consequence, an advanced look-ahead functionality has to be implemented to ensure appropriate path- and dynamics-planning. It is clear that the described functionalities are essential for high-quality-machining. On the other hand, these functionalities require very small cycle-times. Once again it has been shown that robot-based machining systems are dependent on enhanced computational power as well as the reduction of sensor and actuator costs. Since these criteria have already been met, it is only a matter of time until robot-based machining systems have overcome the described

obstacles and will be increasingly installed.

IV. CONCLUSION

Today, robots are mainly used for handling operations. Nonetheless, the economic development forces companies to increasingly deploy flexible, lean and efficient production systems. Robot-based machining systems are able to perform machining, handling, inspections as well as pre- and post-operations. Installing a robotic workcell for machining can reduce costs and space requirements. At the same time it increases net throughput.

The development in technology, in other words the reduction of sensor and actuator costs, the steadily increasing computational power and the boom in lightweight constructions, have been pushing robot-based machining system to become a serious option. This tendency is supported by robot and CNC manufacturers as well as robot integrators. Almost every challenge that robot-machining was posed to, has been met. It has been shown that current research in this field is dedicated to encounter the obstacles robot-based machining systems still have to overcome. Research and economic development give reason to expect that robots will be increasingly applied as machining robots.

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