I Motivation

Handling operations are a key factor for mass production of fiber-reinforced composites. Especially the handling and draping of air-permeable and flexible preforms is challenging.

The gap in the production chain becomes more and more apparent as the need for mass production of fiber-reinforced composites with their excellent properties, such as high specific stiffness and strength, arises. When utilized correctly, this class of materials is a key element towards energy-efficiency and efficient use of resources.

Another application in which fiber-reinforced materials offer great advantages are mechanically highly strained and accelerated applications such as machine tools and components in the automotive sector. A great reduction of moving masses is possible whilst maintaining the same, or even better, mechanical properties.

In addition, fiber-reinforced plastics can be finely adjusted in their material and component properties by combining different matrix materials, fibers and fiber structures as well as fiber orientations. These properties permit the manufacturing of highly integrated components with multiple functionalities in one part.

FRP can be divided into short fiber, long fiber and continuous fiber materials. Reinforcement with short and long fibers allows improved properties, but does not raise them to a level at which they could compete with conventional materials. For mechanically strained parts, and in order to fully utilize the before mentioned advantages of the material, the use of continuous fibers is necessary. Manufacturing of continuous fiber-reinforced components has so far, except for some specialized solutions, been a mainly manual process. One of the reasons for this lies in the fact that the sensitive textile materials cannot, or only with limitations, be handled with the existing automated handling methods.

In order to allow mass production of FRP components the process chain must be fully automated and monitored. The so far manually conducted sub-processes are not feasible for mass production and one of the reasons why fiber-reinforced plastics cannot yet compete with conventional (metallic) materials in regard to costs. Additionally, the poor reproducibility of manual production results in comparably low precision in placement of the fibers, furthermore underlining the need for a consistent and automated production chain. Hence it is imperative to realize an automated handling mechanism suited for textile blanks.

Whereas impermeable composites can be gripped by classical techniques of metalworking, currently, the problem of automated handling of textile blanks is not fully solved [1]. Technical textiles and their structures are sensitive regarding mechanical loads perpendicular to grain (shear forces) [2]. The approaches which have been developed so far have significant downsides and are hence not fully suited for mass production. Currently most commonly utilized is the needle gripper technology, which penetrates the textile blanks, hence causing damage and displacement to the fibers. This results in a negative influence on the properties of the finished part. The problem of fiber displacement is also existent when using Bernoulli or clamp grippers. Use of a suction gripper is energetically highly inefficient due to the permeability of the material and also brings the risk of deformation of the handled textile blank. Besides improved cost effectiveness, automated handling offers even more advantages. Smaller tolerances in manufacturing
result in improved material utilization and properties. This for example allows smaller part dimensions whilst maintaining the mechanical properties, saving weight and material whilst cutting down on costs.

To fulfill these new requirements, existing approaches were evaluated and new technologies were further developed at the Fraunhofer IPT. For the handling of air-permeable textile blanks, a new gripping mechanism based on electrostatic induction was researched and developed. Unlike common gripping technologies, electrostatic gripping allows mass-production compatible handling of flexible textile blanks, permitting cost-effective mass manufacturing of fiber-reinforced parts. The gripping mechanism is based on dielectric polarization of the gripped good, inducing evenly distributed attractive forces between gripper and gripped good.

In addition, kinematics for adaptation of the textile blanks to a curved surface have been developed. These newly developed gripper kinematics improve the currently manually realized processes and permit automatic handling processes. The blank is picked up from a flat surface (e.g. cutting table) and placed on a concave or convex surface without fiber displacement or damages.

Furthermore, an alternative system has been developed for handling without an external power supply. This technology is based on the adhesion mechanism similar to the feet of a gecko and offers the advantage of adhesion even during a total breakdown of the external power supply.

All gripper systems show strengths and weaknesses in different applications. Hence the gripper technologies must be rated depending on the specific application.

The following grippers were tested and evaluated using dry fibers, dry and saturated preforms as well as cured parts: Different Bernoulli grippers (see figure 3), needle grippers (see figure 4), fan grippers, vacuum grippers, bellow grippers, freeze grippers and adhesion grippers.

Using the Bernoulli gripper as an example, the strategy can be outlined as follows: The gripping force of the Bernoulli gripper is created using airflow over the surface of the gripped good. This airflow results in a lowered static pressure, inducing a gripping force of approximately 0.2 N per module. Due to the airflow only little, if any, direct contact between gripper and gripped good occurs. Possible contamination from the handling process can be easily cleaned from the surfaces.

The stationary air flow between gripper and gripped good results in constant gripping forces, allowing reliable pick-up and release of goods. Only little damage or deformation is caused by this gripper, but aeroelastic effects in the outer areas may damage the structure.

For operation of this gripper, only the gripper itself as well as a source of pressurized air is required. The consumption of pressurized air is rather high, but the system is relatively affordable. Pick-up, placement and separation properties of the system are sufficient.

Based on these characteristics a database has been created to allow a quick overview over the best suited technologies for a specific application. This was realized at the Fraunhofer IPT with the software tool “HandSup”.

2 Evaluation of different methods

During preliminary studies, different industrially available gripper systems (see figure 1) were evaluated by the Fraunhofer IPT regarding their gripping characteristics. Especially the gripping of dry, saturated and stiff fiber-reinforced parts has been evaluated. As fiber materials glass-, aramid- and carbon fibers were chosen and tested in form of fabric, non-crimp fabric as well as preforms.

Different criteria such as the gripping force and damage to the fiber structure were monitored and used to create an evaluation matrix.
HANDLING OF PREFORMS AND PREPREGS FOR MAS
PRODUCTION OF COMPOSITES

Fig. 1. Types of existing gripper systems

Fig. 2. Radar chart of the Bernoulli gripper for dry fabrics

Fig. 3. Evaluated Bernoulli gripper

Fig. 4. Evaluated needle gripper

Fig. 5. Design process of the handling Software “HandSup”

Fig. 6. Graphical user interface for entering the requirements of a particular application with generated evaluation results
3 Self-Adapting Gripper Kinematics

3.1 Design Concept of the Octopus Gripper

The Octopus gripper was developed by Fraunhofer IPT based on the fin-ray principle and allows an adaptation to curved shapes. One of the advantages of this technology is the fact that no actuators with corresponding feedback control systems are required. Furthermore these kinematics allow automatic adaptation to given convex as well as concave contours for the first time. The adaptation of the gripper arm to concave surfaces is enabled by compressible spring elements in the upper side of the framework structure (see figure 7 left-side).

Fig. 7. Function principle of the self-adapting arm and demonstration of the Octopus gripper

3.2 Multifunctional Handling System

The Octopus Gripper was designed for the handling of textile structures. During the deformation-free pick-up and handling of preforms and produced components, the octopus gripper kinematic allows an adaptation to three-dimensionally curved surfaces such as RTM tools, wind turbine blades or aerospace components such as wings or fuselages. For such applications the octopus gripper offers a reliable and affordable solution.

The nature-based principle was implemented into a prototype gripper system. Besides the kinematics, the gripper’s interfaces, connections and orientation of the individual gripper modules were researched.

The advantage in comparison to other systems based on the fin-ray principle is a feature which allows a reproducible neutral position, as the kinematics are locked in this position by limiting elements. This allows displacement- and wrinkle-free pick-up of goods placed on a flat surface. An adaptation to concave surfaces is not possible in this configuration, as the adaptation in this direction is stopped by the limiting elements. Hence this new system features additional elements which can be compressed to permit adaptation to a concave geometry whilst allowing a reproducible neutral position (see figure 9).

Besides the capability for self-adaptation, the kinematics can also be positioned e.g. by a pneumatic cylinder at the end of the arms. By implementing a position-controlled mechanism a defined position can be set. This is realized in the prototype system with a three-point controller, whilst the use of pneumatic cylinders in combination with pressure regulating valves allows a defined contact pressure to be used.

The utilized pneumatic cylinder is sufficient for the task. The correlation between pressure and force allows efficient control of the forces used. The conducted experiments showed that this force control is not required in the configuration with compressible elements in the kinematics, as these spring elements will give way, hence defining the contact pressure. Hence a position-controlled actuator is sufficient for operation, eliminating possible conflicts between force and position controls.

Another challenge is the combination of these kinematics with gripper modules. For a working system, both the grippers and the kinematics must be combined in a functional configuration. The current prototype utilized needle gripper, but the kinematics can also be combined with Bernoulli grippers, vacuum grippers or electrostatic gripper pads. For all gripper mechanisms it is extremely important that the correct orientation of the gripping elements towards the surface of the gripped good is maintained. The gripper elements must follow the adaptation of the kinematics, but must not induce additional strain into the gripped good. Hence a pivoting mechanism was integrated in between the arm segments, allowing a symmetrical orientation between the segments (see figure 10). This was achieved using leg springs on both sides of the gripper modules, ensuring symmetrical orientation. Tests have shown that this principle works reliably, allowing stable pick-up and release of the gripped goods.
4 Gripping mechanisms
4.1 Electrostatic gripper

Besides the self-adapting kinematics, a new form flexible gripper technology, called electrostatic gripper, has been developed further. This gripper polarizes the handled object and hence induces a gripping force [3, 4]. For this purpose different potentials are applied to the gripper electrode, resulting in an electrical field [5].

Opportunities

The new form flexible electrostatic system allows a reliable and damage-free handling of air-permeable and easily deformed textile blanks for the first time. Textiles with a grammage of up to 800 g/m² were successfully lifted with the new gripper system.
Release of the handled good is achieved with the newly introduced multi-potential power source (see figure 13) and a switching sequence (see figure 14) which reliably minimizes the occurring oriented polarization as well as the resulting parasitic attractive forces. This ensures a reproducible and reliable release of the gripped good regardless of the material being handled. Rigid organic sheets can be manipulated, too. The electrostatic gripper technology offers high potential for improving the handling process in the production of composites, as the system offers many advantages in comparison to the existing handling technologies.

The gripping technology utilizes evenly distributed surface attraction and can hence handle goods without distortion or shifting. Additionally the handled goods can be separated from stacks reliably. End-effectors with different pads interconnected to clusters, which can be activated individually, can be useful for handling of different cutting geometries, which change during the production.

**Function Principle**

The gripper was developed based on fundamental research and is based on the principle of dielectric polarization of the gripped good which had not yet been applied to fiber-reinforced parts and blanks before this project. Different voltages are applied to a gripper electrode, inducing an electric field. The gripped good is polarized by the shifting of charges and hence attracted to the gripper. The resulting attractive forces are virtually evenly distributed over the gripper’s surface.

This effect was researched looking for an application as a gripper. For this research, a first prototype system had to be designed and built. This unit is equipped with two high-voltage power supplies, allowing a negative and a positive potential to be created simultaneously. To connect the voltage sources to the different channels, a high voltage switching array is used (see figure 14). This allows different fields to be generated by the gripper. Due to the independent controls for the switching array and voltage sources, this setup offers maximum flexibility in regard to field strength and type.

On this setup, the occurring effects as well as gripping forces were analyzed. Based on the results from these experiments it is possible to determine gripping characteristics for this system, allowing the determination of the next steps in research.

With the newly introduced multi-potential source it was possible to reliably minimize the occurring orientation polarization as well as the resulting parasitical gripping forces. Experiments have shown that polarizable materials continue to induce an electric field due to the remaining orientation of charges, hence causing gripping forces even after the gripper has been turned off. This effect makes reliable handling in an industrial application impossible, as the attractive forces diminish very slowly. Further trials resulted in a technology which allows reliable release of the gripped goods. By inverting the potentials whilst reducing the amplitude of the voltage multiple times, a defined reduction of the attractive forces could be achieved. This method is only possible with a multi-potential source, as the fields have to be weakened symmetrically around the ground potential. This made reproducible release of the gripped goods possible without the use of additional mechanisms.

By using flexible electrodes, it is also possible for the first time to adapt to curved surfaces (see figure 15). This allows the gripper as well as the gripped good to be adapted continuously.

Long-term trials have also shown that the gripping forces do not diminish over time. If the potential remains activated, the gripped goods will adhere to the gripper’s surface indefinitely and will only be released after the potential has been turned off respectively the release loop was run.

Further effects could be observed during build-up of the gripping forces. For example, it could be observed that the gripping forces were diminished after multiple gripping cycles. This effect could be circumvented by grounding of the electrostatic contact surface. For this, the gripper is placed in contact with a grounded surface without carrying a gripped good. It is presumed that the air molecules are ionized partially due to the high electrical fields and afterwards attracted by the electrical field. This may result in weakened attractive forces towards the gripped good.
developed gripper system throughout the production chain, offering great potential for automation as well.

4.2 Gecko gripper

The Gecko gripper generates the gripping forces without an external energy supply. The gripping good is attracted by Van der Waals forces which are induced by the polymer sheet. The gripping and lay down process is similar to the principle by which gecko feet can be attached and released from objects. To pick up an object, the gripping pad is rolled out to build up the adhesive forces between the work piece and gripper. The release mechanism works in reverse. Upon release, the separating forces are greatly reduced by peeling of the polymer sheet.

Conclusions: Electrostatic gripping

The electrostatic gripper system shows tremendous potential for handling of light and air-permeable materials such as textile blanks. In combination with the octopus kinematics it is even possible to combine draping and handling in one system, offering an ideal solution for large-scale automated production.

Composite sheets, currently also difficult to handle in automated processes, can be handled with the
Opportunities
This technology is able to handle almost any kind of surface. In addition, the goods are held in place even after a failure of the power supply. Nevertheless, flexible goods can be rolled in during the release process. In addition, the system is vulnerable to contamination, since the adhesive effect cannot be switched off. However, the polymer sheet can be washed to remove particles contaminating the surface.

Conclusions: Gecko gripper
The gripping method generally works for handling relatively rigid materials. The drawbacks, such as vulnerability to contamination, mean that the gecko gripper cannot compete with common gripper systems such as vacuum grippers.

5 Handling of thermoplastic composite sheets
Within the EU large-scale research project "FibreChain", the Fraunhofer IPT is developing concepts for handling of thermoplastic composite sheets during the whole production chain. The main challenge is the handling of thermoplastic composite sheets during heating, as the moldable material must be pre-tensioned to prevent major distortions during handling or forming. Research at the Fraunhofer IPT focused on a clamping approach which is spring-tensioned to allow permanent tension on the sheet and additionally allow material to be drawn into the forming process as needed. This is required, as e.g. a dome shape being formed into thermoplastic composite sheets will cause the material to be shifted, requiring additional material to be fed from the sides of the form. This is achieved by a guided clamp with springs for tension.

Another challenge lies in the heating process, as the clamps must be able to withstand the heat of the heating process and in addition not cool down the thermoplastic composite sheet excessively, as this will cause it to harden inside of the clamp, making the necessary shifting of the material impossible.

To achieve a reasonable compromise, the current prototype concept consists of multiple smaller clamps which are independently mounted to allow maximum flexibility.

Additional research is being conducted regarding heating and temperature regulation of the clamps to ensure consistent temperatures throughout the process.

6 Summary
In summary, it can be stated that a significant knowledge and experience growth was generated by researching the different gripper technologies. In particular, the growth of knowledge lies in the field of the electrostatic gripper, as almost no experience with electrostatic gripping has been gathered before. It is found that electrostatic gripping has distinct advantages over other gripper technologies. The principle is a good and reliable way to separate textiles. In addition, air-permeable semi-finished products, which were previously manipulated only with great difficulties and limitations with needle grippers or under a huge amount of energy with vacuum grippers can be handled, now. Consequently process steps can be automated, which means a significant technological advance has been achieved.

The above presented self-adaptive gripper kinematics, called octopus gripper, can be transformed into an industrial system with the gained experience.

Great potential lies within the combination of the self-adaptive octopus gripper kinematics and the electrostatic gripper technology by using flexible electrostatic pads (see figure 18). The electrostatic gripper itself offers many unique advantages. One of the main features of this technology are the virtually uniform gripping forces, allowing damage- and deformation-free handling of sensitive goods. The possibility of selective pick-up from stacks as well
as functional integration of application-specific features furthermore qualifies the electrostatic gripper for mass-production applications with short cycle times.

Research at the Fraunhofer IPT has shown that great synergy effects can be achieved when combining these unique advantages with the features of the octopus gripper kinematic. This fin-ray principle based technology, requiring minimal control electronics whilst maintaining maximum flexibility, permits draping of textiles on both concave and convex surfaces. By implementing a flexible gripper electrode for the electrostatic gripper, the combination of these two technologies was made possible at the Fraunhofer IPT.

By combining both technologies, it is possible to pick up and place textile blanks on curved as well as flat surfaces. Furthermore it is even possible to pre-drape the handled good during the handling process, reducing damages to the textile and further reducing cycle times.

The researched principles can provide an important step towards the transfer of fiber-reinforced plastics into mass production. In the long term this will result in great economic and ecological advances, as the technology is cost-, energy- and weight-saving compared to other solutions.

Fig. 18. Generated synergy effects by combining Octopus gripper and electrostatic gripping principle by using a flexible pad

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