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Manufacturing of textile preforms with an intelligent draping and gripping system

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Abstract

In this paper, a novel pixel-based draping and gripping unit will be presented. To monitor and control the draping during the forming of a stack of semi-finished textiles, the pixels are equipped with integrated sensors. With these sensors, it is possible to adjust the tangential sliding and the normal holding force at each pixel. The sensor principle is based on the electrical conductivity of carbon fibers. Electrodes inside the gripping system allow a conclusion to the gripping force between the gripper and the carbon textile. Therefore, the gripping force can be adjusted to the special boundary conditions during the draping process.

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Keywords: Handling; Sensor; Fiber reinforced plastic; Forming

1. Introduction

The use of lightweight materials becomes more important for many areas. Reduction of weight has positive effects especially in electric mobility on driving range or the necessary battery size of the vehicle [1]. Adequate to this one increasingly tries to produce structural components of the vehicle out of light but still resistant materials like fiber-reinforced plastics and others to save weight. This will lead to a higher consumption of carbon fiber in the automotive industry within the next 20 years [2]. The use of lightweight materials in the field of the automotive industry must meet a set of requirements. This field demands high output figures, short process times, and cost-efficient processes [3]. These requirements are prohibitive through manual execution of necessary process steps. Nonetheless, many production processes for components made from fiber-reinforced plastics, like Resin-Transfer-Molding (RTM), are characterized by manually executed sub-processes [4]. However, this procedure has the potential to produce components in fast sequences through continuous automated sub-processes [5].

The first step to be able to infiltrate a component with the RTM-process is to create a preform. A preform is a dry but still near-net-shaped semi-finished product whose fiber shows a resistant orientation [6]. To produce such a preform, frequently multiple layers of different textile pre-cut fiber are stacked to a layer structure, remodeled, and fixed to each other [7]. The building of a layer structure is accordingly handling-intensive. Likewise, this applies to remodeling of the fibers to the desired shape. This is also called to drape.

The basic idea of a drape gripper is the combining of both sub-processes handling and draping into one system. This would allow production of preforms, which will be infiltrated, quicker and therefore cheaper. A range of systems already exist that implement handling and draping simultaneously [8][9][10]. The unique selling point of the here presented drape gripper is the support of the drape and handling process through integrated sensors inside the gripper surface.

2. Requirements of a draping system

A system to handle and drape the semi-finished product's location must meet the requirements of both sub-processes, handling and draping. The preform's construction sequence through the draping gripper can be divided in the following sub steps and is illustrated in Fig. 1.

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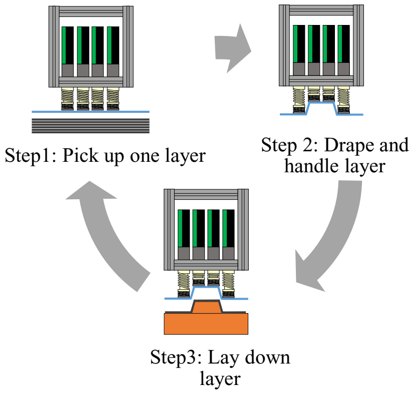

Fig. 1. Process steps of draping and handling in the manufacturing of preforms

First (Step 1), a single layer is taken out of stock. During Step 2 the movement of the layer from inventory to a platform occurs. At the same time the layer is formed from a two-dimensional state to a three-dimensional near-net-shape form. Last, the now remodeled layer is placed on a platform where other layers can already be located at. This sequence is repeated until all required layers are located on the platform. The preform is now completed and can be infiltrated. From this described process, different requirements follow for the drape gripper due to handling and draping. Handling covers the seperation steps of taking a hold of, moving, and laying down the layer [11]. Out of these single steps, especially the intake of a single layer out of storage is a key challenge in automation of handling [12]. This step must also be accomplished in a way that the remaining layers are not affected in their orientation or placement [13]. No impermissible deformation or damage may occur while moving a layer [14]. Likewise, orientation and placement of the grabbed layer must be secured during movement [15]. The separation process, as well as the following movement, must be performed at a high level of reliability so that the course of the overall process is not disturbed.

Demands for the drape gripper also develop from draping. The system requires appropriate kinematics to illustrate the desired shape. Shifts occur in remodeling textiles when the layer is transformed from a two-dimensional into a three-dimensional state. Then again, textiles do not dispose of plastic properties. If a layer is fixed, shifts and non-plastic behavior bring structural deformation [16]. To avoid such errors, the textile must be able to level off while being transformed. Tangential shifts must be possible for the textile. Allowing tangential shifts creates a conflict with requirements of handling. It is demanded to grab the component during movement in a way that no alterations of position and orientation occur. This conflict can be resolved if the drape gripper can allow tangential shifts only in specific parts of the textile and holds every other part securely.

Realizations have shown that many conditions derive from requirements of handling and draping especially for gripping technology. On one hand, gripping technology must allow reliable separation of single layers from big stocks. On the other hand, while reshaping, specific parts of the layer must be securely fixed, as well as other parts the textile must be able to shift. Also, at the same time during these processes, it is necessary to ensure that the textile is not detached from the drape gripper. If the system is supposed to be applicable to different layer shapes and three-dimensional geometries without modification, every gripper needs to be able to turn on or off the allowance or blocking of tangential shifts. A drape gripper's kinematics must also offer flexibility.

3. Implemented draping system

In accordance with the requirements detailed in the last chapter, wbk Institute of Production Science has developed a drape gripper within the research project HyPro (Fig. 2).

Fig. 2. Drape gripper with ten hexagonal pixels

It consists of ten separate controllable hexagonal pixels, while every pixel has a circumference radius of 44 mm. This regular division of the total area into hexagonal fields allows to cover different three-dimensional geometries. Each pixel disposes of a separate controllable z-axis. This allows to implement various three-dimensional shapes. As seen in Fig. 3, grip force to hold the layer is generated by a built-in Coanda-gripper in every pixel.

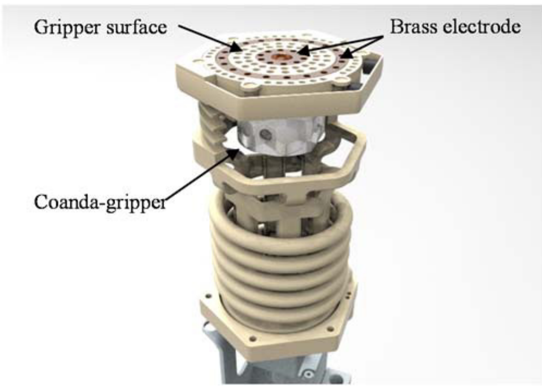

Fig. 3. Structure of a gripper pixel

To control the Coanda-gripper, every unit has a separate proportional valve. It regulates the input pressurized air p_N on the Coanda-gripper, whereby its generated grip force is controllable. On the gripper's surface are two separate brass electrodes. These electrodes form the sensor system with which the pressing force of the textile can be measured on the gripper surface. This allows a control of the gripping process to implement shifts of the textile or separate a single layer out of stock.

4. Sensor based gripping for draping system

4.1. Gripper technology of drape grippers

Multiple requirements for the gripper system of a drape gripper severely limit the solution space of selecting a gripping technology. Generally, gripping technology is classified into form lock, adhesive bond, and adhesive friction [17]. To allow or prevent the in previously identified requirements of tangential variability movements, form-fitting and firmly bonded gripping technologies can be excluded. Grippers in these categories, such as the needle or freezing gripper, do not allow active or very little impact on grip force while handling. Out of clamp-, electrostatic-, Bernoulli-, and low-pressure-surface-grippers, low-pressure-surface-grippers have generally proven to be very suitable [18][13][7][19]. The Coanda-gripper used here is one of these low-pressure-surface-grippers.

4.2. Forces while handling

Low-pressure surface-grippers produce a relatively low differential pressure through a high volumetric flow, which grabs an item to be handled [11]. The necessary airflow can be generated in different ways. A possible principle is the Coanda effect, which is viewed hereinafter. The gripping force to be generated develops by airflow along a fixed crooked surface without detachment. This airflow carries the ambient air inside of the gripper along whereby negative pressure arises [20]. The arising negative pressure p_U inside of the gripper and the actual suction area A_{EFF} result by [21] (Equation 1) in general in the retention force under low-pressure-surface-grippers.

$$F_H = A_{EFF} \cdot p_U \tag{1}$$

To allow the retention force to grab the textile layer securely, it must be bigger than the necessary normal forces F_N and tangential forces F_T to the gripper surface. From this, it follows with the friction coefficient μ between textile and gripper and security S based on [21] that:

$$F_H \geq S \cdot F_N + \frac{1}{\mu} \cdot F_T \tag{2}$$

If the retention force F_H is just big enough to compensate normal forces F_N, few reserves are left over to contain tangential forces F_T. Accordingly, textiles can be moved on the gripper without falling off. Necessary force F_N and producible force F_H depend on many factors. F_N contains the mass of the textile and the effect of gravitational acceleration on itself. Along with it comes the effect of additional acceleration processes while handling and unforeseeable disruptions. Due to these factors, no precise analysis of the necessary force F_N can be made, particularly because all are undergoing temporal changes by handling processes. The arising retention force of the gripper F_H is according to Equation 1 depending on the emerging negative pressure p_U inside of the gripper and the effective suction area A_{EFF}. Which p_U arises inside of the gripper is influenced by the supply pressure p_N and obstacles that must be passed by the airflow to get to the gripper. These obstacles are the perforated gripper surface (Fig. 3) and the grabbed textile. These two obstacles can be taken into account through a combined air permeability R_K as parameters to estimate the arising negative pressure inside of the gripper p_U. Permeability to air can be ascertained by an appropriate test facility under DIN EN ISO 9237. During an experimental procedure 17 different materials were grabbed. Supply pressure p_N has been varied and the arising negative pressure p_U has been measured. An overview of the measurements are shown in Fig. 4

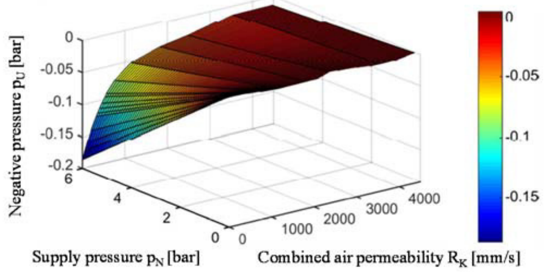

Fig. 4. Negative pressure in dependence on supply pressure and the combined air permeability

These tests intimate that the arising negative pressure p_U is linear dependent on supply pressure p_N under constant combined air permeability R_K. Supply pressure p_N, therefore, is a suitable instrument to control the retention force F_H of the gripper by combined air permeability R_K and the effective suction area A_{EFF}. It is problematic that properties of textiles, like air permeability and other parameters, can change within a single material role [22][23]. This also influences the combined air permeability R_K. It shows that both the evaluation of generated grip force F_H and the required grip force F_N can contain high degrees of uncertainty and can vary temporally while transport a textile. As such, an active measuring method is needed on whose base the grip force F_H is regulated through the supply pressure p_N. This allows an adjustment for unpredictable changes.

4.3. Sensor Technology

Contact resistance between two conductive bodies basically depends on the force that presses both together [24]. Corresponding to this the quantifiable resistance between both electrodes of the gripper area (Fig. 5) declines the more the conductive carbon fiber textile is pressed against it.

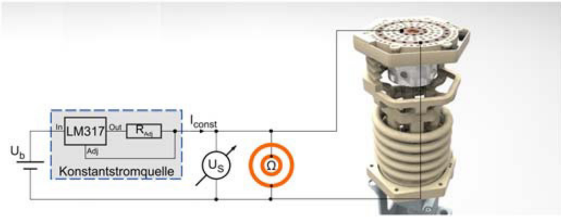

Fig. 5. Sensor principle

Gripper force F_H sucks the textile onto the gripper surface. The mass of the textile combined with gravitational- and other motion accelerations result in the force F_N, which would lead to detachment of textile and gripper surface. Once both forces are set against each other, the resulting contact pressing force F_A of the textile onto the gripper area emerges (Equation 3).

$$F_A = F_H - F_N \quad (3)$$

Electrical resistance can be measured through applied voltage U_S by using a constant current source (Fig. 5). If a textile is grabbed by such an equipped gripper and supply pressure p_N slowly sinks starting from 2 bar, a distribution of the sensor voltage results as shown in Fig. 6.

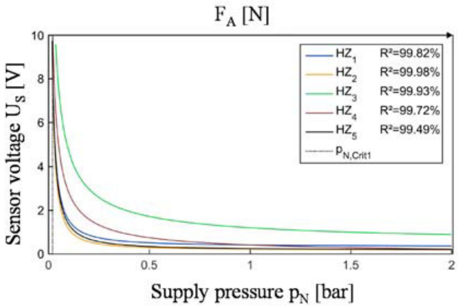

Fig. 6. Distribution of sensor voltage U_S over supply pressure p_N

The graphic shows sensor values of five different textiles, which all weigh 6 g. No other forces or errors besides its own weight force interact with the textile. One can observe that a low p_N leads to an increase of contact resistance between electrode and textile which also increases the sensor voltage U_S. Once a critical point $p_{N,Crit1}$ is reached, the resulting contact pressing force F_A drops to zero and the semi-finished product is released by the gripper. Resistance increases to infinity and U_S takes on the maximum possible value of supply voltage U_b. The resulting contact pressing force F_A is therefore quantifiable by the sensor value U_S. The moment when $F_A = 0$ can occur through measurement of sensor voltage U_S at the time $p_{N,Crit1}$. If a as low as possible contact pressure of a textile onto the gripper surface wanted to be realized, the sensor value U_S must be chosen in a way that it is just before the critical point $p_{N,Crit1}$. The sensors resolution is particularly high by low p_N . Distinction between individual values gets progressively harder for high p_N.

4.4. Control based on sensor values

Contact pressing force F_A can be regulated by supply pressure p_N based on the sensor value U_S. Its relevant control loop is shown in Fig. 7. Control parameter p_N is adjusted by a proportional valve.

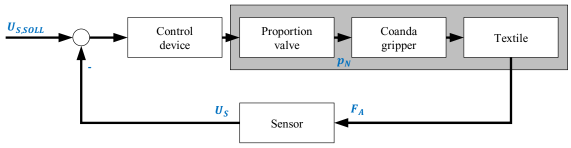

Fig. 7. Control loop of contact pressing force over working pressure of the gripper

The shown sensor history of $U_S(p_N)$ has a non-linear character. For control, linear sequences are more suitable, as controller synthesis is less prone to error [25]. Due to this reason the non-linear sequence of $U_S(p_N)$ is linearized through a non-linear compensation function $\Lambda(U_S)$ (Equation 4).

$$\overline{U_S}(p_N) = \Lambda(U_S) \cdot U_S(p_N) \quad (4)$$

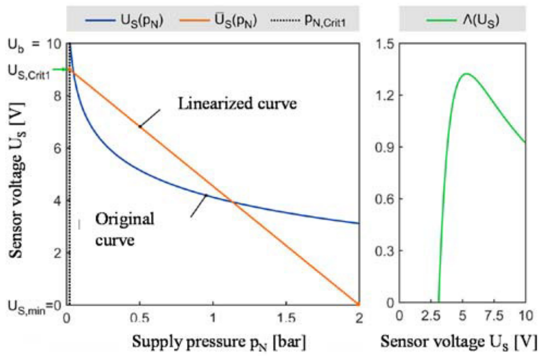

Fig. 8. Linearization of sensor curves

Necessary points to determine a linear curve are the starting point at $p_{N,Crit1}$ with its associated $U_{S,Crit1}$ and the endpoint at $p_N(Z_{min})$ with $U_{S,min}$. To determine this point Z_{min} is needed, which is the minimum alternation of the sensor value in dependence on the alternation of the supply pressure $\Delta U_S(\Delta p_N)$. It depends on technical edge conditions of the evaluation electronics (Fig. 5) like supply voltage U_b and the resolution of the analog-to-digital conversion.

4.5. Separation and calibration of necessary characteristic values

The presented sensor technology and control can also be used to grab a single layer from a multilayer batch. If the grip force used is just enough to take hold of one layer, all the others remain in stock. Furthermore, a reduction of the operative negative pressure p_U occurs the more layers it must penetrate. Based on [26] the operative negative pressure between layer one and two ($p_{U,12}$) can be estimated by Equation 5, while ρ is the density of the textile. This situation favors the separation process. With it the operative negative pressure between layer one and two is smaller than the negative pressure p_U between gripper and layer one.

$$p_{12} = 10^{-4} \cdot \frac{\rho}{2} \cdot (a_{11} \cdot p_U{}^{b11})^2 \quad (5)$$

The minimum contact pressing force F_A can serve as an indicated value for a conversion of a just sufficient grip force. Thereby, the execution of separation is based on the same principle as the toleration of translational shifts of textile remodeling. The most important parameter to implement small grip forces is the size of the sensor $U_{S,Crit1}$, because the textile detaches itself from the semi-finished product at this value. If an appropriate distance κ is kept to this critical value, it allows separation. Calculation of κ has been proven in use by Equation 6.

$$\kappa = 0{,}016 \cdot U_{S,Crit1} \quad (6)$$

Sensor value $U_{S,Crit1}$ of a textile is independent on the mass of the layer by which calibration is realized. Analogous, a simple reference piece of the textile can be used for calibration before the first handling.

A testing stand that works after this sensor principle, carried out 29347 separation tests. Merely three incorrect realizations occurred. A success rate of for the separation process of 99.9898% can be calculated.

5. Conclusion and outlook

It has been shown that the demands on the gripper system of a drape gripper are extremely diverse. General demands of automated handling like execution of separation processes, are required as permitting and denying translational shifts of the textile on the gripper. These richly diverse requirements can be met by a low-pressure surface gripper. Quantification of contact pressing force on the gripper's surface enable in this context a high degree of reliability during the separation process. It has been shown that through measurement of contact resistance between textile and implemented electrodes control is made possible. Now kinematics is available to realize drape processes as well as sensor technology to actively influence contact pressing force on each gripper pixel. The built prototype can be seen in Fig. 9.

Fig. 9. Built prototype of a drape gripper

Further studies will engage with the development and derivation of drape strategies, which will exploit the here presented mechanisms. Combination of controllable deformation and grip force can be used for aimed influence on fiber orientation. Even reduction of probability of defects inside of the textile through draping is imaginable.

Acknowledgments

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