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Model based design of process-specific handling tools for workpieces with many variants in shape and material

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ABSTRACT

A major driver for competition in end-consumer markets is product individualization with regard to functionalities, shape and design. This trend calls for more flexible and versatile production systems. In anticipation of this challenge a new concept for form-flexible handling devices is proposed. It involves a vacuum system in combination with a gripper cushion that is filled with granules. The novel working principle demands a model based design to realize a fast process integration. The feasibility of this concept and the design process are shown in a preforming process. Benefits of such handling tools in versatile production systems are discussed.

1. Introduction

Due to an increasing product variety, the objects that have to be handled in automated production processes vary greatly in their shape, size, weight, surface quality and stiffness. The use of a huge range of different handling devices, such as grippers, in logistic and production is necessary. This results in high costs for procurement, maintenance and storage of this great number of grippers. For an efficient production, these cost have to be cut down; in first place by a reduced number of grippers. But, despite less grippers, the product variety has to be handled by the devices in use. This demands for flexible and adaptable gripper systems. Therefore, the research field of production technologies has to provide novel approaches for factory planning, the development of adapted production processes and the integration of new handling systems which meet the challenges of today's market [1–4].

Besides coping with the rising number of product variants, the handling of non-rigid materials, such as textiles or leather plies, states another challenge for modern production systems, challenges which cannot be solved with existing gripper systems. Currently, grippers on the basis of standard components are used for these applications. New production technologies, such as the fabrication of fiber-reinforced plastics, require solutions that cannot be provided by handling systems for rigid goods. In addition to the handling of limp and often porous materials, process steps such as forming or heating must be considered and integrated into the standard handling process. The integration of functions cannot be realized by currently available systems either.

In summary, highly flexible and adaptable handling systems are required that meet the requirements of a modern production with an increasing product individualization and new production processes. These novel approaches must be designed in such a way that they enable a fast set-up, low acquisition, operation and maintenance costs for versatile production systems. By increasing the adaptability of these systems, also their reusability increases, which carries a high savings potential [4,5].

2. Design of a novel approach for form-flexible handling

The situation as described in the introduction triggered the development of a novel grasping technology from which grippers could be derived which have the ability to meet the requirements of today's market. For the development process three main requirements were considered:

- **High adaptability** of the gripper with a mechanism that is as simple as possible (consisting of a small number or non-active driven parts).
- **Handling of very different objects**, such as complex shaped, flat, limp or porous objects, can be achieved with the novel gripper design.
- **Combination of gripping principles** increases the range of applications that can be considered for a novel gripper concept.

The triggered development process led to a concept for a form-flexible handling technology. This new approach bases on findings as presented in [6,7]. In the following, it will be named *FormHand concept* (form-flexible handling technology). Kunz et al. and Löchte et al. [7–9] present a detailed description of the concept. The following section provides the basis for a further discussion of the FormHand concept.

2.1. The FormHand concept

This section describes the basic working principle of the proposed concept for form-flexible handling devices. The setup is

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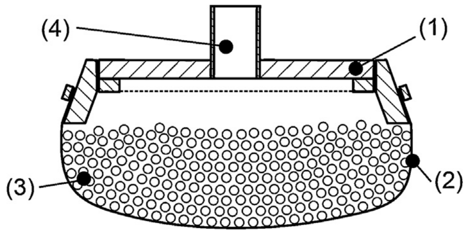

Fig. 1. Setup of a gripper which bases on the FormHand concept.

shown in Fig. 1. A gripper that is derived from the FormHand concept consists of a base frame (1) and a gripper cushion (2). This is filled with granular material (3). The base frame provides a connector (4) for a tube that can lead an airflow through the gripper cushion.

An external blower provides an airflow which leads to a jamming of the particles (see Fig. 2) and a hardening of the gripper cushion. Similar effects are used in concepts as described in [6] for gripping objects by form-closure. This gripping principle is extended by the FormHand concept by a permeable area at the bottom of the cushion. In this area the gripping of an object by the applied airflow (force-closure by suction) is realized additionally, see Fig. 2.

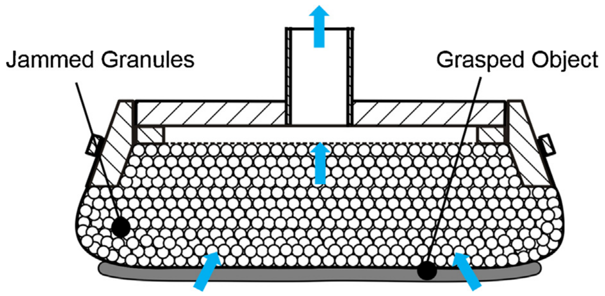

Fig. 2. FormHand gripper with applied airflow while grasping a flat, limp (non-rigid) and porous object, such as a textile cut-out.

After the construction of different gripper samples [7] that were derived from the FormHand concept and their implementation into a robot cell, evaluation tests were carried out. These proved the applicability of the concept for the described challenges of versatile production systems with a high product variety. The consecutive handling of different shaped objects was realized without the need to reconfigure the gripper samples. In this case the process becomes easier and takes advantage of the high adaptability and the combination of grasping principles of the FormHand concept.

Another application of FormHand grippers in an automated preforming process [8,9] showed the need for a more detailed description of the working principle, which allows for a model based and process specific design of such grippers.

2.2. Motivation for modeling

The evaluation tests in an automated preforming process showed the special behavior of non-rigid fabrics, such as carbon or glass fiber cut-outs. Seliger et al. [10] describes this behavior and summarizes the challenges for an automated handling process. In combination with the gripper cushion and the characteristics of the granular material inside it, an iterative design process for each application is necessary. The construction and try-out of each gripper provide better knowledge on the required process variables, which leads to an adjusted design. This procedure evokes a time consuming design process which triggers the need for models that allow for a targeted design of grippers and a direct determination of process variables.

This need is endorsed by the fact that there are no defined or discrete operation states of a FormHand gripper, such as *open* or *closed* gripper jaws. Beyond that, there are no characteristic diagrams that could be used for dimensioning the peripheral environment (e.g. blower or robot) or required process forces for gripping or pressing (e.g. while draping in preforming).

The following section introduces an approach for modeling the FormHand concept with the aim to provide a first step toward a model based process design. A focus lies on defining operation states and identifying their influencing factors.

3. Modeling the FormHand concept

There are several factors that have a direct influence on the behavior of grippers that are derived from the FormHand concept. Fig. 3 gives an overview of these factors.

- The **structure and control of a robot** or a moving unit give a limit to the trajectory of the end-effector. This has a direct effect on the manipulation of the granular material inside the gripper cushion. Due to the movement of the robot the filling can be compacted or distributed in a different way.
- The **handled object or workpiece** have a great influence on the required airflow. Characteristics such as very high or very low stiffness, different weights or sizes have to be considered.
- The **blower** that provides the required airflow and pressure difference for gripping different objects is a part of the peripheral environment which has to be dimensioned and controlled while operating a FormHand device.
- The setup and **design of the gripper** – most important is the selection of materials for the gripper cushion and its filling, the granular material. There are several material combinations with a set of characteristic properties, such as porosity, stiffness, durability or flowability. Additionally, the size of the gripper cushion and the layout of other components, such as the airflow connector, have a great impact on the fluidal behavior of a FormHand gripper.

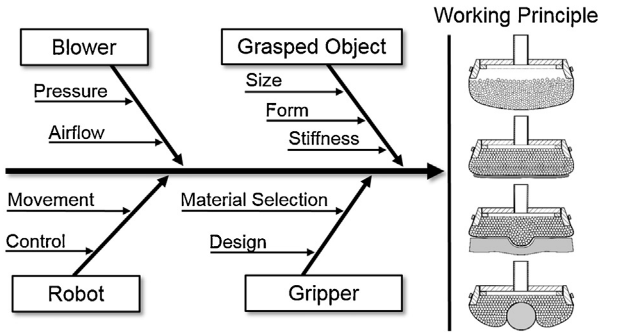

Fig. 3. Overview of influencing factors on the behavior of grippers that are derived from the FormHand concept.

The described influencing factors can be grouped, which allows for a separated modeling of complementary subsystems of each FormHand gripper. There is a **fluid dynamic subsystem** that covers factors such as pressure differences, intensity of the airflow, porosity of the used materials and the handled objects. This is completed by a **mechanical subsystem** that describes the influence of the robot's movement, the trajectory of the end-effector, the material effects while compacting the granular material and the transition of operation states.

The following sections describe these models which are used for a targeted design process. Beyond that, these models are used for planning further evaluation tests.

3.1. Fluid dynamic subsystem

This model bases on the fundamental laws of fluid dynamic systems. It is an analytical description of the subsystem which assumes in a first approximation that the flow resistance inside the gripper cushion is evenly distributed. Besides that, it is assumed