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A novel gripper for battery electrodes based on the Bernoulli-principle with integrated exhaust air compensation

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Abstract

During the assembly of battery cells, handling of the single sheet electrodes is a critical task. The electrodes have to be handled with high accuracy, low mechanical loads and low chemical contamination of the electrodes as well as the production environment. Especially lifting of electrodes with state-of-the-art area vacuum grippers causes immense mechanical stress which may lead to structural damage of the electrodes. This will ultimately lead to lowered performance of the cell or even in total failure of the whole cell. One way to overcome this problem is the use of grippers based on the Bernoulli principle which can lift grippers from a certain distance without direct contact but blow off their exhaust air into the production environment which has to be prevented in the dry room environment. This paper presents a concept to overcome this problem to enable the use of Bernoulli-grippers for the handling battery electrodes.

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1. Introduction and background

Due to the increasing scarcity of fossil fuels and the rising demand for individual mobility the German Federal Government set the objective for Germany to become a leading supplier of electric vehicles. Cost effective and efficient energy storage systems have been identified as one of the key challenges to meet the goal of one million electric vehicles in Germany until the year 2020 [1]. The importance of battery manufacturing is underlined by the fact that about 50 % of the whole battery system costs are composed of the costs for battery cells [2]. At the same time German and European companies do not have as much experience in battery manufacturing as Asian companies. To reach the objective of becoming leading supplier for electric vehicles, production facilities for large format battery cells as well as the corresponding know-how have to be established in Germany [1].

The requirements of large scale batteries for automotive applications concerning reproducibility, performance and safety are high as well as the requirements concerning cost-effectiveness. These goals can be reached by a high level of automation.

One of the critical steps in production automation of battery cells with single sheet electrodes is the automated handling of them. The electrodes have to be handled precisely to achieve best battery performance but with low mechanical stresses induced to the electrodes. Especially lifting of electrodes with state-of-the-art area vacuum grippers causes immense mechanical stress which can lead to damage of the electrodes resulting in the failure of the whole cell. In addition to that the

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production of battery cells has to be carried out in dry room atmosphere [3].

During the assembly of battery cells, handling of the single sheet electrodes is a critical task. The electrodes have to be handled with high accuracy, low mechanical loads and low chemical contamination [4] of the electrodes as well as the production environment. Especially lifting of electrodes with state-of-the-art area vacuum grippers causes immense mechanical stress which may lead to structural damage of the electrodes, which will ultimately lead to lowered performance of the cell of even in total failure of the whole cell. One way to overcome this problem is the use of grippers based on the Bernoulli principle which can lift grippers from a certain distance (lift-off distance) without direct contact. State-of-the-art Bernoulli grippers are not feasible for this use as their exhaust air is blown off into the production environment, which has to be prevented in the dry room production environment. This paper presents a concept to overcome this problem and enable the use of Bernoulli-grippers for the handling of battery electrodes.

1.1. Handling of battery electrodes during production

Electrodes for lithium-ion batteries are thin foils coated with slurry consisting of the active material, generally some additives and the binder matrix. For the anode copper-foil is used usually coated with graphite. For the cathode aluminum-foil is usually coated with a lithium-oxide, e.g. $LiCoO_2$. The way of handling the electrodes during the production process of lithium-ion batteries depends on the packaging technology. In literature four types of packaging are found: cylindrical and prismatic winding as well as stacking and z-folding. The latter two technologies use single sheet electrodes for packaging. During stacking the single anode, separator and cathode sheets are layered one on each other. In Z-Folding the separator is fed continuously and folded after each electrode layer.

The primary difference between the packaging technologies is the use of continuous electrodes during winding. In stacking as well as z-folding single sheet electrodes are used. Although the handling of single sheets is more complex, their use is preferable. Single-sheet electrodes can be produced with higher quality because possible coating failures can be eliminated during cutting.

The handling of the electrodes has to be done with high accuracy as stacking mistakes will lead to a rise of internal resistance. This will result in a lower capacity as well as higher heat generation [4]. Furthermore during lifting the electrodes with a state-of the art area gripper direct mechanical contact to the electrodes is necessary, which induces mechanical stress in the inner structure.

2. Concept of a Bernoulli gripper with exhaust air compensation

2.1. Working principle

Bernoulli grippers are named after and make use of the same-named effect. This effect describes the phenomenon that an accelerated air stream creates a suction force instead of repulsion. The principle of a Bernoulli gripper is shown in figure 1.

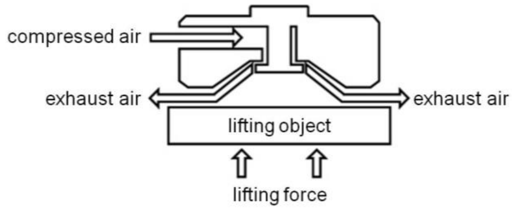

Fig. 1. Working principle of a Bernoulli gripper [5]

This effect leads to the characteristic of Bernoulli-grippers to lift objects from a certain distance without any contact. Unfortunately the accelerated air stream will blow off into the production environment and will take along particles from the surface of the lifting object, in this cas the electrode. This must be prevented for Bernoulli grippers to be feasible for the use in battery production because the exhaust air would contaminate the dry room production environment. This could be done by external exhausting equipment with an additional source of energy as it is presented in the European patent EP2411191B1 [6]. In contrast to that, the concept presented in this paper integrates a Coanda ejector into the gripper without the need of external energy sources. The principal drawing is presented in figure 2.

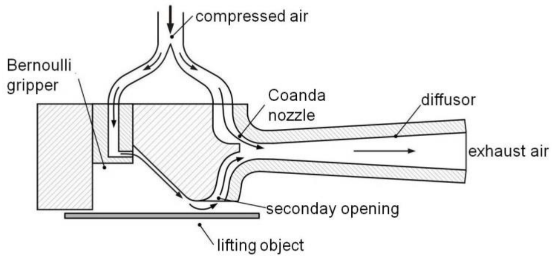

Fig. 2. Principle drawing of new gripper

The basic idea of the concept is to use only one jet stream for lifting as well as the compensation of the exhaust air.

Compressed air is provided at the input flange which is split into two parts. One part is fed into the Bernoulli gripper. The other one is led into the Coanda nozzle which leads to a diffuser. The Coanda and the Bernoulli nozzle are connected through an internal channel, in which a negative pressure is created by the Coanda nozzle and soaks up the emerging jet stream from the Bernoulli nozzle.

2.2. Design of the new gripper

A section view of the gripper is given in figure 3. The final gripper is depicted in figure 4. The cross sectional area of the Bernoulli nozzle have been calculated to 2 $\cdot 10^{-5}$ m². The cross sectional area of the Coanda nozzle has been calculated to 0.67 $\cdot 10^{-5}$ m² to ensure a pressure in the secondary opening that is lower than the pressure leaving the Bernoulli nozzle. In this way most of the exhaust air will be soaked up.

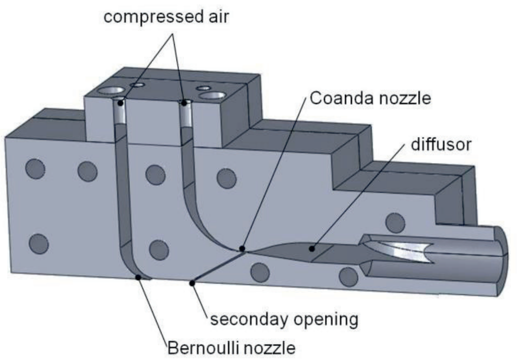

Fig. 3. CAD-model of new gripper

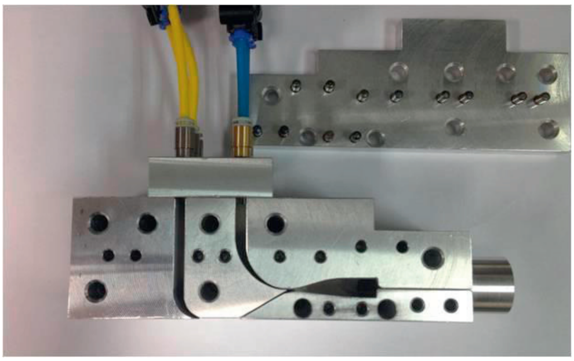

Fig. 4. Final gripper

Two separate input flanges are provided to enable the operation of the Bernoulli and the Coanda nozzle gripper with jet streams of different pressure. The diffuser merges into another flange that fits to a flexible tube. In this way the exhaust air is prevented from blowing off into the production environment.

3. Test procedure

To determine the potential to reduce particle contamination the following procedure has been chosen: At first the behavior of a commonly available Bernoulli gripper has been studied for two different cases. In the first case no object has been lifted. In the second one an anode with a degree of calendaring of 10 % has been lifted, whereas the degree of calendaring indicates the percentage of reduction of the initial coating thickness. The measurement of particle contamination in the closed testing volume has been done using the Lighthouse Handheld 3016 at three different positions within the testing volume. At each position five measurement cycles for a period of 30 s each have been conducted. For this analysis, only particles with a diameter equal or bigger than 10 µm have been considered, as they are in the size of separator thickness and therefore the crucial ones. The pressure of the jet stream entering the Bernoulli gripper has been set to 1 $\cdot 10^{-5}$ Pa. The results are depicted in figure 5.

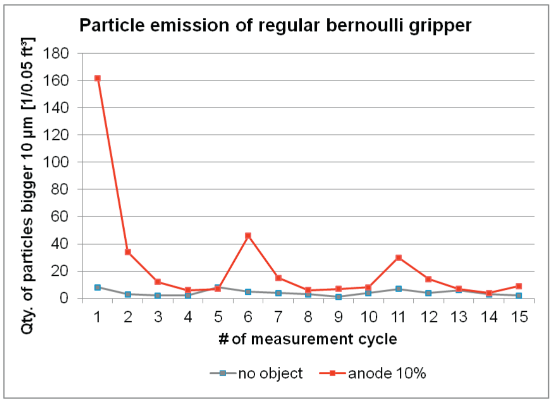

Fig. 5. Particle emission of regular Bernoulli gripper

From figure 5 it becomes obvious, that during the lift of electrodes particles are emitted into the testing volume. The peaks indicate the first measurement cycle after the change of measurement position and the initial lifting for each position.

In the second step of the test procedure the novel gripper has been studied with the same procedure as the regular Bernoulli gripper. The experimental set-up is depicted in figure 6.

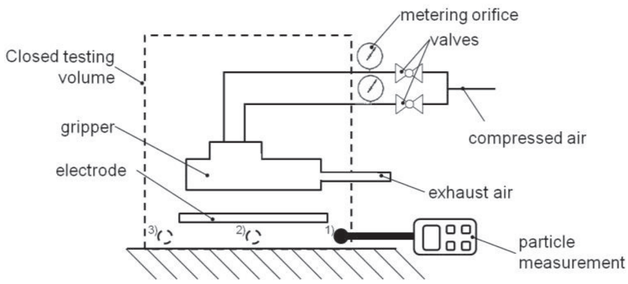

Fig. 6. Experimental set-up

The pressure of the jet stream entering the Bernoulli nozzle has been set to 1 $\cdot 10^{-5}$ Pa. The pressure of the stream entering the Coanda nozzle has set to 2 $\cdot 10^{-5}$ Pa. The results are depicted in figure 7. For most measurement cycles the particle contamination within the testing volume is lower when lifting an anode with a degree of calendaring of 10 % in comparison to lifting no object. This effect is caused by the negative pressure inside the secondary opening which compensates most of the exhaust air. The lifted anode serves as shield towards the testing environment, what prevents the exhaust air emerging from the Bernoulli nozzle from distribution within the testing environment.

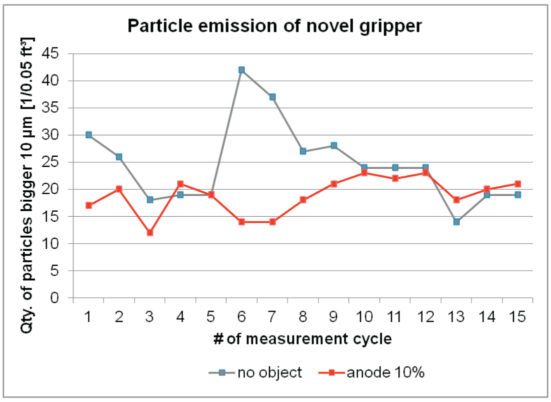

Fig. 7. Particle emission of novel Bernoulli gripper

4. Conclusion and outlook

In this paper a concept for a novel gripper based on Bernoulli's principle has been presented and the general functionality has been shown. The first single-sided prototype has shown potential to reduce particle contamination of the production environment when compared to the use of a regular Bernoulli gripper. Nevertheless further design optimization is necessary to reduce the size of the gripper and to optimize the exhaust air compensation. Furthermore for use in electrode handling it is necessary to integrate two of the presented grippers face to face in a way that forces are compensated. If these drawbacks are optimized the presented concept has the advantage to make use of the lift-off height to optimize trajectories and to reduce mechanical stress during lifting.

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