Servopneumatic Clamping System for the Assembly of Battery Cells in the Area of Electromobility

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Abstract

This paper describes a new application for servopneumatic drives. In a battery module for automotive applications the pouch cells are clamped between frames. During the assembly the frames needs to be clamped permanently. So a clamping system comprising two drives was developed, which moves four clamp fingers each alternating. In the first chapter the application is described in detail. The second chapter includes a comparison of servoelectric and servopneumatic drives for this application with respect to energy consumption, installation space and purchase cost. The developed clamping unit is described in chapter three as well as a verification of the influence of the preload force on the straightness of the stack. At the end of this paper the conclusions are summed up.

KEYWORDS: Battery Assembly, Comparison of drive technology

1. Introduction and Motivation

Battery cells are a key factor for electromobility. Thus manufacturing batteries with high energy density, large storage capacity at low costs is a crucial factor for a sustainable mobility. The same requirements are existing for batteries used in stationary applications, e.g. to balance production variations of renewable energy sources like solar or wind power. Beneath the further development of cell chemistry or new cell concepts, automation of the production process is needed to guarantee a constant quality in large scale which leads to reduce costs.

The public funded project AutoSpEM focusses on the automation of the handling process of battery cells. The project is part of the cluster Electromobility South-West (http://www.emobil-sw.de/en/).

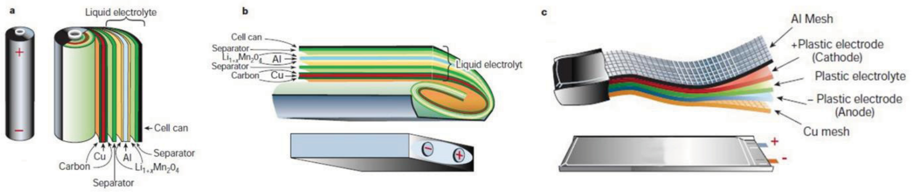

Figure 1: Cell types a) round cell b) prism cell c) pouch cell /1/

For electromotive applications there are existing three main competing lithium-ion cell concepts (**Figure°1**). Round cells or prism cells both have a stable metal case which allows a comparably simple gripping and handling process of the finished cell. For pouch cells instead a polymer-aluminum-compound foil is used as cover /2/. Those cells have the advantage of a higher power density and can be stacked very space optimised. But the mechanical stability is reduced compared with the other cell types /3/. From automation point of view pouch cells are more challenging, so the project AutoSpEM focuses on them.

In the project AutoSpEM two demonstrators were developed. The first one deals with the removal of the cell from the packaging and the subsequent steps for quality control of the single cells. The second demonstrator described in this paper was built to stack the cells and form a battery module.

A battery module with pouch cells consist of three main parts: cell, frame and an intermediate element like foam or a cooling plate. The frame has the function to fix the cell. Thus a cell is placed between two frames, the sealing in the frame structure clamps the pouch cell on the sealed seam. The pouch cell can only be fixed to the sealed seam because the body of the cell needs the ability to change its volume during the charging and discharging processes. The change of volume is possible because of the limp aluminum compound foil as case, and results in a low mechanical stability. A battery module is built by alternating frame, cell, and frame. For this stack the position of the cell-terminals is critical. The terminals need to be place with high accuracy, otherwise the following process-step contacting cannot yield a good quality. Hence one main challenge in battery module assembly is to build a stack with high straightness. This needs to be done in a short cycle of time, otherwise cost-efficient production is not possible. There is an area of conflicting priorities between high stacking accuracy and, due to the short cycles, high accelerations with a sensitive handling object. Due to these challenges the second demonstrator in the project AutoSpEM addresses the topic of stacking with high accuracy. To achieve a good quality the complete process chain was examined. The developed process chain of the demonstrator starts with the positioning of the pouch cell. For this purpose the cell is placed on a table with high precision axes: two linear axes and one rotation axe. The position of the cell is detected on the basis of the terminal position. This is achieved by a vision system, and the cell is placed in a defined position through the table. To obtain a reference between the cell and the frame a combine gripping system is built. The frame is gripped with clamping forces, the development was done by Schunk. The gripper for the frame reference on one edge of the frame and the position of the cell is done through the high precision axes table. Thus the cell and the frame are slanted towards each other. The gripping of the cells is realized with a low-pressure gripper from Festo. The combined gripper system is mounted at a handling system from Festo with high acceleration. After aligning and gripping the compound of cell and stack, the compound is placed into the stacking process. The approach of AutoSpEM is to stack during continuous preload force, i.e. the stack is under pressure the whole time. To realize this permanent clamping force during the building of the stack two axes are needed. The propulsive unit of these axes will be discussed later in this paper. The two axes have to clamp one frame in turn, thus the stack is clamped permanently. The estimated weight of the stacking demonstrator is 130 kg. Is a new compound placed at the stack, the lower axe needs to move up and clamp the upper frame. Hence the two axes are activated alternately. The approximated distance for one step is about 30 mm. After finishing the stack with the desired amount of cells, the battery module will be completed by, for example, tie rod, thus the battery module is grouted. Therefore the two axes have to hold the position after the stacking until the whole assembly process is finished.

2. Selecting and dimensioning of the clamp axis

To realize the clamping unit two drives with a stroke of 500 mm each needs to be chosen which are able to travel to different positions. In principle electric or servo pneumatic drive technology are suitable. For the decision three aspects were considered: The energy consumption, the necessary installation space and the purchase costs.

In the first step a suitable drive technology was selected and dimensioned from the catalogue of Festo.

For servo pneumatic this is comparatively simple. With the help of the axis controller CPX-CMAX as integral component of the valve terminal CPX servo pneumatic solutions with position and force control in closed loop can be realized. As pneumatic axis the standard cylinder DDPC with integrated displacement encoder was chosen. As explained in the datasheet with a piston diameter of 100 mm it is possible to position masses up to 150 kg in closed loop with the DDPC – thus enough for the 130 kg expected in the clamping application. As control element the proportional directional control valve VPWP with a nominal size of 10 mm was selected.

For servo electric application there is a nearly unmanageable amount of possible solutions with spindle or tooth belt drives, different motors and gear boxes as an option which all can be combined. With the help of PositioningDrives, an engineering and selection software for electric drives available on the Festo website, suitable solutions can be defined and compared. Therefore a detailed motion profile must be specified. Then the programme calculates different combinations of motors, drives and gearboxes, which afterwards can be compared by criteria like degree of capacity utilisation of axis and motor, travel time or component sizes. From the roundabout 15 configurations suggested by PositioningDrive the electric spindle drive cylinder ESBF with size 50 was chosen. Essential criteria were the small size and that there is no gear box needed. This reduces the price of the system. A servo motor size 100 of the EMME-AS motor family is needed to reduce the degree of capacity of the motor to an acceptable value. For the motor length the small version is sufficient.

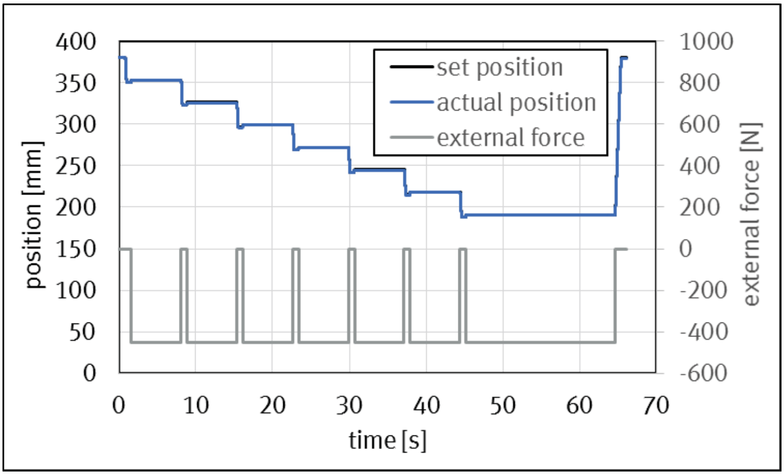

Figure 2: Simulated cylinder behaviour of the electrical drive

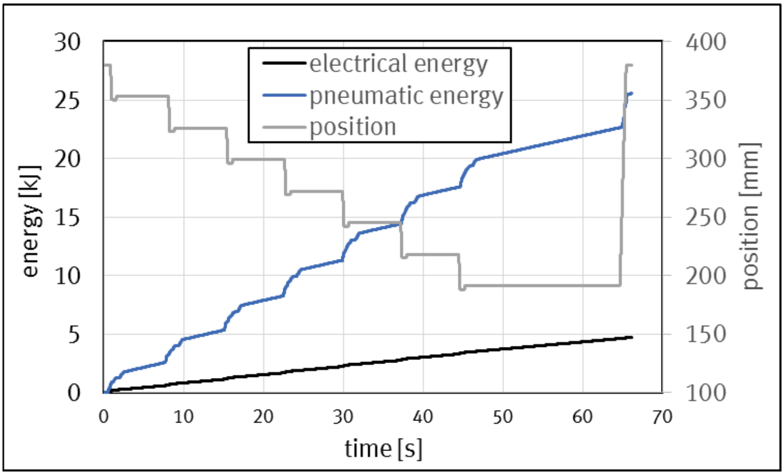

Figure 3: Comparison of the energy consumption

Based on the chosen components for the pneumatic and electric drive, the dynamic behaviour of both systems was simulated with internal Festo tools. A sequence of six steps comprising a cylinder move out, a counter movement and a clamping process with 450 N was calculated (**Figure°2**). After a last step the clamping force was hold for a longer time. This time is needed for fixing the battery module. In reality this step will be longer, but a long time simulation with no movement is not very attractive with respect to simulation time. Thus the simulation was shortened.

The dynamic behaviour of the system was simulated to estimate and compare the energy consumption of the different drive technologies. The simulated energy consumption can be seen in **Figure°3**. The result is at a first sight astonishing. Usually pneumatic drives are attributed energetic advantages for clamping and gripping applications, where a constant force is needed /4, 5/. But for the clamping application a more than five time higher energy consumption of the pneumatic solution is predicted. How can this be declared?

There are several reasons for this result. First of all the high mass of 130 kg needs to be mentioned. To realize a good positioning accuracy in closed loop a big cylinder diameter of 100 mm is needed. This cylinder has a theoretical force of round about 4500 N at 6 bar - thus much more than the weight of the clamping unit. Second reason is that the cylinder movement is disadvantageous for a energy efficient servo pneumatic motion. It is an oscillating movement with changing directions. So also an oscillating pressure level in both cylinder chambers is needed which is combined with a high mass flow. The third reason is an inadequate simulation model. In reality there are changing end stops caused by every new frame set on the stack. This can´t be reproduced with the simulation model accurately. This means, the counter movement will later be realized with force control. But it is simulated by a counter movement with position control which changes into a force control when the clamping position is reached. Unfortunately the small counter movement tends to swing which leads to a higher energy consumption. The last reason explaining the poor performance is the energy consumption during the clamping periods, 1/3 of the energy consumption of the pneumatic system is produces in this time. Normally to hold a force should be the strength of pneumatic. But the energy consumption of the electrical system is 2.5 times lower during clamping. This is influenced by two factors. During clamping there is a “pressure drift” in the cylinder chambers, this means the pressure level is slightly increasing in the simulation. The second and main reason is the internal air consumption of the servo valve in closed position. It would make sense to reduce the energy consumption of the pneumatic system to cero during the clamping phases, e.g. by using an additional seat valve which blocks the cylinder chambers.

Although there are different options to reduce the energy consumption of the pneumatic system we surprisingly need to sum up, that the energy comparison shows clear advantages for the electric solution.

To compare the pneumatic and electric solution related to the installation space at first a definition is needed what the installation space is. In this paper the critical volume using space in the demonstrator rig is compared. This means the motor controllers for the electrical drive as well as the controller and the proportional valve for the pneumatic drive are not considered. The construction size of the compressor station also is not taken into account. Further on the space for cables, fittings and tubes as well as the part of the piston rod which does not sink in the cylinder are neglected although they are in the “critical” area of the demonstrator. For electric drives there are in general two options to arrange cylinder and motor – parallel or axial (**Figure°4**). For the given application it is favourable to choose a parallel kit which leads to a reduced length of the solution.

Because the shape of the construction space of a pneumatic cylinder and an electric drive with parallel kit looks very different, it is not possible to define a true way to describe the necessary installation space. **Figure°5** shows three possible variants to enter this topic. For variant A the volume of the three components cylinder, parallel kid and motor are added. For variant B an L-shaped geometry is laid above the three components. A cuboid in which all components fit describes the volume of variant C.

Figure 4: Axial and parallel kit for electric drives

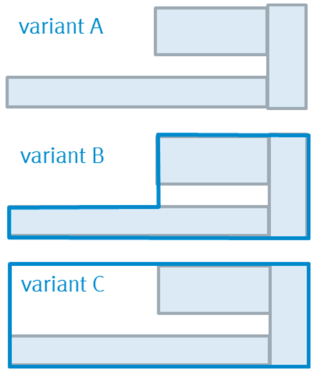

Figure 5: Variants to describe the installation space

As **table 1** shows, the pneumatic cylinder has a slightly bigger volume then the electric drive calculated by variant A. This results mainly from the smaller edge length of 64 mm for the electric cylinder compared to the edge length of 110 mm for the pneumatic cylinder. If variant B is considered, the pneumatic cylinder has a slightly smaller volume, for Variant C the pneumatic cylinder only needs more or less half of the volume of the electric competitor. In summary it remains to be stated that there are differences in the installation space between electric and pneumatic drive. But the differences are not so big that the installation space is a crucial criterion for the clamping application described in this paper.

For the clamping application two clamping units are needed. Thus in the cost comparison for the pneumatic drive one valve terminal with two CMAX modules and two proportional valves, two cylinders as well as the necessary cables are considered for both cylinders. The calculation for the electric drives comprises two components each for the spindle drive, the parallel kit, the motor as well as the cables.

pneumatic drive	**electric drive**		
	Variant A	Variant B	Variant C
8,34 dm³	6,86 dm³	10,29 dm³	15,99 dm³

Table 1: Installation space for pneumatic and electric drive

The purchase costs of the pneumatic system are approximately 63 % compared to the electric system. This is a strong argument to use the servo pneumatic solution. Especially if it is taken into account, that the functionality of the two systems are different. The axis controller CMAX for example is a module of the valve terminal CPX. If the valve terminal is only used to control the two axes of the clamping system, the CPX-System is a significant share of the cost of the pneumatic system. But the CPX comprises a full PLC and more modules like valve slices can be added easily at low costs. This options are not given for the electric drive.

In summary the electric solution has clear advantages in the energy consumption, the lower price is a strong argument to use the servo pneumatic drive. The installation space is – at least in the clamping application described in this application – not a criterion useful to decide between electric or pneumatic drive. Finally the demonstrator was built with the servo pneumatic solution.

3. Stacking process module

For the stacking of the frames and the cells, a new approach which uses a permanently defined preload force during the formation of the stacks has been developed within the project by the wbk Institute of Production Science. This procedure is realized during the project in a demonstrator. For a 24 volt battery module, it is for example necessary to exactly stack seven cells and hence 8 frames. Due to the fact that a relative movement between frame and cell and between different frames cannot be realized without damaging, the frame sealing and accordingly the sealed seam, the stacking of the compounds has to be aligned. Furthermore the composed stack must be clamped permanently, otherwise a shift of the compounds can occur. Thus the concept of the demonstrator provides a clamping of the highest frame with four clamp fingers for the composition of the stack. The clamping of this frame is only released once a new frame which is higher up is clamped by four additional clamp fingers, hence at every point in time the stack is clamped by a defined amount of force. The preload force is raised by two servopneumatic axes, each fixed with four clamp fingers, hence both axes alternately clamp the upmost frame. **Figure°6** depicts the realization of the stacking process. Apparent are the eight clamp fingers which clamp the frames during the stacking process.

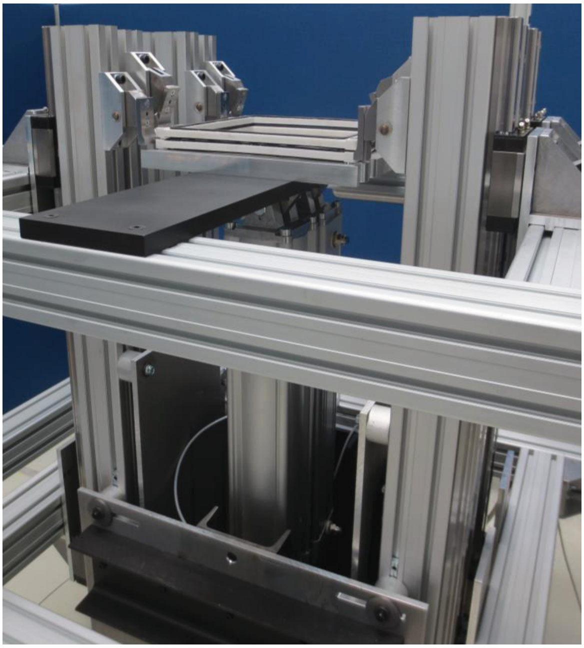

Figure 6: Stacking process module

To ensure that both axes systems with their respective four clamp fingers can move past each other the clamp fingers are arranged in a way the clamp system which is currently not in use is turned away behind the clamp system in use. This turning movement is enabled by a respective mounting. There is an integrated spring in a clamp spring holder to make sure that the clamp system that has been moved upward does not stay in a hinged position. The spring musters the appropriate force to bring the clamp finger after gliding up into an extended position again.

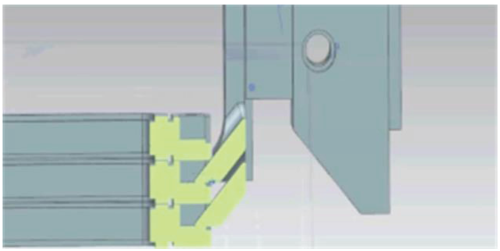

Figure 7: Movement of the clamp fingers

Figure°7 illustrates the consecutive gliding movement of the clamp fingers. The automated process flow of the demonstrator for the construction of battery modules uses the handling system of Festo for transporting the compound of cell and frame to the stack formation demonstrator and putting the frame and the cell on the stack while keeping them in its grasp. The release and the grout by the clamp fingers happens simultaneously, hence never leaving the position of the aligned cell undefined. This defined position is achieved by the table with the high precision axes and the vision system. The low pressure area suction device was designed by Festo to ensure a high position preservation during the grip and handling process. To increase the accuracy of the high dynamic handling system, so-called fine positioning units are used at the demonstrator. This means that attached to the combination grip system there are two connectors that pitch both at the precision table and at the stack formation unit in two precision guiding shafts, guaranteeing a high precision of the cell position with respect to the calibrated guiding shafts. Due to the precise allocation of the cells, the - by help of the frame grasper - aligned frame and the permanent clamping of the frames and hence the cells during the stack formation process, the requirements for the formation of a battery module with only small deviations in straightness are provided.

With the best available technology a battery module is only grouted after the stacking process, allowing for a relative movement of the frames. Therefore measurements of a battery module stack were conducted at the demonstrator where the single frames were put on top of each other without being grouted. This means that the frame grasper gasped the frames and used the handling system by Festo to put them on the stack formation station. Hence frame by frame were loosely put on top of each other. Afterwards the whole stack of frames was grouted. With this procedure the best approach of technology of un-fixed formation of stacks was reproduced at the demonstrator, the clamp fingers where in this approach used only at the final grouting of the stack. Furthermore a stack of frames and preload force was formed to verify the influence of the preload force on the straightness of the stack. In **Figure°8** the results of the three different experiments are shown. The red line shows the straightness of the experiment with no force and just stacking. The blue line illustrates the straightness of the complete grouted stack, and the black line shows the stack with preload. In this experiments four frame has been stacked. It can be seen that the preload leads to a higher straightness of the battery frame stack.

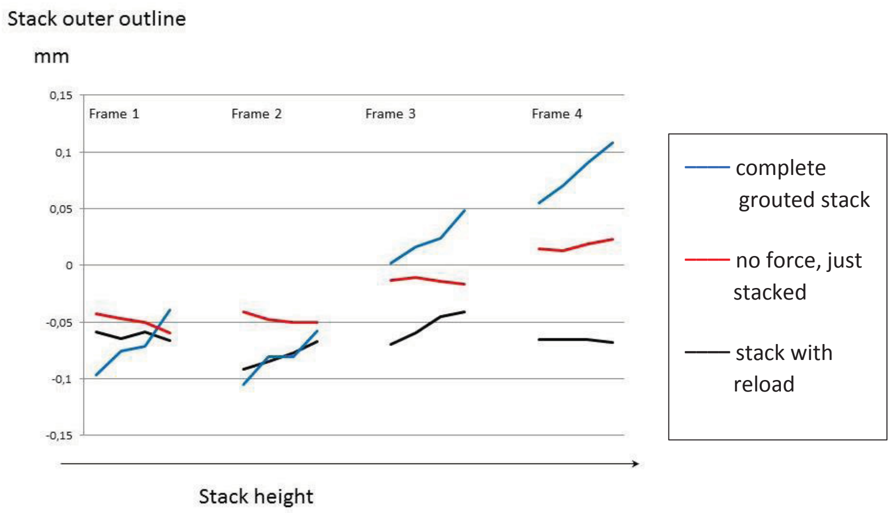

Figure 8: Stack straightness with different stacking concepts

4. Summary and Conclusion

A clamping unit to assemble pouch cells, which are used for electromobility, was described in this paper. To realize a permanent clamping force during the stacking process two clamping drives are needed, which operate alternatingly. The advantages and disadvantages of servoelectric and servopneumatic drives to fulfill the clamping tasks was analyzed. Although in literature a clamping process is described as a preferred application for pneumatic drives with respect to energy efficiency, the performed simulations show a clearly minor energy consumption of the electric solution. At the end the low purchase costs are the main argument to use the servopneumatic drives in the clamping unit.

Aim of the developed stacking process module is to realize a frame stack with high straightness. It was shown that a continuous preload force guaranteed by the servopneumatic clamping units leads to the best straightness of the complete grouted stack.

5. Acknowledgment

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