Battery cell production from coil to stack: integrated, automated and therefore highly flexible

Economical production of various battery cell formats made of different materials in small to medium batch sizes is rarely possible using today's stacking processes. A new approach integrates previously discrete steps in manufacturing to form a continuous, fully automated and therefore flexible stacking process in terms of material and format. High-performance controller and drive systems from Siemens deliver precise control for the Coil2Stack process, making it easy to transfer and ensure its future viability

The field of potential applications for lithium-ion battery technology is growing rapidly, thus driving up demand for flexible production systems. In terms of power density and flexibility, pouch cells made of stacked electrodes and separator sheets have advantages over wound round or prismatic cells, especially when using electrodes with high surface loadings. However, established production systems – and especially stacking systems – are neither particularly material-friendly nor flexible and are seldom economical when frequent changes of cell format are involved. Customised cutting tools, special storage boxes/inlays and gripper systems for each cell format mean high costs, long changeover times and, in many cases, a large amount of scrap. A series of different individual steps and complex handling of the sensitive and expensive materials also have a constant negative impact on quality, productivity and cost-efficiency. However, the constant new developments in materials and applications are forcing equipment and machine builders as well as battery cell producers to move away from dedicated production technologies and go towards more flexible options, ideally using cost-efficient standard components.

Focus on tomorrow's production

The ProZell competence cluster – a network of renowned German universities, research institutes and corporations – is dedicated to exploring innovative solutions for the battery cell production process and the development of new generations of batteries. Within this context, researchers at the wbk Institute of Production Science as part of the Karlsruhe Institute of Technology (KIT) have analysed the current stacking process and developed a highly flexible solution – the Coil2Stack process.

The idea behind this development was to move away from the current multistage, discontinuous stacking process in favour of a continuous, automated solution with just a few simple steps from the coil to the stack. The researchers decided for standard Siemens hardware and software components for the key automation part as the best solution due to technology and economic reasons.

Integrated and automated process steps

In the current process, individual electrodes and separator sheets are cut off long material webs. Then, they are cleaned,

Overall view of Coil2Stack demonstration model

put into buffer storage before being aligned to one another in a number of steps and then stacked by grippers. The systems require a changeover for different cell formats: a process that costs both time and money.

In the new Coil2Stack process, the material web is fed from the coil to an accumulator and automatically aligned while running through a steering guide. A dancer controls the web tension and feeds the material into the technological heart of the stacking system. This innovative core element consists of three radially movable handling segments and integrates the functions of gripping (by means of vacuum) the sheets, separating them (using a circular blade/shear cut), and then placing them on a carrier. Unwinding processes, from the coil and the on-the-fly placing on the stack are synchronised and continuous operations. The handling elements are used to adjust the "diameter" and consequently the sheet length in a wide range (from about 100mm); the vacuum can also be adjusted according to the web width. This means that sheets of different widths and lengths can be produced, therefore also trapezium or pyramid-shaped stacks. That also gives product designers more freedom to realise their ideas.

High-performance control and drive systems for a complete range of tasks

Perfectly coordinated interaction among all moving parts of the system is decisive in terms of achieving a high output and quality. The machine prototype contains about half a dozen controlled linear axes and axes of rotation. This interaction is controlled by a Siemens Simatic S7-1516T "technology CPU" for the programme, logical sequence and motion control of the machine.

The drives and motors on the controlled axes are also from Siemens' standard portfolio. These are essentially one single-axis converter each for the rotary motion of the rotating core element and its translatory up and down motions. Additionally, it continuously compensates web length deviations resulting from the non-circular movements of the core element. Axis movement is implemented by the proven and reliable servo motors from the Simotics S series.

The above-mentioned axis movements are coupled to a virtual master via electronic cam to realise synchronous operation. The master axis follows the speed specified by the machine operator, as does the unwinder. The segments of the core element are automatically positioned once the required sheet length has been entered on the Simatic HMI Comfort Panel. At the same time, the T-CPU calculates the resulting electronic cam – in each case following a rotation of one degree, resulting in extremely precise interaction among all rotary and linear movements. When a sheet has been placed on the table, the stack carrier also moves horizontally at a speed control based on rotational speed, which ensures a precise depositing. The height of the carrier is adjusted as the height of the stack increases. The result is a very precise stack.

In various series of experiments as part of the ProZell cluster, the wbk developed in parallel to the above activities a model-based parameterisation of the system. This means that validated process parameters from a kind of material database can be transferred from the HMI to the control system. As a result, the machine runs with a pre-optimised setting right from the very beginning, thus saving the operator time-consuming tinkering to find the ideal parameters and reducing start-up scrap during product changeovers in the system for future applications in the industry.

Tackling the future with digitalisation

With the objective to gather experience in digital workflows and accelerating the current advanced development of the Coil2Stack process, the wbk is also planning to implement virtual commissioning on a "digital twin". Using 3D-CAD data from the demonstration unit, a digital

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The converting toolbox

When using servo motors, the main tasks of winding, web tension/dancer control, cross-cutting and many others can be implemented by ready-made, standardised motion control functions and function blocks. The simple combination of blocks from Siemens' TIA Portal software platform enables the prompt implementation of specific requirements.

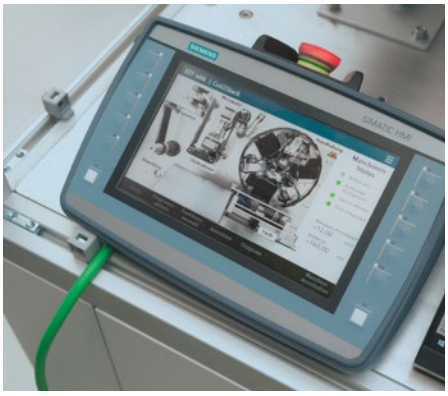
The material web is guided perfectly by the handling elements and ideally placed on the carrier; highly accurate synchronisation is ensured with the aid of end-to-end automation

model was generated in the Siemens NX Mechatronics Concept Designer (MCD) coupled to the proven and trusted Simit and PLCSim Advanced simulation tools. This will speed up PLC programme development, facilitating the machine construction and further shorten the time-to-market and real commissioning for each future roll-out.

The faster, more cost-efficient way to improved flexibility and cell quality

With the Coil2Stack process, the wbk Institute of Production Science has shown that supposedly simple processes such as stacking for battery cells can be further improved with the right ideas and high-performance automation. The new approach basically eliminates time and cost-intensive steps such as aligning the sheets using frame accessories or cameras, storing in magazines and, above all, frequent retooling.

Now it is up to the machine and plant builders (OEMs) to transfer the concept into efficient solutions for production. They can do so with reduced risk, as the process is flexible in terms of material and format and is not dependent on a pre-existing specific manufacturing or customer order. Siemens' extensive portfolio of control systems, drives, motors and HMIs supports simple upscaling and the transfer of research results to production scale. They are able to reduce the amount of engineering involved thanks to features such as ready-made and tested motion control functions. If required, special drive functionalities and further process



Using SIMATIC HMI Mobile Panels enables simple and intuitive operation

optimisation measures are simple to realise by means of individually adjustable technology functions. A further advantage is that standard components and technical support can be accessed quickly all around the world.

New machine concepts and variants reach maturity on the digital twin in a shorter time and with considerably less development risk.

Future battery cell manufacturers will benefit from significantly reduced investment and operating costs thanks to integrated and automated development steps (gripping, separating, depositing), the adaptability of the system for a very wide product range, and now also the continuous, efficient process. Highly accurate web tension control keeps the tensioning stress on the sensitive materials constantly low, thus permanently ensuring high quality and durability of the battery cells. As they are able to process materials with varying length, width and thickness (in this case from 20 to 200µm) "at the press of button" on one system, customised battery cells can be produced economically for the applications of tomorrow, even in small and medium-sized batch sizes, thus securing investments over a longer period of time.

Innovative together

The results are promising and have motivated the researchers at the wbk to raise the stacking process for all three materials (anode, cathode, separator) to the next Technology Readiness Level (TRL 5 – "Technology validated in relevant environment") in a follow-up project. Siemens specialists are involved here too, initially in designing appropriate control and drive systems. The main tasks to be implemented are unwinding and web tension/dancer control with standardised motion control functions and function blocks that are easily combined and adapted to specific requirements. Siemens will also accompany further expansion of the digital workflow.

For example, currently in a follow-up research project, where Siemens is helping to achieve an optimal engineering process through a holistic automation concept including virtual commissioning on a digital twin. Trials are also being conducted with material web simulation. Here the focus is on gaining a better understanding of the material web in a production machine to better control the effects on the product – such as tension, deformations, creasing, tearing, etc. – arising from acceleration and braking procedures.

Formats can be varied by changing the process parameters in a continuous process. "We are speeding up the production process for the efficient, precise and flexible manufacturing of battery cell stacks, while also opening up the production line for a variety of formats," summarises Prof Jürgen Fleischer, director of machines, equipment and process automation at the wbk.

"By combining proven and reliable processes, the new approach opens up unimagined possibilities in terms of the flexibility of future production facilities," says Hannes Weinmann, a research associate at the wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT).

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