Next-generation battery production equipment

Exploring key challenges and opportunities for laser technology

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The surging demand for high-performance batteries in e-mobility and energy storage systems intensifies pressure on machine builders for complex, rapid innovation. Laser processes are indispensable for their precision and versatility. Yet, the industry faces intense cost pressure and geopolitical uncertainties, demanding maximum efficiency and flexibility. This contribution discusses specific challenges of laser technology in mechanical and plant engineering.

In battery manufacturing, a clear shift in production philosophy has been observed over recent years: from cell-to-module (C2M) to cell-to-pack (C2P) and further towards cell-to-chassis (C2C). In the C2M approach, cells are first assembled into modules, which are subsequently integrated into battery packs. This concept primarily represented a compromise between structural stability, thermal safety, and established manufacturing technologies. Modules served as clearly defined, easily manageable intermediate units and enabled relatively flexible scaling – both in terms of module design and manufacturing technology. However, the additional layer of housings, connectors, and management components resulted in increased mass, higher costs, and reduced volumetric efficiency.

With the transition to C2P, this modular intermediate stage is eliminated. Individual cells – cylindrical, prismatic, or pouch cells – are assembled directly into a pack. This reduction in components, combined with higher packing density, increases energy content per volume while simultaneously reducing material, logistics, and assembly effort. C2P has therefore quickly become the standard in many modern electric vehicles.

The most recent development step towards cell-to-chassis goes even further: battery cells are no longer installed in a self-contained battery pack but are structurally integrated directly into the vehicle chassis. As a result, the pack loses its role as a closed unit, and the energy cells become part of the load-bearing vehicle structure. This approach leads to a drastic reduction in weight and a further improvement in volumetric energy density. C2C represents the next stage of high-end battery packs – offering maximum integration but also maximum complexity for production processes and manufacturing technology.

Impact on machine technology

The transition towards C2C marks a profound change in machine technology for battery manufacturing. While C2P production lines are primarily designed to assemble cells into packs and to implement defined process steps such as cell stacking, module handling, pack assembly, screwing, bonding, and functional testing, C2C fundamentally changes the production logic towards large-format, load-bearing components. This requires new equipment technologies.

For machine engineering, this first implies a significant change in handling and joining technology. Instead of compact pack housings, machines must position large-format chassis components and simultaneously integrate cells with high accuracy and tight tolerances. As a result, requirements for load capacity, dynamics, and precision increase substantially.

Overall, the transition from C2P to C2C means that machine technology must become significantly more flexible, more system-oriented, and more extensively equipped with sensors. This transformation requires both new machine concepts and a fundamental reorganization of the production landscape.

At the same time, pressure from Asian competitors is increasing. In many cases, these suppliers are vertically integrated, highly scalable, and benefit from aggressive pricing strategies as well as significantly shorter delivery times.

Impact on laser technology

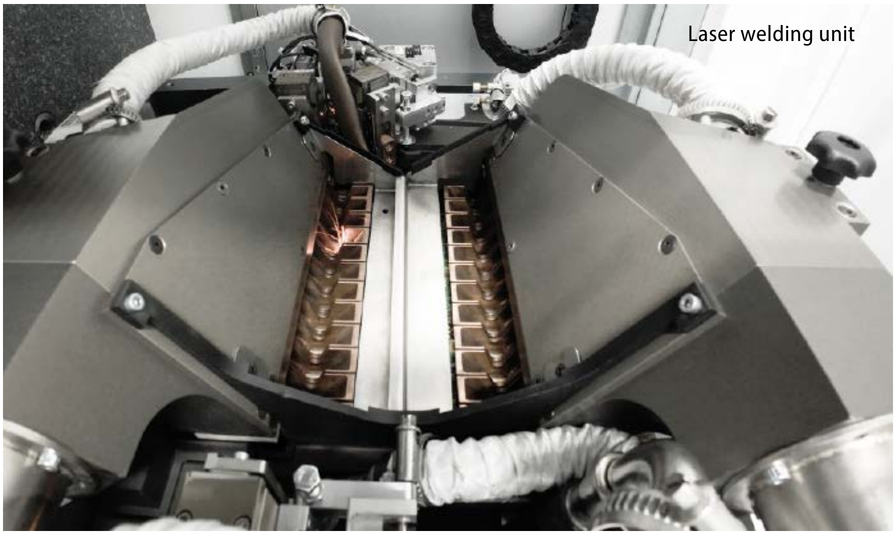
Laser technology is considered a key enabling technology in modern battery production, as it offers a unique combination of precision, speed, and process reliability that is essential for manufacturing high-performance and safe battery systems.

Another central role of lasers lies in welding electrical connections within battery modules and packs. Robust, reproducible, and low-resistance joints are crucial for high power output and safe fast-charging capability. Modern laser joining techniques enable precise welds on busbars, tabs, or cell housings and are capable of handling even demanding material combinations such as copper-aluminum, which are difficult to process using conventional methods. At the same time, laser processes can be seamlessly integrated into highly automated production lines, as they operate with high repeatability and can be monitored inline. This scalability is decisive. Consequently, laser technology is not only a core technology of today's battery production but also a future-proof tool for upcoming generations of energy storage systems.

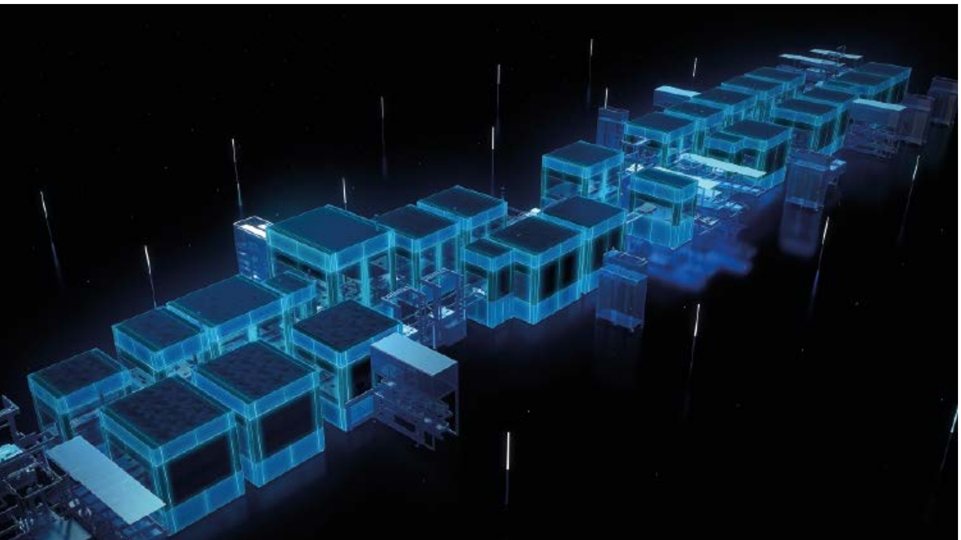
Laser welding machine for large C2C

The increasingly larger systems contain more and more battery cells. Modern systems today include up to 1000 battery cells. With up to 2000 laser welded contact points per system, a reliably functioning and well controlled inline process monitoring becomes increasingly important.

Due to increasingly compressed project cycles on the customer side as well, the current trend is that machine builders are requested to quote machines even before product specifications have been fully defined. As a result, machine builders are increasingly responsible for continuously updating the requirements for their laser system technology as product specifications evolve, while simultaneously making well-reasoned assumptions and communicating them clearly to the customer, thereby actively contributing to the formulation of product specifications.



Laser welding unit



Digital twin of a production line

Digitalization in mechanical and laser engineering

Another often underestimated challenge lies in data processing and system integration. C2C manufacturing generates enormous data volumes due to the high number of joining points, structural welding operations, inline measurements, and optical inspection processes. For each system, several gigabytes of process data may be generated, which must be processed, classified, stored, and transferred to OEM backend systems.

As a result, mechanical engineering is evolving into a data-driven process provider. Machine builders are no longer required to deliver hardware alone, but increasingly complete IT architectures, edge computing solutions, data pipelines, and software-supported quality models. This development marks a fundamental shift towards software-defined manufacturing, where machine functionality, adaptability, and performance are no longer determined solely by mechanical design or laser hardware, but by software-defined system behavior.

To manage this growing complexity, an end-to-end digital engineering approach across the entire lifecycle – from concept to operation – is becoming essential. Model-based systems engineering provides a unified data backbone that consistently links mechanical, electrical, and software domains and thereby forms the foundation for digital twins. These virtual system representations enable early validation, virtual commissioning, and rapid adaptation to design or process changes, even after system deployment.

By combining digital twins with AI-driven engineering tools and the seamless integration of production and field data, manufacturing equipment can evolve into intelligent, data-driven, and increasingly self-optimizing systems. In such architectures, hardware serves as a stable and scalable platform, while software defines process logic, data interpretation, and adaptability. This is particularly critical in cell-to-chassis production environments, where product designs, joining concepts, and quality requirements continue to evolve during ramp-up and series production and must be addressed without fundamental mechanical redesign.

These demands significantly exceed the traditional core competencies of many traditional machine builders and require a substantial expansion of software, data, and AI expertise. The challenge lies not merely in adding software components, but in developing holistic, modular, and update-capable system architectures that ensure scalability, transparency, and process reliability in highly complex battery manufacturing environments.

Conclusion

In summary, the transition to cell-to-chassis manufacturing confronts machine builders with a combination of technological complexity, severe time pressure, structural shifts in value creation, global competition, and increasing economic responsibility. The most critical strategic risks include insufficient time-to-market capabilities, inadequate standardization of internal modules, high engineering costs, and a growing competitive gap compared to highly scalable Asian manufacturers.

At the same time, cell-to-chassis offers significant opportunities for differentiation through excellence in laser processing, inline metrology, data intelligence, and modular production platforms – provided that machine builders succeed in substantially reducing engineering effort and lead times while simultaneously building new competencies in software, body-in-white engineering, and manufacturing data.

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