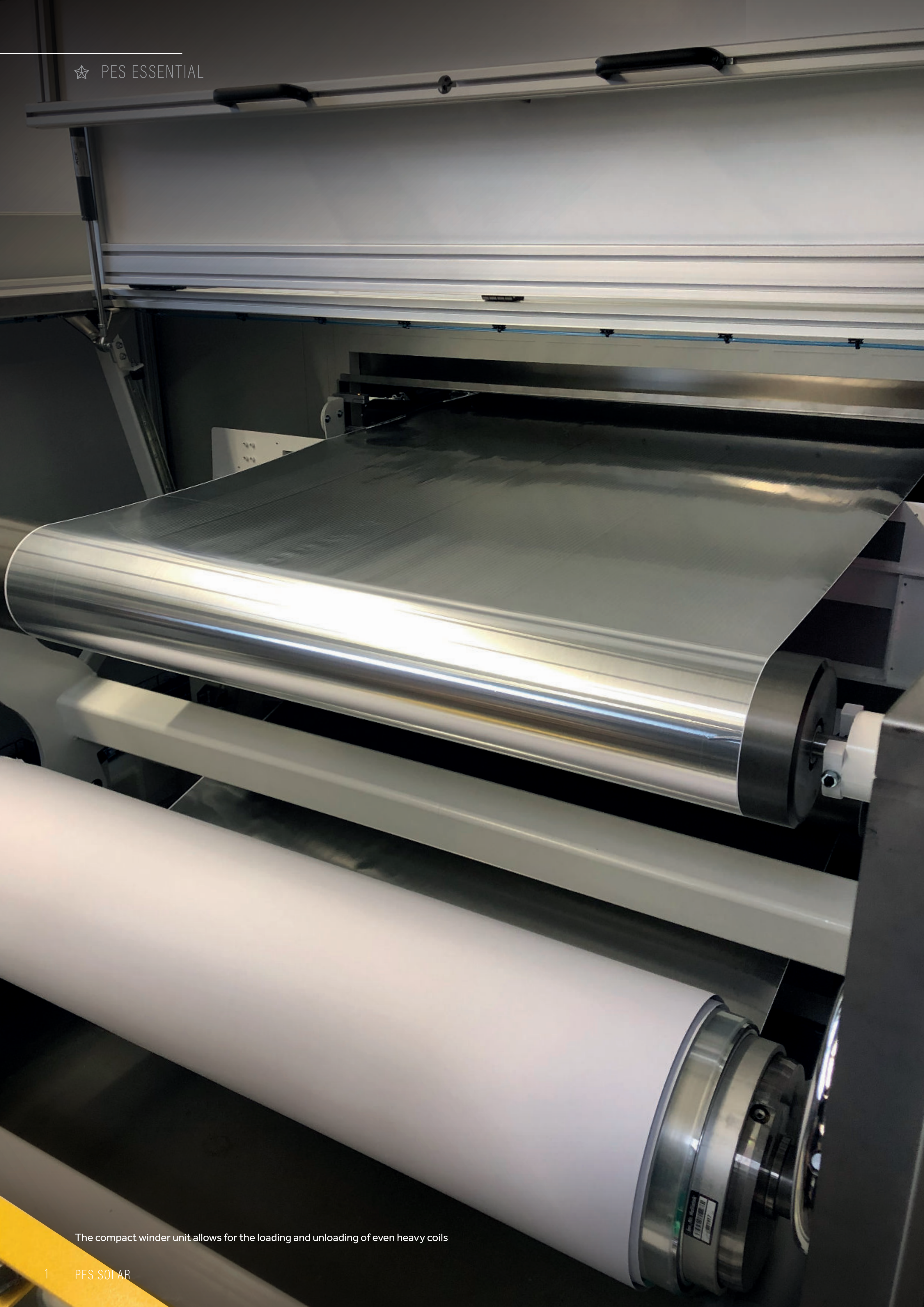

The compact winder unit allows for the loading and unloading of even heavy coils

On wide webs: laser structuring of flexible amorphous silicon PV cells

Numerous material choices and methodologies are available for photovoltaic modules, each presenting a distinct set of requirements, challenges, and opportunities. While creating small-scale prototypes of PV products is feasible, transitioning to industrial-scale production is a whole new undertaking. This article aims to provide insight into the factors, obstacles, and innovative solutions involved in facilitating the mass production of flexible, amorphous silicon solar modules. This was achieved through a fusion of laser processes and roll-to-roll technology.

Over the past decade, 3D-Micromac has engineered and built several laser machines for a wide range of PV technologies and concepts, including tools for half/multi-cell cutting by Thermal Laser Separation (TLS), high-speed PERC cell manufacturing, flexible thin-film organic and CIGS module production among others. Still, when the request for a machine for laser scribing of amorphous silicon solar modules was presented, it required a completely new machine due to its unique design features and production chain.

A machine concept for flexible, amorphous silicon solar modules facing new challenges

In contrast to other flexible PV technologies, where laser scribing processes, referred to as P1, P2, P3, etc., are executed intermittently alongside coating and other procedures, this specific case necessitated simultaneous performance of all three scribing steps. Moreover, integration of a dispensing and curing procedure with the laser processes was essential. To ensure sustainability and economic feasibility in production, the processing had to be carried out on a web wider than one metre and at a high web speed. Additional prerequisites involved guaranteeing zero contact with the active side of the substrate under all circumstances, necessitating the removal of a protective thin-film during unwinding and re-application during rewinding, as well as implementing in-line quality inspection.

The choice between scanning or fixed optics for laser scribing and determining the optimal number of scribes were pivotal considerations. Evaluating factors such as precision, production speed, and material characteristics played a crucial role in making this decision. The selected approach needed to strike a balance between high-quality scribing and efficient production while considering the specific project requirements and limitations. Extensive experimentation and analysis were likely undertaken to find the best combination of laser optics and the ideal number of scribes to achieve the desired outcomes for the flexible, amorphous silicon solar modules.

All these aspects are linked to each other in some way. For example, scanning optics would allow continuous web movement, thus achieving a high production speed. However, this approach also creates a much higher number of so-called stitching areas where two laser scribes connect, which can cause issues with the cell interconnection. Fixed optics reduce those stitches to an absolute minimum. However, they are not suited for continuous operation unless there is an optic for each of the more than 150 parallel scribes, which is neither technically nor economically feasible.

In addition to the aforementioned aspects, numerous other considerations had to be carefully evaluated to devise an optimal machine solution. This solution needed to deliver superior quality and achieve the highest production volume while maintaining a reasonable cost-of-ownership. Balancing various factors, such as process efficiency, material compatibility, and system reliability, was crucial to ensure the successful mass production of flexible, amorphous silicon solar modules. Extensive analysis and innovative problem-solving were integral to arriving at the most effective and economically viable solution that fulfilled all the specified requirements.

Searching for the perfect laser source

As mentioned before, this project's approach to the laser scribes significantly differs from previous solutions, as the three scribes, P1, P2, and P3, must be done simultaneously. They also have to be placed close to each other with low positioning tolerances to minimise the dead zone of the future solar module. The customer already had conducted extensive experiments to come up with suitable process parameters for each scribe and a suggestion for a laser source, a rather robust fiber laser. This laser source was subsequently reviewed and thoroughly tested by 3D-Micromac to ensure compatibility and long-term stability in the expected industrial environment. In their trials, the customer used fixed optics as they had the most experience with this approach.

Applying the laser process parameters to a scanning optics system was also tested to allow for more flexibility. While this approach did work perfectly, it also caused a much higher number of those stitching areas mentioned previously. To minimise the potential negative impact of stitching areas, it was subsequently decided to stick with the fixed optics solution.

This left the task of placing three laser scribes within a few hundred microns of each other open. While scanning optics could easily perform this task, it is much more challenging to do with fixed optics, mainly when space is limited. Based on previous setups the customer had built, a new compact fixed optics setup was designed by 3D-Micromac that allowed for precise positioning of the three scribes while also providing high stability and robustness. By implementing beam-splitting optics into the setup, the number of required laser sources per fixed optics unit could also be reduced, thus cutting costs and reducing maintenance and setup effort.

Step and repeat or continuous loop?

For the dispensing, the customer performed detailed analyses and experiments to ensure optimal results and performance of the solar modules. It was found that the speed of the dispensers can be matched to the scribing rate of the laser so both processes can run in parallel. However, it was also found that the distance between the tip of the dispenser and the substrate surface had to be kept within a range of a few microns to ensure even and uninterrupted dispensing. That meant a fast, closed-loop distance control had to be designed and implemented. After a detailed evaluation of different types of sensors and fast linear stages, a suitable setup was found that allowed for high positioning precision at high speeds while still being very compact.

Based on the laser scribing and dispensing solutions, it was decided that the machine would operate in step and repeat mode. The web would be stepped forward and fixed onto a large vacuum chuck. A gantry setup would carry four processing units, each consisting of fixed optics and dispensing devices at speeds of up to 1 m/s over the web. Once a section of the web was thus processed, the web would be stepped forward, and the process begun anew. The curing of the dispensed fluid would be carried out in a separate area, away from the laser and dispensing area itself.

Finding the perfect web path

The design of the web path was mainly driven by the requirement that there must be no roller contact with the active surface of the web after the protective film had been removed from the coil. This immediately eliminated the use of standard-driven and nip rollers for web movement and for keeping web tension constant. In addition, the coils posed a challenge of their own as they would weigh between 500 kg and 1,000 kg. This seriously limited the options when it came to loading and loading these coils.

A total of ten different variants, most of them with sub-variants, were devised, compared, and weighed against all requirements. In the end, a compact winder unit was designed that allowed for loading/unloading of the heavy coils by lifting tools or an overhead crane, that combined a dancer for keeping web tension constant with a moveable splicing table for easy web splicing as well as an integrated winder/unwinder for the protective film. Due to the nature of its design, the winding unit can be used as both unwinder and rewinder, simplifying operations and logistics.

The versatile: the microFLEX roll-to-roll production system can handle various substrates, material thicknesses, and technologies such as CIS, CIGS, Perovskite, and others

Over two years, 3D-Micromac designed, engineered, and built a new and unique production solution for a crucial part of the production chain of flexible amorphous silicon solar cells.

The microFLEX PV processing area: up to 12 laser heads processing substrates up to 1,400 mm in step-and-repeat-mode

Assembly and commissioning

With all individual requests and processes addressed, the machine design was improved and polished one last time before construction began. Though sourcing components and the construction process occurred during lockdowns, supply chain interruptions, and other adverse events, everything could be completed in record time. The commission phase was marked by extensive cooperation with the customer, where all those involved worked hand in hand to optimise the individual processes, iron out a few rough edges, and bring the machine up to its expected capabilities.

Conclusion

Setting up a new industrial-scale production of any kind is a challenge at all times, even more so when it revolves around a new type of product with new and novel requirements and challenges. Over two years, 3D-Micromac designed, engineered, and built a new and unique production solution for a crucial part of the production chain of flexible amorphous silicon solar cells. The machine's design, set-up, and commissioning could be significantly shortened thanks to the previously successful development project for the laser process and beam guidance. This was made possible in no small part due to the close and productive collaboration between the customer and 3D-Micromac, where both partners combined their respective knowledge and experience to achieve the best outcome possible.

The new machine combines high precision for laser and dispensing processes with high throughput in a roll-to-roll step & repeat setup. It also extensively uses camera systems not only for scribe and dispenser alignment but also for self-calibration, thus improving and simplifying its operation. Currently, the production is in a ramp-up phase, and the first commercially available products can be expected soon.

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