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High speed remote cutting of ultra-thin aluminum foils

Alessandro Ascari[a,*], Erica Liverani[a], Caterina Angeloni[a], Michele Francioso[a], Alessandro Fortunato[a]

[a]*University of Bologna, Viale Risorgimento 2, Bologna 40136, Italy*

Abstract

High speed on-the-fly remote cutting by means of a galvo scanner of ultra-thin (12 µm) aluminum and copper foils has become very attractive in many fields, such as production of batteries for e-mobility applications and packaging in general. The present paper investigates performance and limitations of a commercial galvo scanner in cutting 12 µm thick aluminum foils with a high brilliance single mode 1.2 kW laser source. The main goal is to achieve a good quality cut at a speed of at least 10 m/s guaranteeing straightness of the edges and sharpness of the corners. According to this, the role of dynamic performance of the scanner is investigated, with particular attention to the effect of accelerations and decelerations on the shape of the kerf. The results are characterized by means of optical microscopy in order to assess the overall cutting quality.

Keywords: Laser remote cutting; Batteries; E.mobility; High-speed cutting; Thin foils; Aluminum

1. Introduction

Laser-based manufacturing of components related to the e-mobilty field has become a key enabling technology for producing battery cells, battery packs and electric motors. In particular, welding processes have become very popular, thanks to the availability of many different solutions in terms of laser sources and optics, as demonstrated by Ascari et al. Besides those well-assessed processes, ablation-related ones, such as cutting, scoring and stripping, gained an increasing interest due to their intrinsic beneficial characteristics: non-contact, high speed, high accuracy (see Banat et al.). In this direction several studies demonstrated that laser cutting is particularly effective in processing both coated and non-coated foils for the production of different types of battery cells: cylindrical, pouch and prismatic. In those applications, a very small laser spot with extremely high energy density and fast beam displacement melts and even vaporizes the material and high-performance cutting can be achieved. Moreover, Li-Ion cells for automotive application demand high cutting qualities in terms of small burrs, spatters and heat affected zone (HAZ). These defects, in fact, might lead to micro short-circuits that tend to cause a reduction of the overall cell life and performance. In this direction Lee et al.

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* Corresponding author. Tel.: +39-051-2090494.
E-mail address: a.ascari@unibo.it

demonstrate that the advanced characteristics of modern laser sources and optics allow an accurate and dynamic tuning of process parameters, that make possible to set up an optimized process with low defects and high productivity. Berhe et al. created a mathematical model for top, kerf, clearance, and burr widths and identified the primary physical phenomena and variables impacting cutting efficiency. Jansen et al. pointed out that humidity of the process environment has a significant impact on the quality of the cutting edge. LiFePO4 was cut using five different laser sources by Lutey et al. who also used numerical methods to calculate the depth of ablation during the process. Demir et al. compared the cut quality achieved with green and infrared lasers, emphasizing that pulsed laser induces localized heating with both approaches. As previously stated, the successful outcome of electrodes cutting is significantly influenced by the size of the heat affected zone (HAZ). The composition of the HAZ in relation to pulse width was examined by Schmieder, who found that HAZ is significantly less than the actual deposition width of ablated material. According to Lutey et al., the visible HAZ is barely affected by chemical and microstructural changes in electrode active layers. Since pulsed lasers are frequently used to cut electrodes, a lot of research has been done using these sources. Although lower pulse length was also investigated for quality enhancement, nanosecond pulsed lasers are the most frequently adopted. According to the previous considerations, the main challenge is to minimize thermal damage while maintaining high processing speed: the cutting foil usually travels in highly automated production lines at very high speeds (1-3 m/s), that leads to the need of on-the-fly processing with galvo scanning speeds up to 20 m/s. Currently, there are no studies conducted to assess the cutting quality of foils operating at ultra-high speeds. Moreover, processing highly conductive materials like copper and aluminum represents a significant challenge for electromobility. Due to the high reflectivity, beam sources with high intensities or visible-range wavelengths must be employed to simplify the laser process. In this direction, Luetke et al. investigate cutting of Cu and Al thin foils (6 and 12 µm thick respectively) using two different laser beam sources to establish the achievable cutting quality. Both continuous wave (CW) and nanosecond pulsed mode (PW) operation are exploited. However, this study addresses anode/cathode cutting at a maximum speed of 5 m/s. According to the above-mentioned literature review, the primary goal of the present study is to push the investigation towards much higher cutting speeds. In particular, an nLight single mode 1.2 kW high brilliance laser source is used to cut 12 µm thick non-coated aluminum up to 16 m/s. In order to put in evidence the role of dynamic performance of the galvo, cutting of the same foil was performed on a rotating pulley, so that no acceleration and deceleration of the galvos was needed.

2. Materials and Methods

The equipment exploited in the present research activity was based on a nLight Alta laser source, a Scanlab IntelliScan galvo, a Scanlab RTC6 controller and a Jenoptik F-Theta lens, whose main characteristics are summarized in Table 1. The galvo scanner was mounted on a Yaskawa HP-10 anthropomorphic robot (see Fig. 1(a)). Two different cutting methods were adopted:

1. The cutting path was performed by displacing the laser beam with the galvo.
2. The cutting path was achieved by the rotation of the aluminum foil on a pulley.

In case of cutting with the galvo, the aluminum foil was stretched between two grips so that no contact occurred between its bottom surface and an eventual solid surface. In order to get rid of the inevitable acceleration and deceleration effects introduced by the dynamics of the galvo, some trials were repeated laying down the foil on the surface of a pulley that was, then, kept rotating at given peripheral speeds (see Fig. 1(b)). The laser, then, was simply fired for a given time with no movement of the galvo. This solution allowed to guarantee that the whole cutting path was performed at a constant speed from the beginning to the end. Also in this case the part of the material subject to cutting did not touch any solid surface, so that no unwanted interactions occurred during the process. The processing material was a 12 µm thick aluminum AA 1050 foil.

Table 1. Details concerning laser source and optical path.

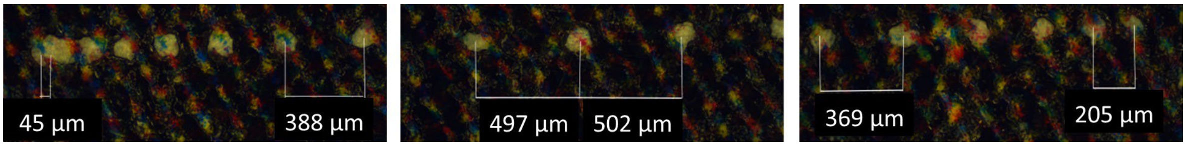
Laser and optics characteristics	
Maximum power	1200 W
BPP	0.42 mm·mrad
Fiber core diameter	14 µm
Collimation focal length	120 mm
Focalization focal length	255 mm
Theoretical spot dimension	30 µm
Scanner aperture	20 mm

(a) (b)

Fig. 1. (a) Laser cutting setup; (b) Pulley for high-speed rotation.

3. Results and Discussion

In order to understand the acceleration capability of the galvo scanner, several pulsed markings were made on black paper in order to achieve a dotted line: by observing and measuring the distance between the dots, useful information could be pointed out in terms of acceleration and actual speed of the laser beam during cutting. Pulse frequency was set to 32.2 kHz, so that a measurable distance of some hundreds of microns occurred between the dots. Fig. 2 shows the results in case of a cutting speed set to 16 m/s. The average distance between the dots in the steady state condition in this case was 500 µm, that corresponded to a steady state cutting speed S=0.5·32200=10304 mm/s, that is 16.1 m/s. The cutting distance travelled by the laser beam from the beginning of the cut to the point where the steady state speed was reached was equal to about 1950 µm. The steady state speed was reached after 10 marked dots, that is after a time t=10/32200=3.1E-4 s. This result corresponded to an average acceleration a=16/3.1E-4=51500 m/s^2, that is consistent with the data reported by the producer of the galvo for the specific model used herein. The tree pictures in Fig. 2 show the different parts of the dotted line: beginning (acceleration), center (steady state), end (deceleration). It is clear that the galvo performs better in the deceleration phase, rather than in the acceleration one.



(a) (b) (c)

Fig. 2. (a) Acceleration phase; (b) Steady state phase; (c) Deceleration phase.

The value of 16 m/s related to cutting speed was the maximum achievable for the scanner used: if a higher value was set in the control software, the results measured through the dotted line strategy were roughly the same as in 16 m/s case. Fig. 3 shows the effect of acceleration and deceleration on high-speed cutting of aluminum foils: the beginning and the end of the cut clearly show an anomalous enlargement of the kerf, due to heat accumulation induced by the low speed.

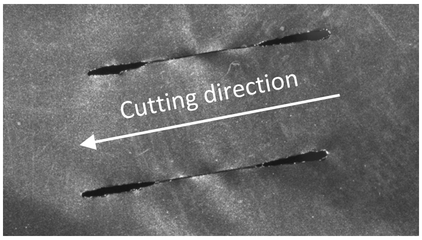


Fig. 3. Effect of acceleration and deceleration in aluminum foil cutting (length 15 mm, speed 16 m/s, laser power 525 W).

In order to guarantee a perfectly constant cutting speed, several trials were repeated using the pulley strategy described in the previous paragraph (see Fig. 4). The rotating device allowed to guarantee a constant peripheral speed up to 20 m/s.

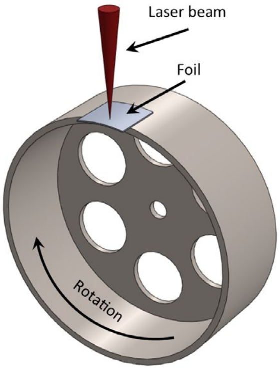
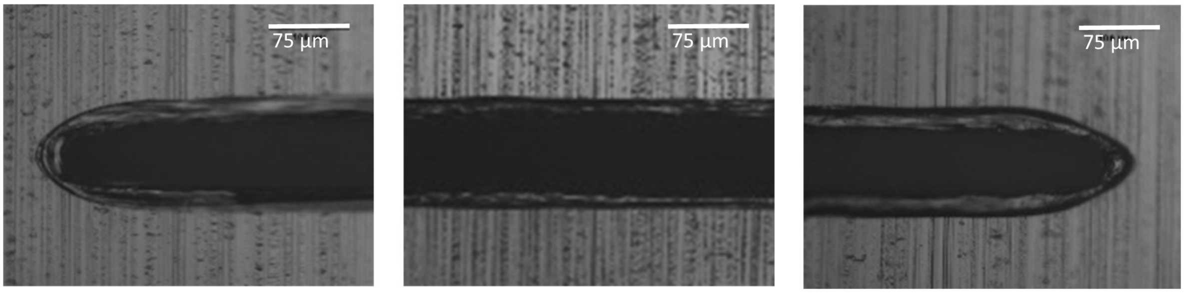


Fig. 4. Scheme of the rotation mechanism.

Fig. 5 shows a 15 mm long cut performed at 16 m/s and 525 W on the rotating pulley: the beginning and the end of the kerf are characterized by a geometry that is consistent with the one of the central part.

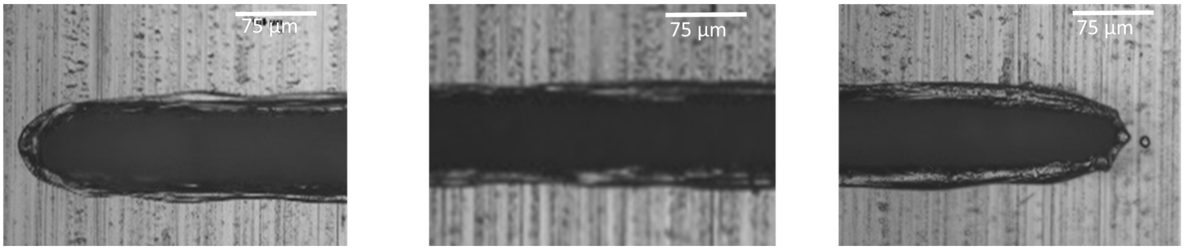


(a) (b) (c)

Fig. 5. Example of constant speed cutting by means of pulley rotation: laser power 525 W, cutting speed 16 m/s, cutting length 15 mm. (a) Acceleration; (b) Steady state; (c) Deceleration.

Considering the beneficial effects of having a constant speed underlined above, a new strategy was set up in case of cutting with the beam displacement performed through the galvo scanner. The cutting line was divided in three parts:

1. 15 mm long acceleration section with laser power set to 0.
2. 15 mm long active section with laser power set to 525 W.
3. 15 mm long deceleration section with laser power set to 0.



(a) (b) (c)

Fig. 6. Example of constant speed cutting achieved with the three sections strategy: laser power 525 W, cutting speed 16 m/s, cutting length 15 mm. (a) Acceleration; (b) Steady state; (c) Deceleration.

Fig. 6 shows the cutting results in this third case: the appearance of the kerf is consistent with the one achieved using the rotating pulley. This result demonstrates that by changing the cutting path strategy of the galvo, constant high speeds can be achieved.

Conclusions and future work

The present paper investigates the performance of commercial galvo scanners in laser high-speed cutting of 12 µm thick aluminum foils. The main achievements can be summarized as follows:

- The maximum speed achievable by the test system was 16 m/s.
- Accelerations and decelerations play a very important role when the speeds are set to the maximum levels: heat accumulation occurs at the beginning and at the end of the cutting line.
- By setting up a dedicated system for constant speed processing, it was demonstrated that an even

and regular kerf can be obtained at a speed of 16 m/s.

- A three-sections cutting strategy allows to extend the benefits of constant speed also in case of cutting with laser beam displacement by means of the galvo.

Future developments of the present work will take into consideration also copper thin foils and more in-depth investigations by means of advanced microscopy (SEM, EDS, profilometry), in order to understand the characteristics of the cutting edge and of the heat affected zone.

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