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High-speed nested scanner for large-area material processing

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Abstract

In laser-based material processing of metals, especially ablation, high power densities are necessary to change the material's state of aggregation. This can be realized using brilliant laser radiation with a small focal diameter. For large-area processing, the laser focal spot has to be guided by an appropriate scanning system with high scanning speeds and an accurate focusing. Therefore, a highly dynamic scanning system was developed in order to increase the flexibility and productivity for application. To verify the technical enhancement, experimental investigations were carried out analyzing the dynamics of the scanning system. At this point, the remote ablation cutting was used as one example of a high-speed processing.

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Keywords: galvanometer scanner; beam deflection; wobble; beam oscillation; remote ablation cutting (RAC); surface structuring

1. Introduction

In the automotive and aerospace industry, lightweight structures consisting of different materials, e.g. metal and organo sheets, are very common. At one point, these dissimilar materials have to be joined. One novel approach, developed at the Institute for Machine Tools and Industrial Management, is thermal joining (Heckert and Zaeh (2014)). A key point in this method is the pretreatment of the metallic mating partner (Roesner et al. (2011)). One possibility is roughening the surface by laser-based structuring (Wirth et al. (2014)). Depending on the parts, the area which has to be treated can be large. In order to be able to produce economically, however, the laser beam must be guided across the surface quickly. In this case, galvanometer-based scanning systems became a technical standard tool. The surface structuring process based on remote ablation cutting (RAC) is characterized by high power densities (about 10^8 W/cm²) and high scan velocities (several m/s) (Zaeh et al. (2010)). Even by using a high power single mode fiber laser (>1 kW), a small spot diameter is required to achieve these power densities (Zaeh et al. (2010)).

2. Laser beam motion

A simple way to fill an area is to move the laser beam along parallel lines. In this case, the beam path length for one transit results of the scanning speed and the on time of the laser. The disadvantages are the time gap for decelerating and accelerating the mirrors between two lines and the resulting laser-off time. To simplify the mathematics, only a line scan in x-direction is tested. Alternatively, it is possible to move the laser beam in a circular path. In this case, the mirrors have to execute a sinusoidal motion without any harsh decelerating and accelerating phases. This motion is limited in amplitude and frequency, caused by the mechanical behavior of the mirrors.

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In typical scanning setups, both the line scan and the wobble motion are realized by two mirrors in x- and y-direction. This leads to the situation, that a large mirror has to move fast in complex paths, which results in moderate processing speeds limited by the high inertia of the mirrors.

The trajectory consists of a linear motion in x- and y- direction (see figure 1):

$$x(t) = v_{scan} \cdot t + r \cdot \sin(\omega \cdot t)$$
$$y(t) = r \cdot \cos(\omega \cdot t) \qquad (1)$$

with $x(t)$ = x-coordinate, $y(t)$ = y-coordinate, v_{scan} = line scan speed, t = time, r = radius, ω = wobble frequency. This results in a combined path velocity:

$$v_{Path} = \sqrt{[\dot{x}(t)]^2 + [\dot{y}(t)]^2} \qquad (2)$$

One approach to speed up the laser beam motion is to split the line scan and the wobble motion in two separate scanning units (see figure 2). A small mirror aperture will execute the oscillation with very high frequencies and the large mirror aperture will process the line scan motion. Thus, the laser beam aperture and the resulting spot diameter are limited by the small aperture.

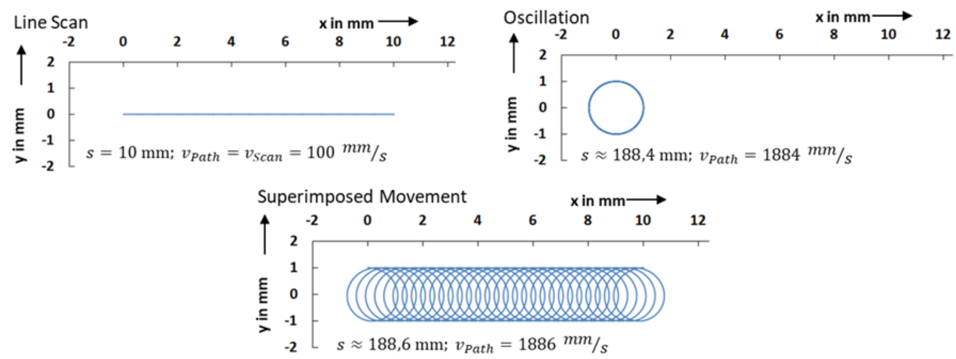

Fig. 1. Superimposed beam movement (wobble) as a result of a simultaneous line scan combined with a oscillation movement

3. Experimental setup

A continuous wave Yb:fibre laser with a maximum output power of 3000 W was used for the experiments. The shaping and deflection of the laser focal spot was carried out by means of a galvanometer scanner, whereby the laser focal spot of a diameter d_f = 60 µm can be guided at a path velocity of several meters per second over the 1 mm thick sample plate. For processing, the well-established automotive steel 22MnB5 was used, whose chemical composition is specified in table 1. The hot formed steel is additionally dip-melt-finished with an AlSi coating.

Table 1. Chemical composition of steel 22MnB5 in weight percent (Thyssenkrupp (2013))

	C	*Si*	*Mn*	*P*	*S*	*Al*	*Cr*	*B*	*Ti*
min	0.20	0.20	1.10			0.02	0.15	0.0008	0.020
max	0.25	0.40	1.40	0.025	0.01	0.06	0.35	0.0050	0.050

The specialized scanning unit, consisting of the small wobble aperture and the large line scan aperture, leads to a complete new scanhead design called the ‘nested scanner’. Below the standard collimation unit, the laser beam is guided through the 21 mm oscillation unit. After that, the laser beam gets focused by a movable lens and a focusing optics. At the end of the scanhead, the laser will be deflected by a standard scanning unit with 50 mm aperture.

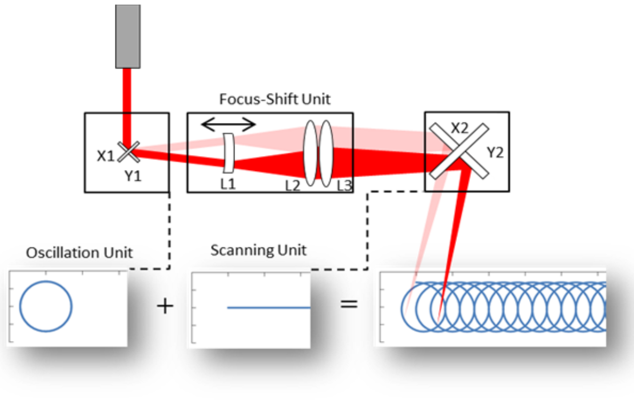

Fig. 2. Nested Scanner – principle of operation

4. Results and discussion

4.1. OEM scanner dynamics without oscillation unit

To analyze the dynamics of the OEM scanner with 50 mm aperture and to predict its influence on complex trajectories, an experiment was carried out where the effect of both axis could be tested. The oscillation unit was deactivated for the tests. Thus, the superimposed beam movement was performed only by the scanning unit. During the tests, a circle with a fixed path velocity of $v = 5$ m/s, a defined frequency f, and an adapted amplitude A_{tar} was marked on a steel plate. The relation between the parameters can be seen in equation 3:

$$A_{tar} = \frac{v}{2 \cdot \pi \cdot f} \tag{3}$$

The circular kerfs on the surface, marked by the laser, where analyzed with a light section method. The measured radius A_{act} of the samples as a function of the corresponding frequency f, compared to the target radius A_{tar} are shown in figure 3. Each point in this diagram represents three samples. By reasons of a low standard deviation this value was not affiliated in the graph to guarantee a better clarity (see table 2). The x-direction represents the vector perpendicular while the y-direction denotes the vector parallel to the scanner's flange axis.

Table 2. Comparison of the adapted amplitude to the measured amplitude for the OEM scanner.

f in Hz	A_{tar} *in mm*	$A_{x,\,act}$ *in mm*	*StDev - X*	$A_{y,\,IST}$ *in mm*	*StDev - Y*
38	20.941	20.839	0.014	20.785	0.133
50	15.915	15.747	0.027	15.659	0.025
63	12.631	12.370	0.006	12.232	0.015
75	10.610	10.282	0.017	10.123	0.043
100	7.958	7.486	0.010	7.283	0.021
150	5.305	4.591	0.005	4.354	0.021
200	3.979	3.031	0.014	2.778	0.009
300	2.653	1.292	0.008	1.165	0.010

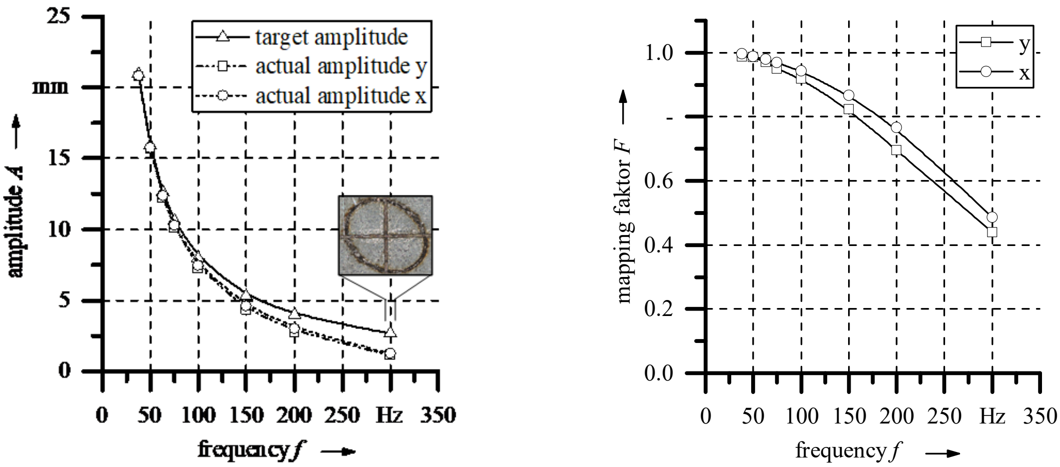

Fig. 3. Actual amplitude compared to the target amplitude for x- and y-direction (left); Mapping factor for x- and y-axis (right)

It can be seen, that the amplitude A is frequency dependent. With higher frequencies, the maximum possible amplitude decreases. Simultaneously, the aberration of the target value (A_{tar}) to the real value (A_{act}) rises. This leads to smaller circles than planned. The aberration of the real value to the target value depends also on the axis. The x-axis has a higher mapping factor than the y-axis (see figure 3). This leads to a distortion of the primary adjusted circle, resulting in an ellipse. This is caused by the characteristic of the scanner. If the mechanical inertia is too high, so that the mirror would move to slow, the scanning system keeps the target frequency and adjusts the amplitude. To avoid this error, the velocity of the path could be reduced, which will lead to a higher mapping factor. Furthermore, the process time to structure the surface increases, so the productivity for the used scanning system decreases. Another disadvantage of this scanning system is the disparate behavior for the two axis in the scanner.

4.2. Processing examples

For the first tests of the new nested scanner, a laser pointer was moved (see figure 4). The regular vector path (ARGES head) was executed by the scanning unit. The overlaid wobble motion was realized by the oscillation unit. The differences of the pictures result of the parameter variation. The vector path speed was constant, the wobble amplitude and the wobble frequency were changed.

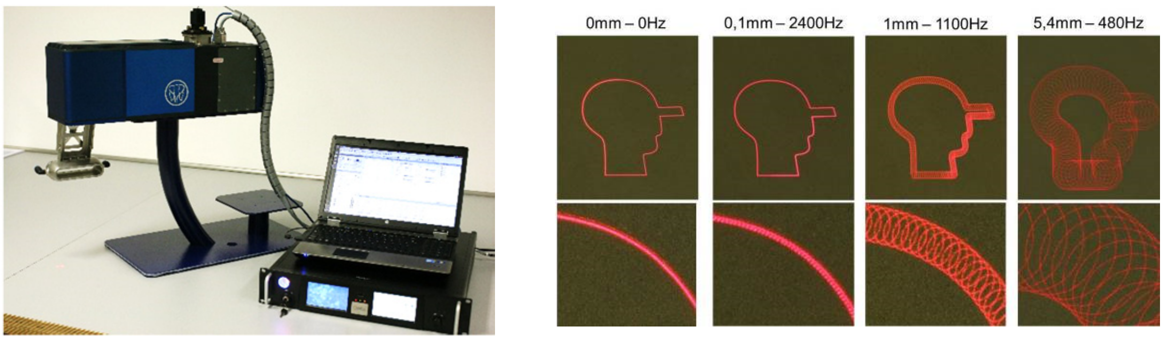

Fig. 4. Nested scanner setup with laser pointer (left side); variation of wobble amplitude and frequency by oscillation unit at constant scan speed (right side)

Additionally, a direct comparison of a standard scanner and the nested scanner was carried out. The beam path speed of the nested scanner is four times higher and so the laser power and the processing throughput can be four times higher without any losses in wobble amplitude.

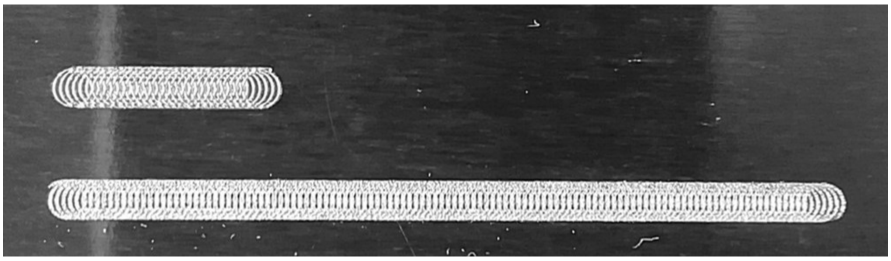

Fig. 5. Wobble performed at a given time of 0.1 second only by the scanner unit (top line) and with oscillation unit (bottom line)

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