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Advanced galvo control enables efficient laser micro processing

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- Invited Paper -

Abstract

During the past decade the laser was established as a standard tool for high power applications like welding, cutting and brazing. But also for high precision tasks ultrashort pulsed lasers with high repetition rates have been successfully proven for various industrial applications especially in display manufacturing, electronics and medical technology.
The requirements of these applications are quite different and make it necessary to enhance existing scanning systems in order to provide high productivity and high quality at the same time for each individual application.
Our presentation discusses how currently existing galvo scanning technology works, its limitations and how the new *SCAN*ahead control can improve the obtainable result in laser processing with galvo scanners.

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1. Introduction

Increasing the throughput is a key-factor for the industrialization of laser micro machining processes. Especially the duty cycle of the laser machine needs optimization in order to maximize the laser-on time of the system. Defining the duty cycle from a scanning point of view as the percentage of time at constant scanning velocity there are different approaches for galvo-based laser machines:

The first approach is the optimization of the scanning strategy with respect to the scanned pattern reducing the number and duration of jumps and turning points without active laser processing. E.g. for patterns with high filling ratios this can lead in one extreme to line by line scanning approach.

Besides an optimization of the scanning strategy, the optimization of the dynamic behavior of the scanner is another option. When only a specific pattern is scanned, the parameters of the galvo control, like maximum speed or tracking delay, can be optimized for this specific application maximizing the duty cycle of the machine for this application. This became more and more popular with the availability of digital control boards as used in the intelli*SCAN* series. But the draw-back of this approach is that the scan system loses performance for scan patterns that differ from the design basis.

When using either high-speed or high-acceleration galvo systems for micromachining applications, standard galvo systems with an analog position detector reach their limits regarding accuracy. Fortunately, recent developments on scan systems with digital encoders for low inertia scan systems for precision applications proof more and more that it is possible to build reliable systems for the demanding combination of speed and accuracy.

But still, the conventional way of controlling galvanometer scanners using a constant tracking delay and constant scanner delays will always result in a scanning solution optimized for one specific application. Especially when working with scanning speeds significantly lower than the scanner's maximum speed a part of the scanner's performance is sacrificed. Hence, in order to allow an optimal usage of galvo performance a new control concept is necessary.

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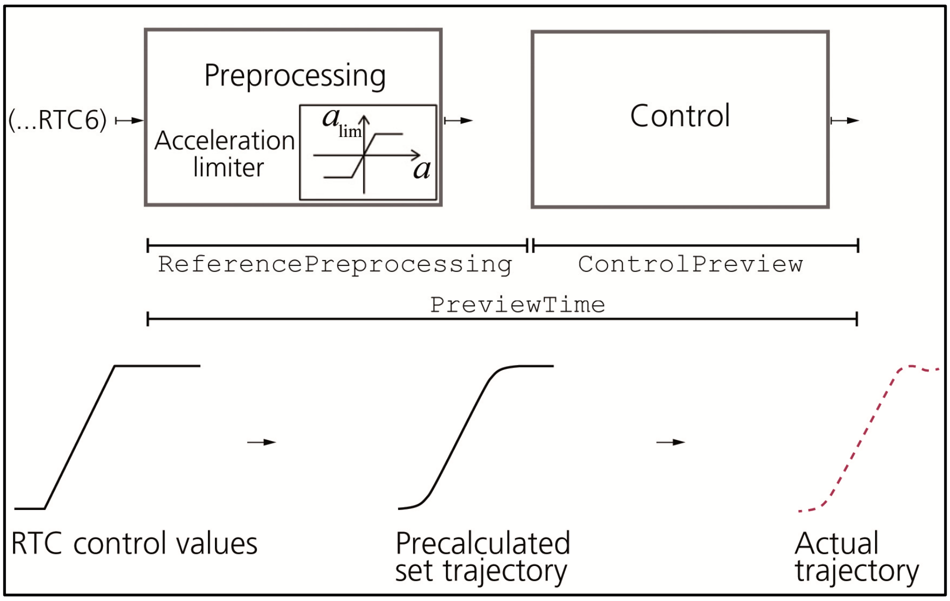

Fig. 1. Structure of *SCAN*ahead servo control.

2. New *SCAN*ahead control

The excelli*SCAN* scan heads are equipped with a new *SCAN*ahead servo control. This innovative control concept avoids a tracking error and uses the maximum acceleration capability of the galvanometer scanners for all galvo movements.

Key in this new approach is that a preprocessing unit analyzes associated theoretical accelerations which are then limited to match the scan system's actual acceleration capabilities.

The result is a precalculated set trajectory of acceleration-limited control values. The required time for this is depicted as ReferencePreprocessing in figure 1. The galvanometer scanner control successfully traverses the precalculated set trajectory (actual trajectory in figure 1) – but only with a temporal offset (the control preview time ControlPreview). This enables full usage of scan system dynamics.

The entire temporal offset between RTC control values and galvanometer scanner motions (ReferencePreprocessing plus the control precalculation time called ControlPreview) is named PreviewTime. The term PreviewTime highlights the excelli*SCAN* scan head's capability to know the RTC control values in advance by a precise amount of time (1,2 ms) to ensure execution accurately in time.

The precalculated set trajectories with limited, constant set accelerations cause an acceleration time to vary in accordance with speed changes. This means scanner and laser delays needed for taking acceleration time into account are also dependent on speed. These can be automatically calculated by the RTC6 board.

For synchronous laser control, the laser control signals likewise need to take the PreviewTime into account which can be done using the RTC6. This also applies for any other control signals intended to be transmitted synchronously with scanner motion.

2.1. Differences between conventional and SCANahead control

The new *SCAN*ahead galvo control varies completely from conventional galvo control. The main differences are displayed in Figure 2.

Scan heads without *SCAN*ahead technology exhibit a characteristic temporal offset called tracking error ts. The tracking error ts results from the implemented servo control structure which means that the tracking error duration ts is a metric for the dynamics of a scan head. However, the tracking error ts is (at ”normal” speeds) practically independent of scan speed and only affected by the selected tuning.

One problem with this approach is that the tracking error can introduce undesirable artifacts during marking, for example, “necking” in circles and arcs. Furthermore, although a tolerance (maximum value) is specified for the tracking error, the exact value can be serial-number-dependent, as the systems have to be tuned individually. This means that the exact value must be experimentally determined for each individual system.

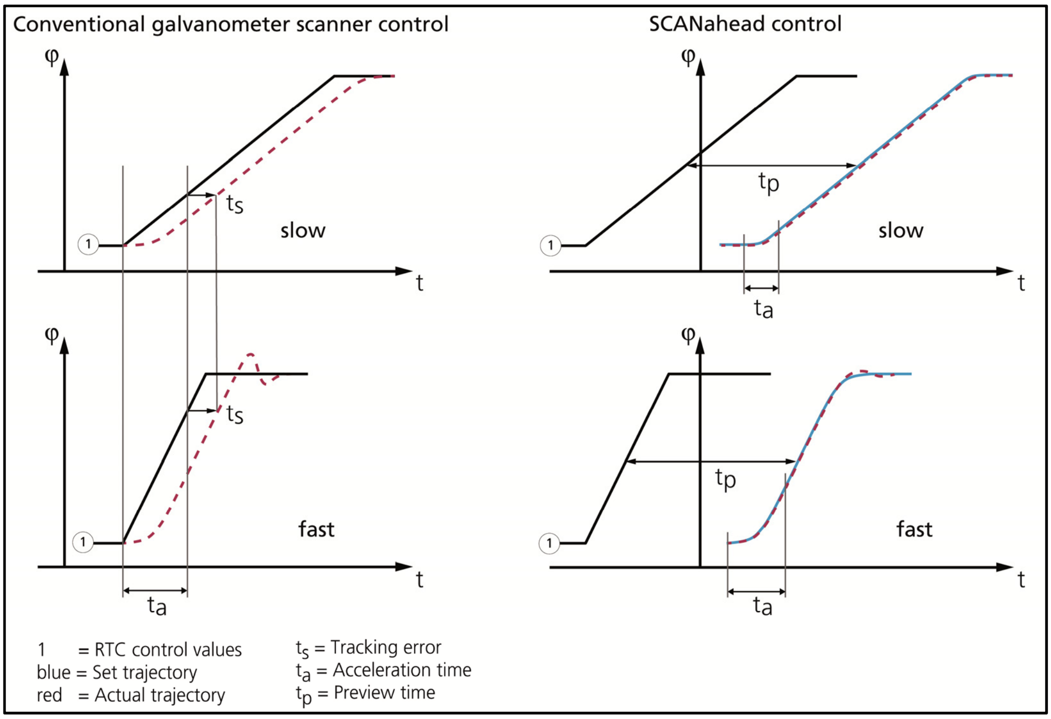

Fig. 2. Comparison: Conventional galvanometer scanner servo control and SCANahead servo control.

For scan heads with *SCAN*ahead technology, the temporal offset is not the tracking error ts. Instead it is the fixed, pre-defined precalculation time PreviewTime tp. The precalculation time PreviewTime tp is qualitatively different from tracking error, as it is not a metric for scan head dynamics. Instead, from the RTC control values, a physically traversable trajectory gets precalculated within the PreviewTime tp. This physically traversable trajectory serves as input to the galvo control.

Also for the generated trajectory the two approaches vary significantly. For the conventional control the trajectory of RTC control values gets smoothed by servo control. The result of smoothing is not precisely known in advance. And it is dependent on the selected tuning. In negative acceleration phases, significant undesirable overshoot may occur.

The duration of acceleration phases is practically speed-independent. Thus the same amount of time is always required to reach the desired target speed. This means that, particularly at low speeds, the acceleration potential is not fully exploited and the process times of applications are therefore not optimal.

Using the *SCAN*ahead control based on the trajectory of RTC control values, a traversable acceleration-limited set value trajectory gets calculated and transmitted to the servo control. Deviation of the final actual value trajectory from the RTC control value trajectory is therefore known in advance (because precalculated).

The *SCAN*ahead control ensures constant acceleration (at the maximum capabilities of the scan head) in acceleration phases. The duration of acceleration phases thus is minimized, although speed-dependent. Resultingly, scanner and laser delays need adjusting in accordance with marking speed.

2.2. Adjusting Scanner delays

For conventional galvo scanners you can set scanner and laser delays and these do not need adjusting for changes in speed. There are rules of thumb for sizing the delays, but truly optimal delays always require empirical determination for each case of application. Furthermore, delay values need to be determined for each tuning.

With the new *SCAN*ahead control used in the excelli*SCAN,* scanner and laser delays must be set differently in accordance with speed. Thanks to constant acceleration and precalculated set positions, the relationship between speed and optimum delays is likewise mathematically known in advance.

The RTC6 board can automatically determine the optimal speed-dependent scanner delays and laser delays. It then also sets them dynamically in real time during list execution.

Provided that the specified marking speed makes sense, the users can effortlessly and immediately create markings with high contour fidelity (without the need to determine and optimize delays).

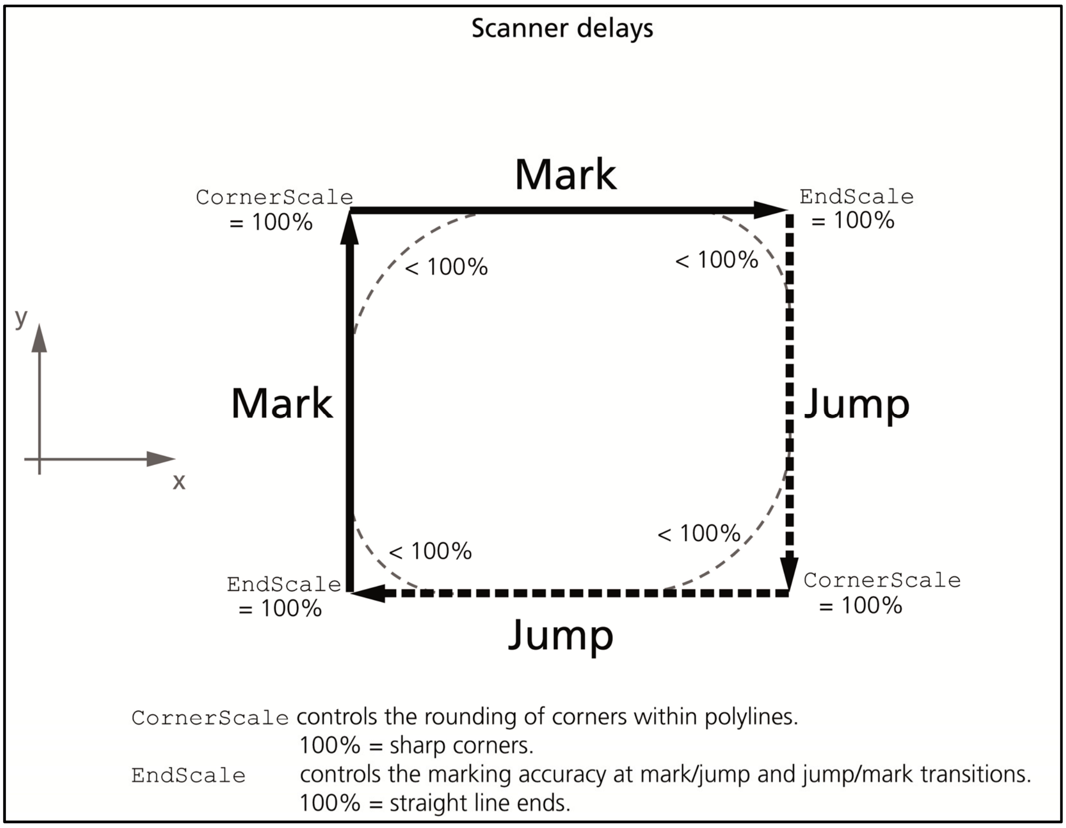

Fig. 3. Influence of the parameters EndScale and CornerScale.

This contour fidelity can be adjusted with the parameters Corner-Scale and EndScale. The parameters allow to optimize processing results among optimal contour fidelity and optimal process speed at the cost of contour fidelity (process optimization). The effects of these parameters are shown in figure 3.

Laser delays are influenced by an additional parameter AccScale that allows to influence energy deposition at line ends by partially or entirely showing or hiding acceleration phases. This is done by specifying the percentage of the acceleration time where the laser is switched on. Also a fine-tuning by laser delays is available. It permits to set a temporal offset for the laser switching time points, for example, to compensate signal propagation times.

3. Results and Conclusion

*SCAN*ahead control fully exploits the galvos' dynamic performance potential. The results in comparison to a system with conventional galvo control are shown in Figure 4. Scanner delays are set zero for this experiment.

The *SCAN*ahead control produces far less corner-rounding at a wide range of speeds compared to conventional galvo control. Therefore smaller scanner delays are required to meet the applications specified corner rounding. The processing time is reduced this way. Furthermore, the *SCAN*ahead control ensures precise traversal of the defined set circle even at high circle speeds. This substantially simplifies correct processing of circles and boosts productivity thanks to increased trajectory velocities. In contrast, tracking errors of traditional scanner control produce a necking effect during high-speed circle traversal. The control effectively behaves as a low-pass filter that attenuates control-signal amplitudes at high circle frequencies.

Concluding the new *SCAN*ahead approach enables galvanometer scanners to use their complete dynamical performance independent of the programmed geometry. The highest benefit compared to traditional galvo control will be reached when programming patterns that combines high speed vectors or jumps with very short vectors or corner radii.

Additionally, the Autodelay function that automatically sets the speed-dependent scanner delays offers a more intuitive way of working with a galvanometer scanner staying closer to the results and their deviations than translating this information into scanner delays.

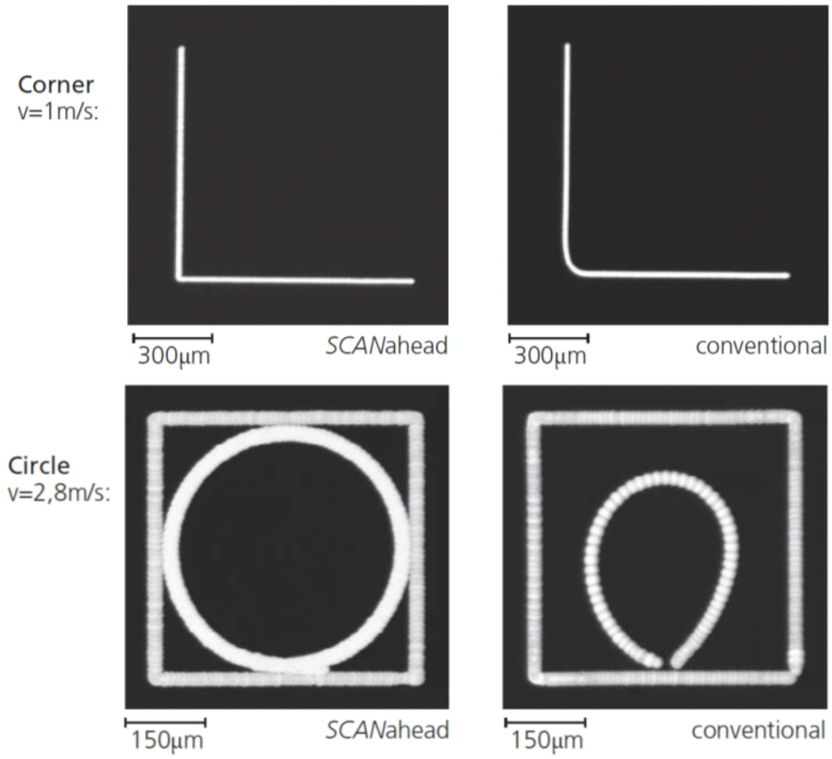

Fig. 4. Marking results illustration the differences between conventional control and *SCAN*ahead control.

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