LASER SYSTEMS EUROPE

Whitepaper

Galvanometer Scanners with Digital Position Sensors Meet Industry's Toughest Challenges

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Dr. Michael Breit and Dr. Hans-Joachim Muenzer

Countless applications rely on laser processing systems driven by highly dynamic galvo scanners, which precisely position the laser beam onto workpieces. For each application, mirrors mounted on the galvanometers accurately guide the laser. These systems' core components are a galvo motor (based on moving magnets) and a position sensor, which alone accounts for much of the scanner's performance. Until recently, analog detectors have typically been employed, but their fundamental limitations become apparent when highest dynamic performance and precision are needed.

Analog position detectors usually use an optical detection method that is cost-effective for many of industry's laser applications: A motor-shaft-bonded element between an LED light source and a photo-detector casts a shadow onto the detector, with intensity fluctuating depending on the shaft's rotation angle. Assorted thermal properties of the employed components produce unwelcome drift effects that can only be partially mitigated. Such disadvantages are now overcome by switching to digital position detectors.

Figure 1

Precision molded part manufactured via 3D laser printing

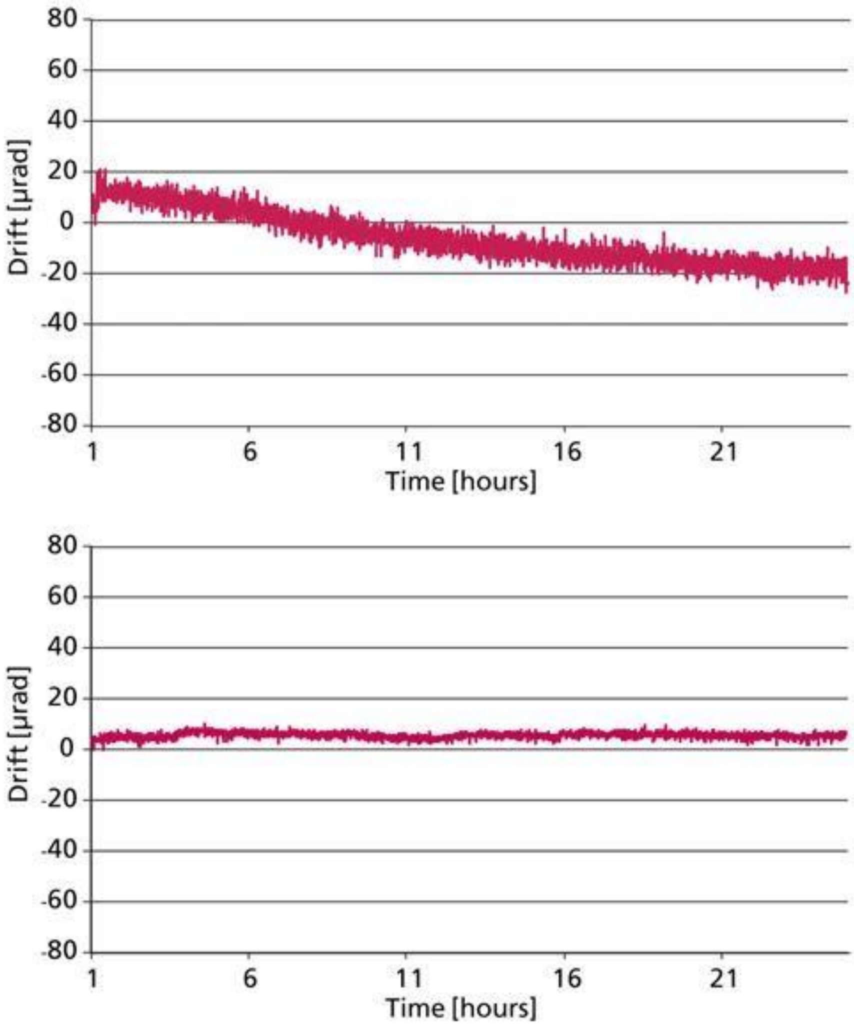
Source: EOS

Enhanced Stability

Digital technology improves both precision and long-term stability. A key application for digital galvos is the creation of precision molded parts in 3D printing, as shown in Figure 1. Here, the laser must precisely and repeatedly retrace the tiniest of structures, sometimes for hours at a time.

Likewise benefitting from low-drift scan systems are industrial applications that span across multiple shifts in 24/7 production. Measurements indicate that the galvo scanner's position detector (PD) again plays a decisive role in long-term drift. The analysis takes into account whether a scan system deviates from its assigned position due to ambient temperature fluctuations or other factors. During measurement, the temperature-dependent portion can be minimized by ensuring stable external temperatures. Whether measured across eight or 24 hours, differences in long-term drift for analog vs. digital systems are substantial, with digital encoders being clearly superior (see Fig. 2).

Figure 2



Long-term stability differences of galvo scanners with various position detectors, based on optical measurement data

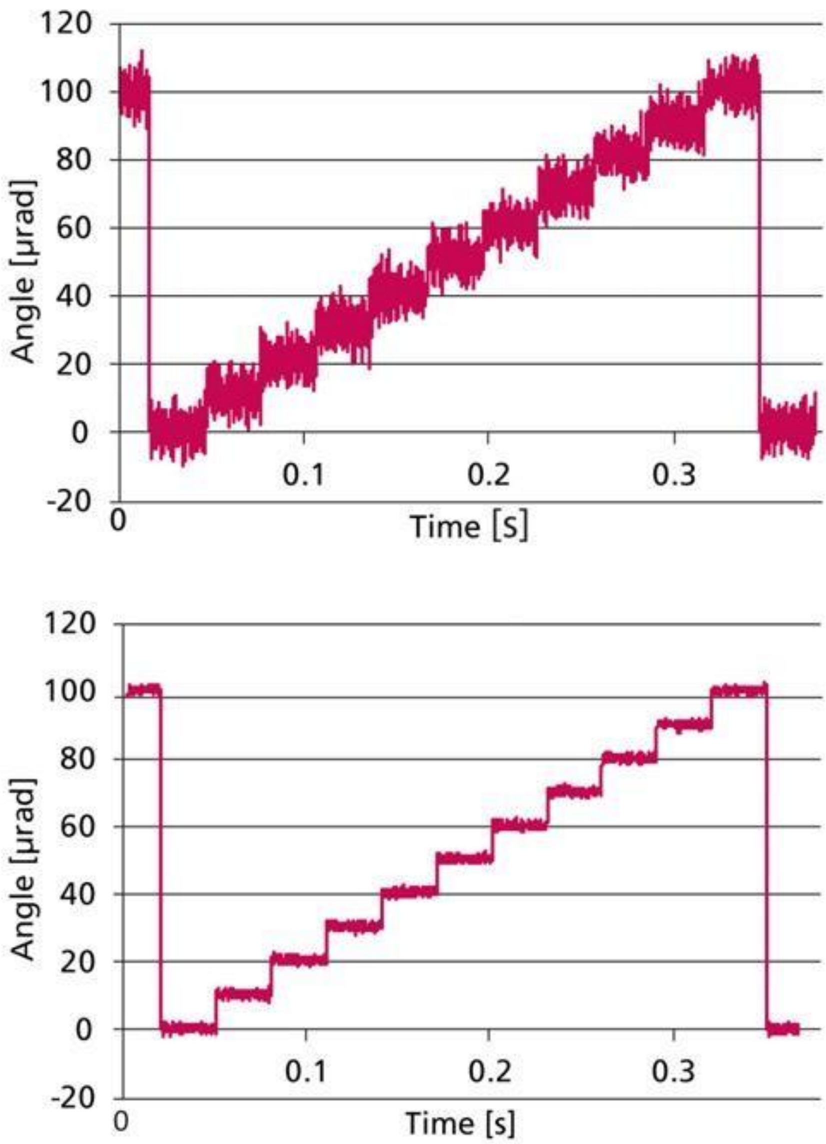
Above: analog P
Below: digital PD

Source: SCANLAB AG

More Precision, Thanks to Digital Signals

A galvo scanner's precision is impaired by high-frequency noise (1-20 kHz), called dither, primarily emanating from its analog position detector. Via a step scan with ten very short jumps in the 10-µrad range, Figure 3 illustrates the qualitative differences in positional stability for analog vs. digital sensors. The analog encoder's resolution limit has obviously been reached, while the digital position detector readily continues functioning precisely.

Figure 3



A scanner's measured angular position when executing ten defined 10-µrad jumps

Above: analog PD
Below: digital PD

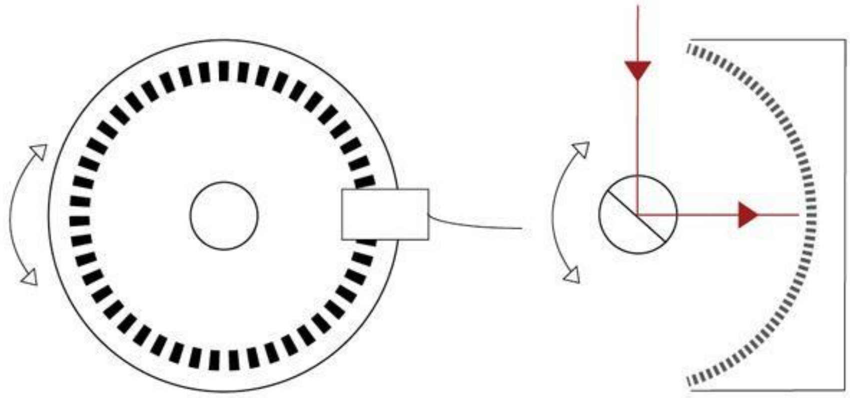
Source: SCANLAB AG

Guided Tour of Encoder Technologies

To date, digital position detectors have used incremental encoders – where an encoder disc is attached to the scanner rotor for detection of a bar code (see Fig. 4). The basic element of such optical encoders is this encoder disc, featuring a radial, lined scale. As the scanner axis rotates, the disc moves past a stationary detector unit. Each line passing by the detector causes a bright-dark transition. Depending on the scale's spacing and radius, hundreds to thousands of bright-dark transitions occur across the full angular range. To determine rotational direction, the detector provides a second signal phase-shifted 90° with respect to the first. The resulting combination of sine and cosine signals is also known as a quadrature signal. Because this oscillating signal no longer suffices for absolute position determination, an absolute reference position needs to be ascertained.

The key advantage of digital encoders over analog PDs is that the former are much less sensitive to disturbances, and therefore can exhibit significantly lower noise/drift. Nevertheless, such "classic" encoder technology has dynamic performance limitations, because increasing the resolution (while keeping line spacing constant) requires a larger scale radius, and hence a larger disc (see Fig. 4). This results in significantly higher inertial mass, which limits dynamic performance.

Figure 4



Key differences in construction of commercially available digital position detectors

Left: common principal of digital encoders employing an encoder disc

Right: SCANLAB's patented “light-pointing encoder” design with reduced-inertia mirror at rotor end

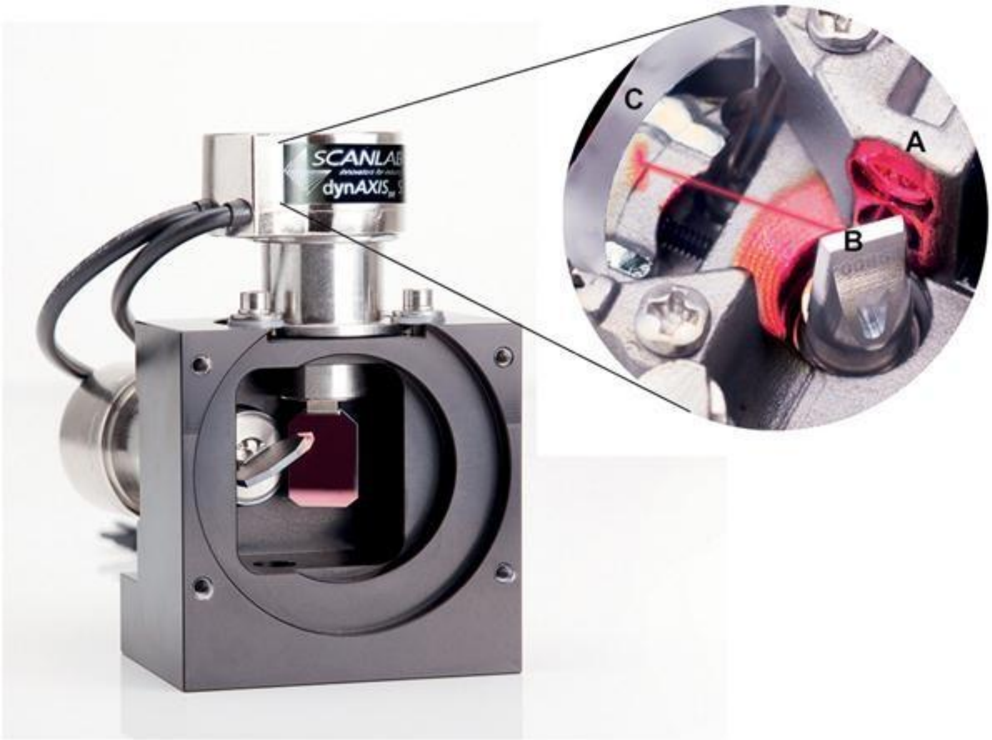
Source: SCANLAB AG

Peering into the Black Box

With its patented digital se-encoder (SCANLAB-encoder), SCANLAB has succeeded in breaking past current dynamic-performance limitations – while simultaneously retaining the highest precision. Here, a new inferometric measurement method is utilized in which a laser diode illuminates a stationary concave reference grid via a small rotatable mirror connected to the rotor (see Fig. 4). The laser beam's deflection angle is twice the mechanical angle of rotation. The diffraction image reflected by the reference grid gets reflected back to the rotor mirror and forwarded via special optical elements to the detector for analysis.

Mirror rotation leads to diffraction-pattern changes at the detector, which transforms them into a sinusoidal quadrature signal. A parallel second beam path (and the markings defined there) integrated into the illumination path provides the additional referencing needed for determination of absolute positions.

Figure 5



Functioning of SCANLAB's digital se-encoder

Source: SCANLAB AG

Figure 5 shows the technical implementation. The se-encoder's massless laser beam (A) scans the stationary scale (C). Other than the inertia-reduced mirror (B), no further components are required that can increase inertia.

Significance for Users

The exceptionally low moment of inertia now permits compact galvanometer scanners, with correspondingly small mirrors, to be used for their remarkable dynamic performance potential. For the first time, such galvos can be employed in high-dynamics applications such as micro-processing, where ultra-short laser pulses and high repetition rates require ever faster scan speeds. Digital encoder technology's advantages can also be harnessed in processing of electronics and displays, semiconductor lithography and creation of VIA holes, as well as micro-structuring.

Over the past 12 months, digital se-encoder technology – in single-axis dyn*AXIS*$_{se}$ galvo scanners and intelli*SCAN*$_{se}$ 2D scan systems – has demonstrated both its industrial suitability and excellent cost-effectiveness.

Authors:

Dr. Michael Breit, Head Product Management, SCANLAB AG

Dr. Hans-Joachim Muenzer, Head Scanner Development, SCANLAB AG

http://www.scanlab.de