Advantages of digital servo amplifiers for control of a galvanometer based optical scanning system

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ABSTRACT

Long-standing industry demand for "extended status messages" from galvanometer-based scan heads and ever-increasing dynamical requirements in industrial laser materials processing, e.g. due to advancing laser sources, have lead to the development of digital servo controls for galvanometers.

The advanced control algorithms of a digitally controlled scan system lead to highly improved dynamics compared to an analog type where only a very limited number of parameters are used to tune the system to a certain dynamical requirement. Additionally, the abundant data acquired during control with a digital scan system are available for further processing.

This paper discusses advantages of having such real-time feedback in laser-based materials processing applications and how e.g. process parameters like scan-speed and velocity can be used for quality control, applications development, or advanced laser control.

INTRODUCTION

The popularity of lasers in industrial, microelectronic, and medical applications is steadily growing. Lasers have established themselves across a wide range of materials processing tasks – among them marking, micro-machining, rapid prototyping, cutting/routing, welding, micro-via drilling and embedded passive sensor trimming. These successes have been facilitated by significant progress in laser technology – higher laser powers, improved beam quality, shorter wavelengths, longer component lifetimes – and advanced focusing and handling systems that move and position the laser focus onto the work piece.

Compared to conventional technologies, laser-based materials processing offers some key advantages. Small heat-affected zones allow precise and stable processes even in combination with very sensitive materials. Furthermore, laser processes are contact-free, and thus provide a degree of flexibility unattainable using tool-based mechanical processes. Non-contact techniques aid in material cleanliness and integrity, and the absence of wear and tear on tools also leads to important cost advantages.

However, these advantages can only be realized if focus quality and positioning onto the work piece are highly controlled and this necessitates very precise beam positioning and focusing systems. Fast and precise ways to position the laser focus on the work piece are galvanometers. These are rotational drives with high resolution and acceleration within a certain angular range, to which high reflectance mirrors are attached. Typically, galvanometers are found in two-axis setups that deflect the laser beam in two dimensions. Unlike their "flying optics" counterparts, galvanometer-based systems usually keep the focusing optics stationary. As only the mirrors, with very small inertias, need to be positioned by galvanometer scanning systems, they allow the highest dynamics and process speeds, as well as the shortest positioning times. This leads to higher throughputs and much more efficient use of costly investments such as UV lasers.

Usually galvanometers are equipped with closed-loop position control to allow very fast and precise positioning of the mirrors mounted on their motor axes. Traditionally, analog driver boards are used to tune galvanometers to specific requirements. Now the first scan heads with digital driver boards like the intelliSCAN® 10 are being introduced to the market. Figure 1 illustrates a general outline of a laser scan-head system and its constituent components.

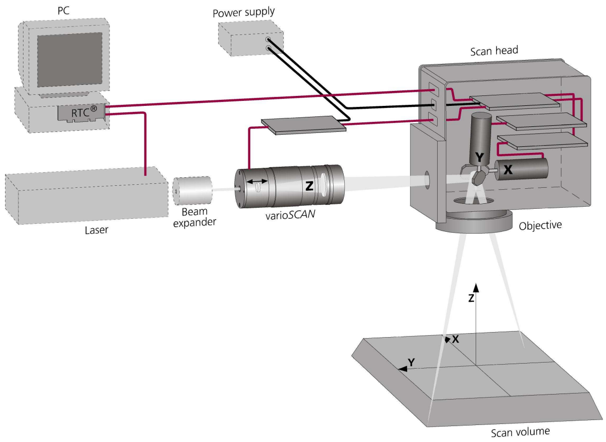

***Figure 1:** The constituent components for a laser material processing system are depicted above. The scan head consists of a pair of mirrors mounted onto galvanometer scanners rotated by (analog or digital) servo amplifiers. A digital interface is used to transfer the control data from PC to scan head and to make the feedback signals available when having digital servo amplifiers. To focus the laser beam in a scan volume or onto a work piece e.g. a flat-field objective and/or some pre-focusing optics (varioSCAN) can be used[3].*

Status of current analog technology

To move and position the laser beam precisely on the work piece, a position detector inside the galvanometer scanner provides closed-loop feedback to the controller board. The controller compares the actual position to the commanded position, constantly adjusting the current through the galvanometer to correct for any differences. Although universally accepted and highly advanced, analog servo electronics do have limitations as they use a fixed control structure with a limited number of fixed parameters. This limits the performance of the system and the versatility as the tuning of the analog driver board is optimized for a certain requirement like vectors or steps and cannot be adjusted to changing dynamical requirements. Additionally such a fixed parameter set cannot accomplish changes in the scanner motor e.g. with scan angle or time (ageing), temperature etc.

These limitations can be overcome by digital servo controllers, which use a much more complex parameter set. As a more integrated system, it also offers easy access to a variety of parameters opening up extensive possibilities for diagnosis and communication between the scan-head and control computer.

USER BENEFITS OF DIGITAL SCAN HEAD TECHNOLOGY

SCANLAB has developed a new generation of digitally controlled scan-heads such as the intelliSCAN® 10. These fully digital scan heads are based on a digital servo board with a DSP system for each galvanometer axis. The intelliSCAN® 10 uses a highly advanced control algorithms based on a simulated galvanometer model instead of a fixed set of tuning parameters. This allows achieving a performance far superior to the fastest analog systems.

Higher dynamics and throughput

Throughput of a laser system is determined by several factors like maximum scanning speed along a vector, jump times between vectors as well as by so-called scanner delays inserted between two subsequent vectors. The delays compensate for the inertia of the scanners and ensure the programmed pattern is scanned completely, even in corners. The galvanometer model used on the digital servo boards allows, higher scan speeds as well as shorter jump times and scanner delays by always selecting the best parameters for a certain situation. This allows higher throughputs and lower process times in a production environment.

To tweak performance it is possible to switch on-the-fly between various control algorithms, each being optimized for a certain process pattern such as vectors or steps. Micromachining applications benefit from control algorithms optimized for high precision. Especially in combination with the advanced thermal management and the lower heat generated by the digital servo boards this leads the higher precision and thermal stability of the system.

Enhanced communication channels

The digital servo architecture allows a wide variety of data signals to be returned to the controller board. This opens up implementation of a wide range of additional benefits to the end users. During a transition period where scan heads with analog drivers are replaced by a digital version, an extended version of the established XY2-100 protocol will be used to send data from the scan head to the PC via SCANLAB's RTC® 4 board. Additional status channels transmit data to the controller board continuously. This allows monitoring a comprehensive set of galvanometer scanners' parameters during operation or carrying out comprehensive troubleshooting in the event of an operational malfunction. With the ever-increasing data available from the scan head and due to some severe limitations of the XY2-100 protocol, the full functionality of digital scan head technology will be realized with the introduction of a new protocol.

The current intelli*SCAN*® version interfaced with an RTC® 4 board allows to access the following scan head data:

- Actual Position – Actual angular position of the corresponding axis.
- Set Position – Set angular position of the corresponding axis.
- Position Error – The net difference between the actual and set position.
- Actual Velocity – Actual angular velocity of the corresponding axis.
- Operational Status – This data type contains additional information about the current operational state.
- Supply voltages, temperatures, and currents throughout the system can be queried for further analysis and to protect the scan system from malfunction or destructive usage.

Real time monitoring

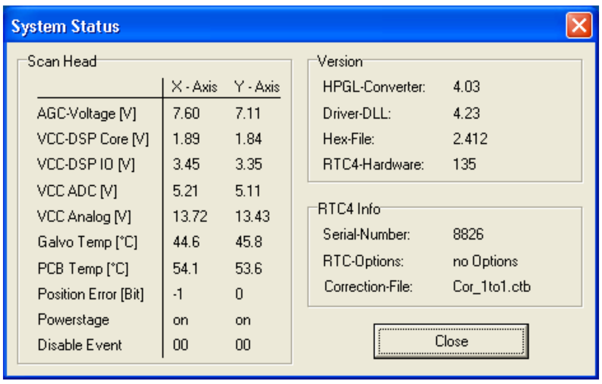

Figure 2: *Scan-head operational output interface showing the most frequently used status parameters.*

Real time monitoring of the galvanometer parameters makes it possible to validate a process lot's integrity. Should an irregular operational state occur, the customer could quickly detect the problem, make a correction, and then document the corrective action. In many industries requiring traceability, having access to detailed operational states is indispensable. Having specific operational data verification ensures that consistency and quality control exists from lot to lot, daily throughout the year. Figure 2 is an example of the monitoring the data for diagnostic purposes at the graphical user interface when querying data from the digital servo electronics. Data for each axis is shown independently and updated continuously.

There are many examples in industry that require such monitoring ranging from medical devices to automotive components. A simple example as shown in Figure 3 is the marking of the inside of bottle caps as a promotional lottery used by consumer package goods companies to entice the purchase of their product. It is necessary for a company to ensure that they are fully aware of the number of potential sweepstake winners. Real time monitoring alleviates the potential of a process miss-queue going unnoticed. If an event occurs stopping the process, it can be restarted with confidence that serialization will resume in the correct sequence. Applying this benefit to much more life critical component processing will save manufacturers time and money.

Further laser systems used for surgery (e.g. Lasik eye surgery) can run a check-up cycle, which is recorded and compared against a reference pattern. This ensures and documents the correct functionality of the laser system for each individual patient. Additionally the scanner movement can be checked in real time and also recorded during the surgery allowing to implement automatic emergency stops in case of any unusual operation.

Figure 3: *Marking of bottle caps for promotional lottery enticing consumers to purchase product.*

Serviceability

The serviceability of the scan head is enhanced with the ability to monitor the multiple status signals available from the digital servo. There is built-in protection of the scan head system in the event of an abnormal operational state. The scan head will suspend operation during this state, yet will continue to send status signals to assist with the diagnosis of the condition even from a remote location. Once the condition has been satisfactorily corrected, operations can be re-started in the appropriate sequence. An operational profile can be established to enable the customer to control maintenance cycles based on hard data should the necessity occur to be compliant with governing regulatory requirements. The customer is able to query this data from a remote location providing a means for a centralized control center for operations in several locations and if necessary, forward the data for further analysis or consultation. Systems integrators could log into their customers systems, accessing scan head status information or run diagnosis patterns and therefore might be able to diagnose or correct malfunctions from their centralized service department without sending service personnel to the customer's installation site. This allows big savings in maintenance cost and allows rapid reaction 24 hours a day.

Process optimization

Figure 4: *Shown is the scanned track against the set position. Variation in speed is shown by the different colors, from red for slowest to blue for fastest.*

Monitoring of the scanned tracks and speed are now available with the digital data signals returned from the digital servo electronics. Having access to this data opens up the opportunity for the customer to implement advanced control functions of both, the scan head and laser for process optimization. Figure 4 is a simulation showing a comparison of the actual scanned pattern relative to the set position. The scanned position data is recorded by processing the desired pattern with moving scanner motors but switched-off laser or even in the office with a scan head just connected to the PC and no laser at all. The customer is able to evaluate the simulation, and make a determination if scanned track satisfies the quality criteria for a particular process and determine the right laser frequency (see Figure 5 and Figure 6). Neither (sometimes-expensive) parts have to be destroyed during optimizing scanner control parameters nor is it necessary to perform time-consuming checks e.g. by inspecting processed parts with a microscope. This can significantly reduce time and costs, associated with setting up new processes and is particularly interesting for laser job shops, which process many different parts with varying quality requirements.

Monitoring of the track speed is available and variations can be displayed though different colors as shown in Figure 4. The red color shows lower speeds in the corners of the markings resulting in sometimes-unwanted burn-in effects. Speed variations are typical for high-speed scanning applications and are caused by the inertia of the mirrors when changing directions. The real time speed feedback from the scan head opens up speed-dependent laser control by adjusting the laser parameters to the actual galvanometer speed thus enabling both, faster processing and higher quality at the same time.

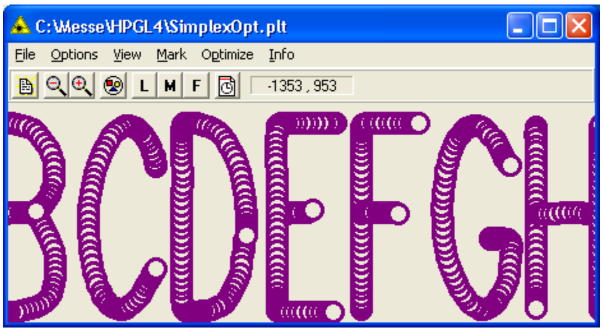

Figure 5: *Simulation for marking 1000, 1-mm high characters per second. The necessary marking speed is 3.6 m/s and the simulation shows laser spots around 50 µm done at a laser repetition rate of 100-kHz.*

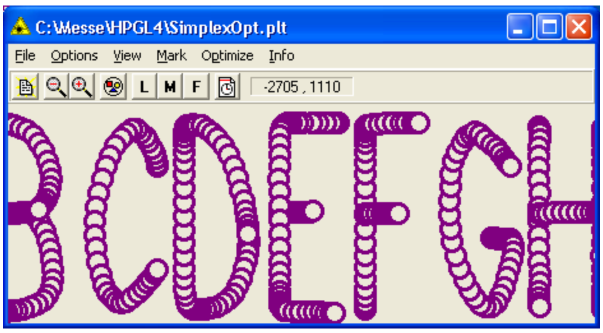

Figure 6: *Simulation with the same laser parameters as in Figure 5, but now 1300 characters per second with a marking speed 4.5 m/s.*

Outlook

Following generations of intelli*SCAN*® series scan heads will allow firmware updates and customizations adding new, additional control algorithms as well as customized features and parameter sets. A highly advanced safety concept and self-tuning capabilities will be implemented. The self-tuning will for example allow ageing control and its compensation ensuring stable high performance operation of the scan head over its full lifetime. Additionally it enables the longs-standing demand to exchange burned or damaged scan mirrors in the field without sacrificing scan head performance.

CONCLUSION

Although universally accepted and highly advanced, limitations in analog servo electronics has lead to newly developed digital servo electronics for control of galvanometer scanners used in galvanometer based scan-heads, providing numerous advantages to the user of laser systems. Based on a digital servo board with a DSP system for each galvanometer axis, these scan heads feature highly advanced control algorithms achieving performance far superior to the fastest analog driven systems. The extensive number of signals and communications from the scan head bring a multitude of benefits for the system user.

Real time monitoring make advanced diagnostics possible as important galvanometer status parameters such as position, speed, current, and temperature enable advanced remote diagnosis and process documentation. Operational status history provides traceability of process consistency, verifying quality control. Monitoring system operating statistics at the component level offers the opportunity to schedule routine maintenance intervals, avoid unnecessary downtime during critical production periods, and enhance the serviceability of the scan head system.

Monitoring of the scanned tracks and speed provides the user with the information to optimize both the scan head and laser parameters for best productivity and quality. Advanced control of the scan head enables modification of the tunings specific to the current scan track on-the-fly, thus always creating the optimal dynamic condition. As a further enhancement of the process, data from the digital servo is used to synchronize the laser frequency to the galvanometer dynamics. Future generations of digital scan heads will enable firmware updates adding new control algorithms and customized parameters to ensure galvanometer-based laser processing continue to push the forefront of technology.

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