The Tool Laser Beam with New Degrees of Freedom

Optomechatronic solutions enable a real-time programmable beam quality

Thomas Kimme and Benjamin Quellmalz

Highly dynamic drives, e.g., piezo or voice coil drives, enable a high-frequency deflection of the laser beam on the workpiece surface. Modern solid-state lasers allow modulation of the specified laser power in frequencies of several kilohertz. If these possibilities are combined strictly synchronously, the result is previously unavailable technological advantage on the component to be processed: the programmable beam quality. Using the example of specific optical and machine solutions, the following describes how these possibilities have been realised for industrial use and proves the technological advantages on application examples in the processes of laser welding and laser powder cladding.

Beside the "classical movement axes" for generation of the relative movement tool-workpiece, laser machines for material processing are equipped more and more with beam deflection systems of higher dynamics (among others in the form of scanners). Beside the reasons

- increase of the achievable acceleration and
- increase of the achievable machining speed

in the relative movement tool-workpiece, these systems are also integrated in laser machines under another target figure – the influence on the specific processing technology.

For many years, e.g., the so-called "wobble optics" for fast single-axis deflection of the laser beam has been known. Two-axis scanners are also used to influence the focal spot geometry acting on the workpiece. With these auxiliary means new technologically helpful possibilities have been found which, however, in their practical implementation do not regularly use to full capacity all possibilities of the existing technology and thereby give away considerable technological potentials.

What potentials are meant here? The potentials of the synchronisation of various dynamic systems of a laser processing solution. The components

- laser beam source with the major feature "output",
- movement system with the major features "path position" and "path speed", and
- beam shaping system with the fast geometrical changes of the beam on the component surface

are regularly operated without being synchronised to one another or coordinated. The causes for this are quickly recognisable: classical numerical controls (NC) of machine tools (which are also typically used in laser machines) are overburdened with the required processing speeds. A parallel "control world" for scanner systems has been established and in addition a general control technology dilemma exists: complex systems, such as the entirety of a laser machine considered here, typically consist of a multitude of separate, often digitally working single components which cannot be synchronised to each other.

However, there are technical possibilities to reduce or remove the above-mentioned disadvantages. A special and additional claim exists, however, if this task should be solved as universally as possible, in a likewise applicable way for a variety of scanners and laser beam sources and to the greatest possible extent without special hardware. This way the range of applications can be increased, the service situation even in case of small quantities can be maintained at high level and especially the quality of the single components available at the market can be integrated into an overall system without additional development activity. These previously mentioned aspects apply especially from the perspective of a manufacturer of such solutions.

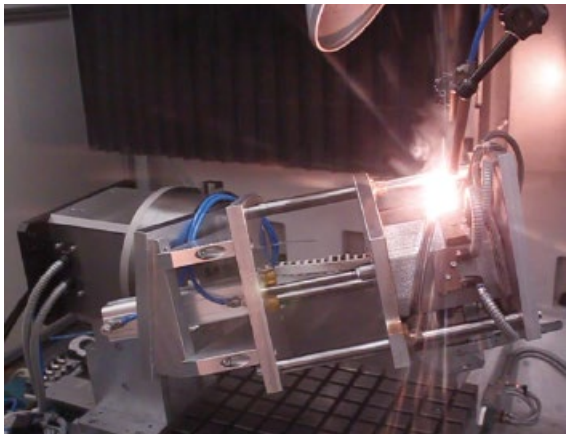

Fig. 1 Programmable beam quality bridges gaps while welding exhaust parts.

Practical implementation

Modern, Ethernet-based real-time bus systems are the backbone of modern machine tools as well as laser machines. They enable cycles of data transmission in millisecond-dimensions between all components of one machine and allow modern, extendable, well maintainable solutions. In case of a comparison of the systems (hardly technically distinguishable in many points, introduced at the

Info: Programmable beam quality

Strictly speaking, in case of the lasers customary in the market for material processing, the beam quality cannot be programmed or changed in real time. Thanks to a rapid spatial and temporal modulation of the laser beam in the processing spot the de facto result of a programmable beam quality can be achieved.

market) which is carried out under the aspects

- transmission of large data volumes for µs precise data
- fast safety functionality (cross communication)
- jitter « 1 µs

the standardised and disclosed systems Ethernet Powerlink with the safety protocol openSAFETY were selected and taken as a basis for hardware and software developments. For the implementation of control and measurement operations in frequencies of up to 40 kHz within the scope of a joint research and development project a universal bus interface solution implementing fast analogue and digital input and output signals using the standardized Powerlink protocol was developed and produced.

Important aspects from the user's point of view on the subject are the following:

- How can a technological solution be practically parameterised / described / documented?
- How can a technological solution be transferred from the machine A of the manufacturer X (if necessary a technology will be created on a development plant of a research facility) to the machine B of the manufacturer Y (this has been designed and built, if necessary, for the series production)?

For the processing path of the laser beam on the component one solution has been known for decades – DIN 66025.

For the description of the "programmable beam quality", a system that can describe beam shaping operations with as little effort as possible with sufficient accuracy and in addition can be integrated – without interferences into the NC system according to DIN 66025 – into the NC machines was developed. This system of the "scan matrix" describes one period of the beam modulation. A human and machine readable form of XML file was selected to describe differently complex scan operations on the component surface in a relative reference to the TCP. For this reason, this description form is completely detached from the practical technical implementation in the laser machine. This course of action is known to the programmer of a NC machine as programming of the TCP path. He describes in the NC programme the processing motion on the component surface and must not worry about when what motors of the machine must be located in what position – this task is taken over by the (machine kinematics specific) TCP interpolation.

By analogy, in case of the specific beam modulation hardware the control of a laser machine can also generate from a scan matrix the necessary actuation information for the hardware. The scan matrix describes one complete period in so called "optical axes":

- position relatively in the feed direction (on the workpiece surface),
- position relatively transversally to the feed direction (on the workpiece surface) and
- laser beam radius (on the workpiece surface)
- laser power in an appropriate number of support points. If necessary, further signals important in the scan period can be integrated into the scan matrix (e. g. trigger signals for data logging at a certain point in the scan contour).

Fig. 2 LV Midi with five axes and LV SpinScan for real 3D treatment.

The structure of the scan matrix in the currently practised form allows, in the author's view, the use for all single- to three-axis scanning systems with or without laser power modulation.

Unfortunately, real beam shaping solutions (as well as other machines) have only finite dynamics. This inertia behaviour impedes the parameterisation of the systems – "trial and error" loops are often practised.

By means of a transformation matrix, parameterised according to the specific technology, an automatic (in case of known inverse transfer function) conversion into the corresponding setpoint values for the optical axes can be carried out. If instead of the inverse transfer function only the transfer function of the scanning system is available, the system behaviour can be simulated and iteratively parameterised in advance (without tests on the real component) using the procedure of the numerical simulation.

For the beam shaping in the solution realised at Laservorm, all scanner systems available at the market can be used, as long as the control interfaces are designed as an analogue interface or according to the industry standard XY2-100.

Technical implementation examples

In current universal and special-purpose machines the possibilities of the programmable beam quality are offered completely NC integrated. For example, speed- or position-dependent offsets and scales of the beam shaping contours or laser power specifications can be calculated. All these functions are available to the user in the NC programme. This way, beside the extensive technological degrees of freedom the user is also provided with the best tools for the qualification and validation of the processes. One example for such machine solution is the laser machine LV Midi available with three to five axes (Fig. 2).

It can be optionally equipped with a very compact 2-axis scanning system LV SpinScan (Fig. 3) and receives thus (beside the complex laser power modulation available in the standard system) the possibility to apply even complex 2D scanning structures to real 3D-components (the scan contour follows thereby the feed vector in space).

Info: Scan matrix

An open, plant- and manufacturer-neutral description tool for periodical, spatial and temporal modulation of the laser beam relative to the Tool Center Point (TCP) path of the laser on the workpiece.

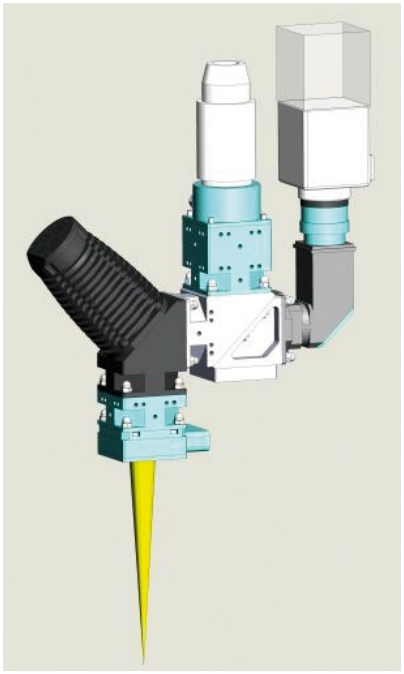

Fig. 3 LV SpinScan

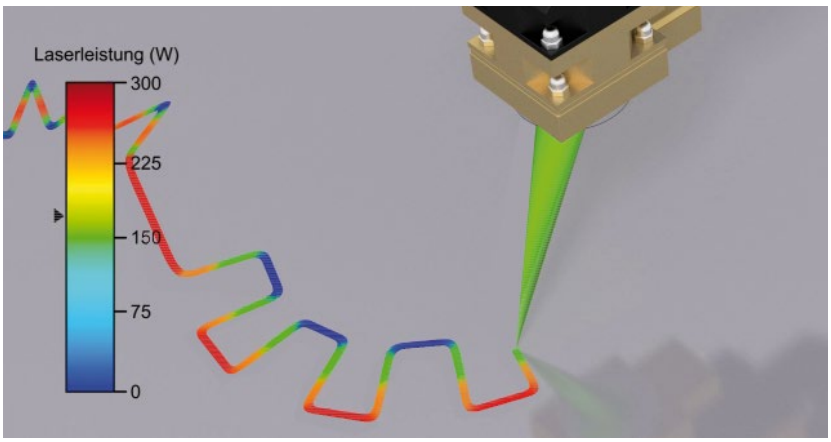

Fig. 4 Programmable beam quality

Application example – welding

During welding successes can be achieved, e. g., with respect to gap bridging. These effects are basically explained in two – randomly combinable – ways:

- Adjusting the energy input (low power density in case of thin-wall mating part, higher power density in case of, e. g., massive mating part) and with this an adjustment of required energy input
- Influencing the molten bath dynamics similar to the pendulum stroke of an experienced TIG welder

Application example – cladding

An essential development goal of the beam shaping solutions was the search for a universally usable tool for the process "laser powder cladding". This process which is also used in the area of the additive manufacturing offers the potential for the production of bionic structures, e. g., for the use in the structural lightweight construction.

By means of the 2-axis scanning system LV SpinScan in a 5-axis NC machine, e. g., the tip repair on blades from power plant turbines or aircraft turbines can be carried out much more effectively than previously known: fluctuating cladding geometries (i. e., the need of cladding beads with different widths within one welding contour) can be achieved by means of a scanning width changeable during the welding. Until now several cladding beads have been placed repeatedly next to each other in a small cross section. But even considerably different heat dissipation conditions on the various blade areas can be effectively counteracted: the energy input can be optimally adjusted to the heat dissipation conditions within the scan contour using laser power modulation. Therewith solutions for welding-critical materials and higher productivity are available.

Outlook

Current developments are concentrated on simplifications in the parameter ability of complex overall systems and integration of real-time control loops in the application of the programmable beam quality.

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Thomas Kimme (Graduate Engineer) studied production engineering at the Karl-Marx-Stadt / Chemnitz University of Technology. Following his graduation, from 1990 to 1992 he was engaged as a research assistant in developments for laser powder cladding. From 1992 to 1994 he worked in the laser centre of the Mittweida University in the research theme "Laser welding of ceramics." In 1994 he initiated the foundation of present Laservorm GmbH where until today he is a managing director and main shareholder.

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Since 20 years, the core competence of the company LASERVORM is the laser material processing in the processes of welding, hardening and cladding. LASERVORM offers its customers, solutions fulfilment from the technology development up to the production commencement, as well as service features during the service life of the machine. There are customised solutions available, either on the basis of type series: LV Mini, LV Midi and LV Maxi or as special machinery LV Special. Customer parts are processed in the mentioned processes from individual parts up to large-scale production in the on-site job-shop.

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