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System Technology for High Speed Laser Welding

Peter Hoffmann, Bernd Pögel, Roland Dierken*

ERLAS Erlanger Lasertechnik GmbH, Kraftwerkstr. 26, 91056 Erlangen, Germany

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Abstract

Improved laser sources in terms of beam parameter product initiated the idea of remote welding with a laser scanner. Various concepts for combining a standard robot with a scanner have been realized during the last years. Key problems have been the missing accuracy of the robot´s guiding behavior, the interlinking of the control units of the base machine and the scanner and last but not least the generation of programs for welding-on-the-fly. Therefore, applications were limited to less complicated joint geometries such as overlap joints on more or less flat assemblies. ERLAS was the first company to decide using laser remote welding for three dimensional processing and butt seam welding in mass production. A new type of machine was born in 2012. Special features of this machine are hybrid kinematics for movement of both, the 3D-scanner by Cartesian Axes and the work piece by rotating and tilting axes. Based on these ideas ERLAS decided to go forward again and place a novel laser welding cell on market.

Keywords: Macro, Processing, System Technology, Joining

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* Corresponding author. Tel.: +49-9131-906613; fax: +49-9131-906666.
E-mail address: r.dierken@erlas.de.

1. The Task

Main objectives of the development included:

- Maximum flexibility with regard to technology and product
- High repeatability and accuracy of the guiding machine
- Easy programmability
- Optimum productivity, reduction of secondary processing time

2. Solution approach

Key ideas were the complete integration of a novel 3D-laser-scanner in a Cartesian gantry, additional axes for work piece orientation and only one master control for all drives of the machine and the scanner. The use of modern NC technology shall allow different ways of program creation: editing, teach-in or offline-programming. Operating shall be simple comparable to that of a milling machine.

Fig. 1 is a drawing of the guiding machine and the kinematic structure. The 3D-laser-scanner is mounted to the Z-axis quill of the Cartesian basic machine. The scanner orientates the laser beam and adapts the focal position (L: length of tool). The rotating table is equipped with two stations. Each of them has a tilting axis (A1, A2) and a rotating axis (B1, B2).

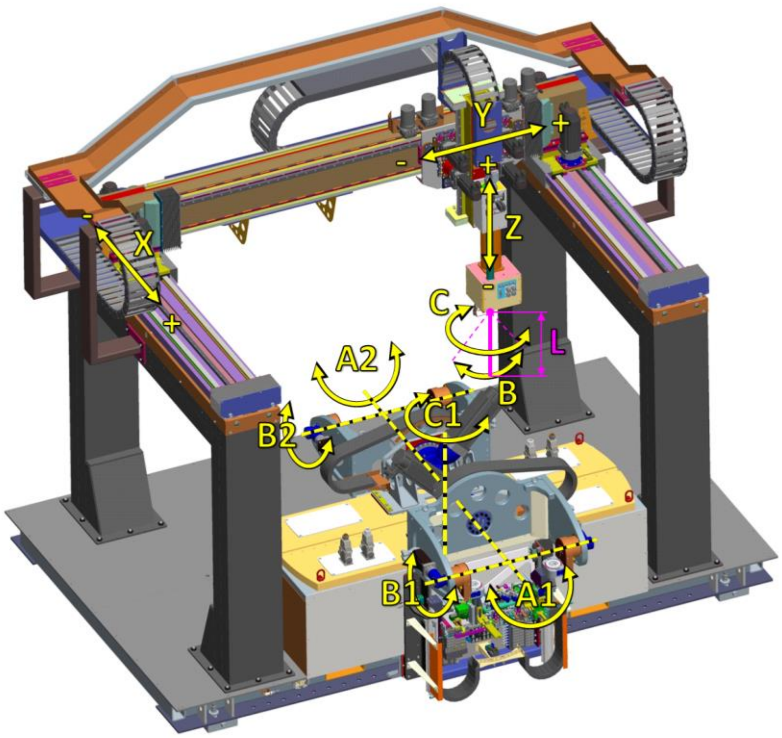

Fig. 1: Kinematics of the laser cell **ER**LASER® UNIVERSAL 522

Fig. 2 is a photo of the machine under construction. With a view to mobility of the machine and reduced commissioning times on customer's site, smaller gantries are built on a stable lower frame which has forklift pockets. The traverse ranges of the linear axes and the load capacity of the work piece axes are scalable to the needs of the application.

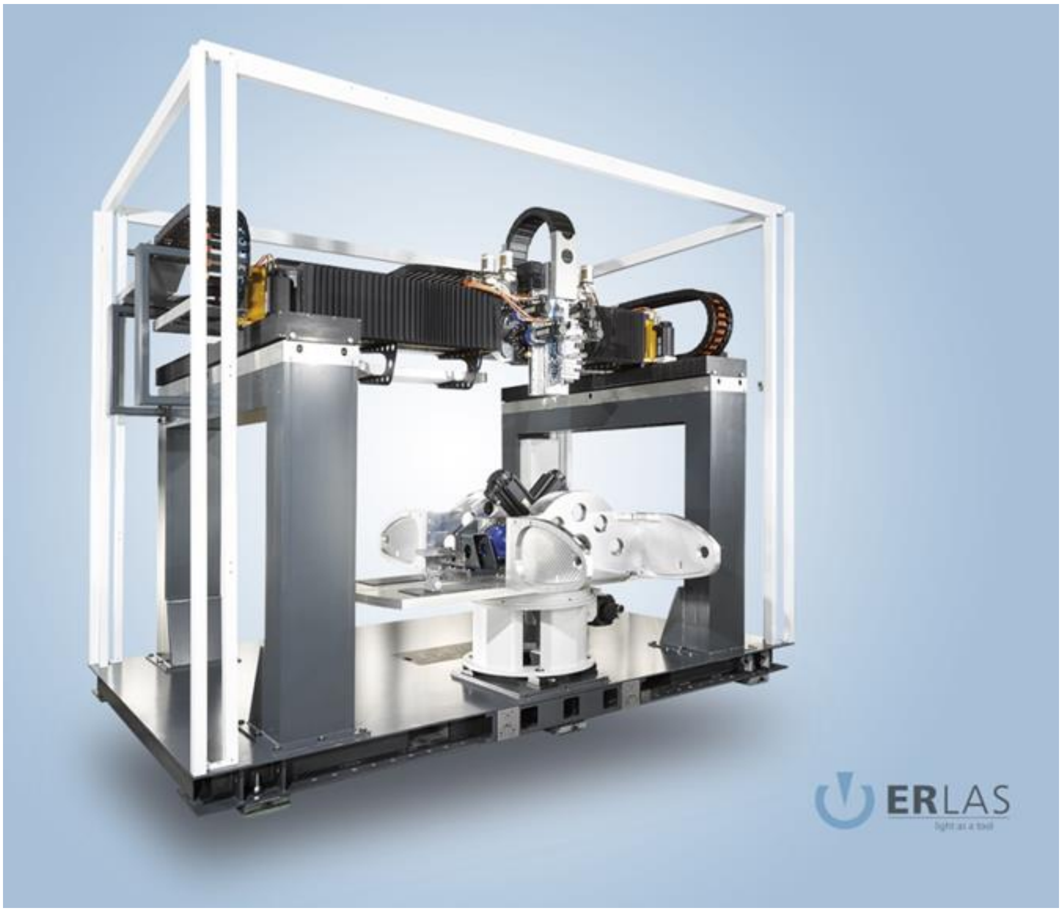

Fig. 2: Laser cell **ER**LASER® UNIVERSAL 522 under construction

Table 1 shows the nominal motion quantities of the basic laser cell.

	X-Axis	Y-Axis	Z-Axis	A1-Axis	B1-Axis	C1-Axis	Scanner-Axes
Max. Speed [m/min]	105	75	45				
Max. Acceleration [m/s^2]	10	10	8				
Deceleration for Emergency Stop [m/s^2]	15	15	15				
Repeatability of Axis [mm]	+/- 0.01	+/- 0.01	+/- 0.01				
Max. Angular Speed [°/s]				430	430	129	573
Max. Angular Acceleration [$°/s^2$]				2.865	2.865	573	28.648
Angular Deceleration for Emergency Stop [$°/s^2$]				4.297	4.297	859	28.648
Repeatability of Axis [´´]				≤ ±30	≤ ±30	≤ ±15	≤ ±1.5

Table 1: Motion quantities of **ER**LASER® UNIVERSAL 522

3. Reduction of Secondary Processing Time

Production time
= primary processing time
+ secondary processing time

Primary processing time
= time with direct work progress
(welding time)

Secondary processing time
= additional time slices, necessary to enable a complete processing cycle
(Feeding of parts, clamping, handling, positioning of laser, declamping,
taking off assembly, quality check)

If the secondary processing time is reduced to zero or has no influence on the cycle time, highest productivity of a laser welding machine is achievable. A technical solution that can best satisfy those requirements is a rotating table with two work stations of identical design and function. In parallel to welding of an assembly the operator or an automated handling can unload the other clamping and prepare it for welding the next assembly. Thus, the cycle time can be reduced to primary processing time plus a portion of time for changing the stations. A quick change of stations is made possible by two measures:

- Fast opening mechanism for the light chicanes at the partition wall
- Integration of the turn table axis as an interpolated and numerical controlled axis.

A collision-free movement of the turntable supposes an in-time positioning of the processing head outside the rotation diameter. By electronic connecting of the axes and continuous monitoring of the actual positions, the turning of the table can start immediately after processing of the work piece has finished, (see **Fig. 3**). Optimum performance of the drives is guaranteed by programming them with a fifth degree polynomial function. In total it takes only 1.7 seconds until the processing of the next assembly can start.

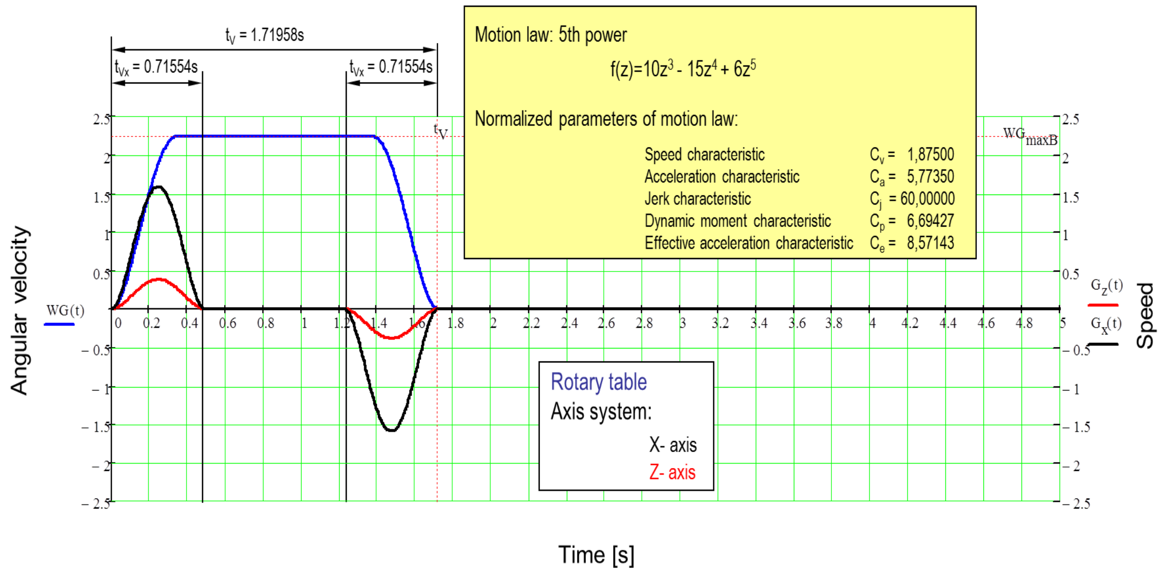

Fig. 3: Motion diagram for changing of the stations

4. Integration of the Laser Scanner

Up until now the control-related integration of the scanner drives has been complicated, in particular, for the following reasons:

- Galvanometric mirrors have been used to date because of speed and accuracy requirements. They rotate proportionally to the strength of the current and their standard interfaces are not able to process the signals sent from an interpolator of a numerical control.

- In consideration of the spatial arrangement of the two mirrors to the optical axis of the incoming laser beam and the method of focusing, a conversion of Cartesian coordinates or orientation angles into rotation angles of the mirrors is necessary. F-Theta plane field lenses ask for a distorsion matrix or a look-up table.

These are the main reasons why scanners have had a separate control. Therefore it has been state of the art to integrate the laser scanner control as a slave which is repeatedly initiated by the master control. So-called welding on the fly is the superimposed movement of the basic machine and the scanner axes. The motion program of the scanner has to factor in the relative movement of the scanner to the work piece. Programming of such systems is only feasible stepwise and based on the recording of the guiding behavior of the basic machine.

The novel 3D-laser-scanner is different from the state of the art in mechanical and optical design. Recently on the market available servomotors with extraordinary powerful motion quantities are used for drive technology (see **table 1**). The rotation of the mirrors can now be numerically controlled and interpolated together with the other axes of the machine.

The 3D-laser-scanner is separated into two modules. A compact scanner unit with a simplified optical design focuses the laser beam before it is deflected by two mirrors, **Fig. 4**.

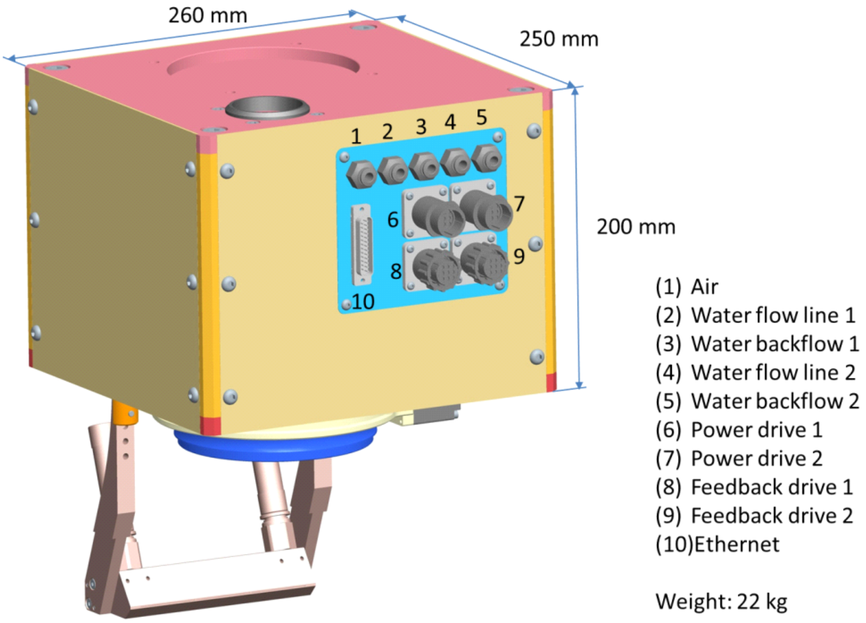

Fig. 4: Scanner unit

The scan field size is 380 mm x 320 mm.

For the variation of image distance and focal position an adaptive telescope is integrated in the sleeve of the Z-axis (between collimating optic and focusing optic). The focal position can be varied within a range of 140 mm.

For the numerical control of the scanner drives, the problem of reverse transformation from work piece coordinates into machine axes coordinates had to be solved. Standard numerical controls provide five axes transformation with three linear axes (X, Y, Z), two orientation axes (B, C) and tool offset data. However, a kinematic model for guidance of a laser beam via two rotating mirrors has not existed to this day. The solution of this problem is to deal with the scanner as a standard tool of variable length, **Fig. 5 left**. For a specific position which the laser beam shall hit it is possible to calculate the necessary angular positions of the scanner mirrors, **middle of Fig. 5**. These calculations have to consider the spatial arrangements of the incoming laser beam, the turning axes and the deflecting mirrors as well as the effect of the protection glass acting like an optical parallel plate. **ER**LAS has developed such an algorithm and tested in simulations. A superimposition of the virtual and the real kinematic model shows that the same position is reached by neglecting deviations in the incidence angle, **Fig. 5 right**.

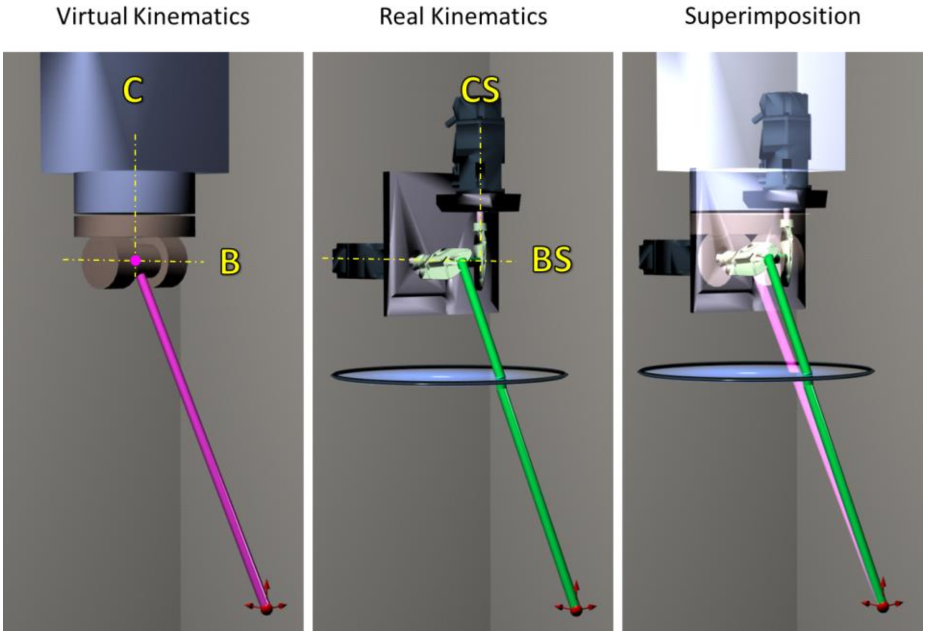

Fig. 5: Kinematic models for the deduction of an algorithm for reverse transformation

Regarding the motion quality the calculations have to be done within the interpolation cycle of the numerical control (1 ms). Against the background of an own development environment, a separate slave control has been integrated in the system architecture, **Fig. 6**. For both, the master control and the operator, the laser beam is simulated as a gimballed tool of variable length (L). The point of rotation is put into the rotation axis of the second mirror. In order to assure that the real laser beam hits the spatial point described by three Cartesian coordinates and two orientation angles, the slave control undertakes a real time computing of the necessary mirror orientations (BS, CS) and the image length (L) and sends interpolated position data to the drive amplifiers of the scanner system.

5. Outlook

The modular design of the laser cell allows an easy modification to the needs of the customer. The axis system, the work volume and the feeding technology can be adapted to any production task. By replacing the scanner with other working heads the machine is also usable for laser cutting, cladding or hardening.

Due to the extensive possibilities in programming, the **ER**LASER® Universal laser cell is a machine tool which is equally well-suited for both the flexible use in medium sized companies and for mass production.

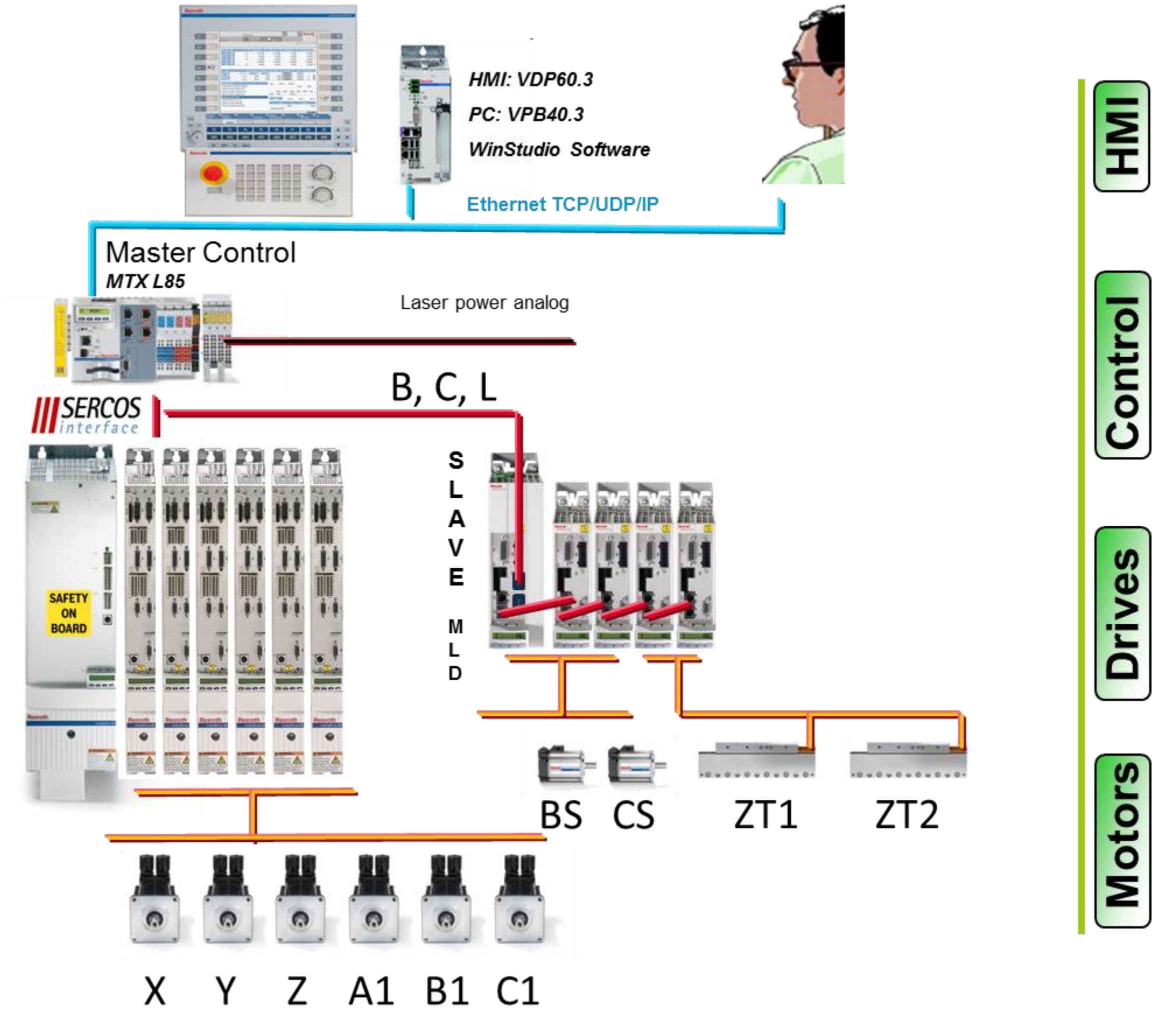

Fig. 6: System architecture of **ER**LASER® UNIVERSAL 522

In principle all kinds of fiber guided laser systems can be integrated. Using diode pumped laser sources and drive technology with regenerative power supply units, the energy consumption is reduced to a minimum and contributes to an environmentally friendly production.

The above-mentioned facts combined with further attributes like the 5 axes of the guiding machine, the 2 working stations as well as the 2 additional axes of each working station generate an absolutely novel concept of an allround machine for laser material processing: the **ER**LASER® UNIVERSAL 522.