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HIGH POWER DIODE LASER BEAM SCANNING IN MULTI-KILOWATT RANGE

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Abstract/Manuscript

During the last years a new laser beam scanning system for heat treatment of metals with high power diode lasers was developed. The new external scanning optics is an optional tool, that can be used with common standard high power diode lasers (focal distance ≥ 300 mm). It works with high power diode lasers in the multi- kilowatt range up to 5 kilowatt laser power. The new system opens the door to a wide field of applications, that were not possible before. Heat treatment of metal surfaces with a track width of more than 50 mm at once is one of the capabilities.

Furthermore different approaches were gone to make the handling of the system more easier for the user. Real-time temperature control with cycle times in the range of microseconds ensures a reproducible hardening result even for complex 3D- shaped parts with difficult heat flow conditions. The latest status of the developments and examples are presented.

Introduction

Temperature controlled laser beam hardening with high power diode lasers (HPDL) is state of the art since years and the advantages of this technology compared to CO_2 laser beam hardening are known.

The compact size of diode lasers and equipment, the high efficiency and the high absorption coefficients for diode laser radiation on clean or oxidized metal surfaces make the HPDL to an ideal tool for laser beam hardening and other local heat treatment applications. Because there is no need for coatings to get the laser power into the material it is possible to measure the real surface temperature during the heat treatment process with pyrometers and, of course, to control the process.

Nevertheless the beam shape of a HPDL beam is often not suitable to achieve the wished power density distribution or temperature field at the surface of the part and the width of the hardening zone is limited by the spot dimensions. A lot of fix optics are available for this purpose, but often spikes in the intensity profile are detrimental to hardening applications. Furthermore they can not be flexible adapted to the needs of the application. With standard fix optics the best utilization of available laser power is not possible in most cases, because the wrong aspect ratio of the nearly rectangular laser spot results in a lower width of the heat treatment zone and laser power is wasted this way.

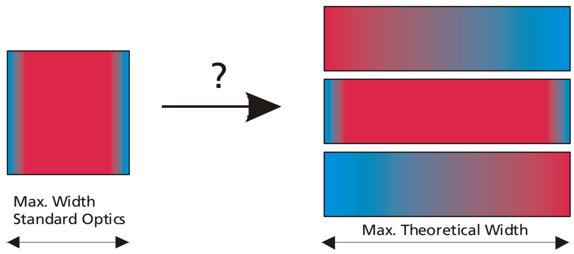


Figure 0 Aim of the development: How can a standard HPDL spot be shaped to a line spot with optimum aspect ratio and defined intensity distribution

Aim of the developments was to combine the advantages of laser beam scanning, well known for CO_2 and Nd:YAG lasers, and the advantages of the HPDL beam technologies into a compact HPDL laser optics.

Components of the laser scanning optics

Figure 1 4 kW HPDL laser head with external scanning optics

The special optics mainly consists of 6 components:

- Flat 90°- deflection mirror
- High speed pyrometer for temperature measurements
- Coated glass plate to reflect the temperature signal to the pyrometer
- Scanner with special scanning mirror for the diode wavelength range
- Air cooling nozzle to cool the scanning mirror
- Water cooling for flat mirror and scanner

The optics was connected to a 4 kW HPDL (DL040S, DILAS Mainz, Germany). All mechanical components are made of Aluminum and are water cooled to resist scattered laser light.

The design of the optics is typical for this kind of Nd:YAG or HPDL optics. Main problem was to find a scanning mirror with high reflectivity for the combination of two different wavelengths (808 and 940nm) and 45 ± some degrees angle of incidence. Standard metallic mirrors are only conditionally suited, because the loss of laser power on the mirror surface is in the range of 5% and more.

Different kinds of mirror materials (i.e. copper, fused silica) and coatings were tested successfully. One possible variant of mirror coating shows the following diagram.

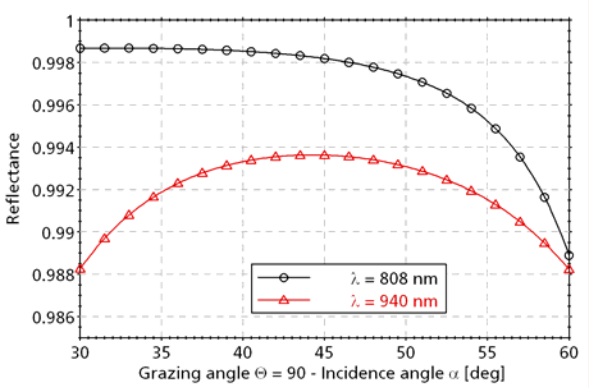


Figure 2 Reflectance of special mirror coating vs. grazing angle for two HPDL wavelengths (calculated values, Stefan Braun, Fraunhofer IWS Dresden, Germany)

Even for high scanning angles (i.e. ± 5°) the mean reflectance is about 99,5%. This means a loss of laser power of only 20 Watts, when a 4 kW HPDL is used. The low absorption factor on the mirror surface is a precondition for a long-time stableness at full laser power.

Scanning functions

To achieve a quasi-stationary temperature field on a metallic surface during heat treatment it is necessary to scan the scanning mirror with high frequencies (100 – 200 Hz). This requires a very powerful scanner with maximum peak power of more than 1000 Watts, when non-sinusoidal scanning functions shall be available. The influence of scanning functions on the heat treatment result show chapter "Examples" in detail.

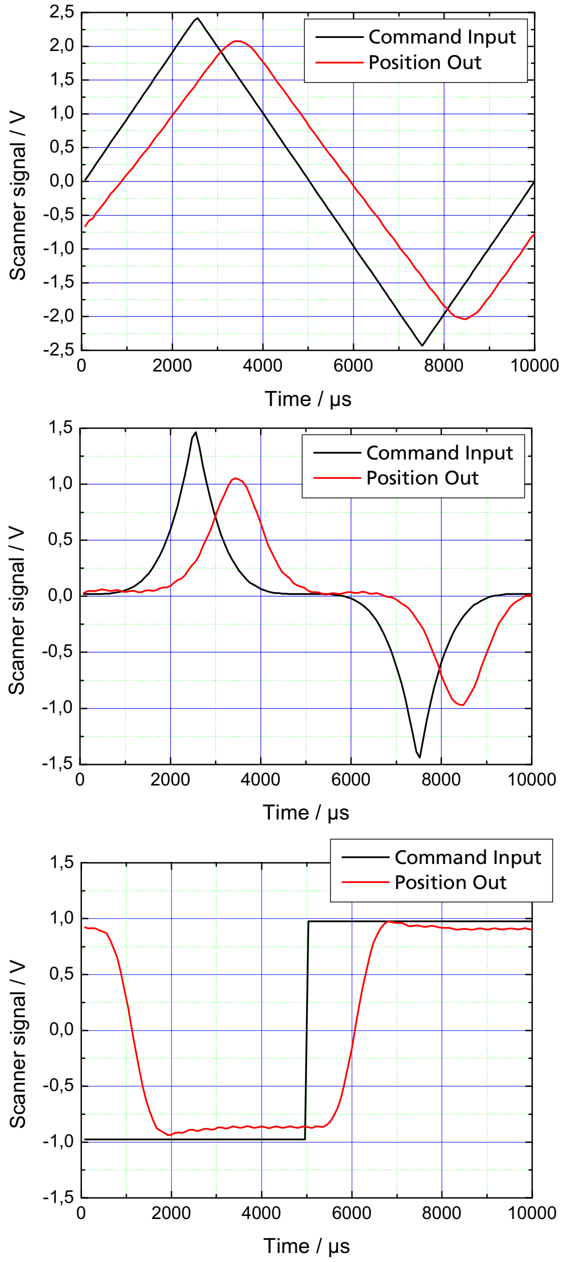


Figure 3 Examples for scanning functions at 100 Hz Triangle / Peak / Rectangle (Scanner signal 10 Volts = Scanning angle 15°)

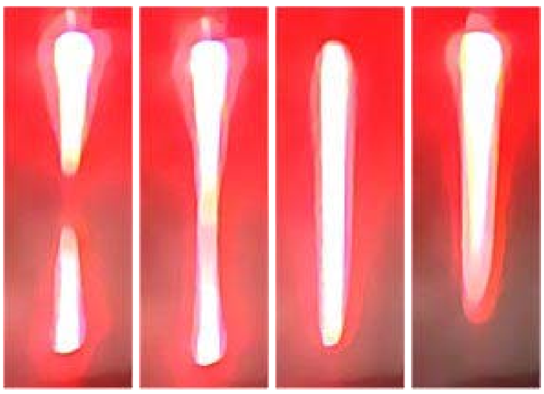
Because of the inertia of the scanning system there are physical limits for the shape of the real scanning function (see figure 3). Therefore it has to be considered, that the real scanning function does not meet the given scanner signal accurately. The examples show the flexibility of the used scanning system. Different kinds of scanning functions (sine, triangle, rectangle and more) can be generated after optimum tuning of the scanner driver.

The high flexibility is necessary to influence the laser power density distribution and temperature fields only via change of the scanning function.

Temperature fields

It was tested, what kind of temperature fields can be generated as result of different scanning functions. The temperature was measured coaxial to the scanned laser beam with a cycle time of 40 µs. A second possible variant was tested additionally. The temperature field was scanned by an second pyrometer scanning system. Both variants are working well and result in the same temperature distributions. To ensure a stable process over a longer period a temperature guided laser power control was applied. [1]

To detect the laser power density distribution directly, a camera system with a sensitivity for the diode wavelength rang was used. To see the intensity profile only, the experiments were done at low laser power and temperatures < 200 °C.



1 2 3 4

Figure 4 Laser power density distribution, detected with special camera (spot size: about 6 x 80 mm^2), optimisation via scanning function

Picture 1: Result of scanner sine function
Picture 2: Raised intensity in middle zone
Picture 3: Homogeneous intensity distribution
Picture 4: Wedge-like intensity distribution

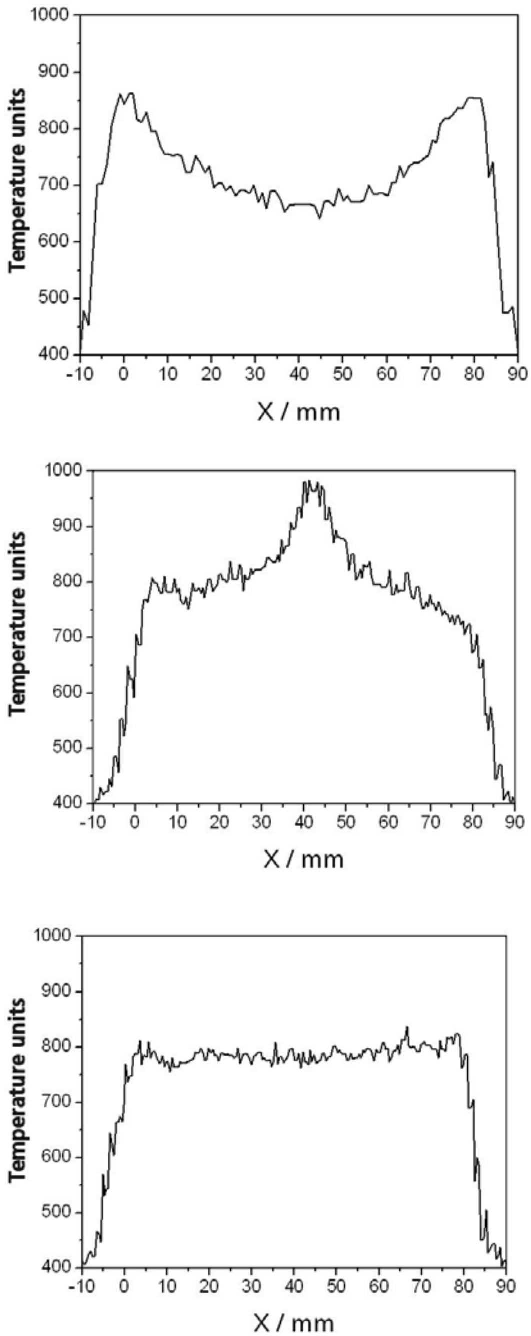


Figure 5 Different measured temperature profiles, generated by only change of the scanning function under same process conditions,
Heat treatment of a steel sheet,
laser spot size: about 100 x 6 mm^2
(vertical temperature axis not calibrated!)

The first picture in figure 5 shows a typical temperature profile when scanning a sine function. Two maxima near the edges of the scanned laser line were detected. A corresponding result can also be found by computer simulation:

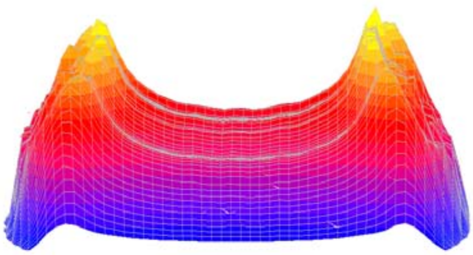


Figure 6 Typical laser power density distribution, scanning with sine function, laser: RS6000 (TEM20), computer simulation [2]

The second temperature field in figure 5 was generated with a scanning function similar to the peak function in figure 3 (second diagram). The reason for the temperature peak in the middle zone is the long delay time of the laser spot in the middle of the scanned line.

The third picture in figure 5 shows a temperature distribution with almost homogeneous temperature over a width of 80 mm. It is mostly the aim of a laser heat treatment to heat treat a defined area with a defined maximum temperature. Therefore this kind of homogeneous temperature field is very interesting for most applications. The homogeneous temperature field can not be generated with a standard scanning function (sine, triangle, rectangle, …), but it was necessary to calculate a arbitrary scanning function with a special software tool. The tool has the capability to create scanning functions for each kind of laser and spot size and user defined power density distributions. The optimization of 100 and more scanning function parameters is done with a special software algorithm, based on a typical evolution algorithm. [2]

Examples

Heat treatment of stainless steel

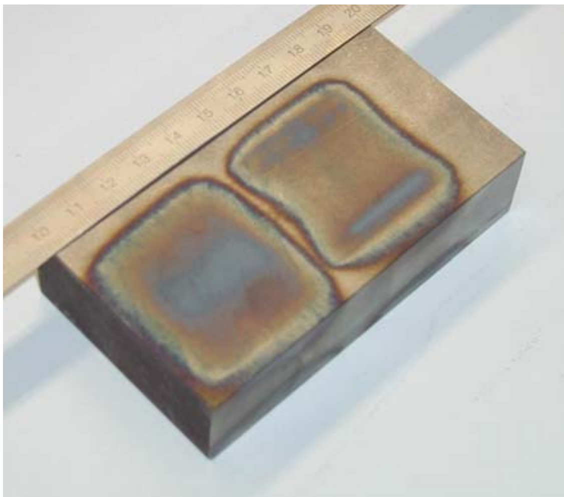


Figure 7 Heat treatment of stainless steel with 4 kW HPDL and scanning optics, track width > 30 mm, Left: triangle scanning function, right: sine scanning function

The heat treatment of stainless steel with high power diode lasers is very difficult, because the surface of the material reacts very sensitive to maxima and minima within the laser spot intensity profile. So the maxima near the edges of a sinusoidal scanned laser line result in temperature maxima at these positions. The result of this kind of heat treatment is not very suitable for most applications:

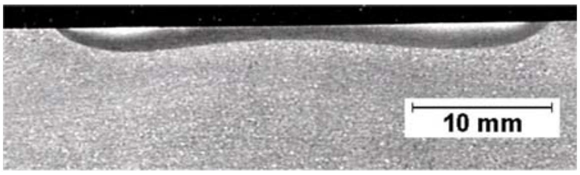


Figure 8 Cross section thru right track in figure 7, Heat treatment with scanned laser spot (sine function)

In contrary to the sine function a triangle scanning function gives a very different result.

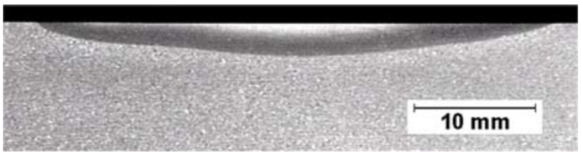


Figure 9 Cross section thru left track in figure 7, Heat treatment with scanned laser spot (triangle function)

The maximum temperature was reached in the middle zone of the laser spot. Towards the edges of the laser spot the temperature decreases continuously. Reason is not only the laser power density distribution, but also heat conduction and surface oxidation effects, that intensify inhomogeneities As a result of the special temperature field hardness and hardening depth decrease from the middle to the edges too. To achieve a homogeneous hardening depth and hardness a arbitrary scanning function with a characteristics between sine and triangle shape has to be used.

Heat treatment of carbon steel

Figure 10 Heat treatment of carbon steel with 2,5 kW HPDL and scanning optics, track width: 27 mm

The result of the heat treatment was a large track with dimensions of about 200 mm x 27 mm.

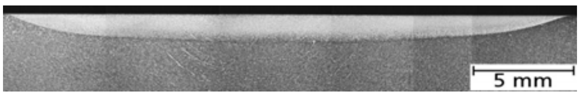


Figure 11 Cross section thru hardening track of figure 10, hardening depth: 1,4mm, track width: 27mm

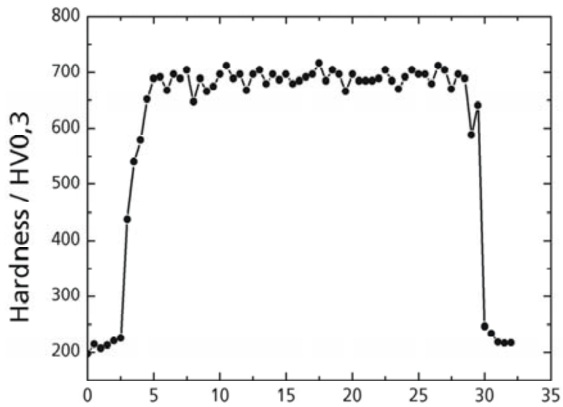


Figure 12 Hardness distribution, carbon steel, hardened with HPDL and scanning optics, measurements in cross section (see figure 11) parallel to heat treated surface

Surface hardness and hardening depth are distributed homogeneously across the hardening track.

Heat treatment of steel sheets

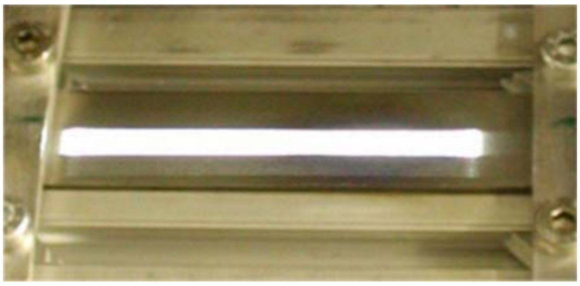


Figure 13 Heat treatment of steel sheet with scanned laser beam, width: 85 mm, Laser: 2,5 kW HPDL

Because the heat conduction out of the heat treatment zone for thin metal sheets is not very intensely, it is possible to heat treat very large zones at once. An area of about 100 mm in width can be treated effectively using a 2,5 kW laser only. It is estimated, that there is a good potential to heat treat larger zones, when a 4 kW laser is used.

Software development

To make the handling of the laser scanning system easier for the user, special software tools were developed:

- Calculation of optimum scanning function for given laser spot and wished spot size and power density distribution
- Waveform generator to send scanning function to the scanner
- Measuring and recording of real scanning function and temperature signal during the process
- Real-time closed-loop temperature control (different options available, i.e. maximum temperature control)
- Analysis of process data after the process
- Fine-tuning of scanning function considering the real local temperatures

These software tools run on a standard-PC with a special I/O-card.

For the next future the following developments are planned:

- Real-time control and optimization of the scanning function
- Additional interfaces for external control via CNC

Summary

An external scanning optics for high power diode lasers was developed, that opens the door to the multi-kilowatt range. Tests with diode lasers up to 4 kW power were processed successfully.

Using the new system applications like laser beam hardening of different steel grades and heat treatment of sheet steel and more are possible. Main advantage is the very high flexibility to adapt spot size and intensity profile to the needs of the application. In comparison to standard fix laser optics larger track widths of the heat treatment track are possible. Hardening zones with a width of more than 40 millimeters were generated on massive steel parts. But this is not the limit for the optics, when thin sheet metals or other materials are treated or more laser power is available.

Special software tools make it easy to control the complex laser scanning process. A precise temperature control ensures the high quality of the heat treatment result.

It is estimated, that the system is ready for industrial use in October 2004. Possible applications are i.e. hardening of cutting tools for automotive parts and large guideways, hardening of turbine blades and heat treatment of weld seams and many more. [3], [4]

References

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[4] R. Dierken, S. Gropp, P. Kugler, S. Gottschling, P. Hoffmann, Randschichthärten von Großwerkzeugen mit dem 4 kW Diodenlaser. HTM Härterei-Technische Mitteilungen, Zeitschrift für Wärmebehandlung und Werkstofftechnik. Carl Hanser Verlag, München HTM 56, pp. 314-320, 2001.