

INTEGRATED LASER SYSTEM FOR HEAT TREATMENT WITH HIGH POWER DIODE LASER

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Abstract

Due to the innovation in the field of high power diode lasers applications during the last years, heat treatment by using diode lasers has become very successful. However, at time this technology is most commonly used for simple two-dimensional geometries.

An important industrial sector is the heat treatment of tools for sheet metal forming. At present conventional hardening processes are applied. But mostly it is not necessary to treat the complete surface of the tools but rather small local tracks like cutting edges. This results in smaller distortions and less rework time. Because of these advantages, industry and the automotive industry in particular ask for an integrated laser hardening system for complex three dimensional tools.

In cooperation with various industrial partners such a system will be developed. The complete system has to blend into the industrial process chain and machinery in operation and consist of a framework of different software and hardware modules. The state of the development is demonstrated and the potentials of this system will be shown.

Introduction

Short product development cycles are an important advantage in the business world particularly in the automotive industry. The tools shops as a major branch of this industry are especially subject this condition. Bigger design diversity and fewer number of items are other important demands. In the near future the car bodies will be made of high-strength steels with innovative coatings. This results in higher strain, stress and wear of the tools for sheet metal forming. The heat treatment of these tools will become a key technology.

Common heat treatment processes like oven, flame and induction hardening having critical disadvantages. High distortion and reconditioning, long machine and process setup time and high costs are some of this negatives facts. Figure 1 compared the process chain of the manufacturing of a typical metal forming tool. The left column shows the time consuming and costly conventional way. The right column demonstrates the target laser process.

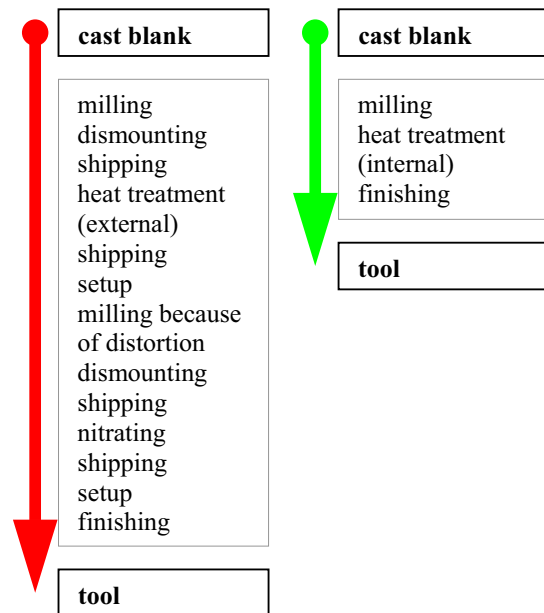


Figure 1. Comparison of the process chain.

A solution could be the use of laser energy for heat treatment. Laser hardening is not a new technology. CO₂ lasers are successfully in use for years [1], [2], [3]. But heat treatment with a CO₂ laser is not applicable and efficient for every application. The lower absorption of blank steel for the CO₂ wavelength requires a coating that must be removed after

processing. The latest developments show the increased practicality of high power diode laser in the field of heat treatment [4], [5]. The determining factors for the superior performance of this type of laser are:

- the beam shape, which is very practical for hardening,
- an energy efficiency up to 50 %,
- an absorption of around 80 %,
- a compact construction for a laser power up to 6kW.

However, most of the known high power diode laser hardening machines that are in industrial use, are expensive special purpose machines. That means extra investment and highly trained employees.

Together with industrial partners a concept of an integrated laser hardening system was developed. Following the basic concept, detailed information will be illustrated and about the most important modules.

Basic concept

A new system will only be accepted by the industry if it really simplifies the work and processes. That is why the way of the implementation of new systems in an existing process chain is extremely important. In order to make real technological progress, all requirements by tool producers, customers and system developers for such an apparatus have been comprehensively analyzed. This provides the basis to describe and classify the intentions for the project that is described in detail in the paragraphs below. With this information a general schematic with the most important modules and the flow of data and controlling information can be designed (see figure 2). To create all of the shown modules a special interface concept was developed. Thereby the interior functions of the modules are not defined. The system becomes much more flexible when only the interfaces are fixed because the single modules become removable, adaptable and better integrable. For the consideration of the next paragraphs a classification in process and system technology is important.

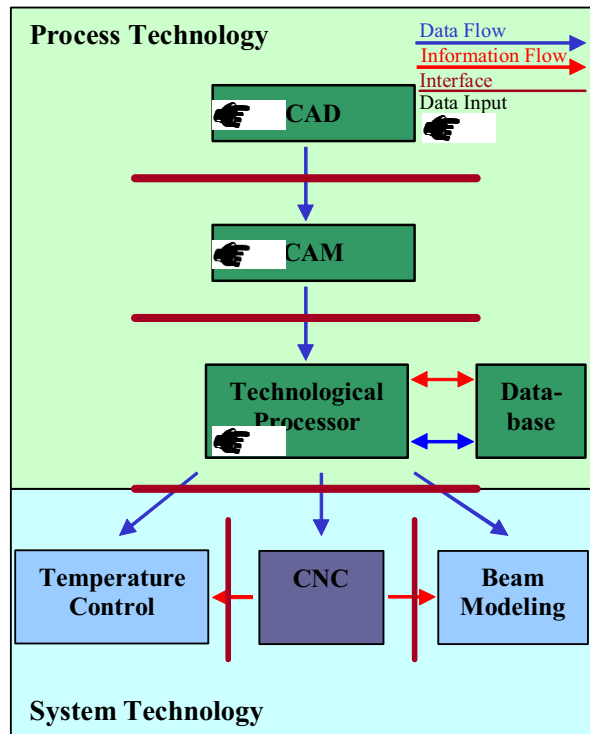


Figure 2. Process chain schematic.

Process technology

In the field of 3-D machining it can be assumed that every potential customer is using a CAD (computer-aided design)-system. It is common that all engineering design elements particularly the definition of the zone for heat treatment, are done during the design phase. For this project a very flexible way to define the hardening track was developed. The CAD-engineer draws three lines at the 3-D model, as shown in Figure 3. The middle line is the path of the normal to the surface (black line). The left and right gage limits the track width (blue and red line). The used CAD-system therefore is optional as long it is 3-D capable and supports the layer or group feature. Even the used data files are freely selectable because the interface supports many different types. So the customer can still use his familiar CAD-system.

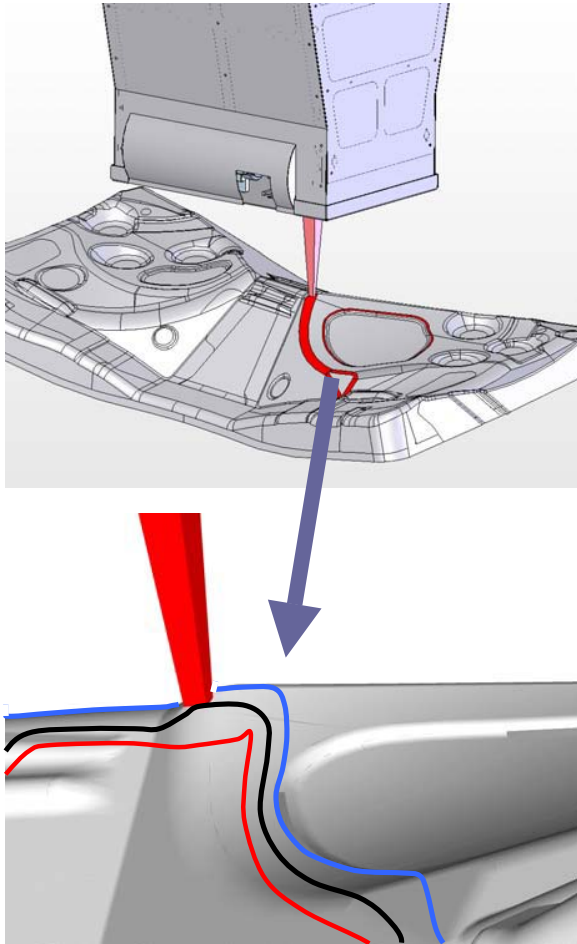


Figure 3. CAD definition of the hardening track.

The following modules will do the processing of the data for the hardening track automatically. One of these modules next in line is the CAM (computer aided manufacturing) system. In principle the choice of the CAM-system is free. But to use all features of the entire system some very special functions are needed. These functions aren't parts of conventional CAM-systems. But basically an upgrade of all usual CAM-systems by the producer or service is possible, with an adequate effort. The interfaces between CAM-system and the other modules are collected at a catalog of requirements and can be used for upgrading.

The CAM system has to process all information from the CAD system including the virtual hardening track. It has to calculate and transform this data to support all following modules. The most important task is to generate the NC-code for any kind of machines. For this it has to control at least five machine axes and one additional axis of rotation which is necessary to control the preferred direction of the laser beam. Furthermore the perpendicular irradiation of the laser has to be

ensured by this CAM system. For this project a professional CAM system has been purchased by the WICAM GmbH. The software is available in at least five languages. Figure 4 shows a screen picture of this program. The big advantage of using a professional and industrially accepted CAM-system is to have an open interface to the user-site and to get a standardized interface to the following units of the process chain.

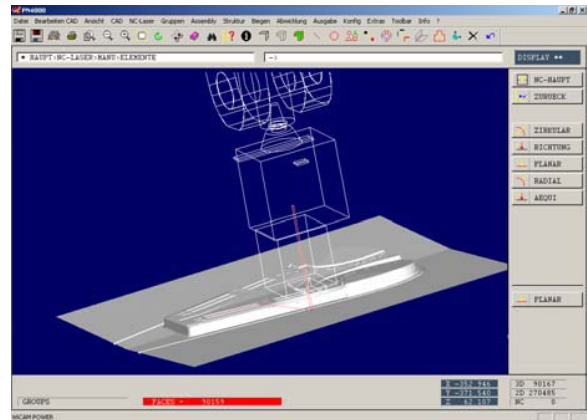


Figure 4. CAM System PN4000 / WICAM GmbH.

The next module is the technological processor. This module is the kernel of the entire system and includes a complete process simulation program. At present this module is in the early development stage. First investigations with simplified simulation software show the feasibility of the planned method.

Usually software for the simulation of heat transduction is state of the art. But mostly these simulation programs are very complex and expensive software packets including many features, which are not necessary for the simple simulation of the hardening process. This intricacy and the requirement for highest precision result in long calculation cycles, making this commercial software inefficient. The intention must be to develop an easy to use software system only for one purpose, the heat treatment process. This software must simulate complex 3-D geometries and has to calculate and optimize all hardening process parameters automatically. Constant hardness and depth of hardness can so be assured. Special expertise about the heat treatment process is not necessary. Sub specimen, trails and expensive metallographic tests can be avoided. The needed computing time for the simulation must be optimized with sufficient accuracy. To fulfill these requirements in a first step a software tool for 2D applications was developed [8]. It is planned that the technology module has all interfaces to connect this software to the entire network. The operation of this software will occur

intuitive or automatically. Furthermore the technology module has to transfer all generated data to a data base system, which is necessary for the quality assurance concept. But the most important task is to control all following modules, which are directly bound into the system technology.

System technology

The system technology includes all devices which are directly responsible for the controlling of the heating process. All through the process, technology modules pre-generated data can be transferred to these system components automatically by using defined interfaces.

One requirement from the customer is that the complete system must be working with all available machines. That means robots, machines with Cartesian coordinates, combinations of both and additional well known machine controllers. An important fact for the communication between machine controller and periphery is that no special purpose solutions are needed. Standard machine functions are sufficient to control all system devices. That makes the integration in an existing machine easy and cheap. The main system components are shortly mentioned below.

Laser

The complete system is developed for the use of a high power diode laser. The high efficiency, the comparatively low purchase price, the low service and maintenance demand, the very small installation size and the optimal beam characteristics for laser hardening make this type of laser the favorite. The diode-lasers used for this project has a laser power of up to 4.5 kW.

Based on the flexible interface concept the entire system is able to work with every kind of laser. This could be interesting for users, which are already using other lasers like CO₂ or Nd:YAG-Laser.

Beam modeling

The final generation of the hardening track, which was chosen by the design engineer and processed by the pre-processors, occurs by a scanning system. Therefore the beam is reflected on an oscillating mirror. The frequency of up to 200 Hz allows consistent hardening results also by high feed rates. Furthermore the dispersal of laser beam intensity can be controlled very flexibly by this scan frequency even on 3D geometries. The scanning system allows amplitudes to generate hardening tracks with adequate widths. The track size is not limited by the scanning system but by the used laser because the laser power correlates with the track

width. With the 4 kW diode used here, laser tracks of 40 mm / 1.575 Inch can be created [6].

Temperature control

An essential part of the system is the temperature control unit. To avoid initial melting the temperature on the surface must be measured by pyrometer and the laser power must be controlled. The system used here ensures a constant temperature of +/- 5K. All signals generated through the controller can be monitored and recorded [7].

All shown components are successfully in industrial use since years. The challenge was to combine all components in one system. According to the interface concept all modular devices have been revised. Now all system components can be used very flexibly and the integration in any machine is very simple. Each single module is easily interchangeable. That results in positive in maintenance and service and the module upgrading is less complex respectively.

Prototype

To test the entire system a prototype has been developed and produced. Figure 5 shows the CAD model with dimensions with (upper left corner) and without case sheets.

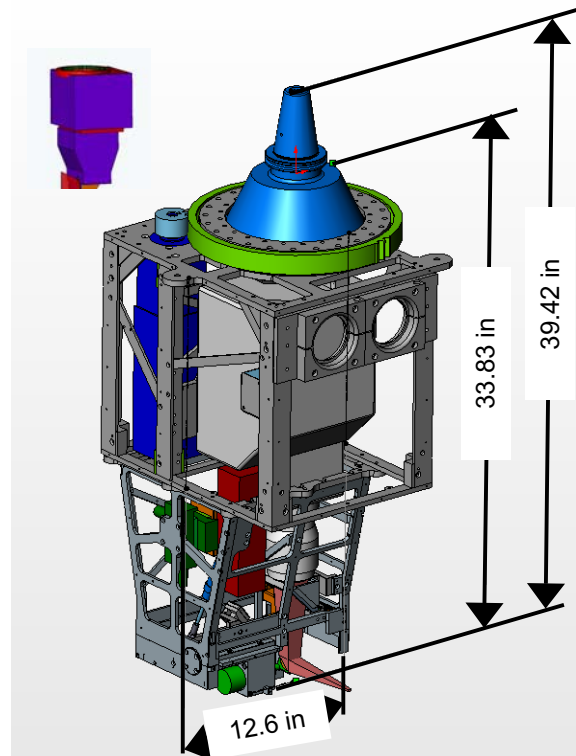


Figure 5. CAD model of the prototype.

This prototype includes all modules among a Rofin Sinar high power diode laser with 4 kW and a motor for a rotational axis. All integrated optical devices are monitored by many different sensor elements, which are necessary for laser safety. For that purpose a new sensor has been developed to inspect optics that are installed in the high power laser beam. Figure 6 shows a picture of the real prototype.

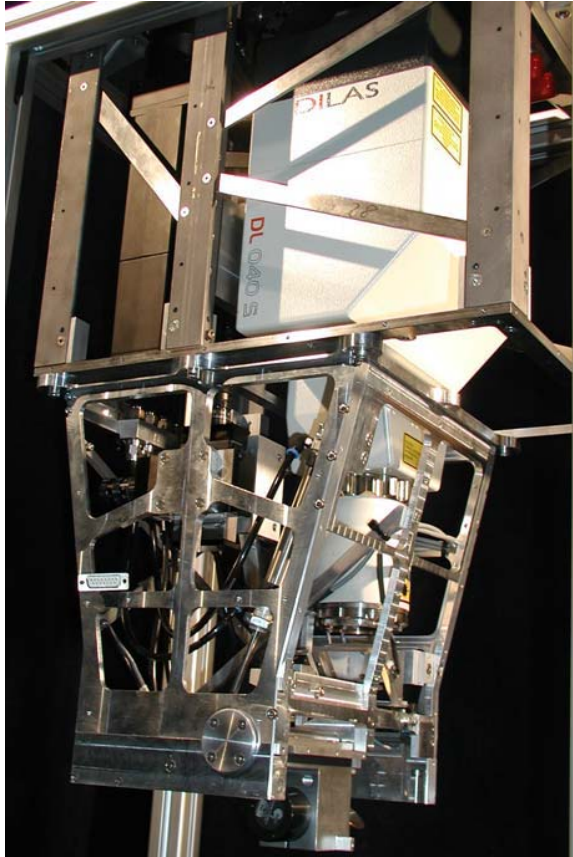


Figure 6. Prototype.

The weight of this tool is around 80 kg / 176 Pound. The module has a standard tool cone and can be gripped by the machine with the normal tool holder automatically like a milling cutter. There is no manual work necessary for preparing the hardening equipment. The module is designed and calculated for feed rates of 20 m/min / 65.62 ft/min and accelerations of 1.5 g.

It is planned to integrate this prototype in a mill center as shown in figure 7. To allow laser applications the machine has to be encased completely (see figure 8). Furthermore the machine safety concept has been totally redesigned. The entire machine, with following characteristics:

- length of 13 m / 42.65 ft,
- width of 9 m / 29.52 ft,
- height of 7 m / 22.97 ft,

had to get a 100% closed housing. A complete monitoring of all safety relevant elements like doors and windows of the machine case is required.

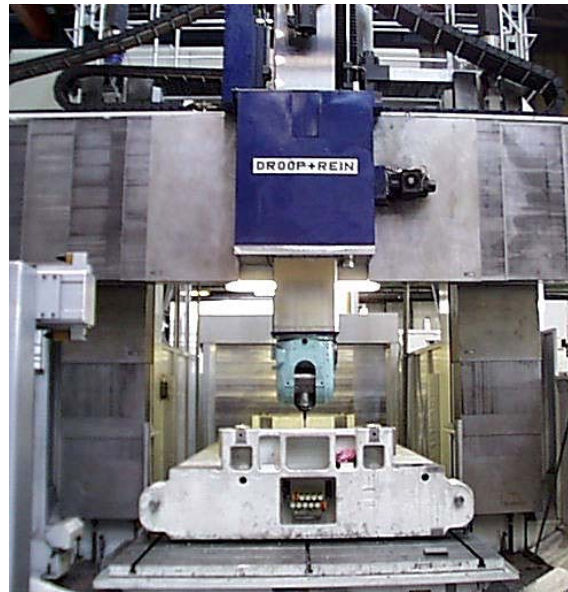


Figure 7. Machine used for first tests.

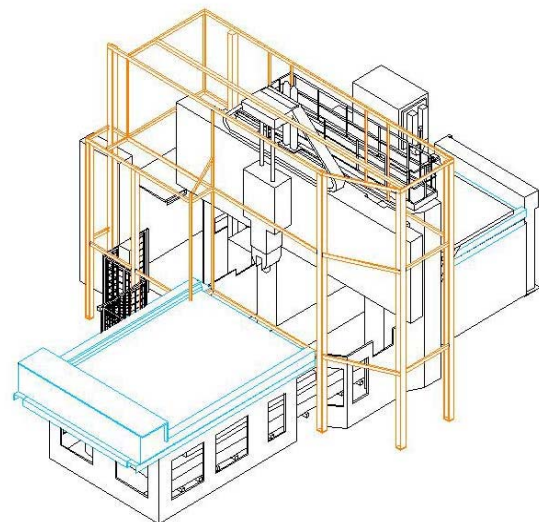


Figure 8. Housing construction of the complete machine.

Conclusion

A novel comprehensive system for heat treatment of large 3-dimensional tools for sheet metal forming using high power diode lasers has been developed. The entire system can be integrated into the industrial process chain. It enables to process from the point of CAD-design to the point where the unique part is already hardened automatically. Test parts and expensive acceptance trials aren't necessary for the heat treatment process.

A flexible interface concept has been conceived. This concept takes into consideration the needs of all future users of this system. This system is adaptable to any kind of machines and controller even for robots. For that purpose many necessary single stand-alone components were developed, redesigned and combined. This included software as much as hardware systems. In detail many devices, for example a temperature control unit, a scanning unit and a CAM-System are already in industrial use. Other parts, including the heat conduction simulation software, are in the development phase. A prototype of a hardware module including all hardware components is already manufactured. The final functional test will occur presently by the integration into a mill center and the treatment of real 3-D tools.

At the moment there are two entire systems already ordered by industrial customers and two more hardware modules are under construction. This vested interest of industry at this early state shows the immense potential of this integrated laser system.

Acknowledgement

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