

Online Quality Control in High Power Laser Welding

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Introduction

The progress in using high power lasers in high volume production leads to the strong need for automated and integrated quality control systems. Today the laser welding devices are part of fully integrated assembly lines. A lot of different processes are required for the product and every step has to be checked out for quality properties. Active quality control and weld supervision can help the manufacturer to reach the high quality standards given by ISO 9000. Especially the online quality control adapted to the laser welding process is able to influence the outcome in a way to get only good parts or at least to deliver an information about the result some milliseconds after the weld. Trace ability of security products is achievable by storing the data collected by these control systems.

The single steps of quality control like seam tracking, plasma monitoring, weld pool analysis and topographical analysis of the bead are well know and industrial proven. The step ahead is to integrate these technologies into an intelligent laser weld tool for easy and cost saving operation.

Regions for online quality control

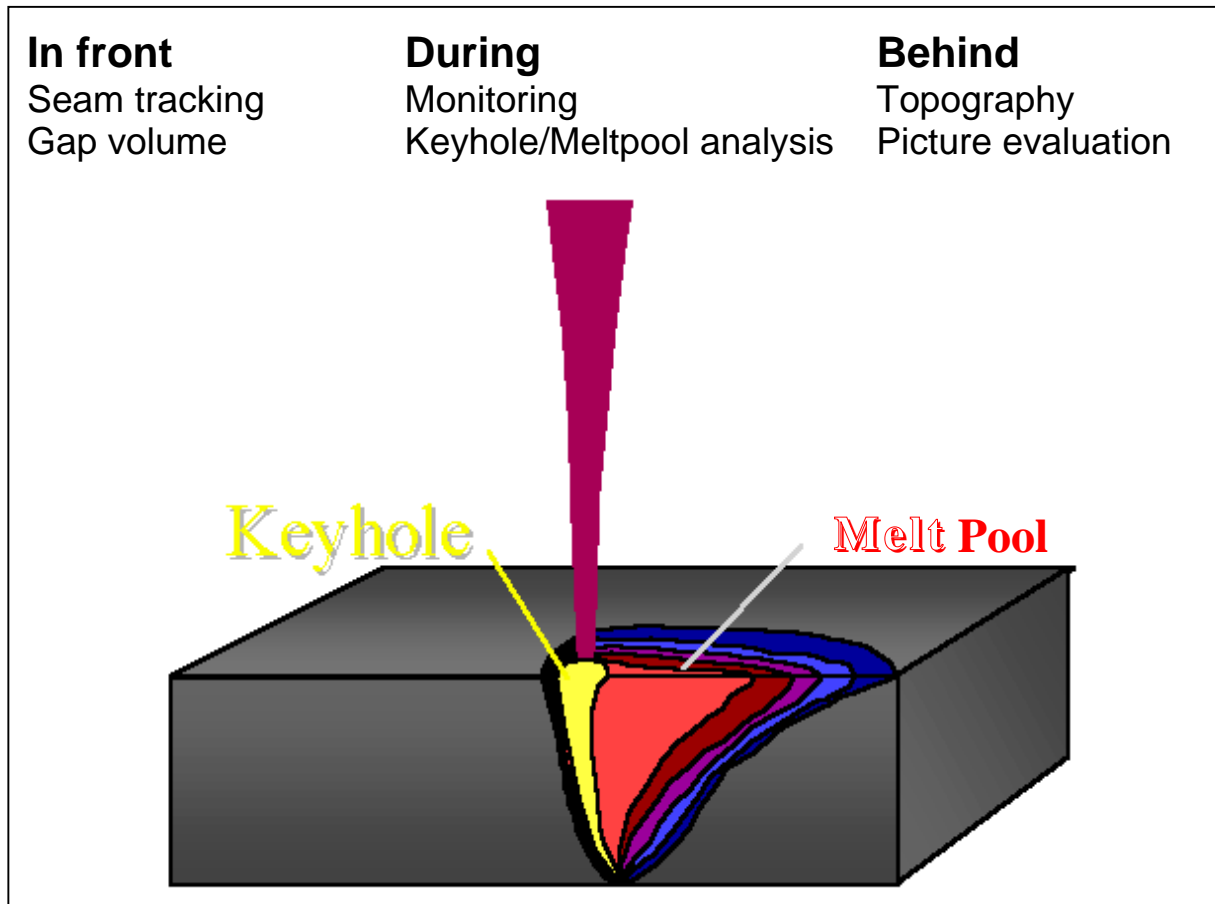
The meaning of online quality control is that all sensors contributing are working time parallel and closely attached to the welding tool. No additional time or operator is necessary to perform this control or analysis. No special inspection station is needed. Destruction of the welded parts is avoided.

There are three regions where the online quality control is performed.

First region in front of the welding process the so called seam tracking.

The second region is the welding process itself. So called plasma monitoring systems or camera based systems evaluating optical signals out of the weld process or the melt pool.

The third region is located behind the welding head. In this region the weld is finished and the investigation of the solidified bead is possible.



Picture 1: Regions for online quality control

Especially in the region behind the weld tool other investigation methods are available like ultrasonic or eddy current online testing. Even if there are several applications where the reliability of these system are shown the common access to online quality control is to use optical sensors for the optical laser tool. Maybe future progress will change this situation.

It is obvious that in the region behind no control in the meaning of influencing the weld process is possible. On the other side, the quality of the welding process can be enhanced most by the seam tracking and the determination of the gap volume in front of the welding head. There are some approaches to use the plasma monitoring signals to control for example the laser power for constant penetration. In plastics welding with diode lasers and in surface hardening processes temperature sensors are controlling the laser power to avoid a damage of the specimen. Maybe in future high power welding processes can be controlled also by this means.

Failure categories in serial production

Laser welding is a multi parameter process. A key for the successful use is to consider the special properties during the design of the product. Metallurgical aspects, surface layers, contamination, positioning of the joint, edge preparation as well as tolerance problems have to be taken into account.

The selection of the appropriate laser source and equipment as well as the optimisation of the weld parameters are other key factors.

In the serial production this work has to be performed properly before starting the production. But during the serial production a lot of unknown parameters will influence the welding result. The task of the quality control is to deal with these unexpected parameters and provide an alarm to the operator to check the process.

The European standard EN ISO 13 919 provides a list of failure categories which can be used as a guide.

To find the appropriate quality control process it is necessary to ask for the reason why a particular failure occurs. This shows the difference between the classical quality standards which are only caring for the ready welded seam and not for the process which is providing a lot of quality information itself.

Failure categories	Reason	Quality control
Cracks	metallurgical problems misalignment	topographical analysis* Joint tracking [1]
Porosity	metallurgical problems Keyhole collapse oil/grease pollution	no access monitoring monitoring
Lack of fusion	lack of laser power focal position changed process gas changed weld speed changed gap width misalignment	monitoring melt pool analysis seam tracking
Incompletely filled groove	gap width	monitoring volume measurement topographical analysis
Holes in the seam	gap width	monitoring, topographical analysis
Incomplete penetration	lack of laser power focal position changed process gas changed weld speed changed	monitoring melt pool analysis

***only if visible from the surface**

Picture2: Failure categories and adequate online quality control methods

Applying the seam/joint tracking and the online monitoring the most severe weld failure are detectable or avoidable in many cases. Topographical analysis can supply additional information. Using high frequency picture evaluation devices the costs of these systems are comparable or higher than the cost of the seam tracking system. These systems are not in the focus of this contribution.

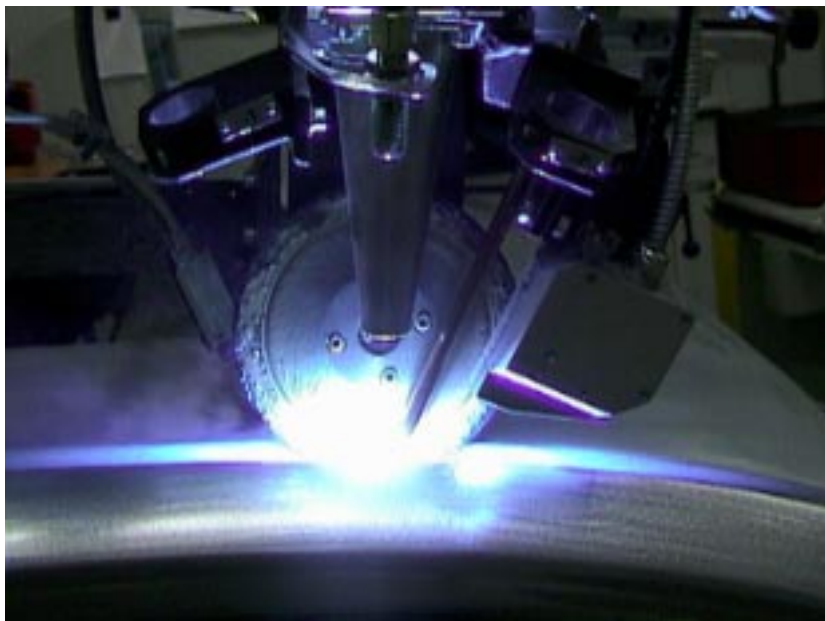
Seam Tracking

Spreading the laser welding process to car bodies or more general to welding of stamped sheet metal parts active control of the welding for example with joint tracking became obvious. Today nearly every roof seam welding by CO₂ or Nd:YAG laser is utilising a seam tracking system. Special seam types like the fillet weld on the overlap joint needs a very precise guiding of the welding tool. In the more standard overlapp welding the narrow roof channel often causes the need for the seam tracking. With welding speed around 5m/min the accuracy of the robot is not sufficient to keep the welding head on track. The seam tracking camera **Picture 3:**



Picture 3: Seam tracking the camera is guiding a welding head for Nd:YAG laser Welding

in front of the welding head can use the edge of the overlapping sheet to guide the welding tool laterally. The pressure wheel keeps the vertical position constant.



Picture 4: CO₂-Laser welding of roof seam. The seam tracking camera is guiding the welding head laterally the pressure wheel vertically.

In tailored blank welding flexible clamping concepts and the new development of non linear seam leads also to the necessity of seam tracking. To get constant welding results the accuracy of the track has to be better than 0.1mm at welding speed of 10m/min.

Not only the camera resolution typically better than 0.05mm is relevant to keep the welding tool on the track but also the slides or the guiding machine are influencing the result. The seam tracking camera is measuring the track position 10-50mm in front of tool centre point. The correction movement is done some milliseconds later depending on the welding speed. The exact knowledge of the camera position during the measurement is of the same importance as the camera accuracy itself. For this reason we are using special designed slides for moving the welding head and the camera to become independent of the position measurement system of the robot. Our seam tracking system has no need to communicate with the robot control about the actual position and we don't influence the robot control to perform the correction movement. The interfacing is done by simple digital I/Os. To optimise the dynamic behaviour of the position control loop it is easier to work with our small linear drives than with the changing behaviour of robots axis depending on the actual position.

Special software routines with precorrection of the robot inaccuracy and software filters to smooth the axis movement are other elements to achieve sufficient tracking behaviour.

Measurement of the gap size and calculation the amount of filler material is used for a closed loop control of the wire feed for example in hybrid welding. Supervision of the gap size can provide quality relevant data to reject blank or to stop the welding process and check the clamping condition in tailored welded blank application.

In Process Monitoring

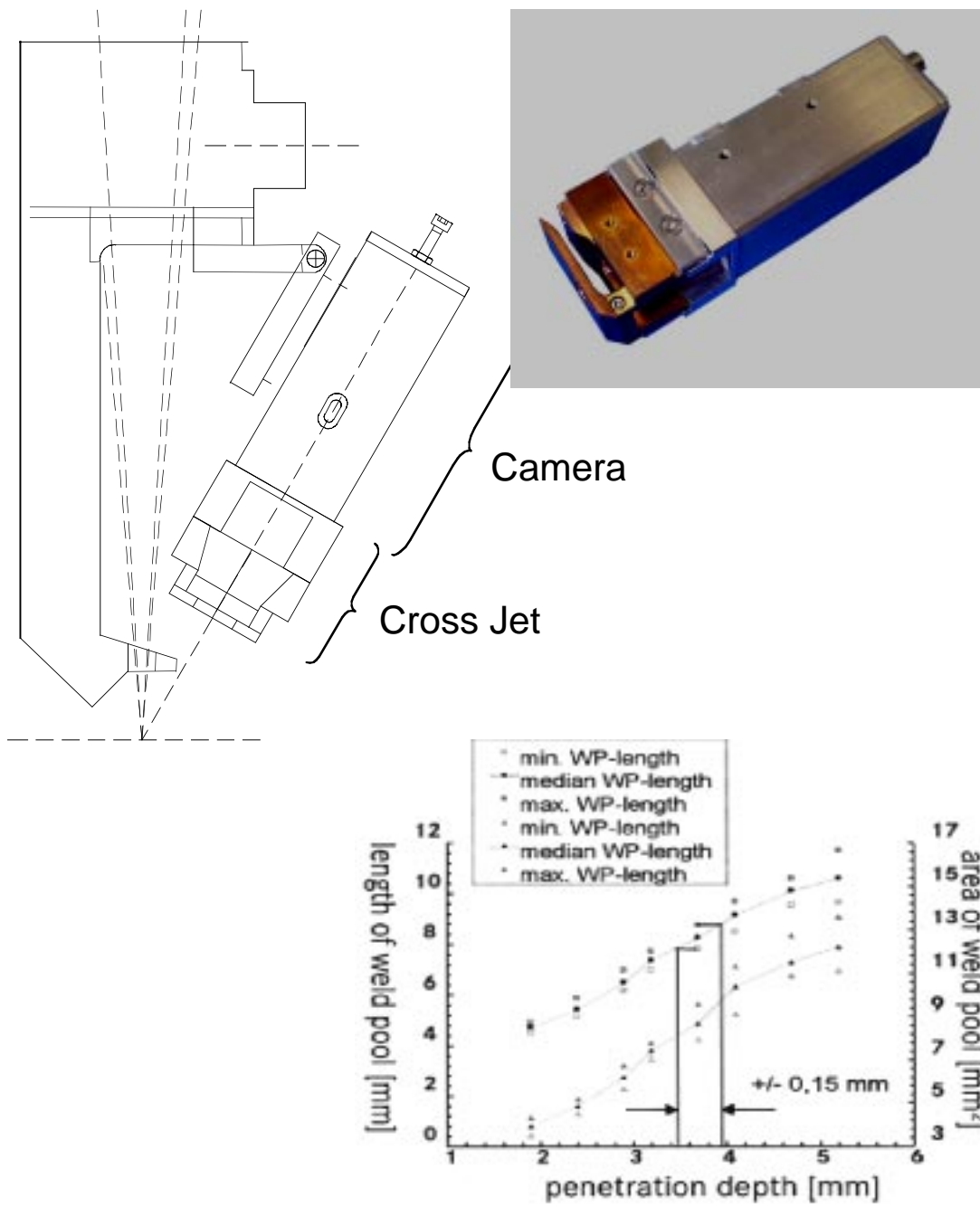
There are two different approaches to go into the in process monitoring. The camera based system (QUALAS) is evaluating geometrical and thermal properties of the keyhole and melt pool by picture processing. On the other hand there is the photodiode based plasma monitoring system (Laser Welding Monitor).

Qualas

In many laser welding applications a constant penetration depth is the most critical quality parameter. Lack of penetration can cause early breakdown of gear wheels and other power-train parts. The typical seam type is butt joint with several millimetres of penetration. Often the welding is done with CO₂ lasers.

With a special designed camera obtaining an infrared view of the melt pool the area and the length of the melt pool are measured. There is a linear dependency between length of weld pool and penetration depth. Deviation from the exact penetration depth down to +/- 0.15mm are detectable.

In other applications this system is used to detect a complete through welding. Misalignment of the weld edges and increasing gap size are also visible in the picture of the keyhole in this application. If the trough welding is complete there is a dark spot in the middle of the bright shining keyhole. If the gap is to wide the circular shape of the keyhole is sliced in two half circles. Misalignment of the edges is changing the circular appearance of the keyhole unsymmetrically.



Picture 5: QUALAS camera, a typical set up in CO₂ laser welding and the qualas principle (a linear dependence of weld pool length and penetration).

The Laser Welding Monitor

A standard method is the Online Monitoring of optical emissions out of the interaction zone [2]. Photodiode based sensors are measuring the emissions. The curves are recorded with a data acquisition computer. To decide if there is a failure in the seam the recorded curves are compared with the taught in baseline of a good welding process. Failure evaluation and 100% documentation is supported by customised software on this PC based platform. The Laser Welding Monitor (LWM) represents a multi detector systems for CO₂- and Nd:YAG-lasers which is widely used in the automotive industry.

In the following we are focussing on the quality control of Nd:YAG applications in tailored blank welding.

Tailored blank welding with lasers is widely used in the worlds car manufacturing industry. With the growing number of sheets and the use of these sheets in more critical parts of the car body there is an increase of quality requirements. Today the rate of defective sheets has to be down to a range of a few parts per million.

The laser welding process is very reliable and the progress of laser welding machine technology has reached a very high level. Nevertheless there is a need for a 100% supervision, and quality control to guarantee a low failure rate. Especially small mechanical defects at the welding edges, mechanical stress in the sheets, oil contamination or other pollution can influence the seam quality.

Some influencing factors are:

Welding speed

A welding speed of 12m/min or 200 mm/s which is achievable for blanks with a thickness of 1mm on the one hand and a failure size of smaller than 0.5mm on the other hand leads to a high detection frequency. Photodiode based detectors processing analogue values can reach easily the region of several 100Hz or kHz.

Repeatability, Edge preparation and Clamping

The principle of the so called plasma monitors has a strong need for repeatable and constant welding conditions. If there are big oscillations in the baseline of the so called good welding the detection ability for failures is reduced. Constant edge preparation and excellent clamping is evident [3].

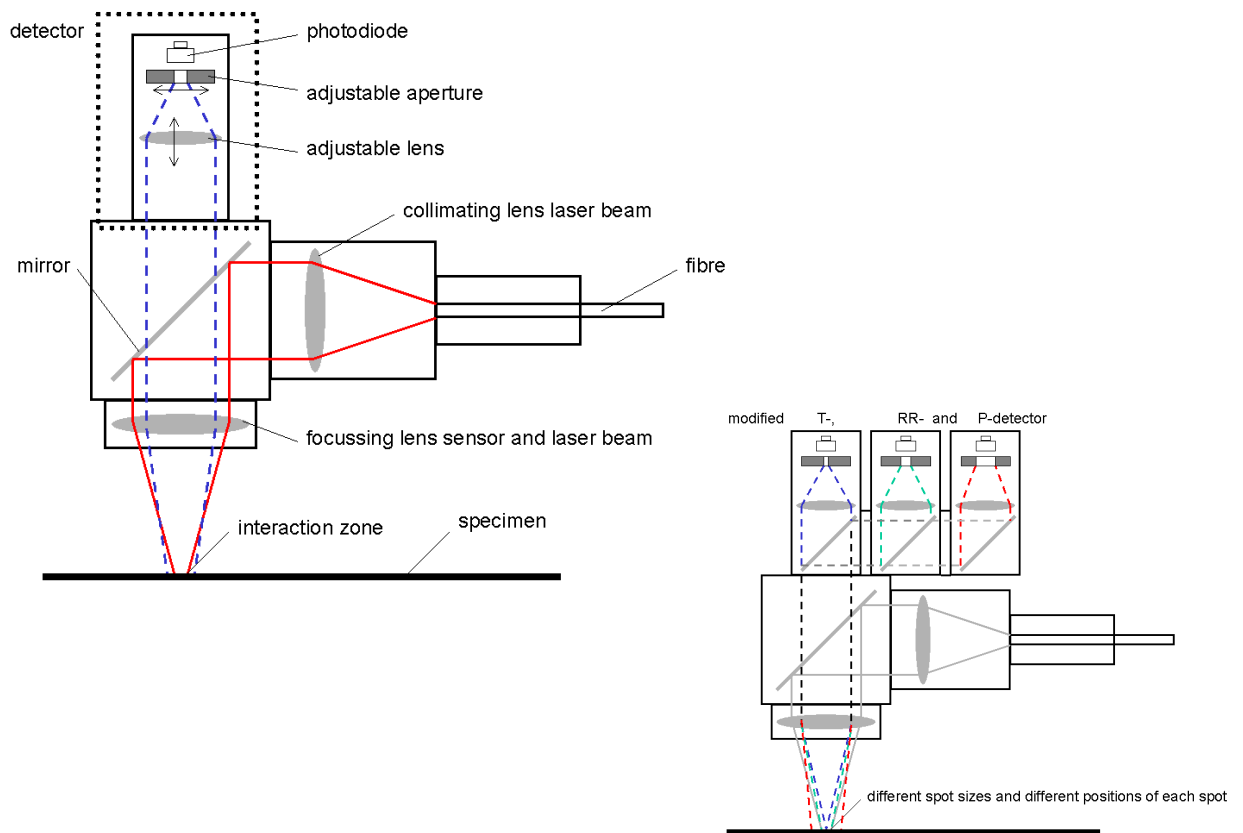
Zinc coating and oil layers

Zinc coating galvanised or hot dipped is increasing the fluctuations of the baseline especially if there is no assistance gas to control the plasma or the metal vapour plume as it is common in the Nd:YAG-welding process. A varying amount of oil on the sheet surface is a standard situation in the blanking industry. In the most cases there is no influence on the quality of the laser welded seam. But the evaporated oil is visible in the traces of the Plasma Monitoring system and diminishes the validity of the trace evaluation.

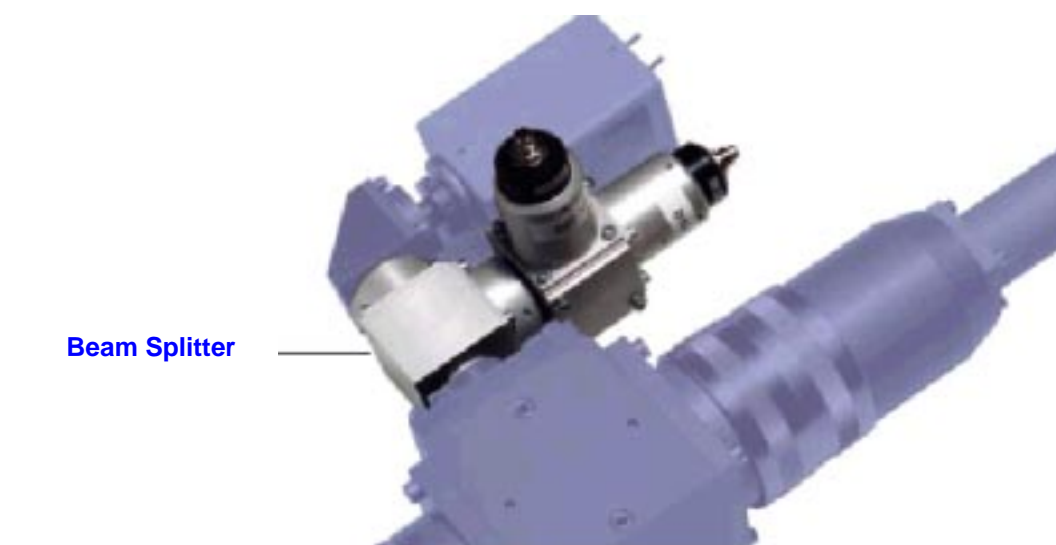
Partial fusion

Different sheet thickness is common for the tailored blank welding applications. Using only a plasma detector is not sufficient to decide if there is a mismatch between the track of the welding head and the welding edge. The use of multi detector system utilising one or more temperature detectors can increase the detection probability of this severe defect.

Specially designed sensors are improving the signal to noise ratio to reach the required detection level



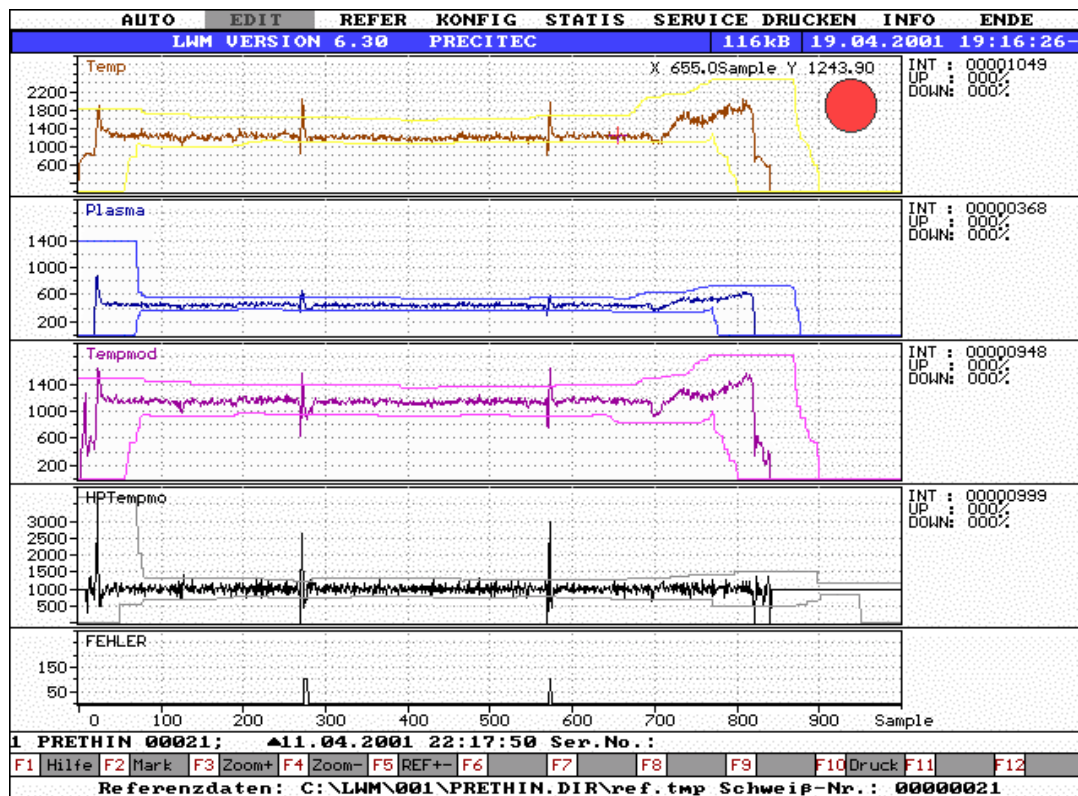
Picture 6: Laser Weld Monitor sensors mounted to 90 degree Nd:YAG welding head. The Plasma, Temperature and Backreflexion sensor are containing adjustable apertures to select the relevant field of view. This set up is improving the signal to noise ratio and the hole detection ability.



Picture 7: Temperature and Backreflexion detector mounted to a standard welding head with observation camera

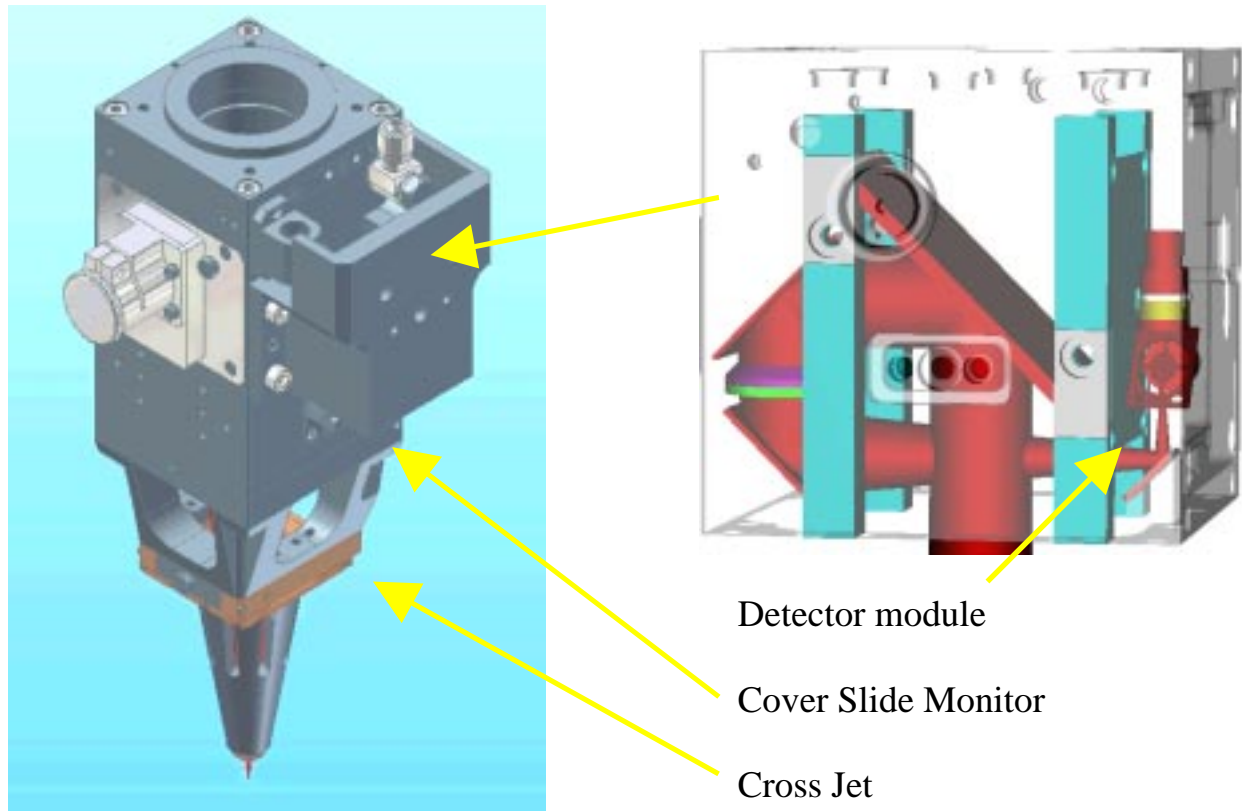


Picture 8: Selective temperature and standard backreflexion detector mounted to an observation unit fitting to welding heads which are not prepared for monitoring purposes.



Picture 9: Traces of tailored blank weld with two artificially introduced defects. These defects (small holes in the seam) are clearly visible as spikes. The spikes are exceeding the tolerance band of the good welding process and are leading to a reject of the sheet.

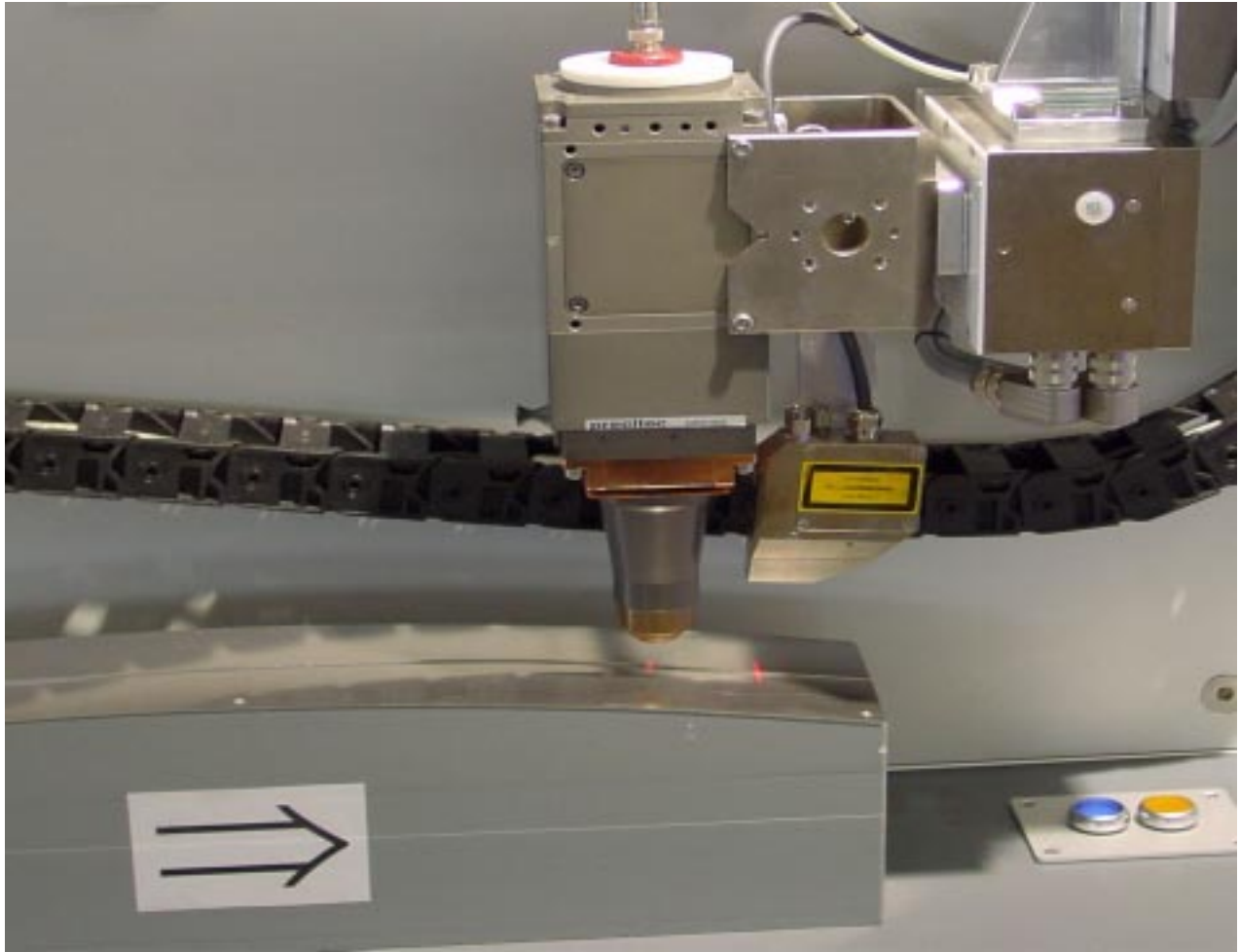
Pictures 7 and 8 are showing typical set up of detectors using standard welding heads. To reduce the outer dimension of the welding head especially in robot guided welding Precitec KG did find a way to integrate the complete sensor set up into a new High Power welding head.



Picture 10: High Power Nd:YAG welding head with integrated sensor modul for Laser Welding Monitor

This welding head is containing all the features which are necessary for high power Nd:YAG laser welding with a strong impetus on quality control. Not only the integrated sensors for the supervision of the welding process but also active devices to avoid weld failures are built in. The Cross Jet with supersonic air flow reduces the pollution of the protective window to a minimum. The cover slide monitor which provides an alarm signal in case of severe pollution. There is no possibility to weld with undetected power loss due to contaminated optics. The media guiding for cross jet air and process gas are manufactured into the walls of the solid aluminium housing. Thermal or mechanical destruction of outside cables or hoses is impossible.

The mounting flange which is designed for quick exchange in case of a crash provides the option to mount the camera of the seam tracking system. This welding head combined with the seam tracking system and the linear slides represents a complete technology package for the quality controlled laser welding process.



Picture 11: High Power Nd:YAG welding head with integrated monitoring sensors and seam tracking camera mounted to 2 axis slide as a complete solution for quality controlled laser welding applications.

Conclusion

After several decades of using laser technology for joining in automotive industry the use of online sensoric is evident. A big variety of sensors and closed loop control is commercially available. The major topics are the seam tracking to handle the tolerances of the parts for example in car body applications or non linear tailored blanks and the so called plasma monitoring for supervision of each part. Geometrical melt pool analysis is a camera based approach to gather quality relevant information.

These sophisticated optical sensor system has to be integrated into the laser machines which are working in the rough industrial environment. The use of closed loop control systems which are integrated in the welding head / tool are reducing the complexity for the machine builder and the operator. These integrated systems are the basement of a quality controlled laser welding process.

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