Optical radiation in laser welding and cutting.

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Abstract

This paper concerns the health and safety aspects when YAG laser based processing in the form of welding and cutting is performed. The health and safety aspects for the Hybrid welding process with a combining of a YAG laser and a MAG process is in addition considered.

Relevant European standards and main requirements concerning health and safety in YAG laser based processing are described.

The European project 'DockLaser' is concentrated on laser processing techniques and equipment for the final assembly area in ship new-building and repair.Work safety and approval is focus of one work package in the project. A part of the project is to create guidelines and solutions for the qualification of the processes and safe operation of equipment, test and evaluate the equipment and processes under practical conditions.

Results from the 'DockLaser' project related to practical measurements of reflected laser radiation from the processes Hybrid and YAG-Laser are described.

Keywords: *YAG-laser hybrid welding. Radiation. Safety. Laser materials processing,*

Introduction

This paper deals with the special health and safety aspects regarding YAG laser based materials processing with focus on hazard when the human eye or skin is exposed to laser radiation.

The most important standards applying in Europe on the area with a short introduction to each standard is found in this paper.

Additional selected measurements of reflected laser radiation in different laser processing situations performed under the European project 'Docklaser' are presented.

YAG-laser process

YAG laser systems used for welding and cutting consist of a number of elements as shown in figure 1. The laser radiation is generated inside the laser and transmitted through a flexible fibre to the laser head. The laser radiation is focused by optical elements in the laser head to increase the power density thus being able to melt the material to be welded or cut.

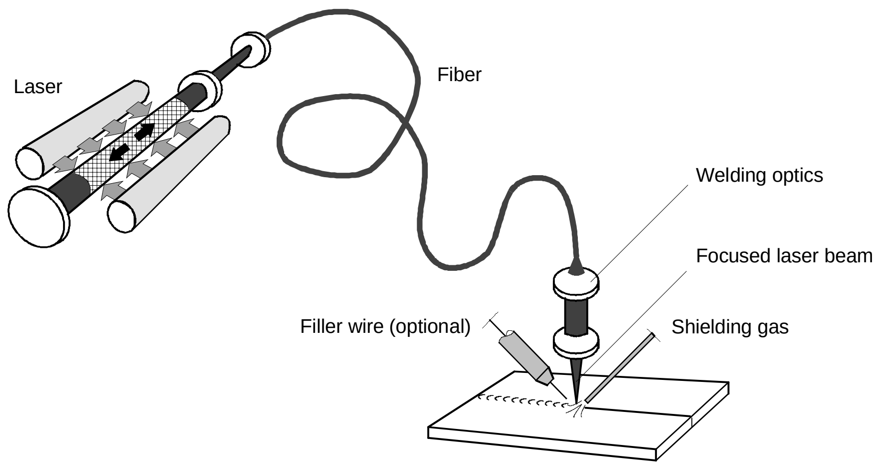

Figure 1 *Principle sketch of the YAG laser welding process*

YAG laser radiation and other hazards

In conventional arc welding, the only optical radiation emitter of concern is the welding arc, but in laser material processing, also the laser beam itself is of concern. It is therefore convenient to talk about secondary (collateral) radiation (radiation from the welding arcs and the laser induced plasma) as well as primary radiation (the laser radiation).

Especially related to the YAG laser process safety arrangements must be set up in order to avoid the 1064 ηm laser radiation being absorbed by the human eye. Due to this wavelength of the radiation, being very close to the visible range, severe damage to the retina of the eye is possible if sufficient precautions are not taken.

Safety aspects of the YAG-laser based systems are therefore of major concern and it is thus of vital importance to be able to shield the operator(s) as well as other personal.

Hybrid YAG laser hazards

Hybrid YAG laser welding is a combining of the YAG laser and an arc welding process (typically MAG welding) to work in the same melt pool to obtain the advantages of both processes.

Health and safety related to the hybrid process can be analysed in theory by separating the process to the laser and the MIG/MAG process, and consider the basic elements for each process technique. Two main principal hazards have been identified: Optical radiation and fume and gasses – see figure 2.

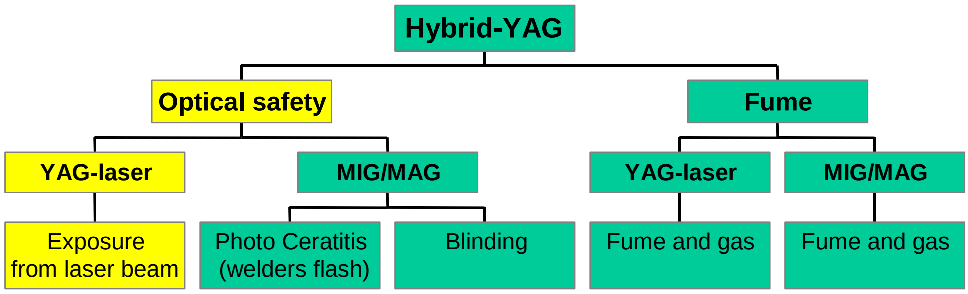

Figure 2 *Optical and fume safety related to the Hybrid welding process.*

Optical radiation is assessed to be treated as two separate processes where the hazards have to be added, figure 2. The assessment is based on the very different optical spectre of radiation from the two processes. As the two processes to some extend are working separately only taking advantage from each other, this should be a fair assumption. Secondary radiation is described below.

Seen as a whole it is the laser radiation that is the dominant safety hazard. The optical hazards related to the MIG/MAG process are definitely not as critical but still a serious problem.

Secondary radiation

Concerning secondary radiation two phenomenon's are possible to arise. Photo Ceratitis, often described as "welders flash" has a quite frequent occurrence among arc welders, and is painful but normally without permanent damage. Blinding is the second risk, which is rare but might cause permanent damage to the eye.

In both situations the risks and the safety aspects are well known and intensively described in the literature. End users who deal with arc welding are normally familiar with these safety aspects.

In the case of pure YAG laser welding the secondary radiation is without significance.

In the case of the hybrid process it is the MAG process parameters that dictates the level of secondary radiation. The levels of UV- and visible radiation can be very intense in high power MAG welding of steel.

However the laser process is automated and that removes the operator from the processing area, thus less hazardous. If required personal safety equipment like helmets, clothes and protection glasses are standard.

Emission of fume and gas

The emission of fume and gas are a lot more difficult to predict, as this depends a lot on the actual process situation. The deposition rates of filler material and the process synergy have a particular impact on the fume and gas emission. The best compromise before getting those data will be to add the emission from the two processes.

Similar as for secondary radiation the laser process is automated which removes the operator from the processing area, thus less hazardous.

Other hazards

Of other potential hazards than the laser radiation hazards from the laser processing equipment can be mentioned:

- Mechanical hazards (Moving parts as gantries and robots)
- Electrical hazards (High voltages)
- Noise hazards
- Thermal hazards
- Vibration hazards
- Secondary radiation (primary from the MAG-process)
- Fume and gases (both from laser and MAG-process)
- Fire or explosion

These kind of hazards from laser processing are <u>not</u> covered in prEN ISO 11553-1, and instead the laser machinery should comply as appropriate with other relevant standards on the respective fields.

Risks of escaping laser radiation

The optical safety hazards have to be clarified before discussing which safety principles are relevant to study in details. The complete YAG laser beam path has in general potential risks of failure thus the emission of laser radiation is out of control. The nature of emission is different depending on which part of the system having a malfunction. Possible critical situations are described below starting from the laser source and ending in the production facility – see principal in a YAG laser system in figure 1.

Laser Source

Laser radiation is generated inside the laser cabinet and guided to the beam path by an internal optical system. Hazardous situations might crop up if a malfunction occurs in the optical internal beam path. Consequently laser sources have to abide with strict legal regulations to prevent hazardous laser radiation to the surroundings.

Beam path

The beam path is defined as the transmission of the laser beam from the laser source to the welding head. It consists of two connectors, one in each end, with a flexible fibre in between transmitting the beam. The beam path is also regulated by legal requirements, to ensure a safe operation.

Two critical situations are possible to occur during operation due to operator error or damage which are, emission of laser radiation from a free fibre end if the welding head is not connected, or emission from a broken fibre.

The beam path has to abide with strict legal regulations to prevent unintended emission of laser radiation outside the beam path from happening.

Welding head

The welding head has two principal optical functions. When the beam enters the welding head from the connected fibre it is collimated through a lens. Secondly the collimated beam is focussed, through a focussing lens, to fit the demands for the actual application to be welded or cut.

The far most critical situation is the possible emission of the collimated beam. This could occur if the focussing lens is not in place due to an operator error. The safety distance for the incidence is easily in the kilometre-range if pointed to the eye.

The emission of the focussed beam is always present, as this is the physical “tool” in the system. The safety distance is typical shorter by an order of magnitude, due to a larger divergence of the beam.

Processing area

The emission of laser radiation in the processing area is quite severe as the focussed beam is used in the weld process without any coverage. Furthermore the focussed beam will be reflected from the melt pool emitting in random directions. A worse case will occur if the welding head is positioned without a work piece in front, thus emitting a focussed beam out to the surroundings.

The most critical situation will occur if the welding head is positioned without a work piece in front, and not having a focussing lens mounted in the welding head, thus emitting a collimated beam out to the surroundings.

Safety precautions against laser radiation and relevant standards

In general humans shall under no circumstances be exposed to laser radiation exceeding the maximum permissible exposure (MPE) limits.

Normal practice is to reduce the safety risks for a laser installation to the class 1 for all personnel including the operators of the laser cell.

The safety aspects are well defined regarding the laser source and beam path through strict legal requirements to be fulfilled by the manufacturer of laser systems (e.g. prEN ISO 11553-1, prEN ISO 11553-2, EN 60825-1 and ISO 12100).

However the processing zone and the surrounding area is a lot more complicated as specific needs must be incorporated in the safety solution. A risk assessment shall be performed in each production situation according to the guidelines in prEN ISO 11553-1 and prEN ISO 11553-2.

The easy approach is to surround the complete area by a rigid enclosure being able to resist the heat load from the laser beam. This is for many applications the selected solution used, but when handling large components this is rather inconvenient and costly.

In the case of large construction e.g. ship sections, there can be a need for an enclosure which only cover a part of the section (the processing area). In this case there will be a need for some sort of flexible seal which seals against the section maybe both horizontal and vertically.

The European standard prEN ISO 11553-1:"Safety of machinery – Laser processing machines" Part 1: "General safety requirements", 2002, covers radiation hazards and hazards generated by the laser interaction with materials and substances. It also specifies the information to be supplied by manufacturers of such equipment.

The acceptable level of radiation and maximum permissible exposure time is very depending on the actual situation when emitting a laser beam. The European standard on this field is the EN 60825-1: "Safety of Laser Products – Part 1: Equipment classification, requirements and user's guide". This standard deals with the safety of laser products. The standard covers laser radiation in the wavelength range 180 mm to 1 mm, and indicates safe working levels of laser radiation and introduces a system of classification of lasers and laser products according to their degree of hazard.

Maximum permissible exposure (MPE)

The EN 60825-1 standard specifies maximum permissible exposure (MPE) values, which represents the maximum level of laser radiation to which the eye or skin can be exposed without injury.

MPE limit values are for users, set below known hazard levels, and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposure, and should not be regarded as precisely defined dividing lines between safe and dangerous levels.

In any case, exposure to laser radiation shall be as low as possible. The MPE are divided into two levels one for skin exposure and one for ocular exposure the later being significantly lower than the first.

The MPE value for a YAG laser (wavelength = 1064 nm) depends on the exposure time and on the beam divergence.

Nominal ocular hazard distance (NOHD)

The EN 60825-1 standard contains guidelines to calculate the nominal ocular hazard distance (NOHD), which represents the safe distance to a laser source. The hazard potential for class 3B and 4 lasers may extend over a considerable distance.

Laser guards

The standard EN 60825-4: “Safety of laser products - Part 4: Laser guards”, specifies the requirements for laser guards, permanent and temporary (for example for service), that enclose the process zone of a laser processing machine and specifications for proprietary laser guards.

This standard applies to all parts of a guard including screens, panels and other part of a protective housing. This is described more detailed in chapter 8.

Safety goggles

In the case of potential risk of exposure of the eye, the use of safety goggles are a convenient solution. The labelling and use of safety goggles are regulated by the European standard EN207, in the case of goggles for operators. Safety goggles for service are regulated by the European standard EN208.

Filters

The use of filters as viewing screens is also regulated by the European standard EN207 [4.1]. In the case of using manually controlled YAG laser for welding and cutting in shipyards, it is very likely that windows made of proper filter material in a local enclosure around the processing area are needed.

Danger zones

Danger zones in which hazardous laser radiation is a potential risk must be defined. If the operator of the laser is in a danger zone while the laser is functioning, the laser shall (in accordance with ISO 11553-1) be equipped with means for direct control of machine motion, beam direction and beam stop. The operator’s use of safety goggles is in this case required.

The design of protective devices, such as shutters, guards, beam dissipation devices and deterring/impeding devices shall meet the requirements in EN 60825-1 and ISO 12100.

Access to the welding area should be possible by overriding the safety system. It is recommended that only trained technicians can be allowed entering the working zone. The requirements in ISO 11553-1 most be followed.

Access of other people than the operators to the danger zone must be prevented.

Laser Guards

The standard EN 60825 – 4 “Safety of laser products” specifies the requirements for laser guards, permanent and temporary, that enclose the process zone of a laser processing machine, and specifications for proprietary laser guards.

This standard applies to all parts of a guard including screens, panels and other part of a protective housing. Material intended to be used as screening material against laser radiation has to fulfil the requirements stated in this part of EN 60825.

Laser Source and Beam Path

The Laser source and its beam path (Laser, beam delivery, in-coupling, LaserLightCable (LLK) and optic) are normally completely controlled against irregular light output.

Coming into a sealed beam delivery the laser beam is coupled into the fiber. At the in-coupling unit the controller is detecting scattered light to make sure that the light is completely transferred into the fiber. The LLK is having a control at both sides (in/out) to detect if the fiber/optic is plugged and connected well. The fiber itself is covered over the full length by an electrical device. This is detecting mechanical damage and uncontrolled light output.

Every irregularity is opening the safety cycle and is switching of the laser light at this beam path.

Measurements of reflected laser radiation in the Docklaser project.

Practical measurements of reflected laser radiation during welding with a YAG laser and welding with the hybrid process YAG/MAG were performed in the European project Docklaser.

The practical experiment and measurement work took place in the laser laboratory setup at IGM in Rostock in week 14 in 2004 by SLV-Rostock, SLV-Halle and FORCE Technology.

The aim of these measurements was to get more knowledge about the level of hazardous reflected laser radiation from the YAG-laser process as well as the hybrid process to the surroundings under normal processing conditions by use of the laser processing equipment relevant for the Docklaser project.

Laser Processing Equipment

One of the laser processing equipment systems employed in the Docklaser project for the measurements of the laser radiation was a tractor guided hybrid (YAG/MAG) welding system as seen in figure 3.

Figure 3 *Tractor guided system applied for butt and fillet hybrid laser welding in the Docklaser project.*

Measuring equipment

A detector connected through a flexible fiber cable to a spectrometer was placed in different positions in order to detect the reflected laser radiation under different welding setups – see principle left in figure 4.

The spectrometer was a SM 241 Near Infrared CCD spectrometer made by CVI-Laser with a spectral response of 880 nm to 1600 nm. All the radiation measurements were controlled and logged through the software program SM32Pro on a PC – see right photo in figure 4.

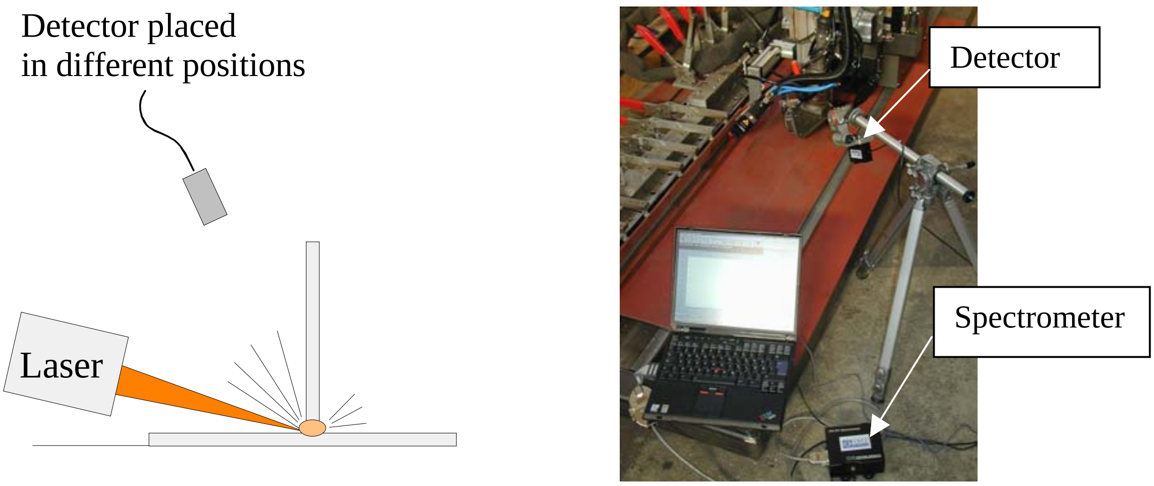

Figure 4 *The detector was placed in different positions under different welding setups to measure the laser radiation reflections from the process*

Laser-, MAG- and hybrid-welding

Measurements of reflected laser radiation were made during fillet welding of unalloyed plates – a vertical standing plate with thickness 8 mm to a base plate with a thickness of 10 mm. The fillet grooves were grinded before welding to remove the primer. The welding was carried out on 500 mm long plates by use of the tractor guided system.

The detector for the radiation measurements was fixed on a tripod in a position 650 mm from the plate- see the detector position in figure 7.

The tractor guided system applied for fillet welding in the initial measurement tests are seen in figure 7..

The position of the detector is also shown in figure 7.

With the detector fixed in this position shading in some varying degree of the reflected radiation would occur as the tractor moved forward.

The shading was mainly caused by the laser head and the laser sensor.

Figure 5 *Tractor guided system applied for fillet welding and laser radiation measuring detector in position (650 mm from test plate*

In order to compare the level of radiation from three different welding processes the measurements of reflected radiation from fillet welding was performed by use of:

- MAG welding,
- YAG laser welding and,
- hybrid YAG/MAG welding

The radiation measurements were sampled with a frequency of 1 Hz, and with a integration time of 50 ms. The filter 100 was mounted in front of the detector.

MAG-welding

The pure MAG welding was made with the welding parameters:

- Wire: 1,2 mm G3Si1
- Gas: 90% Ar/10% CO_2
- Weld speed: 1000 mm/min
- Voltage: 22 V
- Current: 220 A

A single measurement of the radiation distribution from 880 to 1600 nm during pure MAG-welding is seen in figure 8:

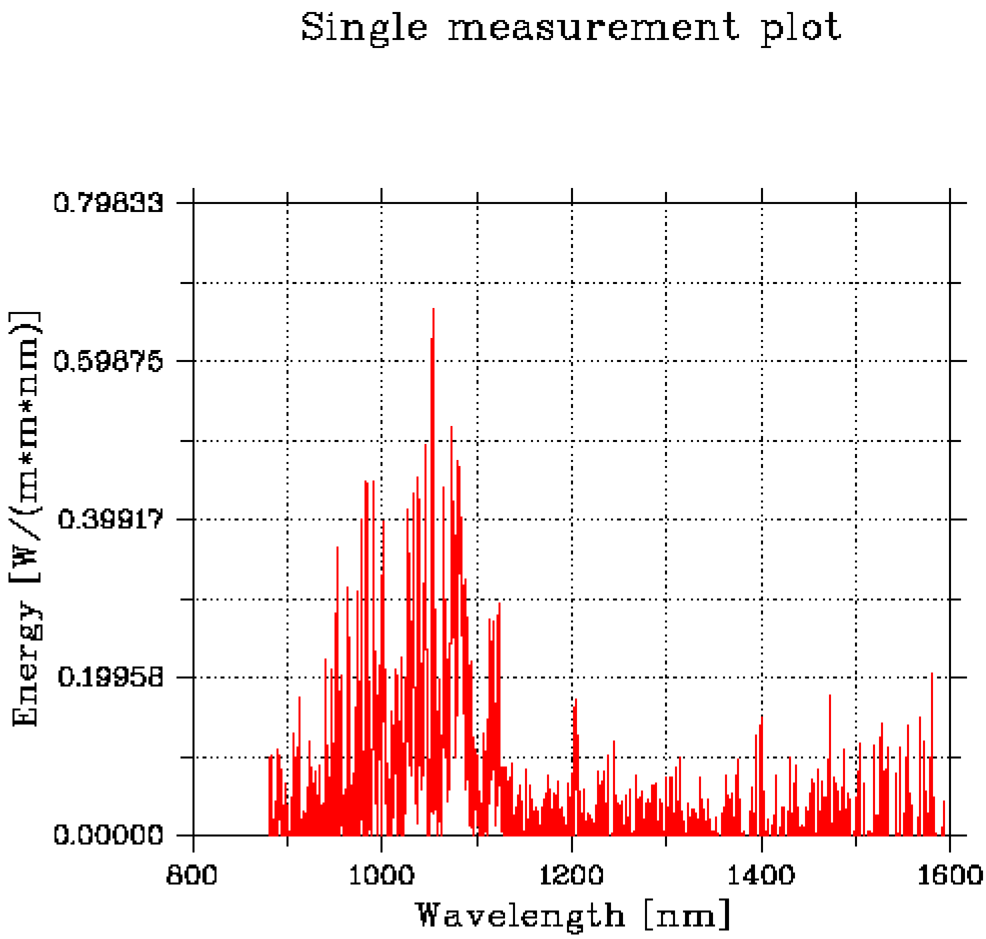

Figure 6 *Measured radiation from pure MAG-welding*

Laser-welding

The pure laser welding was made with the welding parameters:

- Weld speed: 1000 mm/min
- Laser power: 4000 W

A single measurement of the radiation distribution from 880 to 1600 nm during pure laser welding is seen in figure 9:

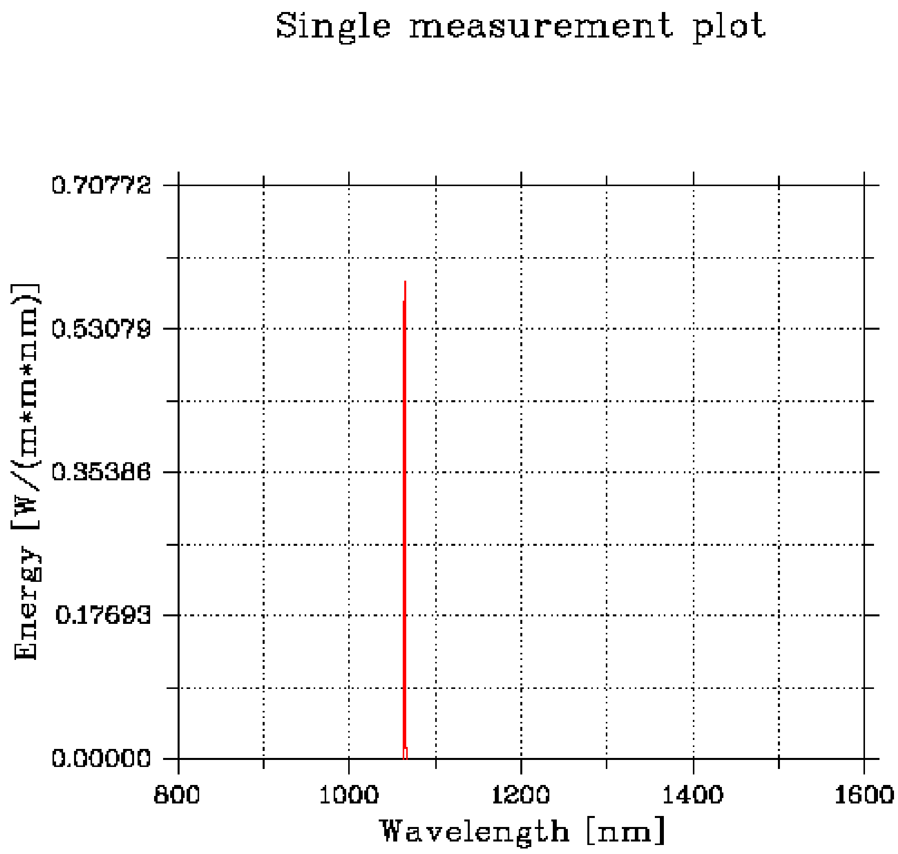

Figure 7 *Radiation from pure YAG laser fillet welding*

The typical YAG-laser radiation close to 1064 nm is clearly seen in figure 9.

It is seen that the level of radiation close to 1064 nm during pure laser welding (figure 7) is at the same level as during pure MAG welding (figure 6).

Hybrid-welding

The hybrid welding was performed by use of the same MAG and YAG laser parameters as shown above.

A single measurement of the radiation distribution from 880 to 1600 nm during hybrid YAG/MAG welding is seen in figure 8:

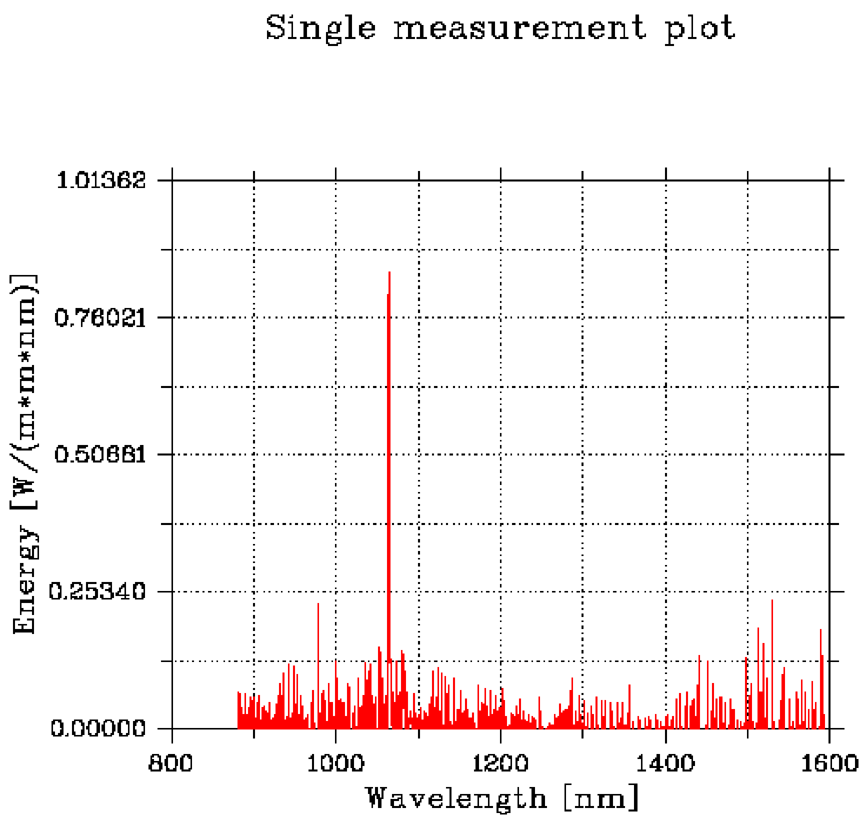

Figure 8 *Radiation from hybrid (YAG/MAG) laser welding*

Comparison of radiation from MAG, pure YAG and hybrid MAG/YAG
Measurements of the reflected radiation in the wavelength interval from 1062,78 to 1065,51 nm from welding with the three different processes in 25 seconds are compared in figure 9:

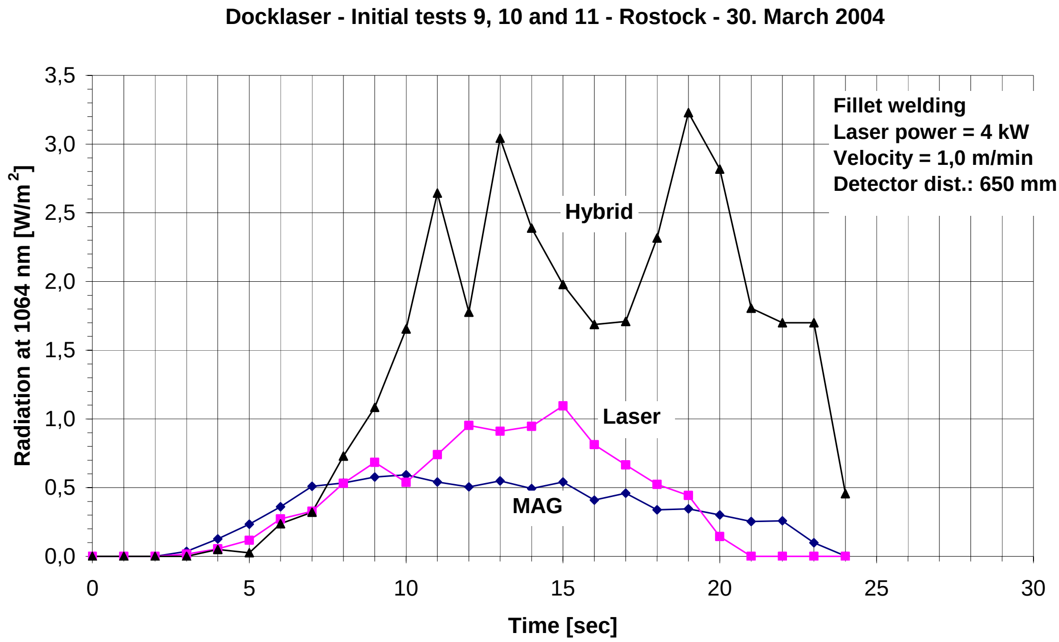

Figure 9 *Comparison of reflected radiation from respectively pure MAG, pure YAG laser and hybrid (MAG/YAG) fillet welding in the wavelength interval from 1062,78 to 1065,51 nm measured in a distance of 650 mm.*

In figure 9 it is seen that the reflected radiation is a little higher during hybrid welding compared to pure MAG welding or pure laser welding.

In addition it is seen that the reflected radiation from the pure MAG welding and the pure laser welding in the analyzed wavelength interval from 1062,78 to 1065,51 nm are similar.

For all three processes, the level of radiation in the present measurement position is considerably below the limit of hazardous radiation, which for a YAG-laser in 10 seconds is 50 W/m^2 according to EN 60825-1/A2.

Final remarks to the measurements of reflected radiation in the Docklaser project

The measurements of reflecting radiation were made under normal processing condition where the laser beam was absorbed into the parent metal. If the laser beam accidentally is not absorbed, higher levels of reflected radiation will most likely occur.

Furthermore it must be taken into account that the measurements were made in a certain position to a certain time, and that reflections to all other directions at this time are not measured.