Weld Process Inspection

A visualization and monitor system for hot and molten metal processes such as welding and cutting

Gregory Flinn, Gregor Federau, Bastian Lampert and Ulrich Oechsner

Welding in remote and hazardous conditions presents a demanding problem to the robotic systems developer, in particular if the process needs to be monitored in-situ. However, through proper application of a small suite of in-house optics and photonics technologies, Hamburg specialist Schäfter+Kirchhoff already has the solution to hand.

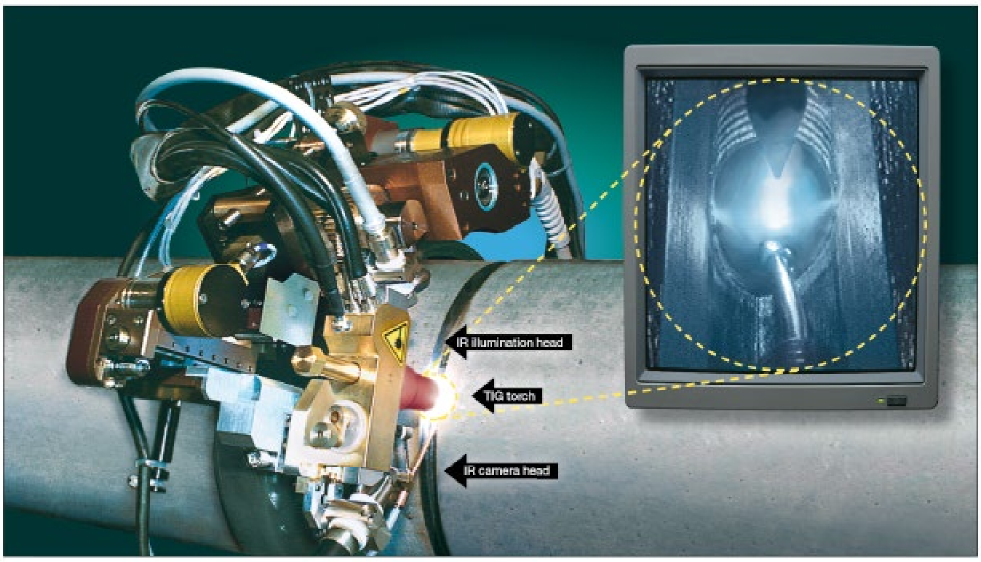


Fig. 1 Arc and laser welding monitor permits remote observation and control of arc and laser welding operations.

The problem with welding in remote and/or adverse environments is that the task can range from difficult to outright hazardous. Welding operations, for example, for underwater pipelines or in radiation-exposed locations within nuclear power plant facilities are just two of many such tasks. But it is in exactly this type of location that the weld needs to be guaranteed to be of the highest possible quality – failure of the joint is not only difficult and costly to repair, but the environmental consequences can be enormous. Real-time in-situ monitoring of the weld is a must.

But help is not so far out of reach. As far back as 1980, Hamburg optics and photonics specialist Schäfter+Kirchhoff was already looking into this problem. Today, with the increasing diversity of molten metal processes (e. g. using lasers) and the pressing issues surrounding the imminent need to decommission large numbers of nuclear power facilities, the requirement for specialist monitoring systems is greater than ever. Nonetheless, the difficulties in designing an adequate monitoring system for e. g. remote welding operations are far from trivial – the operator/monitor must remain remote from a process that is intrinsically, and that has long remained traditionally "hands-on only". Fig. 1 shows an exemplary laser welding monitor for orbital welding.

Addressing the problem

Remote inspection turns out to be more complicated than expected, although modern optics and photonics technologies do manage to provide sufficient solutions to each problem.

By far the first and possibly most obvious issue is the high intensity short wave and UV/VIS optical emission generated at/by the weld bead and the rapid fall-off of this intensity away from the bead. Even though modern CMOS camera systems have significantly enhanced performance, for example through on-board control over the absolute and relative dynamic range, this is by far still insufficient to provide adequate (video) visual contrast across the physical space (weld bead, electrode, melt pool and cooled seam) illuminated by the welding process itself. As discovered by Schäfter+Kirchhoff, what is needed is sufficiently strong complementary illumination so as to perform a contrast (dynamic range) reduction for the volume in question.

As it turns out, the spectrum of emission generated by weld bead does not show pronounced maxima around 800 to 850 nm, and this more or less independent of the type of arc welding process employed. By using selective filtering, this spectral region serves well as a window for in-situ welding inspection. Adequate contrast reduction is then provided by a combination of powerful illumination from readily-available NIR laser diodes, spectral filtering to remove other wavelengths emitted by the weld bead (predominantly UV, VIS and IR), and neutral density filtering to reduce the remaining overall intensity to levels suitable for modern digital cameras (Fig. 2).

Coupling the laser diode light into optical fibers helps to address the requisite remoteness of the task as well as the need to ensure mobility of a robotic welding head. Separation of the

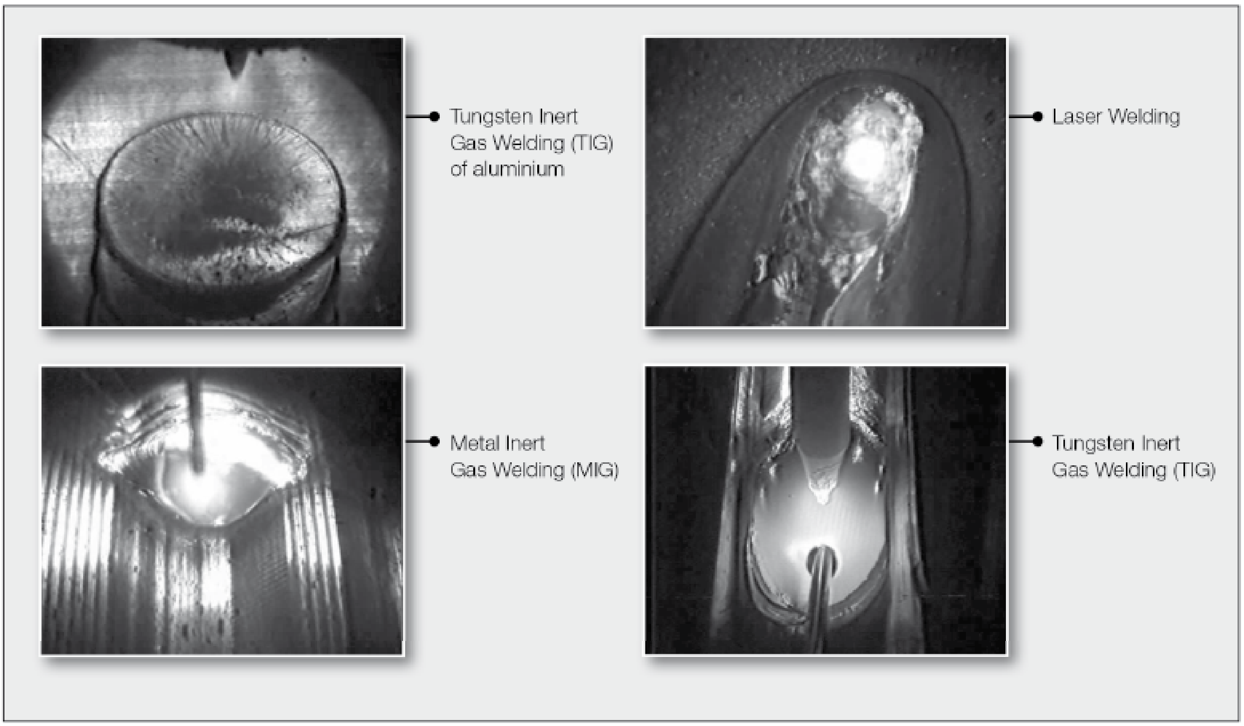


Fig. 2 Still images of different welding processes. For videos see www.sukhamburg.com/products/arc-welding-monitor.html

light source from the point of illumination is also critical in ensuring a very compact (and thus easily integrated) head design. Remaining design challenges center around suitable optics for coupling light into, and for beam shaping the light out of the fibers, and in providing adequate capture into the camera system.

All of these technologies lie well within the scope of Schäfter+Kirchhoff's long established expertise in optics and photonics technologies.

Design of the weld inspector

The "arc and laser welding monitor" is based on an approach patented in 1985. It takes advantage of the ready availability of powerful laser diode lasers in the near IR (830 nm) as the light source and uses protected fiber cable more than 30 m long for flexible light guiding. Around 10 W of optical power from multiple laser diodes is coupled into 200 µm optical fibers, and these bundled together to provide several watts of supplementary illumination around the welding bead.

A modern and compact CMOS camera system is mounted close to the process in order to optimize the field-of-view and thus maximize definition and resolution in the captured images. Camera and optic miniaturization are critical to the performance of the overall system as this enables maximum flexibility and capability. The camera operates at 500 fps and (if necessary) can be incorporated into a water-cooled tube. The camera includes the aforementioned spectral interference (notch) and neutral density filters, and has a fixed f-stop and focal length that need no further adjustment following initial setup. The objective lens has a small diameter aperture that assures a large depth of focus, suitable for close range work. Lastly, a replaceable optical window protects the camera optics against weld splatter and thus helps to maintain image quality. The entire system and layout around the weld bead is illustrated in Fig. 3.

Applications

Videos available online and still images (Fig. 2) captured for a variety of welding processes – such as arc (TIG, MIG/MAG) and laser welding – clearly demonstrate the benefits afforded by the monitor system. Even on video, comparison with traditional viewing of the process through welder's glass, the gain in visual acuity is vast. For laser welding, for example, the form of the keyhole generated by the laser is clearly visualized.

The monitor system allows the welding process to be studied remotely and without hazard to the operator, thus lending itself to applications in which human inspection may be prohibitive due to environmental dangers, hard to reach locations and time and financial costs. Higher quality welds won through better process monitoring in these instances also translate into reduced long-term maintenance and repair costs – in certain environments the

Company

Schäfter+Kirchhoff
Hamburg, Germany

Schäfter+Kirchhoff has accumulated a lot of experience in the development of optomechanical and optoelectronic systems for use in research, aviation and in space, as well as for demanding medical and industrial applications. Schäfter+Kirchhoff designs and manufactures their own CCD line scan camera systems, laser sources, beam-shaping optics and fiber-optic components, including laser beam couplers, fiber collimators and fiber port clusters for customers worldwide.

www.sukhamburg.com

multiple benefits here are both obvious and significant.

The monitor system has been successfully integrated into orbital welding (Fig. 1) and pressure tube welding systems used for joining large format metal tubing. Tubing with wall thicknesses of 80 mm and upwards is intended to remain maintenance-free for many decades, and weld failure in this type of application is highly undesirable.

Due to the depth and the high aspect ratio of the required weld in this instance, these types of welds are made iteratively, i. e. the welding head 'orbits' the join multiple times, internally or externally, building up the seam across the entire thickness of the tubing wall. The high aspect ratio of the weld gap and the location of the robot head on the inside or outside of large format tubing pose no problems for the compact monitor system.

Outlook

Further potential application areas include underwater in-situ inspection of laser welding operations for oil and other pipelines, and in-situ inspection of laser cutting and laser material deposition (LMD) processes using metals. Laser additive manufacturing (LAM) applications using metals (e. g. Selective Laser Melting, SLM) is an up-and-coming materials processing technology that is positively begging for proper process monitoring in order to better understand and develop the process, and to enhance component reproducibility in a (mass) production environment. However, the delicate melt tracks (30 µm spot size), the high speed of the laser spot (signifying a much more rapid process) and the wide field of view (i. e. large working distances) are all issues that need to be investigated.

There are also obvious benefits both as an educational tool – for example, when comparing and demonstrating different welding process – and for documentational and R&D work. In particular for qualifying, for example, (laser) welding/cutting tools for nuclear power plant (de-)commissioning, this monitor system could prove invaluable.

DOI: 10.1002/latj.201500023

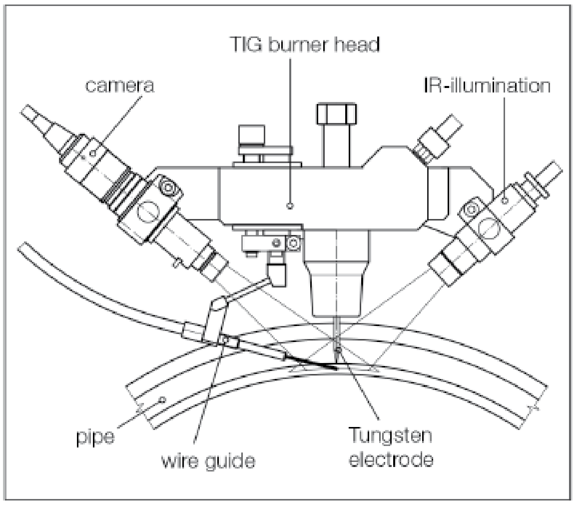
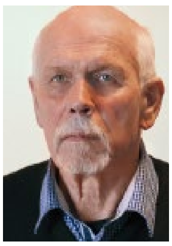


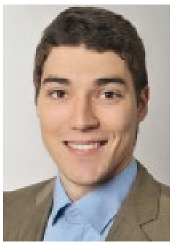
Fig. 3 Optical scheme of a welding monitor.

Authors

Gregory Flinn is an independent photonics professional with over 30 years of experience in teaching, R&D, industry and publishing of laser, optics and optoelectronics technologies. Working as a freelancer since 2004, he provides business development and marketing consultation as well as publishing and copywriting skills for photonics SMEs.



Gregor Federau became owner and managing director of Schäfter+Kirchhoff in 1976 and put the company focus on opto-mechanics. Since then, the company has grown from just a few employees to over 35 in 2015. He has been working on the visualization of welding processes for over 30 years.



Bastian Lampert studied mechatronics at the Technical University Hamburg-Harburg with a focus on digital image processing. He joined Schäfter+Kirchhoff in the beginning of 2015 and works as a project engineer.

Ulrich Oechsner studied physics before completing his doctoral thesis at the University of Hamburg. After research in the fields of electrophysiology and physiological optics, he joined Schäfter+Kirchhoff in 2000. In 2015 he became the second managing director.

Dr. Ulrich Oechsner, Schäfter+Kirchhoff GmbH, Optics, Metrology, and Photonics, Tel.: +49 40 853 997 0, Fax: (+49) 40 853 997 79, E-mail: info@sukhamburg.de;
Dr. Gregory Flinn, Putting Photonics into Context, Tel.: +49 179 1001395, E-mail: mail@gregoryflinn.net, Web: www.gregoryflinn.net