New optical design for remote laser welding with finest focus

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Larger scanner mirrors can be moved faster with the help of linear induction motors than with ordinary galvo systems. Combined with the appropriate optical elements, longer working distances with smaller focus diameters can be achieved in laser welding.

In remote welding, the welding process is performed at a distance with a laser (**figure 1**). This method is especially suitable in process applications where high track and positioning speeds are required, e.g. many short welding seams (quilting seams) or spot welding. Due to the high power density at the focal point, the material to be worked heats up until it reaches its melting point, thus fusing and welding. The focus is then moved along to the next welding point with a deflection system. The work piece does not have to be moved and is not subject to external forces during the welding process. The working distances and focus diameters that can be achieved are determined by the beam quality of the laser, by the energy necessary for the respective process and not least by the optical elements involved.

Usually, laser radiation is transferred to the laser head through optical fibres. First the exiting light is collimated by suitable optical elements and then focused again as an image of the end of the fibre. The quality of this image and the image scale determine the focus diameter on the work piece.

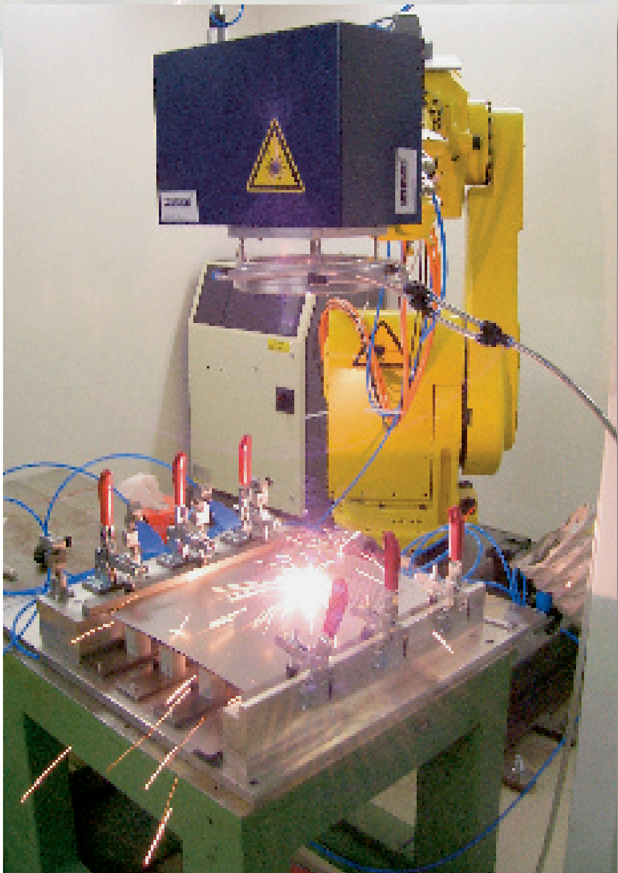


Figure 1: *Remote-Welding-Systems allow a highly dynamic, precise positioning of the laser beam for material processing*

In a standard fibre imaging system, for example, a fibre coupled Nd:YAG-Laser is collimated by a multi-lens optical element (**figure 2**). With a typical numerical aperture of 0.11, a fibre diameter of 200 µm, and collimating optics with a focal length of 80 mm, the result is a collimated beam with a diameter of approx. 17.5 mm. Welding lasers often have an average power of 5 kW or more. With a power this high even minimal absorption results in a rise in temperature within the lens system and thus in a change of the position and size of the focus area. Thus quartz lenses are used in all optical elements of such systems. Compared with standard glass like BK7 they absorb only a minimum of the laser light and their crystal structure is very stable so that an irregular change in the refraction index due to inhomogeneous

Originally published in German in Photonik 3/2007

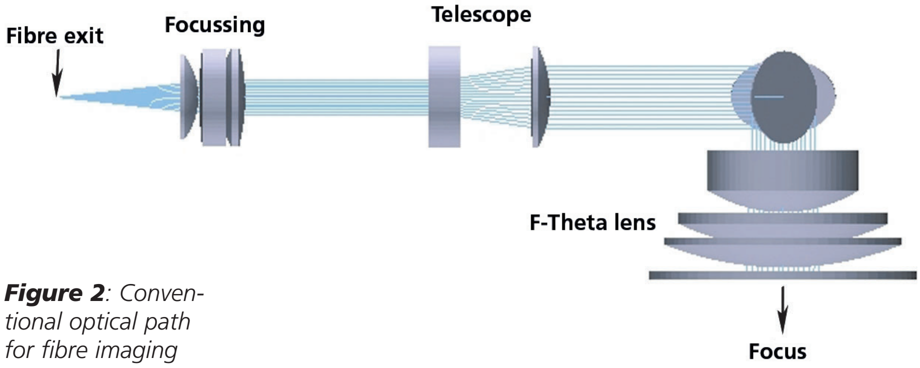


***Figure 2**: Conventional optical path for fibre imaging*

temperature distribution can be avoided as much as possible. Such a slight thermal lens and thus a continuous focus size are a prerequisite for steady and reproducible welding or cutting results.
The beam is focused using a scan lens with a focal length of 500 mm. In addition, the collimated beam is expanded between the collimating optics and the scanner with a telescope. The focus plane of the scan lens is shifted via a divergence alteration of the telescope, so that differing component heights can be compensated for.
The telescope magnifies the effective focal length of the collimating optics by the expansion factor utilised. Thus the reproduction scale, which is defined by the ratio of the focal length of the focusing optics and the collimating optics (including the telescope), is reduced as well – and the power density on the work piece is increased.
As the light is not passed through the focusing optics uniformly but is scanned, the thermal stress in the lenses is inhomogeneous and very high, even though the beam diameter is expanded to approx. 30 mm after the telescope. This results in non-static shift in focus due to thermal lensing. However, in principle the resulting thermal lens can partially be compensated for by aid of the telescope since part of the shift in focus then occurs within the depth of focus. Therefore the processing result within the processing volume is more homogenous.
The additional expansion of the beam diameter, however, necessitates a large aperture for the scan system. The scan lens used must also take this into account, i.e. the lens diameters of the optics must be very large (in this example almost 130 mm) to achieve sufficient processing volume.
In the system presented here a magnification of roughly 3.5 results, i.e. for a fibre with a core diameter of 200 µm, the result is a spot size of approx. 700 µm. To limit costs (already higher because of the necessity for quartz lenses), slight spherical aberrations are permitted in the optical design of the scan lens. This, however, leads to a slight blurring and thus to an enlarged fibre image. Instead of a 700 µm spot, a spot diameter of approx. 800 µm is the result (edge length in **figure 3**).
For a conventional galvo scanner, with an aperture big enough for the 30mm beam, a working plane of approx. 210 x 210 mm^2 can be achieved. The working distance is approx. 580 mm. By means of the telescope the focal position can by varied by ±100 mm, without causing the aberrations to increase too much. Here the resultant magnification and thus the spot size fluctuate by ±10%.
To achieve a longer working distance (or area) with the same focal size, the beam would have to be expanded further as focal optics with a larger focal length would be necessary. This is in turn limited by the mirror diameter of the deflection system and its actuating force and inertia. With mirror diameters of 200 mm and over, the Thor-System of KeySysTech GmbH can power considerably larger mirrors than conventional galvo scanners with a high actuating force, and can position them exactly. Linear induction motors and a special mounting of the mirror ensure that the angle of the mirror can be set quickly and precisely within approx. 0.001°. When turning the mirror, the focus moves over a sphere (astigmatism). However, as welding occurs over a flat working field, the focus is updated at the same speed by adjusting the sliding lens.
The scanner works with the so-called one-scanner-mirror technique, where the laser beam is deflected by a mirror that can be rotated on two axes. This mirror is placed before the whole focussing system (**figure 4**).
The optical components designed and produced by Sill Optics in cooperation with the Laser Zentrum Hannover for Thor, are in this case not subdivided rigorously into collimation, expansion and focus, but have

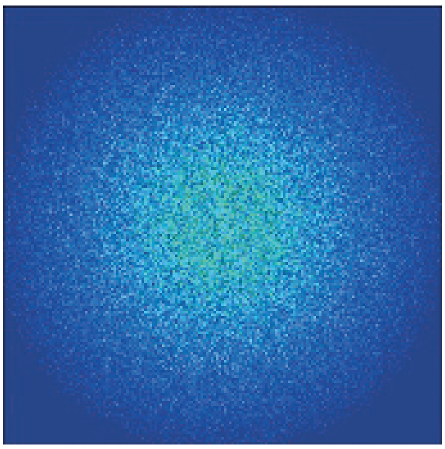


***Figure 3**: Focus image of the conventional system with an effective magnification of 3.5. The fibre with a diameter of 200 µm is imaged with a diameter of 800 µm, due to spherical aberrations*

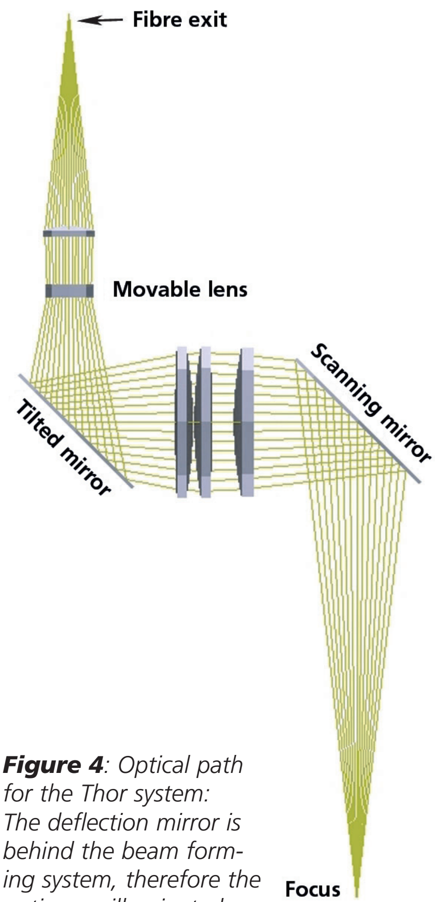


***Figure 4**: Optical path for the Thor system: The deflection mirror is behind the beam forming system, therefore the optics are illuminated statically and thermal lensing is continuous and measurable.*

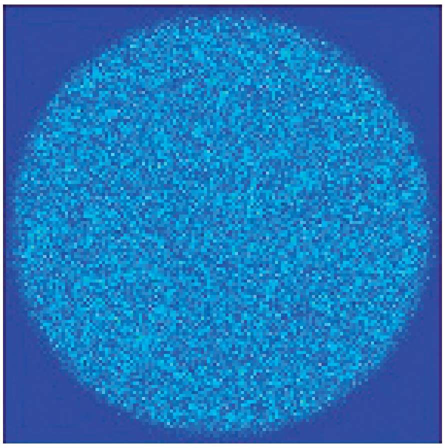


***Figure 5**: Focus image of the Thor system with a magnification of 1. The 200 µm diameter fibre core is reproduced at the same scale*

been optimised as a complete system. The two quartz lenses collimate and expand the relatively small beam diameter of the fibre coupled, high power laser to approx. 35 mm. To keep the system compact, a tilted mirror has been integrated. The subsequent lenses, with a diameter of approx. 115 mm, focus the highly divergent beam. Due to the large bundle diameter it was possible to use another type of glass with maximum transmission here instead of the comparatively expensive quartz glass.
Here too, the problem of thermal lensing can be limited with the help of a variable focus system. Since the laser beam is first deflected by the mirror und not scanned through the optics it does not alternatively meet the cold or pre-warmed volumes of the lenses. Instead the lenses are always subject to the same optical power. The associated thermal lensing is thus more easily predictable or more easily determined in advance. The compensation for focal position is easier and more accurate in these systems.
The effective magnification of this optical system is 1, i.e. a fibre of 200 µm generates a spot of 200 µm. The working field that can be realised is 200 x 300 mm^2, a figure comparable with ordinary systems of the same working distance. However, the focal diameter is now considerably smaller. The edge length in **figure 5** is 200 µm.
Alternatively, the new design allows for a certain flexibility. By omitting the last lens of the focus element, the effective magnification can be changed from 1 to 3, at the same time retaining excellent reproduction quality. The edge length in the figure is 600 µm (**figure 6**), noting that the working field and the working distance are also scaled by factor 3.
Long working distances not only protect the welding system and the optics from welding spatter, they also enable the working of larger components. With the Thor system, many short welding seams with small focus diameters and thus high power densities can be realised across large working fields. Therefore, process management is much more flexible, and "cold" traverse paths are considerably reduced. This technology is suitable for use with robotic arms, with which large components can be machined without additional set-up time.
The good reproduction performance opens up new fields of application. For micro applications, for example, round welding of airbag initiators as well as the manufacture of (generally hard to weld) titanium housings for cardiac pacemakers are being contemplated at the LZH. Both applications place great demands on neat welding seams and on being gas tight. Another application in medical technology are markers for stents – conventional stent material (nickel/titanium) is hard to detect with X-rays, so small discs of better visible materials are welded into the ends of the stent to better highlight their exact position inside blood vessels.

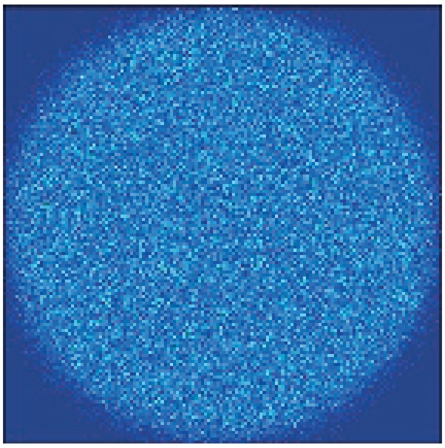
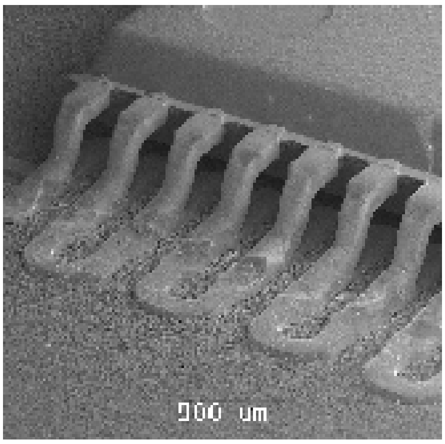


***Figure 6**: Focus image of the Thor system with its modified optics (magnification x3) The fibre with a diameter of 200 µm is reproduced with a diameter of 600 µm*



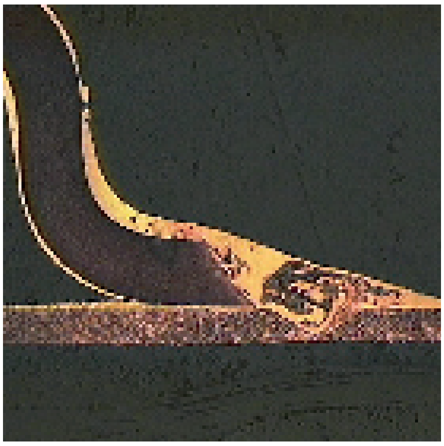


***Figure 7**: A possible application of the scanner is the welding of micro electronic components. The welds shown were, however, not realised with the new scanner*

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Originally published in German in Photonik 3/2007