LiM 2011

Process Monitoring using the Principle of Reflection Diagnosis

Dominik Hertle, Manuel Sieben*

LPKF LaserWelding, Gundstr.15, 91056 Erlangen, Germany

Abstract

Although transmission laser welding is highly reliable and characterized by high levels of process parameter repeatability, unforeseen influences can give rise to unsatisfactory welding results in practice. Therefore an early on detecting of defective welding has to be warranted to avoid defects in the weld seam. Unlike most of the other conventional monitoring methods used with transmission laser welding, the reflection diagnosis technique involves the direct analysis of the welding seam. In addition to measuring the height of welded components, it can also be used to detect a wide range of faults, and therefore ensure the quality of the seam.

Laser welding; plastics; process monitoring; reflection diagnosis; process diagnosis.

1. Process monitoring

Numerous welding methods – such as ultrasound welding, vibration welding or hot plate welding – have been around for a long time to join together plastic components. These established welding methods were successfully joined several years ago by the transmission laser welding method. This sophisticated technology harnesses the power of lasers: the laser beam penetrates the overlying cover with only minor absorption before hitting the joint zone where the laser energy is absorbed by the underlying part to be joined. The thermal conduction optimized by the clamping pressure heats up the laser-transparent part causing local plasticization and therefore an adhesive bond between the two parts (see Figure 1). According to his high power density, his long life time and his small power fluctuation the laser as energy source is used as tool for high quality connection of components from automotive and medical engineering as well as from the consumer products industry.
This modern technique not only boasts very strong welding seams, it also causes minimal thermal and mechanical stress to the parts being welded together. In addition, it has huge potential in the light of the ever advancing miniaturization of the parts being welded together. This technique is also favored by research organizations and industry because of its outstanding ability to weld even highly complex 3D welding seams when the flexible beam guidance system is combined with a robot. Transmission laser welding boasts enormous potential for this application because alternative methods fail to satisfy many of the specifications and have therefore long reached the limits of their ability.

Although transmission laser welding is highly reliable and characterized by high levels of process parameter repeatability, unforeseen influences (such as tolerances in the component properties) can give rise to unsatisfactory welding results in practice. Therefore an early on detecting of defective welding has to be warranted to avoid defects in the weld seam by an appropriate control of the welding process. Also products with defective weld seams, which appear in spite of the welding control, have to be detected and separated to avoid fatal field failures. A process monitoring system is therefore essential to guarantee the quality of the welding seam when using transmission laser welding in industrial applications. A suitable process monitoring system enables the detection of typical welding errors such as cavities, pores, faulty connections between the two parts being welded, or setting paths of inadequate length. The process control methods used to date in transmission laser welding are as follows:

- Burn detection
- Melt travel monitoring
- Temperature monitoring
- Camera-assisted vision systems

2. Burn detection

Burn detection is a method used to reliably detect surface scorching of plastics welded with a laser. The second generation of burn detection is focused on the identification of failures on the beam-entry side of the laser transparent part. Such burned areas usually only have the size of several tenth of a millimeter and therefore have no verifiable influence to the strength of the weld seam. According to functional and aesthetic reasons such residues of burning are not tolerable at some applications. The radiation emitted by such scorches ranges from the visible
through to the infrared spectrum. If radiation is detected in these wavelengths, the burn emission pattern is easily distinguished from the background noise.

3. Melt travel monitoring

Melt travel monitoring is the most rugged testing method, suitable for quasi-simultaneous welding processes. This method allows detection of both direct and indirect errors. The principle applied is that only so much material is melted to satisfy the production tolerances of each individual component. This process allows the reliable creation of tight welded seams which satisfy protection classes IP67 and IP69K. Depending on the specific process implemented, the welding procedure is halted when defined limits are reached: such as time, melt path or a fixed stop.
4. Pyrometrics

The inspection of laser welding processes by pyrometrics provides explicit increased detection rates. A system developed by LPKF offers a fast response time at changes of temperature and enables thereby an automatic rating of the weld seam quality. A pyrometer records the electromagnetic radiation in the infrared range (temperature radiation) to monitor the quality of the welding seam. The weld is considered satisfactory if the temperature curve remains within predefined upper and lower limits (the curve envelope). Surface errors such as burn marks or cratering in the area of the welded seam result in anomalies and corrections. The pyrometer signal can also be used to detect material fluctuations or different fiberglass concentrations along the welding seam. It is also possible to detect faults on the inside of the welding seam. But the analyses also showed that pyrometrics can be used only with a restricted selection of polymers and the detected signal shows a high variability.

![Figure 4: by pyrometer detected process radiation and set process limits](image)

5. Camera-assisted vision systems

Online CCD monitoring is already in common use for strongly contrasting pairs of materials, such as opaque/black. Monitoring systems of this kind are particularly easy to integrate with contour welding methods. The smallest faults in a welded seam can be reliably identified when using the appropriate evaluation routine (Figure 5). Moreover, the monitoring system can also analyze the width of the welded seam and record it as an extra quality criterion.
6. Reflection diagnosis

With the exception of camera-assisted vision systems which directly monitor the quality of the welding seam, all of the other methods described above monitor the welding procedure by indirectly analyzing the quality of the welding process. In the case of burn detection for instance, welding errors are deduced from the nature of the emitted light, or by the emitted temperature in the case of the pyrometric method. In the case of melt travel monitoring, conclusions are drawn on the quality of the welding process from the nature of the setting path. Unlike these techniques, reflection diagnosis directly monitors the quality of the welding seam. The principle of reflection diagnosis is that the component is illuminated with a defined test radiation (e.g. laser light), whereby part of the light is reflected at the boundaries. One boundary is missing where welding has taken place because the plastic parts have melted together. The reflected signal is therefore so low that it is no longer detected. In contrast, a very clear second peak is present wherever there are gaps in the welding seam (Figure 6).
These phenomena can be described using the Fresnel formula

\[ R = \left( \frac{n_1 - n_2}{n_1 + n_2} \right)^2 \]  

(1)

This states that the reflectance \( R \) (ratio between reflected and incident light intensity) is dependent on the refractive indices \( n_1 \) and \( n_2 \) of the media at the boundary layers. Accordingly, the smaller the difference in the refractive indices at a boundary horizon, the lower the reflectance at that point. If the difference between the refractive indices is zero, there is no reflection. The measurement beam of the triangulating sensor is therefore reflected as long as there is a definite boundary surface between two media with different refractive indices. There is no clear boundary layer in zones where two plastic components have been welded together because the plastic parts merge into one another. There will therefore be no reflection of the sensor beam in this zone. Thus the sensor detects only one peak as long as it is directed on a welded area, otherwise the sensor detects two or more peaks (Figure 7).

Figure 7: Reflection behavior of the measurement beam when testing a welded component (left) and next to the welding seam (right)
There are also clear boundary layers wherever inclusions or foreign bodies are present in the transparent material or in the welding seam, or when optically detectable scorch marks are produced by the welding process. This process monitoring principle can therefore also be used in practice to detect faults of this kind in the welding seam. Moreover, the distance between the reflecting horizon and the sensor can also be calculated from the position where the reflected beam hits the detector. This not only enables the different types of faults to be differentiated from one another, the known separation between the sensor and the tool holder also allows the height of the welded component to be detected, and the setting path to be calculated.

As shown in Figure 9, the faults or foreign bodies in the welding seam can be detected down to sizes of just a few μm. If appropriate sensors are used, it is possible to detect the inclusion of a wire with a diameter of 110 μm in the welding seam, or even a human hair with a diameter of 65 μm.
7. Available sensor heads

Two different types of sensors have been used to date for reflection monitoring:

- Laser triangulation sensor
- Confocal sensor system.

In the chromatic confocal measurement technique, polychromatic light (white light) is coupled into a fiber optic cable, and focused on the surface of the object being tested by a lens configuration in the sensor head containing specially aligned lenses: the controlled chromatic deviation of the light splits it into separation-dependent monochromatic spectra. The alternative laser triangulation sensor head works by laser triangulation. This method basically means measuring angles to calculate distances. Measuring technology usually uses lasers for this purpose by projecting a point of laser light onto the object being measured. The light reflected by this object is detected by a receiver at a measured angle corresponding to the distance. In an analogous way to the confocal sensor, a signal peak is recorded for each reflected beam. The reflection diagnosis principle described above therefore means that the two measurement systems can be used for process monitoring.

8. Conclusions

Unlike most of the other conventional monitoring methods used with transmission laser welding, the reflection diagnosis technique involves the direct analysis of the welding seam. In addition to measuring the height of a welded component, it can also be used to detect a wide range of faults, and therefore ensure the quality of the seam. It is suitable for instance for materials used in car lights. The three dimensional welding method used in this application (LPKF TwinWeld3D) uses this diagnosis system to control the processing parameters. Reflection diagnosis will also be available in future for the other laser welding systems in the LPKF portfolio: it can also be combined in principle with quasi-simultaneous welding and contour welding.

References

[1] Frick, T.; Polster, S.; Wiengarten, M.: Laserstrahl-Kunststoffschweißen als Verbindungstechnik in der Elektronikproduktion. Geiger, M.; Polster, S. (Hrsg): Laser in der Elektronikproduktion und Feinwerktechnik – LEF 2005. Bamberg: Meisenbach, 2005, S. 96 - 105
[2] Geiger, R.; Brandmeyer, O.; Frick, T.: Hybridschweißen von Kunststoffen – Durch den kombinierten Einsatz von Laserstrahlung und Heizstrahlung beim Schweißprozess eröffnen sich völlig neue Anwendungsfelder. In: Joining Plastics - Fügen von Kunststoffen 1 (2007), Nr. 2, S. 144 – 152
[3] Hofmann, A.; Hierl, S.: Methoden der Prozessüberwachung beim Laserdurchstrahlschweißen von Kunststoffen. Geiger, M.; Polster, S. (Hrsg): Laser in der Elektronikproduktion und Feinwerktechnik – LEF 2005. Bamberg: Meisenbach, 2005, S. 96 - 105
[4] Hertle, D.: Untersuchung und Realisierung eines Prozessüberwachungssystems für das hybride Laserdurchstrahlschweißen von Kunststoffen. Diplomarbeit, Universität Erlangen-Nürnberg. Erlangen 2009
[5] Müller-Borhanian, J.: Kamerabasierte In-Prozessüberwachung beim Laserstrahlschweißen. Dissertation, Universität Stuttgart. Stuttgart: 2008
[6] LPKF Laser & Electronics AG: Entwicklungsprojekt Hybridschweißen. Erlangen – Firmenschrift
[7] LPKF Laser & Electronics AG: Prozessüberwachung. Erlangen – Firmenschrift