APPLICATIONS OF LASER SEAM TRACKING IN WELDING THICK WALL VESSELS

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Abstract
Laser seam tracking is a well-proven and established method of weld guidance for automated welding systems. It was first developed in the early 1980’s for robotic welding applications [1]. As the technology matured, it was applied to other types of welding automation [2, 3]. This paper presents an overview of applications in welding thick wall vessels. Such applications commonly occur in the fabrication of pressure vessels, offshore structures, pipelines, etc.

Keywords
Laser Seam Tracking, Welding Automation, Adaptive Multipass Welding

Overview
There are currently two main approaches to the use of laser seam tracking in multipass SAW. One uses a relatively simple and low cost system which relies on manual operator input to select the target position for individual weld passes. The other uses a more sophisticated (and more expensive) system which is capable of determining the location of individual weld passes by itself as well as controlling the deposition process.

The first approach uses a relatively simple laser vision system together with a human interface designed to make it easy to position the torch for each weld pass. Typically, the machine operator indicates the correct target position for each pass and the system itself then controls the position of the welding head throughout welding that pass.

The second approach uses more advanced sensors, hardware and software to automate the entire process of making a multi pass weld. This is available for a more limited range of joint types than the simpler system. Typically it is used on narrow gap and semi narrow gap systems and is most suitable where a large number of joints of the same type have to be welded in a production line type of operation.

Introduction to Laser Seam Tracking
The main advantage of laser seam tracking results from the fact that it is a non contact method of controlling the position of a weld head which is based on detecting the geometry of the weld joint. It is not significantly affected by the surface appearance of parts to be welded or by the welding process itself.
The main parts of the system are:
1. a laser sensor
2. a sensor control system
3. some method of positioning the welding head by the control system.

**Laser Sensor Types**
The sensor head normally projects a laser stripe onto the weld joint and detects an image of the stripe on a camera within the sensor head itself. A laser is used because it is convenient to shape into a stripe and because it makes it easy to filter out arc light and other ambient light influences. The design of the sensor head uses the principle of triangulation so that the shape of the stripe in the camera image encodes the three dimensional structure of the weld joint. The resulting video image is sent to the sensor control system. Figure 1 illustrates the principle of triangulation for a single point distance measurement. The laser beam is projecting straight down and is shown in the figure striking surfaces at three different distances. The resulting three image positions are also shown and it is clear that the image position is a function of the distance from the sensor to the surface.

![Figure 1 - principle of triangulation](image)

There are two types of laser sensor in use.

The more common type projects a laser stripe across the weld joint. The stripe is then deformed by the shape of the weld joint. The deformed stripe is imaged by a two-dimensional camera, which can be either ccd or cmos. One advantage of this type of laser sensor is that it contains no moving parts and can be extremely robust. One significant disadvantage for welding deep joints is that the horizontal and vertical fields of view have a fixed relationship partly determined by the
sensor geometry. This makes it difficult, for example, to have a field of view which is relatively narrow but is at the same time deep enough for narrow gap joints. Figure 2 shows a typical laser sensor of the laser stripe type. Of course, the welding environment is a difficult one for optical instruments and laser sensors for welding have to be rugged and robust. Figure 3 shows the same type of sensor as shown in figure 2 after some months of operation.

Figure 2 - laser stripe sensor

The less common type of laser sensor uses a laser spot instead of a stripe. The sensor head contains some way of scanning the spot across the weld joint and some way of descanning the image of the spot onto a linear ccd camera. This type of laser sensor is more complex and contains moving parts. Hence it is inherently more expensive and less robust than the laser stripe type. However, it does have some advantages which may be particularly relevant for welding deep joints. These are:

1. Horizontal resolution is independent of vertical resolution so it is possible to have a small width of field combined with a large depth of field.
2. The linear image sensor only “looks” where the laser is scanning at any given instant. This can improve the performance with joints which are very reflective, such as freshly machined U joints.
3. The laser power can be adjusted for optimal signal quality during each scan, unlike the laser stripe type of sensor in which the same laser power must be applied to the whole stripe.
A typical scanning laser sensor is shown in figure 4.

Figure 4 - scanning spot sensor on narrow gap joint

**Sensor Control System**

The control system extracts the laser stripe from the image and is able to analyse its shape to determine the structure of the joint and its position relative to the sensor head. Knowing the relationship between the sensor head and the welding torch(es), the control unit can then position the welding head accordingly to make sure the electrodes are in the correct place in the joint throughout the welding operation.

As is the case with the sensor head, there are two competing types of control system. The first type is based on a proprietary single board RISC computer including image processing and i/o functions on the same board. This provides a powerful single board solution at low cost. The downside of this approach is the non standard nature of the control system. The second type of controller is based on a standard such as the conventional PCI bus Pentium-based personal computer running a Windows-based operating system. This has the advantage of using mainly off-the-shelf hardware and software components and provides for a highly informative graphical user interface, network connections, etc, but it is much more expensive. It is also well known that the usual Windows-based PC operating systems are not considered to be real time, hence some special measures have to be taken to be sure that the overall system performance is adequate in real time operation.

For thick wall welding applications, the position of the welding head is usually controlled by a pair of linear slides. The slides are themselves controlled either directly or indirectly by the vision system controller.
Welding Thick Wall Vessels

The first applications of laser seam tracking were in single pass MIG welding. Later, as the technology matured, various approaches to multitorch and multipass welding, especially using the SAW process, were developed.

A Simple Approach to MultiPass SAW

Many thick wall SAW joints are welded with column and boom type machines fitted with single or dual torch welding head configurations. Positioning of the electrodes for each pass is typically done by the machine operator. A basic laser seam tracking system can greatly assist in achieving better quality and productivity even while maintaining a relatively simple approach.

A typical column and boom setup is shown welding a 140mm thick test plate in figure 5. The system uses a laser stripe sensor as shown in figure 6.

In operation, the operator positions the welding head correctly at the start of each weld pass and stores this reference position using a simple one-touch operation on the system pendant. He can then start welding immediately with the vision system maintaining the correct position throughout the weld. The size of the joint welded in this particular case and the resulting weld macro are shown in figures 7 and 8. The fact that this machine is the preferred way for the company concerned to prove their welding procedures indicates that the resulting quality is very good. Productivity is also much higher because the operator can start welding each pass very quickly without worrying about alignment during the weld. An additional benefit is that the operator can concentrate on overall weld quality instead of having to focus mainly on torch position.
A Fully Automatic Multi Pass Welding System

There are applications where a significant number of thick wall welds of a similar nature have to be made. This can justify investing in highly automated systems. For example, production of piles for offshore wind turbines is one case where many similar cans have to be welded as efficiently as possible. In this production line type of environment, the large capital investment required for highly automated welding machinery can be justified based on highly efficient welding of many pieces.

Figure 9 shows an automated welding machine for OD circumferential welding of large cans. This is an automated application where a single operator controls the complete machine including three heads welding in parallel. This is only possible by the use of advanced laser seam tracking systems which are capable of making complete multi pass welds automatically.

The system classifies each complete weld into four phases:
1. root pass
2. hot passes
3. fill passes
4. cap passes

During the root pass, the laser sensor tracks the bottom centre of the joint, ensuring good penetration. If necessary, the welding head position during the root pass can be used to mark a reference line on the surface of the part for use during capping when the laser sensor may not be able to detect the joint reliably. The resulting line can also be used as a reference for post-weld processes, such as ultrasonic inspection.
Following the root pass, the system can automatically go on to complete two hot passes which start the filling process with reduced welding parameters to avoid the possibility of burning through the root.

The system then moves automatically into the filling phase. It is during this phase that the system capabilities are fully utilised. Fill welding is considered to take place in a number of layers. Each layer consists of a number of passes. For example, in a semi narrow gap joint, each layer will typically consist of two or three passes. During the first pass of each layer, the laser sensor measures the width of the joint at the current welding position. Based on this width, the sensor system decides whether to make two or three weld passes for this layer. On the last pass of each layer, the laser sensor measures the remaining depth of the joint. When the remaining depth gets below a threshold, the system knows that it is time to stop filling and complete the weld by performing the appropriate number of cap passes.

Cap pass welding is challenging for a laser sensor because the joint may be full and there can be little in the way of geometric features for the laser sensor to recognise. An advanced system can be equipped with a line following camera which acts to provide supplementary input to the overall tracking process. Figure 10 shows the OD Circumferential machine with cap welding in process. The laser sensor is providing height control while the line tracking camera on the other side of the welding head is controlling the horizontal position.
Conclusion
Laser Seam Tracking is now well established in multipass welding of thick wall vessels. It offers significant benefits in terms of both quality and productivity. There are two main approaches, and the selection of the best approach for a particular company and application depends on many factors, including the volume and range of production, operator and maintenance skill levels, experience with the technology, management support for moving forward with new methods as well as the basic ROI calculation.

References
