MULTI SENSOR DATA FUSION FOR IMPROVING PERFORMANCE AND RELIABILITY OF FULLY AUTOMATED MULTIPASS WELDING

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ABSTRACT

Recent developments in sensor hardware and in advanced software have made it feasible to consider automating some of the most difficult welding operations. This paper describes some techniques used to automate successfully multipass submerged arc welding operations typically used in pressure vessel manufacture, shipbuilding, production of offshore structures and in pipe mills.

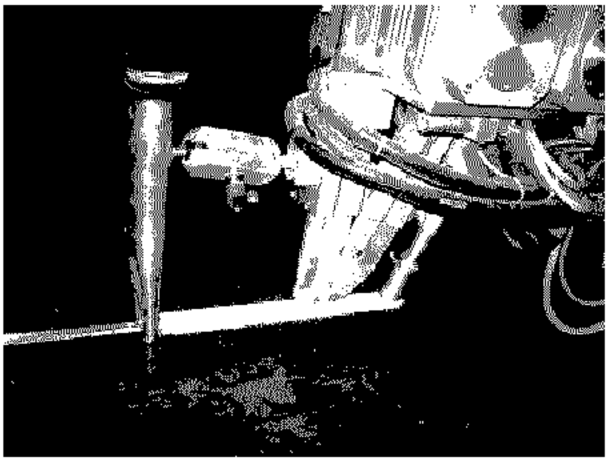

Figure 1 Inside Longitudinal Welding

For various reasons, including:

- the size of the weld joint
- the method of forming joint profiles
- the methods of forming parts from plates
- thermal distortion during welding

there can be significant variation in weld joint shapes and areas, not only from part to part, but also within the same part. For example, if two cylindrical cans are tack welded together but not lined up accurately before tacking, the joint shape and area will vary in a predictable fashion around the circumference of the part. These variations mean that the sensor system must be capable not only of seam tracking but also of sophisticated process control. While adaptive welding has been used with good results in industry for some time [1], it has not previously been applied successfully to such a complex application. Hence, one of the main requirements for these systems is to provide complex process control dealing effectively with a wide range of joint variations.

An important consideration in multipass welds is that a very large amount of value may have been added to the part before a particular welding operation is started. For example, in producing tubular components for offshore structures or pressure vessels, by the time the circumferential outside weld is begun, the plate has been cut, edges have been prepared, the plate has been rolled, and inside and outside longitudinal and inside circumferential welds have been completed and tested. This means that the welding operation must be extremely reliable, minimising the possible generation of any defects. This is a second main requirement for system design.

Many thick wall welding systems are used to manufacture one off or low volume parts. This leads to a third main requirement for these systems which is that they must be able to deal with a large range of joint profiles without significant amounts of setup or programming.

This paper describes a system design and implementation which addresses the main requirements listed above. After initial concept development, extensive discussions with fabrication companies helped to refine the system specification and design. Following the first implementations of the system, product trials led to further improvements. Getting extensive practical experience was a vital stage in achieving good levels of performance [2][3]. This process of refining the system has taken place over a period of some three years, and has led to a very flexible, high performance system which is nevertheless easy to use.

KEYWORDS

seam tracking, adaptive welding, welding process control, submerged arc welding, multi sensor data fusion.

1. Application

This system is designed for thick wall submerged arc welding (SAW) applications where the welding operation can involve many individual welding passes. Typical joint depths range from less than 25mm to 90mm or greater. Typical joint preparations include "traditional" vee grooves and semi narrow gap and narrow gap U-type joint profiles. Joint profiles may be produced by thermal processes or by machining. These two different approaches introduce significantly different issues for the system. Obviously, the system itself must be able to handle both methods of making joint profiles with equal ease.

The overall welding operation is normally divided into a series of phases, usually:

- root phase
- hot phase
- fill phase
- cap phase

During the root and hot pass welds, the prime concern is to achieve accurate seam tracking with tightly controlled welding parameters. This addresses the issue of consistent root penetration and reduces the likelihood of these early weld passes burning through the root face.

The fill welding phase covers most of the welding cycle time. The sensor system must address the following issues:

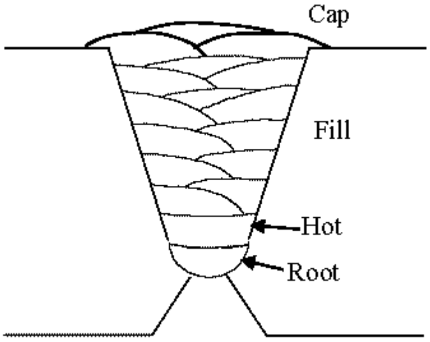

Figure 2 Welding Phases

- accurate placement of each individual weld pass, especially on joint side walls
- automatic calculation of the number of passes required per fill layer
- smooth automatic transitions between passes
- automatic compensation for variations in joint area across the joint, i.e. putting more weld material in one side of the joint than the other
- automatic compensation for variations in joint area along the length of the joint, i.e. putting more weld material in areas where the joint is larger than in areas where it is smaller
- automatic detection of the end of the fill welding phase.

During the root pass, hot passes and for most of the fill welding phase, the joint remains physically well defined. The top edges of the weld preparation can be used as a reference for at least the top of the joint, and the bottom edges of the joint sidewall can be detected reliably and provide useful information about the current state of the partly welded joint.

Near the end of fill welding, and during cap welding, the top edges of the weld joint may no longer be well defined. This means that the laser sensor alone cannot be used as the sole information source. Two other information sources then come into play. They are a Line Tracking System and a Part Memory.

The cap welding phase has similar requirements to the fill welding phase, but the placement of the individual weld runs relative to the original underlying edges of the joint is less critical than during fill welding.

2. System Architecture

To maximise system reliability and to prevent the occurrence of defects, it is preferable to use more than one source of data for weld joint tracking and torch positioning. In the systems described here, three main data sources have been used:

1. laser sensor
2. line tracking system
3. path memorisation

2.1 Laser Sensor

The laser sensor used was specially designed for the large joint types, including narrow gap and semi-narrow gap grooves, found in thick wall SAW. It uses the scanning spot principle in preference to the more common laser stripe principle. While scanning spot sensors are more complex and hence more expensive than the laser stripe type, the benefits significantly outweigh the additional cost. These include:

- immunity to surface type
- immunity to reflection problems
- independence of horizontal and vertical measuring fields
- programmable width of field, scan rate and number of samples

The joint profiles, especially for narrow gap and semi-narrow gap joints, are often machined just before being welded. This presents significant challenges to the sensor which must be able to get an adequate return signal from the steep and shiny sidewall of the joint. Use of a scanning spot concentrates the laser on a single very small spot on the joint and produces a good signal showing the complete joint profile to be obtained.

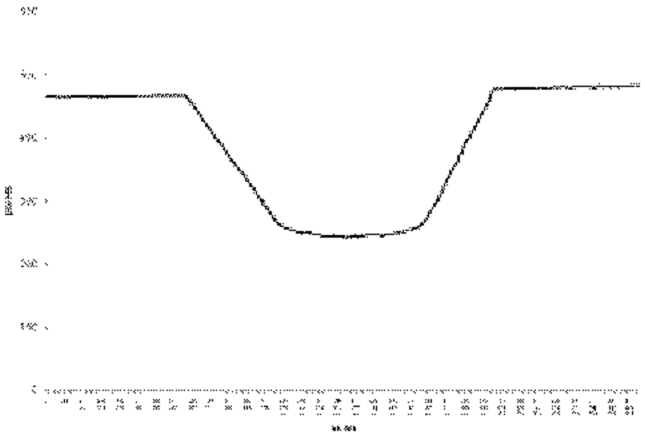

Figure 3 Laser Scan of Semi Narrow Gap U Joint

2.2 Line Tracking System

Although the scanning spot laser sensor is ideal for the root pass weld, hot pass welding and for most of the fill welding phase, it is not ideal for the final fill layer and for the capping operation. This is because the laser sensor works on the principle of detecting physical features of the weld joint. By the time the capping layer is made, the physical features, such as the top edges of the joint, may have been deformed and may not be found reliably. To ensure reliable capping, a Line Tracking System (LTS) can be used.

To enable the line tracking system, a line is made on the surface of the part being welded. This line is made automatically during the root pass. It is a fixed distance from the root of the weld. The two common methods of making the line are by paint (or ink) and by machining. In either case, the object is to produce a narrow well defined line, typically 1-2 mm wide, which is constant in width and is a constant distance from the root of the weld joint. This line can then be used as a reference for horizontal positioning relative to the root. Not only can this be used in welding the joint automatically, it can also act as a permanent reference and can be useful in post welding operations, such as ultrasonic testing.

In the systems described here, the line acts as a secondary information source during fill welding but as a primary information source during automatic cap welding when the laser sensor is not considered reliable enough.

2.3 Part Memory

The third information source used in these machines is a stored part memory. In the case of longitudinal welding operations, this is easy to implement since the part does not move during the welding operation. Hence, important joint reference information which is obtained from the laser sensor can be stored as a function of the position of the welding head along the joint. Typically, information stored in the path memory includes the position of the top and bottom edges, the top and bottom width of the joint, and the current depth of the joint at various points.

Storing the path data is more complex in the case of circumferential welds since the part is usually drifting on turning rolls. Even if antidrift systems are used, they are not normally accurate enough to provide a basis for weld torch positioning. If an accurate part position sensor is available, it is possible to build up a useful part memory, although the position of the part position sensor has to be chosen with care.

2.4 Combining Data Sources

Assuming a valid part memory is available, then the usefulness of the three data sources can be summarised as follows:

Table 1 – Usefulness of Data Sources

Welding Phase	**Laser Sensor**	**Line Tracking System**	**Memory**
Root	√		
Hot	√		√
Fill	√	√	√
Cap		√	√

During the root weld pass, only the laser sensor provides reliable information. This is because the reference line for the LTS is made during the root weld and also because the weld joint memory is first initialised during the root pass. For this reason, the systems described here assume that an operator is present only during the root weld. During the subsequent welding passes, more than one data source is available and hence the individual sources can be cross checked for consistency.

The key to this approach to improving the reliability of the system is the method of combining the data from more than one source. The basic principles used are:

- ensuring consistency
- implementing physical constraints
- computing realistic probabilities of correctness
- combining data sources to maximise overall reliability.

Consistency can be applied both in terms of the signal analysis at any given point and in terms of continuity constraints. Obviously large tubular parts cannot move instantaneously so various constraints can be derived from this. Although significant thermal distortion does occur in these operations, it does so in a predictable manner. Again, constraints can be derived from this and applied to the results of the individual segmentation operations and to combining data sources.

During image processing of both the laser sensor signal and the line tracking camera signal, probabilities of correctness are computed. During the root pass, only the laser sensor signal is used to initialise the part memory. The probability associated with the laser sensor signal is stored in the memory together with the other data. In subsequent passes, the stored data and probability, the current laser sensor signal data and probability and the current line tracking camera data and probability are all combined to determine the current tracking output and process control signals and for updating the part memory. Evaluation of the current sensor and camera probabilities is computed from the instantaneous analysis probabilities and the relationship of the analysis results to the current system state. The revised state estimate includes new probabilities which are also stored in the path memory. This structure is shown in figure 4 below which also indicates the relationship between the sensor system and the machine control plc.

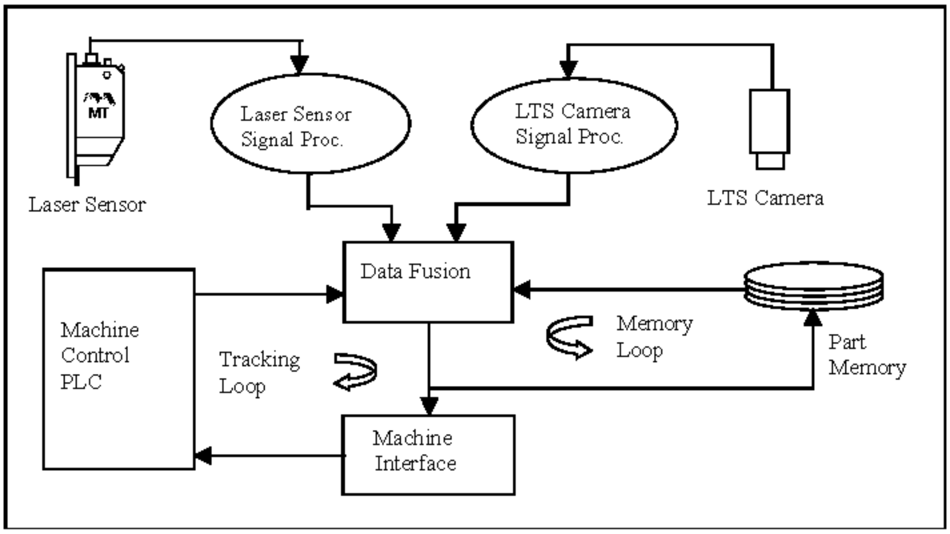

Figure 4 Role of Data Fusion

3. System Operation

The system has two main modes of operation. These are called semi-automatic and fully-automatic. The object of semi-automatic mode is to provide a very flexible means of welding using most of the features of the system. The object of fully-automatic mode is to weld parts as efficiently as possible using all of the features of the system.

The original purpose of semi-automatic mode was to provide a very modular and easy to use system which could be used to test individual system features prior to integration in fully-automatic mode. However, semi-automatic was found to be very useful in many circumstances, such as when a new operator is being trained on the machines, and so it has become an integral part of the system. Some features, particularly adaptive fill, are not available in semi-automatic. Also, selection of the number of passes is not done automatically, instead, the operator is able to indicate where the next pass should be placed from a menu, including tracking positions such as bottom left, bottom centre, root, bottom right, top left, top centre and top right. In cases where the operator wants to be very precise with electrode positioning, dynamic path offsets are also available.

The defining vision for these systems is that they should be able to operate fully automatically to produce a fault free multipass weld without operator intervention. An operator is assumed to be present during the root pass, but not for the remainder of the welding operation.

During the root pass, the part memory is initialised and the root pass stored. Also during the root pass, the weld joint area over the whole weld length is stored and analysed. This is used to determine the maximum, minimum and average weld joint area along the joint. These are used to determine the best selection of welding parameters corresponding to the range of areas encountered. Normally two hot passes are then welded in the bottom left and bottom right positions of the joint.

During fill welding a simple sequence of operations is used for each fill layer. During the first fill pass, the current width of the joint is used to decide how many passes will be used for that layer. During the last pass of each fill layer, the remaining depth of the joint is used to decide if the next layer will be a fill layer or if it is time to start capping.

The number and position of each cap pass is similarly computed from the width of the top of the joint and the remaining depth at the point when the transition from filling to capping is made.

4. Implementation

Systems based on this approach have been used successfully for inside and outside longitudinal applications and for inside and outside circumferential machines.

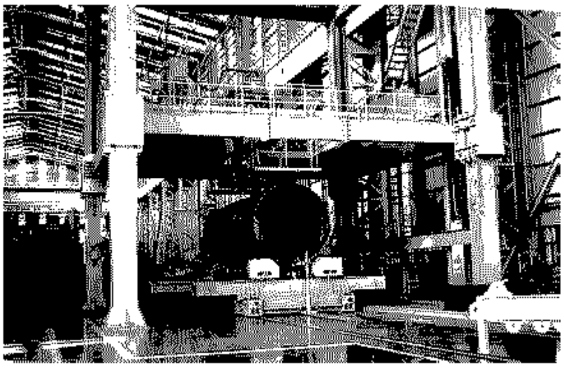

Figure 5 Outside Circumferential Machine with Two Welding Heads

Acknowledgements

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