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PROCESS CONTROL FOR THE WELDING OF LARGE STEEL-UNITS

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Abstract: In the following contribution a sensor and control system is introduced, that makes the recording of the joint geometry and the corresponding settlement of the parameters of the welding process possible. This is based on a new method, which permits the determination of the local joint geometry from the welding currents by the known through the arc sensing. It also allows the regulation of the filling height of the welded seam. A special diligence was putting on a high robustness of the solution to become fair to the particularly rough requirements on a mobile automatic assembly welding machine at the final assembly of large steel components.
Keywords: Arc-Sensor, Welding Parameter Adaptation

1 INTRODUCTION

At the moment some sensor principles with different physic basics are used in the area of the welding engineering. These are used for various tasks. The placement of the workpieces or the torch is often solved sensorial. To adhere a constant tool distance as well doesn't cause any difficulties.

If a complete groove shall be welded automatically then also the exact position of the torch relative to welding joint must be known. This can be realised by the fact that the workpieces are fixed in an exactly known position to each other and to the robot. Also considerable effort must be put on the clamp in of the workpieces. The robot then leads the welding torch according to the suitably predefined track. However, caused by the thermal effects of the welding it often comes to thermal tensions and misplacements of the components. In such cases serious welding defects are inevitably which make a rectification of rejects necessary. The so-called seam following sensors make remedy here. These are sensor systems which relatively grasp the position of the welding joint and make a following of the torch to the differing joint possible. For these arc sensors, inductive sensors and laser-scanner-systems are particularly used. With laser sensors sufficient precessions are particularly obtained in the thin metal area (e.g. laser welding in automobile manufacture).

Very big components which appear at the final assembly in ship- or bridgebuilding cannot be welded together into processing machines any more. In this case the welding method must be brought to the component. From this follows, that the exact position of the groove and their shape is unknown. Also during the welding a permanent supervision is required.

1.1 State of the art on the shipyards

In the shipbuilding the welding of the section or modules is predominantly carried out manually under assembly conditions. As welding-methods the MIG/MAG-welding and welding with stick electrodes (131/135, 111) are used. The picture 1 shows a marine section in the final assembly with put around scaffolds, which make the joints for the welders accessible.

The locomotion along the joint and the position and posture changes leads to an interrupted seams. Are worked with stick electrodes, many additional intermediate craters due to the electrode changing arises. The physically very exhausting, also monotonous job of welding leads to welding defects which must be removed by time- and costexpensive reoperation. Due to the length of the singles seams the use of mechanised welding tractors offers himself [1]. They are distributed for final assembly with the methods SA and MIG/MAG increasingly in the last few years. These tractors take the welding torch away from the hand of the welder and lead them along a track about the welding joint. With the help of mechanical altering facilities the welder must compensate the deviations between track and joint.

1.2 Requests at automation solutions

However a well operating seam following system still not quite frees the operator from the permanent supervision of the process. He doesn't have to check the tracking of the torch any more but he still must adapt the welding parameters to the joint geometry. Only if this job can be taken by a sensor supported control, a real automatic expiry of the welding process is possible.

Solution trials of this problem failed because of the not exactly measurable local joint geometry with simple sensors till now. The in principle suitable laser sensors are exposed to the strong disturbances which come from the open arc. Their application is often connected to restrictions with regard to the joint preparation. The actually very robust metal-active-gas welding then becomes a sensitive method. Another problem for the user acceptance, which should not be underestimated, are the high costs for the acquisition and maintenance of vision systems.

Sensory solutions to the adaptation of the welding parameters to the variable groove width are considered as a necessary next step by the automation of welding. This requires very robust and little susceptible sensors with long maintenance intervals. Another point is the demand for low system costs. It’s also necessary to orientate on a device-independent solution [2].

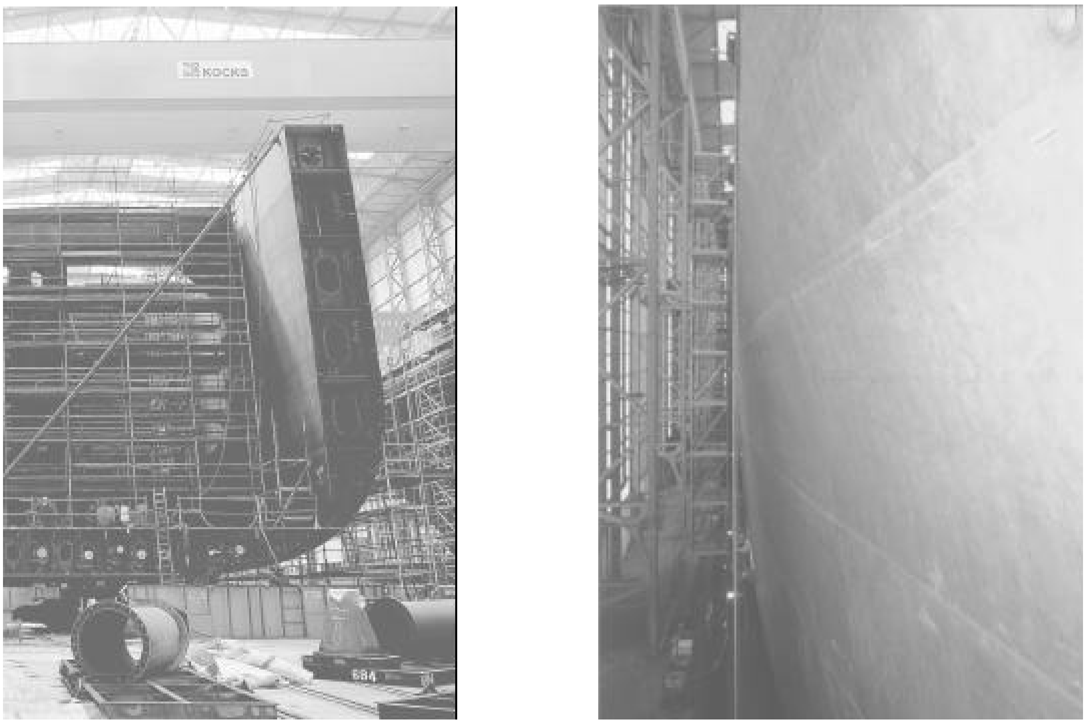

Figure 1. Final assembly of an marine section. The scaffolds can be particularly well seen especially in the left picture (A.P. Moeller Volkswerft Stralsund).

2 THE ARC SENSOR

Arc sensors are narrow to the welding method coupled sensors. They aren't an independent units, which must be assembled together with the torch at the robot arm. Instead of this the tool arc himself is used for the signal extraction [3]. For a better understanding, at first the basic coherence are shortly explained.

Arc sensors are distance sensors which can measure in one dimension. They use electrical parameters of the process (e.g. current, voltage), which are changed via variation of the arc. Here the dependence of these parameters to the arc length is utilised. If during metal-active-gas welding the arc is shifted transversely over a V-shaped groove, the arc length is changed by the inclined groove faces and so the welding current is changed as well. In a fast arc deflection to the groove faces the welding current is rapidly rising for a short period of time. The cross section of the groove is scanned by the oscillating torch. A relation can be observed between the geometry underneath the torch and the oscillating motion [4].

2.1 Determination of the lateral deviation

The torch is oscillated periodically over the groove and the welding current is measured. As long as the torch position is symmetrical over the groove, the distance contact-tip-to-workpiece and thus the welding current will be the same on both flanks. If the torch position is out of centre, a difference in the welding currents will be detected (see also figure 2).

For an optimal function of the arc sensor the arc length must be reduced sufficiently by the fact that the arc is led far enough to the flank. The stroke width becomes greater than the groove width at about 2..3 mm in welding the root to get a full penetrated root run and an acceptable sensory result. In almost all cases a compromise must be become between the welding technology and the sensory requirements. Especially in welding in vertical up-position a too wide weld pool becomes very fast unstable so that a stroke width as low as possible is necessary here. A weaving frequency as high as possible reduces the influence of the inner settlement of the arc [5].

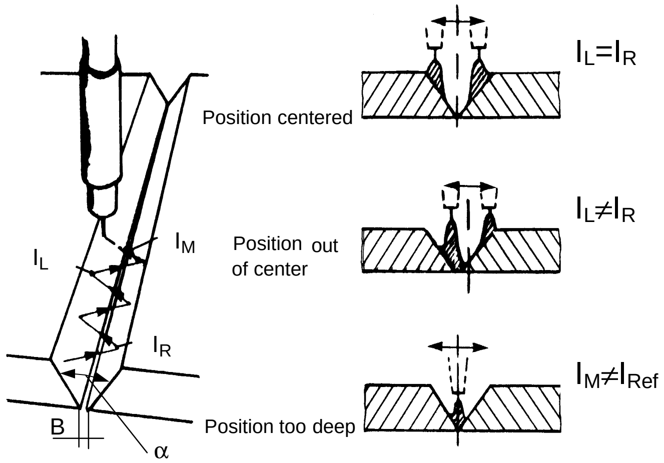

Figure 2. Basic Principle of the arc-sensor by evaluating the welding current

2.2 Joint geometry measurement

In the following a method to the determination of the groove width is developed. Basis is a current profile of the joint measured by the arc sensor.

The joint profile arises by the assignment of the current results to the corresponding torch positions. By a standardisation of the current results the independence is reached to the absolute current intensity (values between min. current and max. current are converted on 0..255). The complete weave amplitude is subdivided into one hundred classes. This makes the following calculations easier and faster since the same indexing of the data always can be used.

The increase of the current intensity is recognisable well at the extreme points of the oscillation (picture 3a). This effect is increased by using a point operator, which is known from the digital image processing, to achieve a enhancement of contrast [6]. At this every current value of a class is multiplied by himself (perhaps multiple) (picture 3b). Besides the effect reinforcements a smoothing is also obtained in the middle area.

To the further examination of the profile a polynomial (max. 4th order) is derived, which describes (picture 3c) the current as a function of the torch position. At first the zero poles of the 1st derivation are derived. The number of the zero poles indicates the manner and situation of the polynomial. The ideal contour of a V-joint can be simplifying described by three straights. The middle straight corresponds to the top side of the last welded layer or the root gap. The two outer straights correspond to the flanks and the angle of bevel. The areas in which these straights are valid, are margined by the evaluation of the 2nd derivation. Starting from the outside the points are searched at which the gradient drops under a specified value. This value is the empirically found half medium gradient of the respective side. For these three areas straights is derived (picture 3d). The intersection points of the three straights set the situation of the centring bases. The root gap or the groove width can be calculated by a conversion with the help of the known width of weaving. In practice prooftestings we achieved a sufficient accuracy in measuring the groove width of approx. ±7%. The groove width found so represents the basis for the adaptation of the welding parameters to the variable joint geometry.

3 FILLING DEGREE SETTLEMENT

If during the welding process the weave amplitude or the speed of travel is changed, then the respectively other parameter must be adapted so that the welding event remains stable and an even filling of the joint is reached.

At this method, described as filling degree settlement, the volume that is brought in with the welding rod must be the same as the volume of the groove (respectively with low losses caused by splatters):

$$V_{Dr} = V_N \quad \text{bzw.} \quad A_{Dr} \cdot v_{Dr} = A_N \cdot v_S \quad . \tag{3}$$

The wire cross cut A_{Dr} charges himself form the constant wire diameter d_{Dr} which is during a welding known. The wire feed rate v_{Dr} is also constant and known.

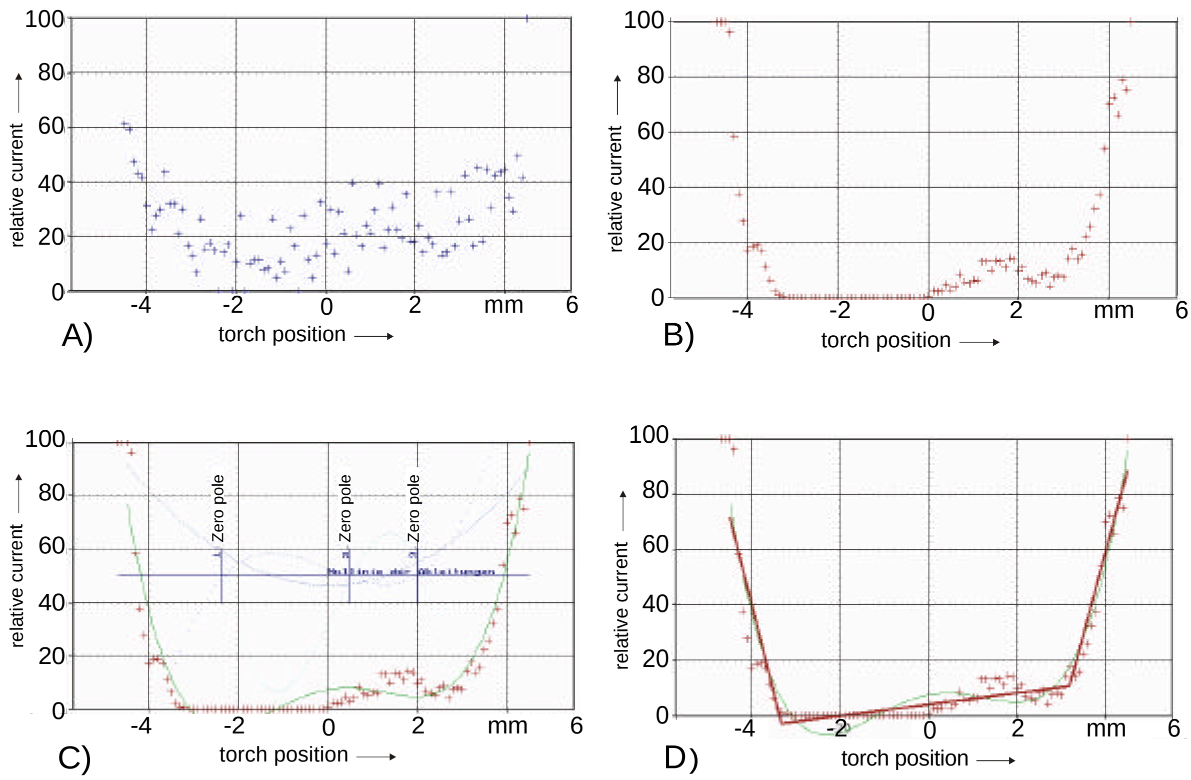

Figure 3. Basic Principle of the arc-sensor by evaluating the welding current

The seam volume V_N is characterised by the groove width *B*, the filling height d_F, the angle of bevel *a* and the welding speed v_S. The angle of bevel is a fixed and known size. The welding speed can be adjusted. The groove width changes during the welding and gets determined by the algorithm described in section 2.2. The desired filling height can't be measured with the arc sensor and therefore is calculated at the beginning of every welding from the parameters adjusted by the operator. The following equations are applied to the calculation. The wire volume V_{Dr} is defined by:

$$V_{Dr} = A_{Dr} \cdot v_{Dr} = \frac{p \cdot D_{Dr}^{\;2}}{4} \cdot v_{Dr} \quad , \tag{4}$$

with v_{Dr} as wire feed speed, D_{Dr} as the wire diameter and A_{Dr} as the wire cross-cut. The seam volume V_N is derived:

$$V_N = A_N \cdot v_S = (d_F \cdot b + \frac{d_F^{\;2}}{\tan a}) \cdot v_S \tag{5}$$

The seam filling height is symbolised by d_F , *B* is the groove width, *a* is the angle of bevel, v_S the welding speed and A_N characterises the weld cross section. Caused by reinforcement and excess weld metal on the root the seam cross-cut becomes around approx. 21% greater then the real seam cross-cut. This fact is been considered by the implementation of a fill factor F_F, approx. 1.21. Then the seam volume becomes:

$$V_{N,real} = V_N \cdot F_F \tag{6}$$

The seam filling height is calculated from these details:

$$d_F = \frac{-b \cdot \tan a}{2} \pm \sqrt{\left(\frac{b \cdot \tan a}{2}\right)^2 + \frac{p \cdot D_{Dr}^2}{4} \cdot \frac{v_{Dr}}{v_S} \cdot \frac{\tan a}{F_F}} \tag{7}$$

With the equation (7) the desired filling height can be determined from the welding parameters adjusted by the operator.

3.1 Implementation of the filling degree settlement

It is an aim of the weld filling degree settlement to regulate the welding speed in a way that in spite of a changed stroke width the desired seam filling height is reached. This must be done in consideration of the energy per unit length of weld *Q,* which must be kept constant in a tolerated range:

$$Q = \frac{U \cdot I}{v_S} = \text{const} \tag{8}$$

Wire feed rate and arc voltage remain constant. The equation (7) can be implemented as a look up-Table (LUT) for all happening groove widths and welding speed quotients in the computer. Through this the calculation gets fundamentally relieved with a simple µ-controller. Known or adjustable sizes are the wire feed rate, the welding speed, the wire diameter and with affordable tolerances the angle of bevel. The filling height is derived (equation 7) from the settings at the beginning of the welding. To this the desired filling height must be adjusted by manual customisation of weave amplitude and the speed of travel at the beginning of the welding (at all layers). Every operator setting of wire speed rate, rate of travel or stroke width causes a calculation of the new desired filling height. The coherence is known between the width of weaving and the welding speed with that.

During the welding the local groove width is adapted by the arc sensor. The welding speed follows the necessarily weaving amplitude so that the desired filling height is always reached:

$$v_S = \frac{A_{Dr}}{A_N} \cdot v_{Dr} = \frac{\frac{p}{4} \cdot D_{Dr}^{\,2}}{\left(d_F \cdot b + \frac{d_F^{\,2}}{\tan a}\right) \cdot F_F} \cdot v_{Dr} \tag{9}$$

The angle of bevel is the only item whose concrete value is based on the assumption of an even joint preparation. Trough the mechanical edge preparation in the subassembly by millcuting or planing and the application of facilities for leading the cutting head during the making of flame cuttings it is possible to get adequate exact angle of bevels. An increase of costs for the subassembly doesn't appear thus.

4 TECHNICAL REALISATION OF AN ASSEMBLY-WELDING-MACHINE

In a joint R/D-project with a welding engineering company from Mecklenburg-Vorpommern the research results were converted in an industry fit automatic assembly welding machine (figure 4). The introduced algorithm of an arc sensor is basis for the control [7].

The automatic welding machine is saddled on the usual tracks of the mechanical welding systems (BUG-O or Gullco-KAT). With a mass of approx. 24 kg and measurements into length, width and height of approx. 50 cm the welding machine is well manageably for a single welder. The integrated tractor leads the welding torch at the track along the joint. Deviations between track and joint are compensated by a two-axled, electrical driven cross-support. The hardware and the control- and sensor concept described abovely, is put directly on the vehicle and replaces the usual external computers. The exact position of the first weld is stored in the memory of the welding machine and can be recalled for the following layers. All settings of the automatic welding machine and the welding power source are carried out using a handheld operating tableau. The Welding Power Source itself is controlled over a manufacturer-independent voltage-lead interface. The welding current is galvanically separated by an external hall transducer which is put on the hose package.

4.1 Results of the practice prooftestings

During the welding prooftestings numerous seams were welded (vertical-up-position and flat position) on different shipyards. A welding technology adapted to the automatic welding machine was elaborated: welded from one side using a ceramic backing run; the joint is kept together with screwing studs. A carried out welding method exam shows the good quality of the welds produced with the developed automatic welding machine. The analysis of the welding shows that an arcing time of 87,9% is reached (in comparison: experienced manual welder-approx. 35%; mechanical welding tractors approx. 50-55 %). Costs can be considerably saved because the automatic welding machine reaches a high arcing time, the quality of the welds increases and during welding automatically the operator is applicable for other workings.

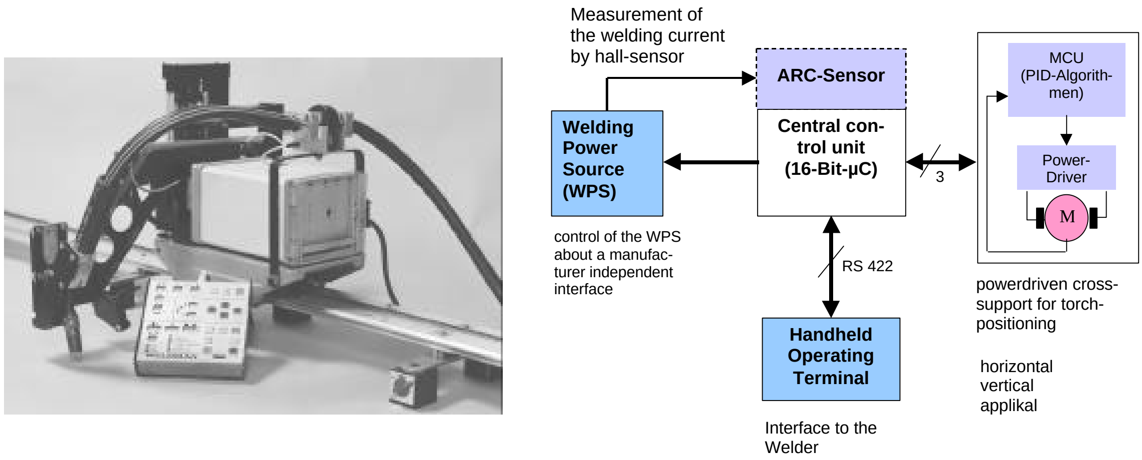

Figure 4. View of the developed automatic welding machine and the basic hardware-concept.

5 SUMMARY

An increasing European and international competition forces steel-building companies and shipyards to savings in the area of the welding production. Higher requirements on the quality of the products and the introduction of quality management systems require more exact manufacturing methods. The introduced concept of an arc sensor for the detection of the joint and the extraction of the essential geometry information represents a robust variant for such solutions. The requirements on the computer power increase with the number of the process parameters to be controlled. If the algorithm of the arc sensor is set up on a robot control, the external computer is saved. However then exists a tight coupling of the sensor algorithm respective to the used robot technology. The collected experiences during the handling of industrial research projects led to the implementation of the arc sensor algorithm on a µ-controller. This has several advantages:

- small form and simple operation of the computer,
- possibility of the field bus connection and
- low costs

By this the arc sensor gets comparable with other sensor systems into size and handling.

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