Weld process management using data visualization†

—Approaches to calculation and display of welding statistical information —

STEVE W. Simpson*, PETER W. Hughes*, MICHAEL Rados*

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1. Introduction

Real-time weld process monitoring is vital for welding industries, and in the case of electrical measurements (voltage and current), a large amount of data can easily be collected during a few hours of welding on a robotic production line. The challenge for welding management is to distill this data and provide immediate visualizations that give salient information on the welding process(es). Most commonly researched is the question of whether welds are satisfactory or faulty, but more general questions, such as whether there is long term drift, whether a particular weld or part of a weld is stable and reproducible, and what the comparative characteristics of any drift or variation are, are also important. At the same time, any weld data processor must be straightforward to use and maintain in a production environment where welding procedures are often changed.

This work focuses on some key issues within this enormous task. Signature image data objects [1] have proven to be useful for real-time fault detection with unassisted electrical sensing, and automated detection with minimal operator intervention is on the horizon [2]. Here, the statistical properties of the signatures themselves are investigated for application to welding management in some simple cases. To develop and evaluate a comprehensive industry relevant data analysis system, it is important to have a laboratory facility available which can emulate the automated welding rate of industry, but with full control of the welding environment. This work also describes our progress in building a facility for this purpose.

2. Experiments

Welds were bead on plate with two 30 mm long, 3 mm deep mild steel coupons positioned along the weld (**Fig. 1**) where the welds became overlap joints. Pulse welding was employed with a contact tip to work distance of 14 mm; the welding head was set at an angle of 50^o to the horizontal in the transverse plane; 1.2 mm wire was used with wire feed speed 80 mms^{-1}; the travel speed was 12.5 mms^{-1}; and the shielding gas was argon-based with approximately 5% CO_2 and 2% oxygen at a flow rate of 15 Lmin^{-1}. Four faults were considered: wire jam before the first coupon; contamination, the parts were not cleaned prior to welding; misplaced parts, a single coupon in the middle of the weld; and no parts, both coupons missing.

Signature images were calculated in the usual way from sets of 8,192 points in one second of voltage and current data,overlapped by50% to give a data point every½sec[1, 2].

One of the simplest statistical properties of a signature set is the overall scatter of the signatures in signature image space. For computational convenience [1], each signature is represented as a set of U coordinates, in terms of a basis set of orthogonal unit signatures $\mathbf{B}_1$, $\mathbf{B}_2$ … $\mathbf{B}_U$. The standard deviation σ_u in each basis direction u can readily be calculated, and summing the squares gives an estimate of the overall scatter Ω_S, which is proportional to the multidimensional volume occupied by the signature set:

$$\Omega_S = 10^{-5}\sum_{u=1}^{U}\sigma_u^2 \quad (1)$$

The factor of 10^{-5} is included for numerical convenience.

To investigate the behavior of Ω_S along a weld, signatures were added successively to a signature set, and Ω_S was calculated at each stage. Figure 1 plots Ω_S for the control weld and three of the faults.

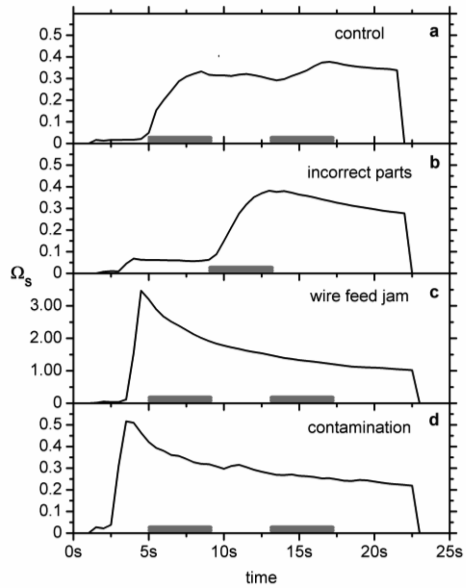

Fig. 1 Cumulative signature image scatter for several faults.

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* School of Electrical and Information Engineering, University of Sydney, Sydney, Australia.

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3. Statistical calculations

For the control weld (Fig. 1a), Ω_S increases during welding past the coupons, however the change for the second coupon is much smaller because information about the overlap weld at the coupon has already been incorporated in the signature image set. For the weld with a single coupon (Fig. 1b) there is an increase at the coupon as expected, while the wire feed jam gives a very large scatter starting at the time of the problem and decreasing as more signatures are added to the set. There is little evidence of the coupons for the contaminated weld (Fig. 1d).

The curves of Fig. 1 provide a statistical fingerprint of the weld that could be employed for fault detection, and the technique could be extended to treat long sequences of welds with signatures accumulated in a single reference set.

The value of Ω_S at the end of the weld $(\Omega_S)_{tot}$ contains information from the entire weld and could be used as a single statistical measure for fault detection. **Figure 2** plots $(\Omega_S)_{tot}$ for the control weld and faults on a logarithmic scale. The standard deviation σ of $(\Omega_S)_{tot}$ from three control welds was calculated and the band of values within one standard deviation from the mean is indicated by horizontal lines in Fig. 2. The localized wire feed jam (yellow bar) is readily detectible with a much larger scatter. The contaminated weld (pale green bar) is detected with a decrease rather than an increase in scatter, evidently reflecting the reduced response to the coupons. When both coupons are absent (green bar), there is clear detection with a marked decrease in scatter since the weld has become uniform.

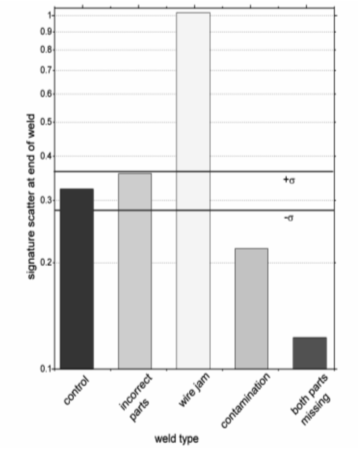

Fig. 2 Scatter $(\Omega_S)_{tot}$ at end of weld for control and faults

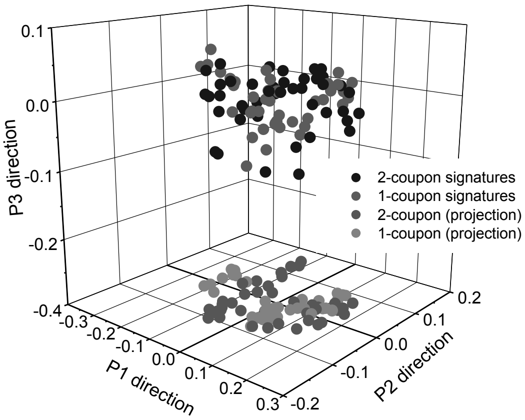

Fig. 3 Signature images in space of first three principal component directions. 1- and 2-coupon welds are shown.

The weld with incorrect parts (cyan bar) does not differ significantly from the control weld (blue bar). This is to be expected because the welds produce a signature set with similar signatures, in slightly different proportions since one coupon is missing. **Fig. 3** compares the signature distributions at the end of the weld for the control weld (two coupons) and the weld with incorrect parts (one coupon). The locations of the signatures are shown with respect to the first three principal axes, with the first, the direction of maximum scatter, and the following, with successively less scatter. Evidently the first axis corresponds to the change in welding between the overlap welding with the coupon and the bead on plate welding without, while the second axis is related to time variation along the weld. Clearly the two distributions are different, and the challenge is how to condense this rather complicated form of visualization into a more accessible form.

4. Automated welding research facility

The study described above with less than ten 250 mm welds is far from the requirement of statistical evaluation relevant to industry with welding at least to the timescale of contact tip wear and replacement.

We are currently commissioning an automated facility (**Fig. 4**) which will allow welding of sixty 24mm overlap joints per laser cut steel sheet. With programmable logic controllers driving the X-Y welding head motion, we expect to weld at 200 welds per hour with procedures representative of real world production, and faults introduced as required.

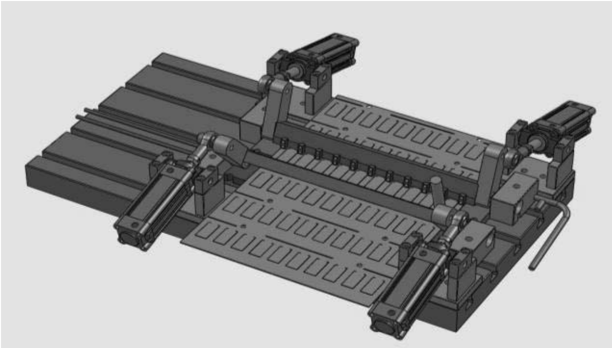

Fig. 4 Drawing showing laser cut plate with pneumatic clamping arrangement. The welding head travels between the brass clamping bars, each of which provides 12 kN clamping load. Pins in the base plate raise the tags to provide shoulders for overlap welds.

5. Conclusions

The use of statistical measures with signature images, leads to the possibility of sophisticated analysis treating both inter- and intra-weld variations in complex robotic weld sequences. Using more sophisticated measures than $(\Omega_S)_{total}$ will allow detection of a range of faults as well as indicators of reproducibility and drift. When combined with an autonomous database processing gigabytes of welding data in the background on a multi-core computer, these measures can provide the basis for a practical weld management system. Computing hardware with the necessary capabilities is readily available. The area where substantial research is required is in deriving the necessary mathematics and algorithms coupled to an appropriate visualization interface for welding managers.

References

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[2] S.W. Simpson, Australasian Weld. J. – Weld. Res. Supp. 54 (2009), pp.41-47.