

**D. Development of GTAW Penetration Control For Shipyard Piping**

*by Dr. Darren Barborak and Troy Paskell, WeldQC Inc.*

Gas tungsten arc welding (GTAW) is widely used on piping in ship construction where code often requires the root-pass to completely penetrate the weld joint. A variety of factors can affect weld penetration, including variations in material thickness, material chemical composition, joint preparation, and joint fit-up. The inherent variation in penetration makes the automation of these pipe welding applications difficult. To overcome these limitations and facilitate automation, a closed-loop weld penetration controller based on the weld pool oscillation sensing (WPOS) technique, was developed and extensively tested for several common material and joint configurations encountered in Naval shipbuilding.

Scoping trials were conducted on Stainless Steel, Titanium, Nickel-Copper, and Carbon Steel piping to characterize the weld pool oscillation signals and their sensitivity to common process perturbations. Screening experiments were conducted to determine which welding parameters and variables had a significant effect on the pool oscillation signal. Further experimentation concentrated on the root pass of V-groove weld joints using consumable inserts in the horizontal 1G position for types 304L & 321 stainless steel piping. Closed-loop control tests determined the controllers' robustness to typical production perturbations such as variable material and consumable insert chemistries, various torch offset positions, various arc lengths, variable joint preparation including joint angle, root face, joint alignment or mis-match, tack size and position, and gaps present between the insert and joint root. Weld quality was quantified by the measurement of the backside convexity or concavity, whether the consumable insert was completely melted, and the lack of gross defects such as incomplete penetration or blow-through.

Test results for GTAW pipe weld root passes indicate that closed-loop penetration control significantly improves weld quality and consistency over comparative open-loop welding procedures. In addition, penetration control improves the processes' robustness to common production perturbations and disturbances, while increasing its operation envelope. Further work is required on the frequency detection algorithms due to the complexity of the weld pool oscillation signals when multiple modes of vibration are present.