Penetration Control During Gas Tungsten Arc Welding

Overview
Assessing the depth of penetration when access to the backside of the workpiece is not available is a formidable task. Most topside penetration sensing methods are indirect, that is they require some means of relating the measured physical phenomena to the unmeasurable quantity, depth of penetration. In such cases, the system’s accuracy and robustness depends upon both the sensor and the model. Methods involving infrared sensors, for example, are susceptible to inaccurate temperature measurements due to varying thermal emissivity and surface conditions, while vision-based systems can be difficult to instrument and operate in the harsh welding environment. Direct sensing techniques, such as radiography and ultrasonic, are cumbersome, expensive, and difficult to fixture in a production environment.

Weld bead geometry control using the natural resonant frequency of the weld pool involves (1) sensing the weld pool’s fundamental frequency, (2) comparing the fundamental frequency to a setpoint, i.e., depth of penetration, and (3) adjusting the total heat input, either through regulating the current or travel speed, or both.

Sensing
A common approach to sensing weld pool oscillations is by monitoring the ac component of the arc voltage signal. In an attempt to improve upon the signal quality, monitoring the diffuse arc light has also been investigated. In both approaches, difficulties associated with traveling weld pools and partially-penetrated conditions have been noted by researchers. An alternative optical method collects the specular reflections of arc light from the pool’s mirror-like surface. Illustrated in Figure 1, an optical probe is positioned at a 45-degree angle to the workpiece. Sensing improvements include an enhanced signal-to-noise ratio (SNR) and the capability of monitoring traveling weld pools and partially-penetrated conditions.

Modeling
The modeling approach employed by Manufacturing Behavioral Science assumes that a weld pool vibrates in a manner similar to that of a suspended liquid droplet, which yields the mathematical relationship for the time of one oscillation as a function of the material’s surface tension, density, and volume (see the equations at the top of the page). Although different weld pool oscillation models exist, they all agree that the natural resonant frequency is inversely proportional to the weld pool volume. Therefore, assuming that the relative proportions of the weld pool remain constant, the depth of penetration can be inferred by monitoring the weld pool’s natural resonant frequency.

Control
The control of the fusion zone by adjusting the total heat input into the weldment is a non-linear, time-varying, asymmetric problem. Manufacturing Behavioral Science relies on a proven self-organizing fuzzy logic controller to emulate the knowledge and skill of a human welder. Figure 2 illustrates the capabilities and benefits of closed-loop, feedback control of a partially penetrated weld pool.

Benefits
The fabrication of precision components is particularly susceptible to difficulties in maintaining uniform bead geometry, in general, and depth of penetration, in particular. Inconsistent root fusion using identical equipment and the same welding schedule can occur as a result of variations in (1) the process parameters, such as material dimensions and joint fit-up; (2) the welding parameters, including welding current, electrode-to-workpiece distance, electrode dimensions and tip geometry, and shielding gas composition and flow rate; (3) the material properties, involving cast-to-cast variations in material composition, surface roughness, and cleanliness; (4) the thermal conditions caused by inconsistent size tack welds or workpiece clamping inconsistencies; and finally (5) the operator’s skill.

Closed-loop feedback control of precision welding processes is necessary to ensure high-quality, repeatable welds under conditions in which unavoidable and undetectable irregularities exist. Contact Manufacturing Behavioral Science to understand how we can cost-effectively apply a MBA solution to your manufacturing process.