Electron Temperature and Density Measurement of Tungsten Inert Gas Arcs with Ar-He shielding Gas Mixture

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1. Introduction

Tungsten Inert Gas welding (TIG) is a widespread technology for joining of metals. However, depending on the materials used different inert gases or gas mixtures should be used to achieve an optimal welded joint quality. Argon is certainly the most commonly used shielding gas, but also argon-helium, argon-hydrogen or argon-nitrogen gas mixtures are used for welding of materials as aluminum or stainless steel alloys.

Pura Argon arcs have been subject of study of many papers. They have been investigated by a variety of diagnostic techniques including emission spectroscopy, Thomson scattering and electric probes. TIG arcs have also been numerically investigated. Here plasma temperature and density have been simulated taking into account different process parameters. Some authors also considered the degrading effect in their model and included gas concentration calculations in their model. However only few works have experimentally investigated atmospheric plasmas with gas mixtures in general and TIG arcs in particular.

Thomson scattering is a well-established diagnostic for simultaneous measurement of electron temperature and density without the assumption of LTE in pure Argon plasmas. This technique does not require the knowledge of gas composition, so it can be applied for diagnostics of gas mixtures. In this work the electron temperature and density of a TIG arc operated with Argon-He gas mixture is investigated. The electron density is validated by spectroscopic measurement of Stark broadening of Ar I 696.5nm spectral line.

2. Theory

Thomson scattering:
- Plasma conditions:
  - collisionless: plasma frequency \( \omega \approx \omega_{pe} \)
  - Electron and ion temperature relation: \( T_e / T_i = 1 \)
  - Heating of the plasma by the laser radiation can be neglected

\[ n_e = \int \frac{d^2\beta}{4\pi} \int \frac{d^2\gamma}{4\pi} \int d\omega \frac{\beta n_e}{\omega} \]

Stark broadening:
- Plasma conditions:
  - Single temperature LTE
  - Quadratic Stark effect: broadening of Ar I 696.5nm line

\[ \Delta \lambda = 0.0014 \frac{n_e}{T_e^{1/2}} \]

TIG process parameters:
- Cathode material diameter: W 98.5%, La2O3 1.5%
- Anode material diameter: copper (water-cooled)
- Electrode gap: 7 mm

3. Experimental setup

Thomson scattering equipment:
- Laser: Nd: YAG (532 nm)
- Beam diameter: 500 μm
- Beam diameter: 50°
- Spectrometer: Czerny-Turner design
- Camera: type of exposure: 10 ns of integrated pulses: 250
- Measured positions: z(θ,φ) = 1.5, 2.5, 3.5, 4.5, 5.5

Stark broadening equipment:
- Image size: 1 mm
- Measured region: 1.5, 2.5, 3.5, 4.5, 5.5

4. Results and discussion

Thomson scattering:

Stark broadening:

Discussion:
- Electron densities measured by Thomson scattering and Stark broadening are in good agreement
- The difference in the measured values is within the accuracy of both systems
- Only reconstruction of positions z = 1, 1.5, 2.5, 3.5, 4.5, 5.5 delivered reasonable plasma composition data
- The reconstruction for the positions further away from the cathode and the plasma central axis was not possible, as possibly single temperature assumption is not valid in this region
- The results for the reconstruction lay in very good agreement with the simulated results for an Ar-H2 TIG arc with the same initial gas mixture, arc current of 200 A and electrode gap of 5 mm

5. Conclusions and outlook

In this paper electron temperature and density within an Argon-Helium TIG arc were measured using Thomson scattering method. This method was validated by electron density measurements using Stark broadening technique. The results of both methods lay in good agreement. Moreover the results of the Thomson scattering measurement could be successfully used to perform plasma composition reconstruction. The results of the reconstruction correspond with the simulation results. This work has shown, that Thomson scattering is a suitable technique for investigation of TIG processes with shielding gas mixtures. In the next step metal inert gas (MIG) welding processes should be investigated. The challenge here lies in the fact that the argon metal vapor gas mixture is optically thick and can not be investigated by spectroscopic methods.