Spatial Spectroscopic Diagnostics of Arc Plasmas by Monochromatic Imaging (published, see [1])

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Abstract

The monochromatic image of a free-burning arc is acquired with a high-speed camera and narrowband filters. The reconstruction of radial emission coefficients by means of an Abel inversion enables the derivation of the arc temperature. Temperatures obtained from the image are consistent with other measurements. With this technique, the time and spatially resolved properties of arc plasmas can be observed.
Keywords: Arc discharges, emission coefficient, imaging, narrowband filter, spectroscopy, temperature.

Arc plasmas used in industrial areas of welding, cutting, spraying, and surface modification are characterized with small volume and large gradients of some parameters, such as electron temperature and density. In order to obtain the spatial distribution of these parameters, the point-by-point scanning method [2,3] has been widely used. Such method, however, is time consuming and therefore cannot be used for the observation of transient phenomena, e.g., arc fluctuations.

For spatially resolved spectroscopic diagnostics, monochromatic imaging has been demonstrated to be a powerful tool. A monochromator was used for inspecting aluminum vapor in a helium vacuum arc [4] and measuring the distribution of excited species in an RF plasma [5]. The technique using interference filters in conjunction with imaging detectors, which is relatively simple and has a very short acquisition time, is also extensively used. The cause of the enhanced glow in the void of the dust particle cloud was revealed by the line ratio imaging of two spectral lines [6]. Moreover, the imaging of continuum radiation in arcs was used to measure the temperature and electron density distributions [7]. The imaging of single spectral line intensities is also a good means to determine the parameters of plasmas. We use it in this paper with a high-speed camera to measure the spatial distribution of temperature in an argon arc.

The arc generated with a direct current power source was burning free at an atmospheric pressure between a tungsten cathode and a water-cooled copper plate anode. The cathode electrode was a 2.4-mm-diameter thoriated tungsten rod ground to a conical tip with an included angle of 60.. The copper plate was 5 mm below the cathode tip. We have used an arc current of 200 A, a nozzle diameter of 10 mm, an electrode extension distance of 5 mm, and shielding gas of argon with a flow rate of 10 L/min.

Fig. 1 shows the 8-bit gray arc image of the ArI 794.8-nm line acquired by a Dalsa CA-D6-0256W high-speed camera with a 955 frames/s resolution. The light from the arc was imaged and collimated before passing through two narrowband interference filters to the detector. The imaging lens with a diameter of 20 mm was placed far away from the arc (with a distance of 400 mm) to ensure that the parallel ray projection condition is approximately satisfied, which is the assumption of Abel inversion. The narrowband filters are with full width at half maximum of 10 nm and 3 nm, respectively. The spectra of the arc that passed through the two filters were recorded by using a spectrograph in advance; no other spectral line was found except for the interested one. In the front of the narrowband filters, neutral filters were placed to reduce the strong radiation from the arc. In such a circumstance, with the aperture of the camera being carefully tuned, the image with maximum intensity but unsaturated was obtained.

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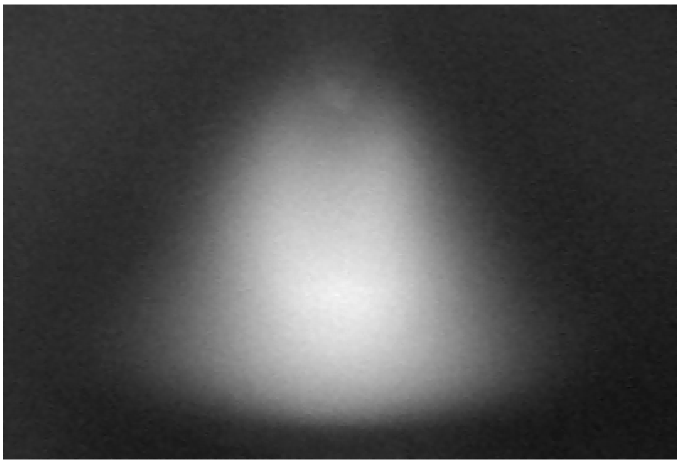

Fig. 1. Arc image of the ArI 794.8-nm line.

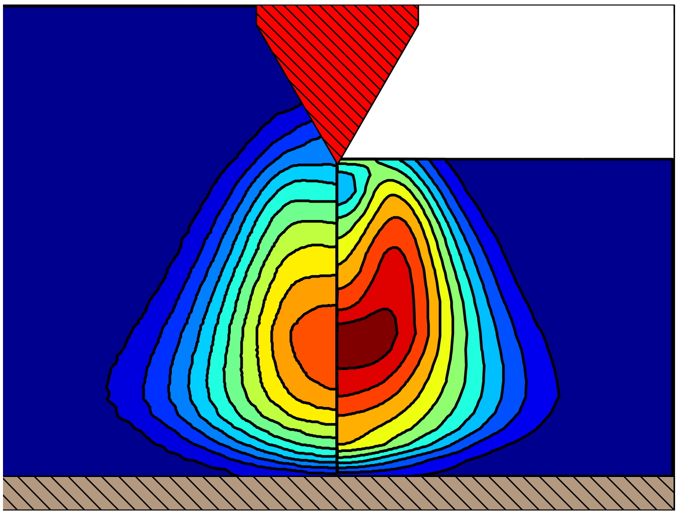

Fig. 2. (Left) Contour plot of the arc image. (Right) Converted emission coefficient distribution.

Fig. 2 (left) shows the contour plot of the image presented in Fig. 1 after symmetrization and noise filtering [8]. It is clear to see that the maximum brightness lies on the arc core near the anode. This is because this area has the largest optical length, and the measurements are line-of-sight integrated emission coefficients. For determining plasma parameters, the radial distribution of emission coefficients must be reconstructed. This is accomplished by means of an Abel inversion, provided that the plasma is cylindrically symmetric and optically thin. Fig. 2 (right) shows the converted emission coefficient distribution. It is evident that the radial variation of the emission coefficient between the tungsten and the maximum value near the anode exhibits off-axis maximum. Such characteristic can qualitatively reflect the temperature distribution of the arc.

Under the assumption of local thermodynamic equilibrium

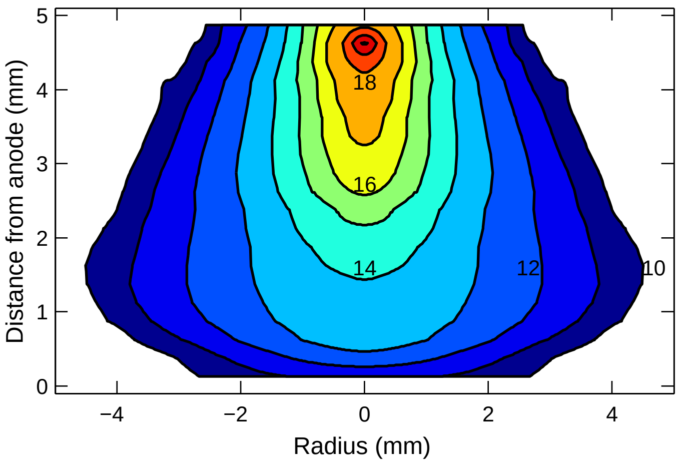

Fig. 3. Spatial distribution of the arc temperature. The contours are labeled in units of 1000 K.

and based on Dalton's law, the quasi-neutrality condition, and Saha equations, the dependence of particle densities on temperature was obtained. Then, the line emission coefficient as a function of temperature was calculated. The calculated curve passes through a peak value at a temperature of about 15 000 K, corresponding to the off-axis maximum of the converted radial emission coefficients, provided that the arc temperature is higher than 15 000 K. Thus, using the off-axis maximum as a calibration point, the radial distribution of temperature can be derived; the details can be found in [2].

Fig. 3 shows the profiles of the temperature measured with the normal temperature method. The peak temperature is about 19 000 K, which is located on the axis near the cathode that is 0.5 mm below the tungsten. This agrees with the results measured by spectrograph methods, where a peak temperature of 22 000 K was acquired [3]. The difference of the derived temperatures may be caused by many factors. Experimental conditions such as the electrode diameter may have some effects; in particular, the electrode extension distance of 5 mm instead of 2 mm will produce core temperatures as much as 1000 K lower [3]. The continuum radiation that cannot be subtracted from the measured intensities will also affect the results; as for temperatures higher than 17 000 K, the normalized continuum emission coefficient is larger than the line emission coefficient (see [2] for details). This will cause the temperatures on the order of 500 K lower. Moreover, the uncertainty in Able inversion was about 5% due to the effect of noise. When all the factors have been considered, it is shown that the measured temperatures are reliable.

In conclusion, the temperature distribution in a free-burning arc was measured by a filter-detector monochromatic imaging system. The results were in agreement with other measurements by a spectrograph. The simple system may be used for time and spatially resolved observation of arc plasma properties.

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