due to recombination of nitrogen atoms in molecules in the arc axis temperature. In the case of argon, which is a monoatomic gas, such maximum does not exist in the arc axis temperature.

We can notice that the experimental results of radial temperature distribution in the zone from the arc axis to the periphery are not quite identical with those obtained according to Maecker theory[5]. Nevertheless, the theory informs us about the shape of the curve of radial temperature distribution in the freely burning arc, so that we can obtain an insight into the effect of the atmosphere components on the arc characteristics.

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3.15 Measurement of temperature and metal vapour density in a welding arc

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1. Introduction

The measurement of temperature and metal vapour density is necessary in order to understand the physical processes in the welding arcs which is important for industrial applications. Very few measurements of that kind have been published.

A metal inert gas welding arc (MIG) in the range 200 — 300 A was observed burning vertically between a 1.2 mm iron wire as anode and metal plate as cathode as shown in Fig. 1. The arc length was about 1 cm. The wire was consumed at the rate of 10 — 20 cm/s and fed continuously into the arc. The cathode plate was moved sideways at about one tenth of that speed in order to distribute the molten material in a string on the plate. Argon was flowing through the concentric nozzle at a speed of 2 — 3 m/s.

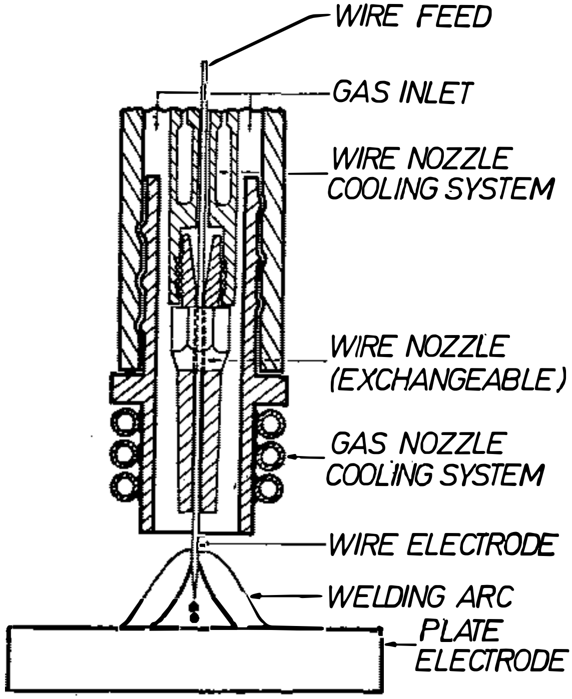

Fig. 1. MIG welding arc.

2. Spectroscopical measurement

High-speed photographs showed that metal droplets were formed and transported through the arc, with fluctuations in the arc position and shape. Therefore, rapid scanning across the arc was applied in 100 microseconds with a rotating mirror, sweeping an image of the arc across the spectrograph slit and covering about 0.05×1 mm of the arc. The lateral distributions of spectral line intensities were recorded photoelectrically on two oscilloscopes. The radial intensity distribution was obtained by the Abel transform assuming axial symmetry. Measurements on an aluminium-argon welding arc were reported in[1]. The measurements on the iron-argon welding arc were more difficult: The arc was conical, the metal droplets were very small and detached from a long finger of melted metal, while a synchronisation of the spectroscopic scan with the instant of drop detachment was not possible.

The spectrum showed many strong lines from neutral and ionized iron, a fairly strong continuum, but no argon lines which indicates a temperature below 10 000 K. A few impurity lines of manganese, copper and aluminium were observed. A typical composition of the iron wire is shown in Table 1.

TABLE 1

Composition of the wire electrode

Fe	Mn	Si	Al	Zn + Ti	C	S,P	Cu
96—97%	1.5%	1%	<0.5%	<0.15%	0.12%	<0.03%	<0.2%

Absolute intensity was measured simultaneously for the following spectral lines (Table 2):

TABLE 2

Data on spectral lines

Spectral line [Å]	E_2 [eV]	g_2	A_{21} [s^{-1}]	Reference
CuI 5153	6.19	4	$6 \cdot 10^7$	2)
CuI 5105	3.82	4	$2 \cdot 10^6$	2)
FeI 4860	5.42	3	$2.7 \cdot 10^7$	3)
FeII 5018	5.36	6	$3.7 \cdot 10^6$	3)
MnI 4823	4.89	8	$5.3 \cdot 10^7$	4)

In local thermal equilibrium (LTE) and without self absorption the power radiated per unit volume in a spectral line is as follows:

$$I\,[W/m^3] = g_2 A_{21} \frac{hc}{\lambda} \frac{N}{U(T)} \exp(-E_2/kT),$$

where N is the number density, U the partition function, and T the temperature, all other symbols for constants being conventional. The assumption of LTE is adequate for high current atmospheric pressure arcs. Self absorption is a serious problem and one has to be very careful when selecting the spectral lines.

At the same time the absolute intensities of all the listed lines, as well as continuum at 4945 Å, were recorded. A tungsten band lamp was used for absolute calibration. The temperature was first determined by the intensity ratio CuI 5105 Å and CuI 5153 Å, after covering the iron wire electrolytically with a 5 — 10 micron layer of copper. The plasma stream, which formed around the anode tip brings the copper vapours uniformly into the arc plasma. With this amount of copper, the CuI 5153 Å line (which is about 1.5 Å broad) becomes about three times more intense than continuum radiation. The CuI 5105 Å line is much narrower and has a much higher peak intensity and too much copper will cause self absorption.

The radial temperature distribution, obtained from the intensity ratio of copper lines has a maximum of 9 000 to 10 000 K just outside the arc center. This is possible because the melting electrode and the droplets cool the arc center but it is not conclusive because accurate measurements there are difficult. Thus the temperature obtained is the upper limit; it is too high if there is selfabsorption in the 5105 Å line. Additional sources of error are smoke around the arc, assymmetry of the arc, and errors in scanning a conical plasma by means of the vertical slit.

The Saha equation for iron S (T) can be written in the following wcy:

$$N_e = S_{Fe}(T) \frac{N_{FeI}}{N_{FeII}} .$$

The electron concentration can also be expressed with the Saha equations of all plasma constituents:

$$N_e^2 = S_{Fe} N_{FeI} + S_{Cu} N_{CuI} + S_{Mn} N_{MnI} + S_{Ar} N_{ArI}.$$

S_{Ar} is negligible in comparison with other Saha equations because of the high ionisation potential of argon.

The right hand sides of these two equations are functions of the temperature only. By trial process one can establish that temperature from both equations which gives the same electron concentration. In this way the densities of all elements in question can be obtained as well as an improved value of temperature and electron concentration. This temperature is about 10% lower than that derived from copper lines, and it is more reliable. It does not change noticeably with current within the range 200 — 300 A. Table 3 gives the average value and standard deviation of about ten measurements for maximum temperature and corresponding metal densities. The maximum temperature was found about 1 mm from the arc axis.

TABLE 3

Temperature and metal vapour densities in units of 10^{22} m^{-3}

T (K)	N_e	N_{FeI}	N_{FeII}	N_{CuI}	N_{MnI}	N_{CuII}	N_{MnII}	N_{ArI}
$(8.2 \pm 0.4)\,10^3$	5	3	4.1	0.9	0.15	0.5	0.4	75
% of N_{total}	5.6	3.3	4.6	1	0.2	0.6	0.4	84

The electron concentration of $N = 7 \cdot 10^{22}$ m^{-3} was estimated independently from the halfwidth of CuI 5153 Å, with Stark constant taken from ref.[5]. Another electron density determination from the formula for the total continuum (e. g. see ref.[6]) gives $30 \cdot 10^{22}$ m^{-3} which is definitely too large.

There is much more manganese in the arc plasma (6% of the metal vapours) than in the wire electrode (1.5%). This agrees with the chemical analysis (6.5%) of the condensed metal vapour which passed a hole in the cathode and was collected as metal powder. The high copper content comes from the coating added for spectroscopic purposes.

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3.16 Time-resolved spectroscopy of a pulsed discharge in a magnetic field

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3.17 Spectroscopic observations of D_2T — tube plasma behind reflected shock front

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3.18 Optical spectrum of the pulsed gas magnetron discharge

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Low density plasmas are strongly influenced by external fields. This is also the case with the cylindrical magnetron diode at low pressure, in which the axial magnetic field set above a critical value, increases enormously the electron paths and probability for ionization. According to the equivalent pressure conception, the system consisting of crossed electric and magnetic fields can be replaced with a system without the magnetic field, where instead of the existing pressure p the equivalent pressure is used $p_{eq}=p\ (1+(\omega_c/\nu_c)^2)^{1/2}$, where ω_c is the cyclotron frequency and ν_c collision frequency. For example, at the magnetic field of the order