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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

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JIŘÍ ŠLECHTA

Praha*

Temperature Measurement in an Argon Jet

1. Introduction

The aim of the contribution is to give a short review about our spectroscopical temperature measurements in an argon jet. These measurements have been carried out in our Institute as a part of the programme of heat exchange between high-temperature gases and their neighbourhood.

In our experiments a plasma-generator has been used as a source of heated gases. The used plasma-generator, designed in our Institute for measuring purposes, is described in [1]. In an argon jet heated by this tool, two regions can readily be distinguished, namely a bright core and a far less radiating outer zone. The spectra of these two regions are different. In the spectrum of the core continuous radiation and neutral argon lines are present. Ionized argon lines are absent. Some neutral argon lines are apparently broadened. This broadening grows with upper level energy. The lines with upper level energy above 15.45 eV cannot usually be distinguished from continuum.

The broadening of the lines decreases fast in the passage to the outer zone and their intensity quenches rapidly, too. In the outer zone there is also the molecular spectrum of nitrogen, showing the presence of air. The contamination of atmospheric air is the only one, which can be proved. There are no lines of electrode metals in the spectrum of the jet.

2. The Measurement Methods

As we did not want to add any contamination into the jet, we started from continuous radiation and the neutral argon lines. We have employed two methods, namely the method of continuum absolute intensity and the method of a spectral line absolute intensity. These two methods were supposed to give sufficiently reliable results in our conditions. The reason for this statement is the fact that energy emitted in our region by argon spectral line as well as by continuum grows very rapidly with temperature.

It is well known that continuous radiation has its rise in changes of free electrons motion states. These changes occur during collisions of free electrons in the main with

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positive ions. In this case, the formula was derived for the spectral emission coefficient j_ν (i.e. power emitted at spontaneous transitions from a volume unit to a space angle unit and related to a unit of frequency) [2]

$$j_\nu = \frac{8\sqrt{2\pi}}{3\sqrt{3}} \frac{Z^2 e^6}{m^{\frac{3}{2}} c^3} \frac{N_i N_e}{(kT)^{\frac{1}{2}}} \xi(\nu, T). \tag{1}$$

In this expression m, e and N_e are, respectively, mass, charge and concentration of electrons, N_i is concentration of ions and Z is their degree of ionization, c denotes velocity of light in vacuum, T is temperature (of electrons) and k stands for Boltzmann's constants, $\zeta(\nu, T)$ is Biberman and Norman's factor, which takes into account departure of ions in question from hydrogen one. Biberman and Norman calculated approximately this quantity for some elements. According to their calculation, for technical important gases this factor is only a function of frequency. For argon Moskvin and Chesnokova [3] supplemented the theory of Biberman and Norman.

The base of the second method (i.e. the method of a spectral line absolute intensity) is given by the formula for the total emission coefficient of the line in question (e.g. [4])

$$j_{mn} = \frac{1}{4\pi} h\nu_{mn} N_a \frac{g_m}{\sigma} A_{mn} \mathrm{e}^{-\frac{Em}{kT}}. \tag{2}$$

Here ν_{mn}, E_m, g_m and A_{mn} are, respectively, the frequency, the upper level energy, the statistical weight of this level and the spontaneous transition probability for the given line. N_a denotes concentration of neutral atoms and σ is the partition function.

The emission coefficients j_ν and j_{mn} are not directly measurable. We can directly measure only the intensities I_ν and I_{mn}, which give power emitted from unit area of a radiating source into a space angle unit. If no reabsorption takes place in the source, it holds

$$I = \int_0^l j\,dx \tag{3}$$

and for the case of an axial symetrical source it is valid

$$I(y) = 2\int_0^X j(r)\,dx = \int_y^R \frac{j(r)\,r\,dr}{(r^2 - y^2)^{\frac{1}{2}}}. \tag{4}$$

This is well known Abel's integral equation. It has the analytical solution

$$j(r) = -\frac{1}{\pi} \int_r^R \frac{\frac{dI}{dy}\,dy}{(y^2 - r^2)^{\frac{1}{2}}}. \tag{5}$$

For practice a set of approximate methods for solution of equation (4) was developed.

3. Measurements

Let us describe now in a short manner the arrangement of our measurement. The measurements were carried out on the plasma-generator with medium length discharge chamber. A grating spectrograph Zeiss–PGS 2 with a grating having 650 lines per mm were used. The plasma-generator axis was located in the horizontal direction. The argon jet was pictured on the slit of the spectrograph. It was measured in the cross-section close to the nozzle of the plasma-generator. When a set of plasma-generator working regimes had been exposured, the plasma-generator was replaced by the tungsten ribbon lamp for graduating of photographic measuring plates. The duration of exposures as well as the spectrographs slit width were the same in both cases. However, when measuring took place, the orifice of the picture lens was used to reduce radiation of the jet. The graduating plate was always developed contemporarily with measuring ones. The absolute graduating curves were gained from graduating plates in the usual way with the aid of the Zeiss densitometer. Vignetation, which occured in the event of graduating, was taken into account.

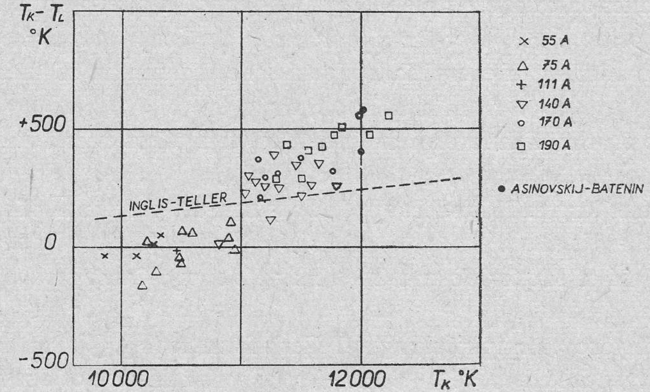

Fig. 1

We evaluated intensity distributions of the line A I 4251 Å and those of continuum close to this line. It appeared that in a number of working regimes the measured distributions departed from symetrical ones. In some cases these discrepancies are rather large. The use of a more accurate method for Abel's transformation is in these events questionable. We have therefore applied the simplest analytical approximate method, in which the measured distribution is replaced by

$$I = I_0 \, e^{-\left(\frac{y}{r_0}\right)^2} . \tag{6}$$

Then it holds for the radial distribution of the emission coefficient

$$j(r) = \frac{I_0}{\pi^{\frac{1}{2}} r_0} \, e^{-\left(\frac{r}{r_0}\right)^2} = j_0 \, e^{-\left(\frac{r}{r_0}\right)^2} . \tag{7}$$

The values of top temperature T_0 (i.e. the largest value of temperature in a given cross-section) were determined from values of the magnitude j_0 with the aid of the formulae (1) and (2) mentioned above. We utilised Moskvin's and Chesnokova's [3] datum for Biberman-Norman's factor and the value of the transition probability $A_{mn}=8.5\cdot10^4$ s^{-1} recommended by Adckock and Plumtree [5]. The values of the concentrations N_e, N_i and N_a were taken from Olsen's work [6].

4. Conclusions

Comparison of the results of used two methods shows that there is good agreement between them in our temperature region. The difference between the corresponding results does not exceed 5 % in this range. Moreover, we may see from figure that the average value of this difference increases with temperature. It shows that some systematic effect takes place here.

The probable cause of this departure is the blurring of a number of spectral lines, which is due to the plasma electric field. This field alters the field in the atom and consequently causes direct reduction of ionization energy. This effect is already calculated in the data of plasma composition. However the alteration of the inner atomic field further causes shifts and the broadening of energetic levels and the broadening of lines as a consequence. In the case of transition from high levels, the entire blurring of the lines takes place. As the electrons on the high levels remain bound, this effect does not appear in plasma composition. However, a number of the lines is missing in the spectrum and intensity of continuum becomes larger. This effect appears as „untrue" reduction of ionization energy.

In the figure there is also marked one of Asinovskij and Batenin's results [7] (precalculated with the aid of Moskvin's and Chesnokova's data). Other results by these authors exceed our range.

In the case of hydrogen empirical Inglis-Teller's formula (e.g. [4]) can be used for correction of the effect mentioned above. In principle, the generalization of this formula for other cases could be based on the reason that high levels of all atoms resemble the hydrogen one. The direct use of this generalization leads to the expression

$$\log N_e = 22.96 = 3.75 \log\left(\frac{\chi_0}{\Delta\chi}\right), \tag{8}$$

where $\Delta\chi$ is untrue reduction of ionization energy, χ_0 is ionization energy of hydrogen. However, this formula does not lead to a full agreement with our difference.

For further perfection of the continuum intensity method it will therefore be necessary to establish more suitable correction.

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Pomiar temperatury strugi argonu

Streszczenie

Artykuł poświęcony jest pomiarowi temperatury strugi argonu nagrzanej w plazmotronie. Pomiary prowadzone były dwoma sposobami: metodą absolutnej intensywności linii spektralnej (neutralnego argonu) i metodą absolutnej intensywności promieniowania ciągłego. Porównanie rezultatów otrzymanych w wyniku stosowania tych metod wskazało na istnienie systematycznej różnicy, niewielkiej w danym zakresie temperatur. Przypuszczalną przyczyną powstawania tej różnicy jest rozmywanie linii spektralnych pod wpływem pola elektrycznego plazmy.

Temperaturmessung des Argonstrahl

Zusammenfassung

Der Artikel behandelt die spektroskopische Temperaturmessung eines durch Plasmabrenner erhitzten Argonstrahl. Die Messungen wurden mittels zwei Methoden (Messung der absoluten Intensität der Spektrallinie und Messung der absoluten Intensität der kontinuierlichen Strahlung) durchgeführt. Durch Vergleichung von Resultaten dieser Methoden wurde eine systematische Abweichung festgestellt, die in unserem Temperaturbereich noch verhältnismässig klein ist. Wahrscheinliche Ursache dieser Abweichung ist eine Vermischung von Spektrallinien unter Wirkung des elektrischen Plasmafeldes.

Измерение температуры струи аргона

Резюме

Статья посвящена спектральному измерению температуры струи аргона нагретой плазмотроном. Измерения проводились двумя способами – методом абсолютной интенсивности спектральной линии (нейтрального аргона) и абсолютной интенсивности непрерывного излучения. Сравнение результатов, полученных ввиду применения этих методов, показало систематическую разницу, в нашем диапазоне температур относительно небольшую. Вероятной причиной возникновения этой разницы является размывание спектральных линий под влиянием электрического поля плазмы.