Optica Applicata VIII/1, 1978

Zuzana Chorvátová, Rudolf Hajossy *

On measurement of neutral gas temperature in the plasma of a spark plug

The temperature of neutral gas in the plasma of spark in the spark plug is determined from the distribution of intensities of spectral lines in fine rotational structure of band spectrum. Spark plug was placed in a pressure vessel with nitrogen. All processing of nitrogen molecular spectra performed on a computer.

1. Determination of temperature from the vibration-rotation spectrum

A temperature of a neutral gas in a plasma can be determined from the distribution intensity of spectral line in fine rotational structure of a band spectrum [1]. The corresponding temperature is called a rotation one. The expression for the dependence of the intensity I of a spectral line on rotational quantum number J in the vibration-rotation spectrum [1] can be modified to the form

$$\ln\frac{I}{S_j} = A - \frac{B'h\cdot c}{k\cdot T}J'(J'+1), \qquad (1)$$

where A (with sufficient accuracy for a considered band) is a constant, J' is a quantum number of internal rotation for upper energy state, S_j is determined by Hönl-London's equations [1] for individual branches R, P, Q. For example for the branch R:

$$S_J^R = \frac{(J''+2)\cdot J''}{J''+1} = \frac{(J'+l)(J'-1)}{J'}, \qquad (2)$$

where J'' is a quantum number of internal rotation for lower energy state, h, k, c are Planck's and Boltzman's constants and light velocity in vacuum, respectively; B' is rotational constant of upper vibration state specific of a given molecule.

The dependence of $\ln(I/S_j)$ on $B'\cdot J'(J'+1)$ is linear of the type $y = A'Kx$, where A' is the y-intercept of the line, K is its slope; therefore:

$$K = -\frac{h\cdot c}{k\cdot T}. \qquad (3)$$

If the slope is determined experimentally, the temperature T could be calculated from the formula:

$$T = -\frac{h\cdot c}{k\cdot K}. \qquad (4)$$

A more detailed description of numerical calcuiations of the temperature will be presented below.

2. Experimental

A block diagram of the experimental equipment s shown in fig. 1.

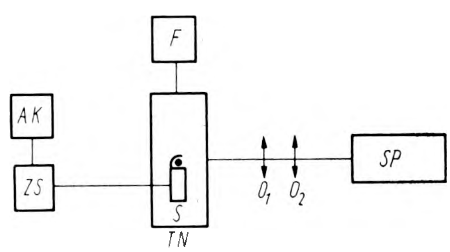

Fig. 1. Block-diagrams of experimental set-up: AK — accumulator; ZS — system of plug ignition, TN — pressure vessel for spark plug; F — bomb of N_2; O_1, O_2 — optical systems in front of spectrograph; SP — spectrograph

A sparking process has been used as a generator of spark discharge. From many known sparking systems, one of the most advanced, namely thyristor sparking, has been selected [2]. This system achieves the best parameters required and enables the simple electrical control of spark start.

The grating spectrograph of PGS-2 type has been used. Experiments were performed in the area of the 1st diffraction order with reciprocal linear dispersion 7,4 [Å/mm]. Spectrum was registrated on the photo-

*) Department of Experimental Physics, Komenský — University, Mlynská Dolina, 816 31 Bratislava, Czechoslovakia.

graphic plate and subsequently processed by a recording microphotometer.

3. Measurements

The structure of N_2 band 380.5 nm (0–2 band of the 2. positive group) has been investigated. This band was selected for measurements because its individual lines were the best resolved ones in the observed spectrum, and they were not overlapped by the lines of adjacent bands. 0–2 band of N_2 is comprehensively described by HERZBERG [1]. His monography presents also the values of vibrational and rotational constants for N_2 molecule. Since the 0–2 band covers the wavelength range from 735.0 to 381.0 nm, blue light sensitive photographic plate has been used.

Exposure time varied from 45 minutes up to 2 hours, according to the parameters of sparking system.

Examples of spectra are presented in fig. 2.

In order to identify a line in a band spectrum the branch (R, P or Q) to what the line belongs and the rotational quantum number of the line must be known.

It is advasible that the intensity of line of individual branches be known. By means of a computer programme [3] we have calculated distributions of intensity in R, P, Q branches for several bands of N_2 molecular spectrum and for different temperature. The kind of the calculated intensity distributions helped us to identify observed lines. It has been shown, that well resolved part 0–2 band (the region of wavelengths shorter than λ_H in fig. 3) corresponds solely to the branch R. It has been observed that towards the head of the band, the minima between lines are increasing (see fig. 3). This is caused by a overlapping of the R and P branches. This region is not suitable for measurement of temperature.

Within the spectral range suitable for the measurement the wavelength, and consequently, rotational quantum number for each of the observed lines, was determined. Quantum number of internal rotation is the first entry for the computer. Relative intensity of a corresponding line is the second (and the last) necessary entry for the computer.

Relative intensity of the line was obtained by means of a characteristic curve of photographic plate assuming that the optical density is known. The characteristics curve, i.e. a plot of optical density values S vs. logarithm of intensity I [4], is defined if

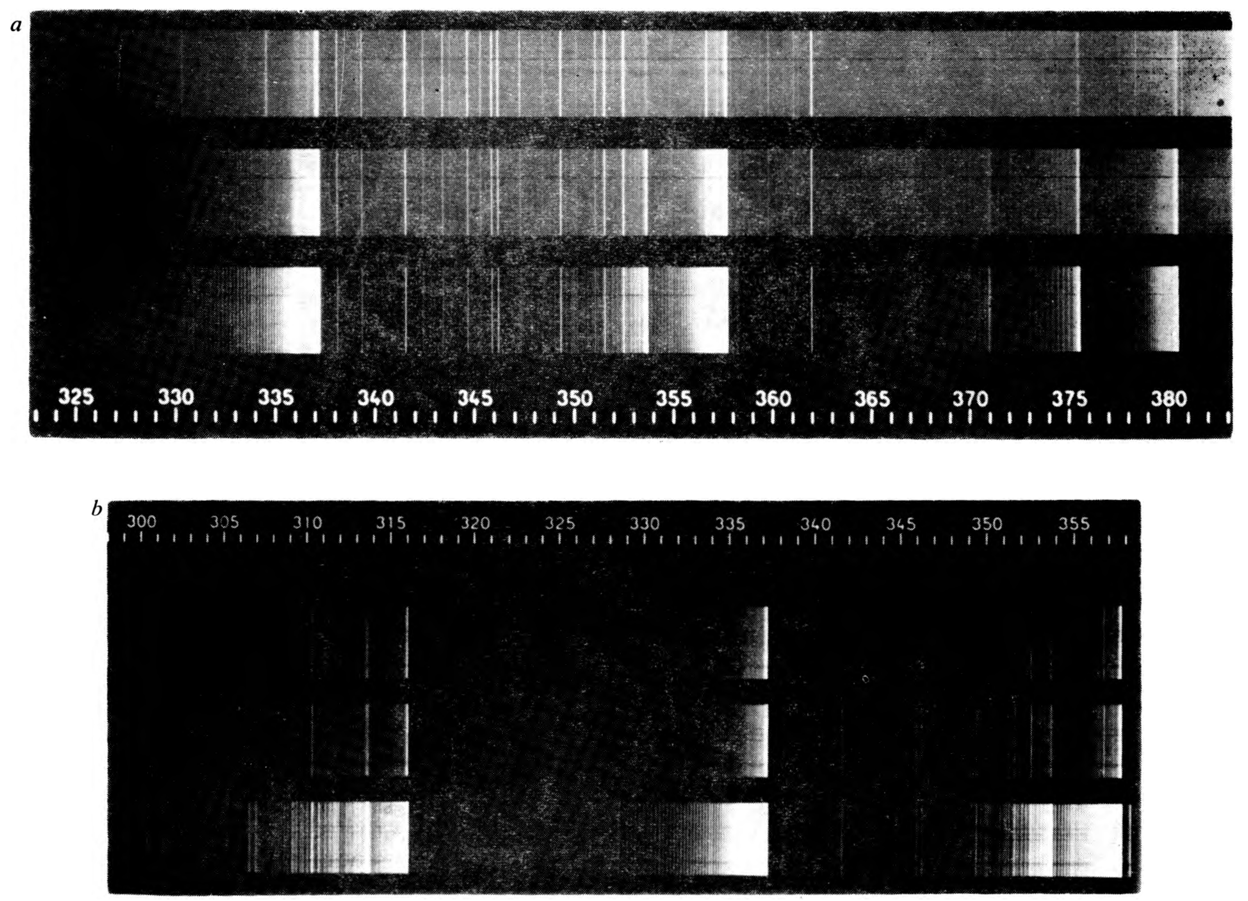

Fig. 2. Examples of spectra: a) vibration transitions: 0–0, 0–1, 1–3, 0–2; pressures — 6.5 atm, 5.0 atm, 3.0 atm, f = 160 Hz. b) vibration transitions: 1–0, 0–0, 0–1; frequencies: 40 Hz, 50 Hz, 100 Hz; p = 1 atm

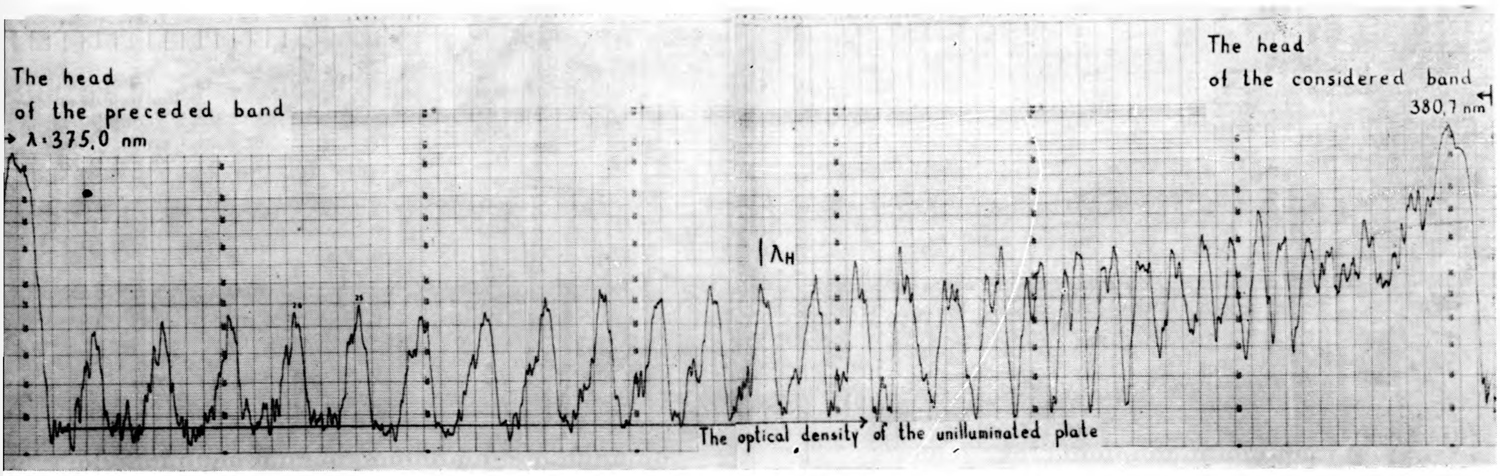

Fig. 3. Example of microphotometric record of spectrum

coordinates of the points A, B, C and D on fig. 4 are known.

Characteristic curve was constructed from the spectrum photographed through a 6-stage filter with

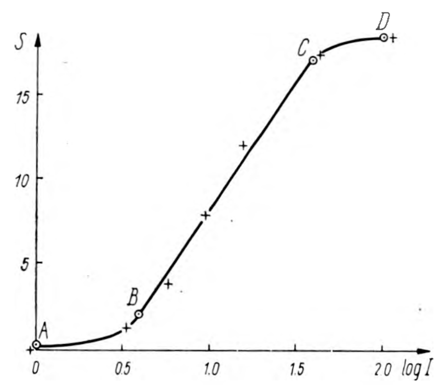

Fig. 4. Characteristic curve of spectral plate BLAU RAPID

the known transparencies of individual stages. From this spectrum a suitable line was selected along which a microphotometer record was performed. Then log I was computed for a given optical density S. Long I determined from experimental data by means of characteristic curve was calculated in a computer.

4. Calculation of rotational temperature

As it was mentioned above, the rotational temperature can be calculated from the equation (4). Using $B' J' (J'+1)$ as abscissa, and $\ln I/S_j$ as ordinate we can constructed a plot from the experimental data. Rotational temperature T can be then determined from the slope of the line obtained. The slope of the line and, consequently, the temperature, was determined by computer employing the least-square-method. Example of calculated resultes and the plot of I/S_j vs. $B' J' (J'+1)$ dependence are presented in fig. 5.

5. Experimental results

Temperature of spark has been measured for different values of spark ignition frequency and of gas pressure in the spark-gap. The frequency varied from 40 to 250 Hz (lower frequencies roughly correspond to high revolutions of engine). Gas pressure was changed from 1.0 to 8.1 atmospheres. Energy E on spark-gap electrodes (evaluated from the voltage on capacitor with known capacity) varied from 24 to 97 mWs. The spark plug employed was that of PAL 14-7 type.

Results are presented in tables 1–4, and figs. 6 and 7.

Table 1

Dependence $T(p)$ by $f = 160$ Hz, $E = 80$ mWs, plot 1

p [atm]	1.0	3.0	5.0	6.5
T [K]	2100	2600	3000	2200

Table 2

Dependence $T(p)$ by $f = 40$ Hz, $E = 80$ mWs, plot 2

p [atm]	3.0	5.0	6.5
T [K]	2700	3300	1400

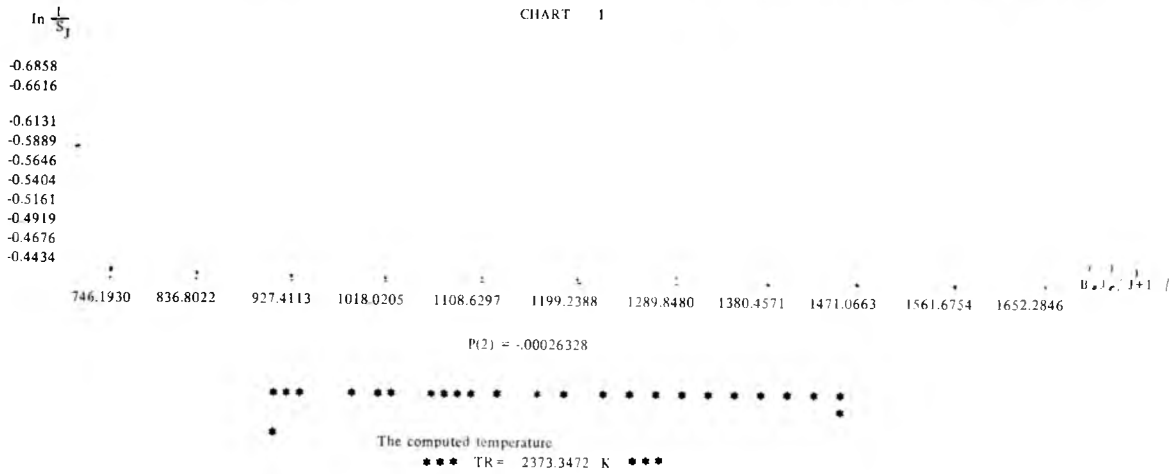

Fig. 5. Example of calculation of temperature, and plot constructed by computer

Table 3

Dependence $T(p)$ by $f = 100$ Hz, $E = 97$ mWs, plot 3

p [atm]	3,0	5.0	7.0
T [K]	1300	1500	1800

Table 4

Dependence $T(p)$ by $p = 1.0$ atm, $E = 97$ mWs, plot 4

f [Hz]	40	50	100	150	200	250
T [K]	1200	2400	2300	2000	1800	2750

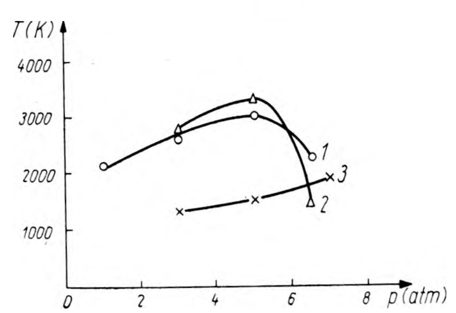

Fig. 6. Plot of spark temperature T vs. gas pressure p

1 – E = 80 mWs, f = 160 Hz; 2 – E = 80 mWs, f = 40 Hz; 3 – E = 97 mWs, f = 100 Hz

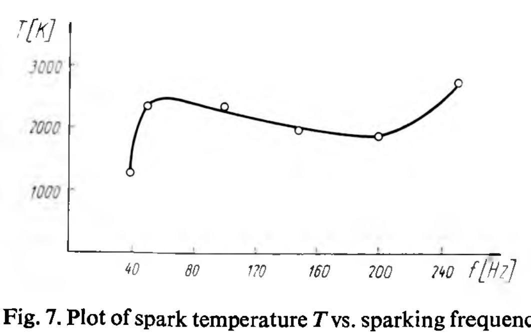

Fig. 7. Plot of spark temperature T vs. sparking frequency (tab. 4)

6. Conclusion

1. From a relatively large amount of computed plots it follows that ln (I/S_J) vs. $B' \cdot J' (J'+1)$ is really a linear dependence. This fact proves that presented theoretical approach is suitable for the measurement of the plasma temperature between the electrodes of a spark plug.

2. The mean temperature during the spark life has been determined.

3. The values of the temperature varied within the interval 1200–3000 K depending on the experimental conditions.

4. The dependence of T on the pressure exhibits a maximum. Physical reasons for the maximum are yet unknown.

5. Errors of individual measurements were treated according to the theory of errors [5]. Deviations of individual measurements reached approximately 7%. Only in a few cases the error was higher than 10%, but it did not exeed 15%.

6. Certain inaccuracy of the method presented is due to neglecting the triplet structure of rotation spectrum (the structure can be seen in the spectrum record).

7. It follows from the measurements that increasing pressure is accompanied by the increasing intensity of a continuous spectrum superimposed upon the discrete one. The method of rotational temperature can be employed in measurement of temperature up to the pressures of 10 atmospheres of N_2. At higher pressures the temperature has to be evaluated from the continuous spectrum.

8. The data found in the available literature refer only to the temperature of spark plug electrodes, the proper temperature of plasma channel between the electrodes being not given. The method of rotational temperature enables to determine this parameter. It may be used when different types of spark plugs are to be compared.

Acknowledgement

The authors wish to thank RNDr Ľ. Fischer, CSc. for help with arrangement of programmes.

Измерение температуры инертного газа в плазме запальной свечи

Определена температура инертного газа в плазме запальной свечи на основе распределения спектральных линий в тонкой вращательной структуре полосного спектра. Запальная свеча была помещена в напорном сосуде в атмосфере азота. Анализ молекулярных спектров выполнен с применением ЭЦВМ.

References

[1] HERZBERG G., *Molecular Spectra and Molecular Structure*, I. *Spectra of Diatomic Molecules*, D. van Nostrand Company, Inc., New York 1953.

[2] RŮŽIČKA V., JANÁSEK K., *Elektronické zapalování*, Amatérské Rádio **11** (1971), 413.

[3] SILNÝ R., Diplomová práca. Katedra Experimentálnej Fyziky PFUK, 1975, Mlynská Dolina, Bratislava.

[4] PROKOFJEV V.K., *Spektrální Analysa Kovů a Slitin II*, SNTL, Praha 1954.

[5] REKTORYS K., *Přehled Užité Matematiky*, SNTL, Praha 1963.

Received April 13, 1977