Temperature evaluation of a hyper-rapid plasma jet by the method of high-speed video recording

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Abstract. In this paper the procedure of comparative evaluation of plasma temperature using high-speed video filming of fast processes is presented. It has been established that the maximum plasma temperature reaches the value exceeding 30 000 K for the hypervelocity electric-discharge plasma, generated by a coaxial magnetoplasma accelerator with the use of the ‘ImageJ’ software.

1. Introduction
Plasma is a basic state of a substance in the universe. It is divided into low-temperature (1 000 000 °K) and high-temperature (above 1 000 000 °K). Different substances transform to a plasma state at different temperatures, which accounts for the structure of the outer electron shells of the atoms of the substance: the easier the atom releases its electron, the lower is the temperature of transition into a plasma state.

Plasma behaviour is characterized by a sufficiently vast set of phenomena, so that in complexity its research is comparable to the study of complex biological systems, therefore it is necessary to be able to diagnose it. The diagnostics itself has a sufficiently important meaning for the practical purposes, and first of all, in obtainment of the controlled thermonuclear reaction. On the other hand, the understanding of the processes flowing in the production facility allows the intentional improvement of its operating characteristics. The difficulty in the measurement of plasma temperature consists in the fact that any device located in the medium with the temperature of million degrees should either cool or burn it. Therefore it is necessary to judge about the plasma parameters at a distance and a ‘thermometer’ should undoubtedly be noncontact. At present there are different methods of plasma temperature measurement, most of them function on the basis of optics law, such as:

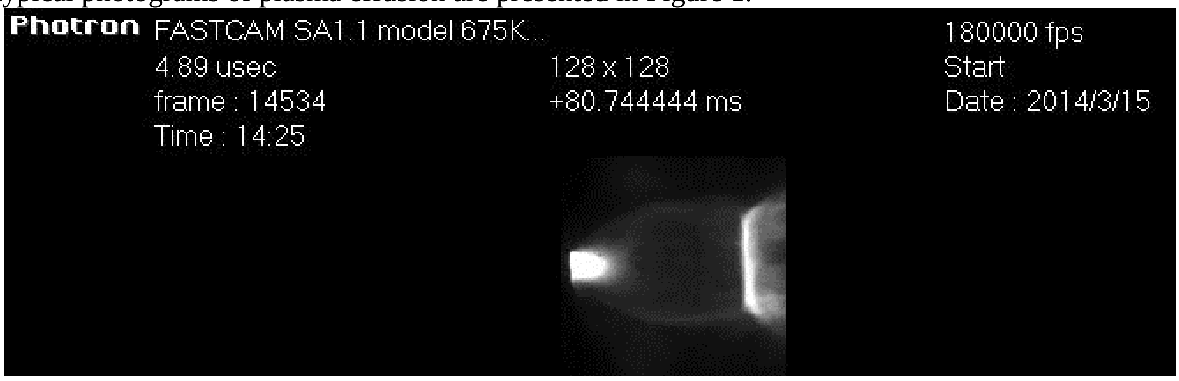
- Thomson scattering. The range of the measured temperatures varies from the tens of electron volts in the near-wall region up to 10–20 keV on the axis of a plasma column. The measurement error in electron temperature does not exceed 10 % in the temperature range 0.3–20 keV;
- Laser-induced fluorescence. The domain of applicability of the method is from 200 to 3000 K. The temperature measurement error of gas or low-temperature plasma nearby 2000 K does not exceed 5 %.

- Doppler broadening of absorption spectral lines [1]. The error of temperature measurements equals ± 5 %. And others.

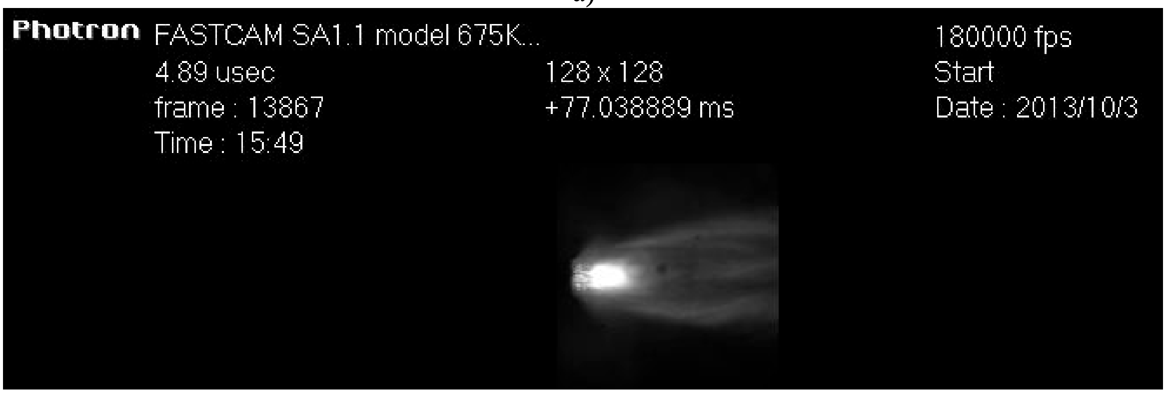
The analysis of the existing methods of plasma temperature measurement has allowed us to conclude that in spite of sufficiently low error in the measurements they have their own drawbacks, in particular the necessity of using quite complicated complex engineering solutions and a subsequent mathematical treatment [2-4]. Besides, the above-mentioned methods function preliminary with stationary plasma. At this the problem of recording of fast nonstationary processes remains poorly investigated. In this paper we suggest filling this gap by our method based on high-speed video recording of phenomena.

2. Materials and methods

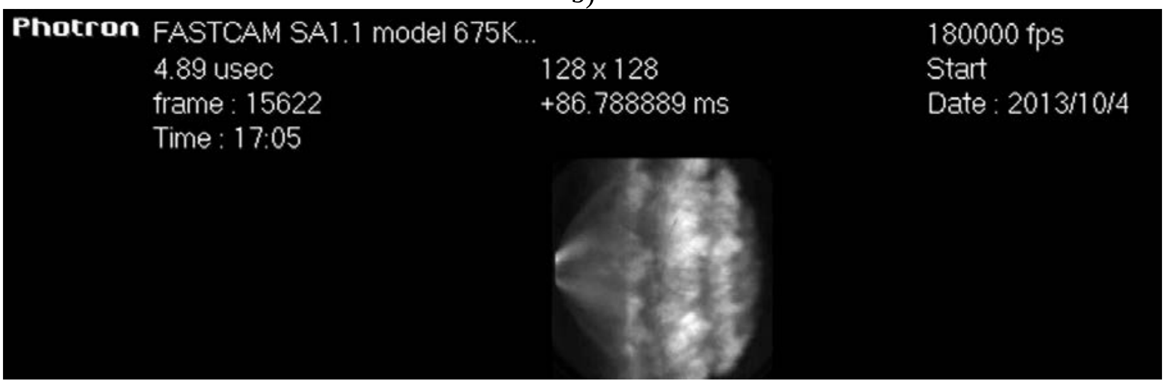
The essence of the method is in the shooting of the entities with the known temperature (standard) and subsequent treatment (calibration curve plotting) and evaluation of plasma temperature of the real process. Hypersonic plasma generated by a coaxial magnetoplasma accelerator [5-7] and recorded by a high-speed camera ‘Photron Fastcam SA1.1.’ has been chosen as an object of the research. The typical photograms of plasma effusion are presented in Figure 1.



a)



b)



c)

Figure 1. Photograms of plasma effusion.

For the experiment a glowing filament of an incandescent lamp of 100Wt power has been chosen as a 'standard'. For the temperature evaluation of the glowing filament a pyrometer produced by 'Raytek' Company (Germany) with the range of the temperature record from 600 to 3000 °C has been used. Plasma shooting has been conducted by means of the monochrome high-speed camera 'Photron SA1.1.' equipped with the installed lens 'Helios 44-2' in a shooting mode: diaphragm is 2.0 with the use of two light filters 'ND64' and 'ND32'. The use of addition light filters provides the record of the 'non-exposed' picture of plasma effusion.

3. Results and discussion

The procedure of plasma temperature evaluation consists in the following: by means of the laboratory autotransformer we change the power of the incandescent lamp (and accordingly the glowing intensity of the filament itself), the temperature of the filament is simultaneously evaluated using the pyrometer, at this the images are recorded with the use of the high-speed camera. As a result of this work we have obtained a series of images of the glowing filament with different level of luminous intensity at known temperatures. The results of the conducted work are presented in the table.

Table 1 – The parameters of glowing filament with different level of luminous intensity at known temperatures.

№	U, B	I, A	T, °C	Power, W	R_t, Om
1	94	0.256	1204	24.1	367
2	128	0.301	1420	38.5	425
3	173	0.353	1664	61.1	490
4	216	0.397	1866	85.8	544
5	246	0.425	1996	104.6	578

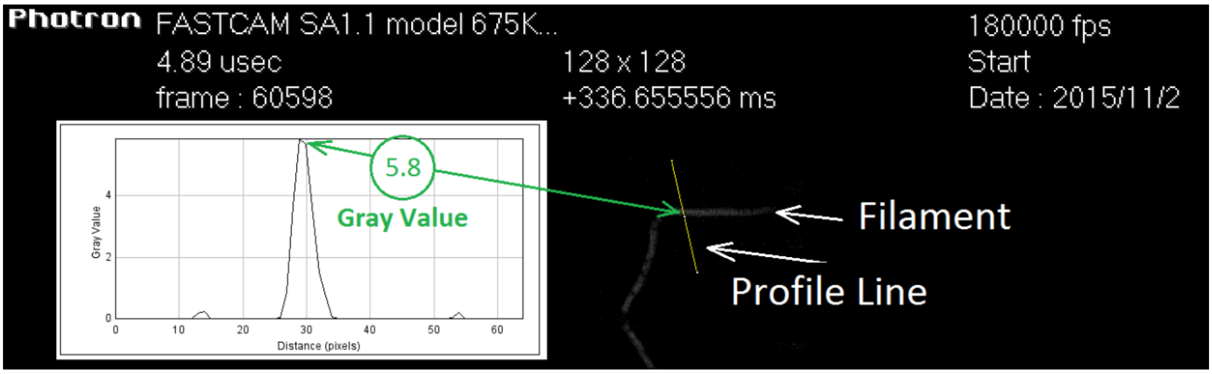


Figure 2. The example of the evaluation of luminous intensity of glowing filament in the gradations of grey.

The level of luminous intensity of the glowing filament (in the gradation of grey) for all obtained images has been evaluated by means of the software product '***ImageJ***'. In order to evaluate the maximum value of filament luminosity in gradations of grey in the photos a line was drawn across the area, which is of great interest. Using a system function of the software '***Plot Profile***' the programme creates automatically an array data with indication of the value in the gradation of grey for each pixel (from 0 to 255). The example of the image treatment is shown in Figure 2.

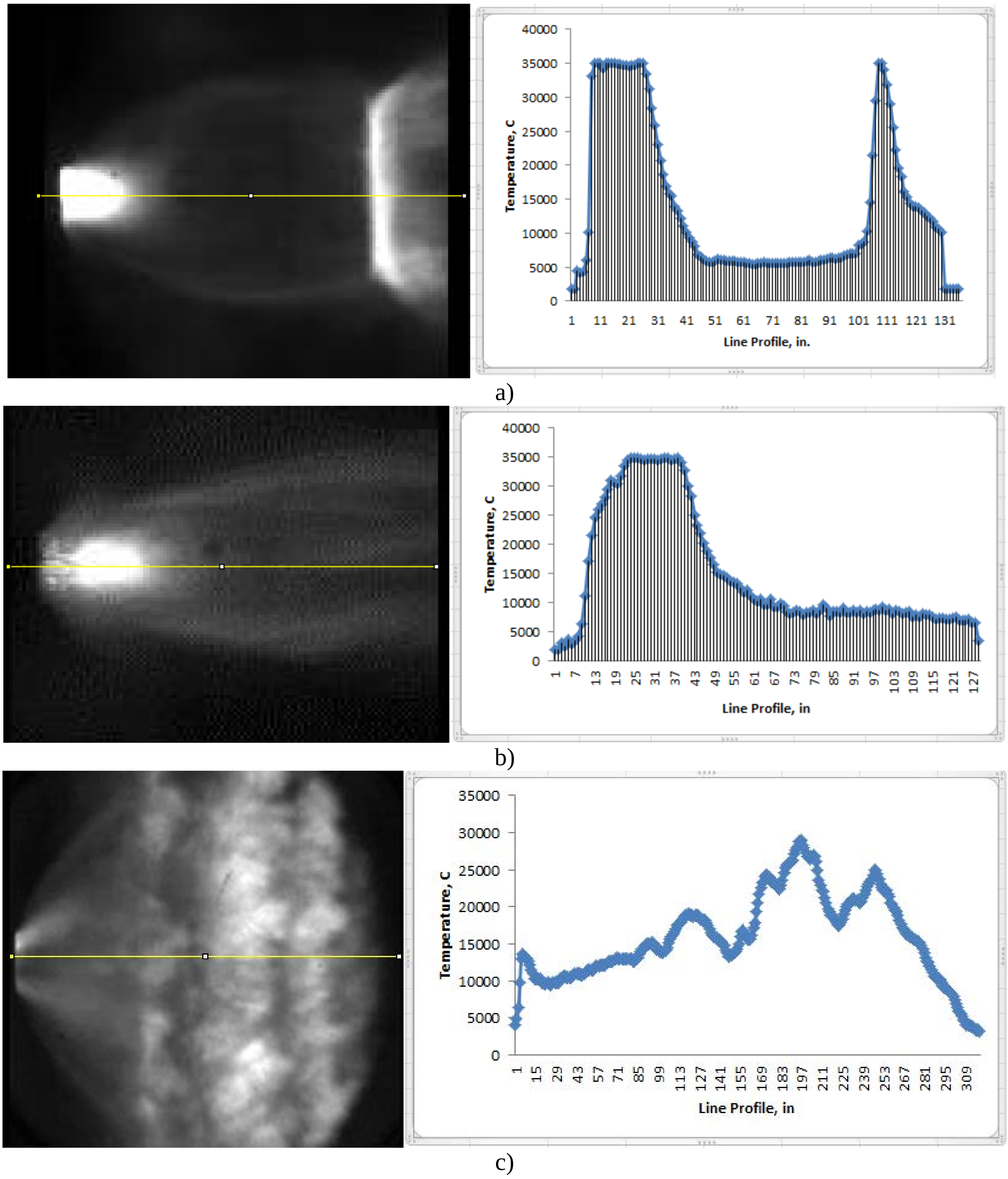


Figure 3. The photograms of plasma effusion after treatment and temperature analysis.

Having conducted the analysis of the photos with different level of luminous intensity we have obtained the array data, the processing of which allowed revealing a describing function – a calibrating curve. The resulting analysis of photograms of hypersonic plasma effusion is presented in Figure 3.

4. Conclusion

On the basis of the conducted work the following peculiarities of such approach to plasma temperature evaluation or, in other words, pros and cons have been found. The advantages of the method are the following: first, this is sufficiently simple technical realisation; second, it is possible to measure the temperature in a semiautomatic mode (realisation of batch processing).

The disadvantages are a higher measurement error (about 20 %) relatively other methods described earlier and impossibility of evaluating the maximum temperature in case of 'exposure' of photo-video shooting or separate elements on it.

The indicated disadvantages are inessential and can be eliminated completely in case of selection and use of more powerful light filters and conducting of the preliminary calibration of the system on the entities with known temperature similar to the analysed one.

5. Acknowledgments

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References

[1] Magunov A 2010 *Photonica*. **3** 43–47
[2] Ivashutenko A S, Martyushev N V, Vidayev I G 2014 *Advanced Materials Res.* **1040** 819–823
[3] Shevtsova L I, Sameyshcheva T S, Munkueva D D 2014 *Appl. Mechan. and Mater.* **682** 188–191
[4] Shevtsova L I, Korchagin M A, Thommes A, Mali V I, Anisimov A G, Nagavkin S Yu 2014 *Advanced Materials Research* **1040** 772–777
[5] Sivkov A A, Ivashutenko A S, Lomakina A A, Shanenkov I I 2015 *Applied Mechanics and Materials.* **756** 325–328
[6] Shanenkov I I, Sivkov A A, Pak A, Kolganova Y L 2014 *Advanced Mater. Res.* **1040** 813–818
[7] Sivkov A, Pak A, Shanenkov I, Kolganova Y, Prosvirin I 2014 *Advanc. Mater. Res.* **880** 36–41