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Increasing accuracy of high temperature and speed processes micropyrometry

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Abstract. The correction factor introduction in the method of measuring the brightness temperature of individual hot particles moving at speeds of 100-1140 m/s with diameter above the diffraction limit of the OES, can solve the problem of the moving objects brightness pyrometry, increasing accuracy of at least 2.5 %.

1. Introduction
The intensive development of the optical-electronic systems (OES) element base allow effectively use them for non-destructive control of high-speed and high-temperature processes [1-4]. The review [5] of modern noncontact temperature control methods has revealed brightness pyrometry moving objects problem due to introduction of more methodological errors in the measurement [1, 6-7]. High speed camera been calibrated at stationary blackbody this introducing error to the moving particles temperature measurement. In this approach temperature is calculating as the average value over the track length, ignoring their size and spatial movement. Therefore radiation superposition of registering particles during their spatial moving doesn’t taking into account. The purpose of research is to develop the methodology revised for brightness micropyrometry.

2. Experimental part
We measured the brightness temperature of the condensed phase sprayed particles. The brightness of the particles registering by the OES, based on multielement matrix photodetector [5-6]. We know that all condensed phase heated particles have a continuous spectrum of thermal radiation. The temperature of the object is determined in the absence of heating current I the filament of standard lamp on the stored value of the current intensity, corresponding to the EOS current output gradation. Thus, brightness of measured object and brightness of standard lamp digital equivalent are compared. The digital equivalent is representing by conformity spreadsheet between filament viewing area pixel brightness of standard lamp TRU 1100-2350 and current passing thought the filament. Digital equivalent is realized on the basis of macro program ImageJ. For determining the particles temperature it is necessary to take into account their linear dimensions. For this purpose the following assumptions are made: all particles are spherical with radius r, l is the particle track length. The particle radiation energy during one EOC shutter time, ie during the exposition time [8]:

\[ E = \int_{t_0}^{t_{up}} \phi(t)dt. \]
During this time, the absorbed light radiation creating the particles image on the photomatrix surface. Replacing the analog signal \( x(t) \) by the sequence, represented by the signal expansion coefficients on an orthogonal basis, is the most common discretization method. Instead of considering the functional dependence of \( x(t) \) in uncountable set of points, we can characterize the signal counting system coefficients \( x_n \). Basis is chosen from the convenience of the physical realization, simplicity of coefficient calculation and accuracy of approximation. Input optical image signal \( E(x, y) \) represents a two-dimensional generally continuous function of continuous spatial arguments (coordinates \( x, y \)) is converted into an electrical signal \( I(x, y) \) described the two-dimensional discrete continuous function of spatial arguments \( (x, y) \) and weight function \( g(x, y) \). Converting the input signal by optical system and the image formation on the sensitive area of the photodetector device can be represented as follows [9]:

\[
I = \int g(x, y)l(x, y)dxdy. \tag{2}
\]

If the particle was unmovable, then charge accumulation was continuous on the same photosensitive pixels area during the exposition time. Track of the moving particle has less brightness.

Suppose that on the image particle has size \( n \times m \) pixels and also suppose that radiation of the particle is constant by their surface. In determining the temperature by thermal radiation, the particle brightness is associated with an average brightness of the particle image:

\[
\overline{I} = \frac{\sum_{i,j} I_{i,j}}{n \times m}. \tag{3}
\]

During the time of particle moving the radiation illuminate area with \( n \times m \) size. On the track length the \( l/m \) of such particles is fit into (Figure 1) [10]:

\[
\frac{1}{l} \sum_{i,j} I_{i,j} = \frac{\overline{I}}{n \times m}.
\]

\[
\begin{align*}
\textbf{Figure 1.} & \quad \text{Discretization signal of a moving particle.}
\end{align*}
\]

Therefore, taking into account the superposition principle, integrated brightness at which we can calculate moving particle temperature in a discrete representation:

If the total brightness of the track pixels at a given exposition time does not exceed 255, then with using the spreadsheet conforming the brightness temperature of the standard lamp and brightness gradations of pixels is possible to determine the temperature of the moving particles. The brightness of a luminous object on the short exposition time is less than brightness of same objects at high exposition time.

During different exposition times particles flies different distances, and consequently, different number of pixels will forming the track. As seen from the graphs in Figure 1, for the same
temperature, and hence the value of the brightness gradations, will correspond different exposition times.

Consequently, it is possible to find the coefficient for translation of image brightness from one exposition to another, and measure the temperature corresponding to the pixel luminescence gradation of the image with different exposition time.

For example, during registering the radiation flux at 150 microseconds we obtain an image brightness of 200 gradations. If the exposition time of the same signal was 26 microseconds, the image had a brightness of 50 gradations. The conversion coefficient is equal to:

\[ k = \frac{I_{26}}{I_{150}} = \frac{50}{200} = 0.4 \]  

For moving particles temperature measurement is necessary to reduce exposition time, calculated with assumption of particle speed constancy during the track registration time.

![Figure 2. Calibration graphs for the OES based on camera with EOC.](image)

Method of converting the image brightness from one exposition time to another with moving particle observation area of one photosensitive cells to the other observation area, consists in follows:

1. Suppose that the emitter is unmovable.

   The charge of each detector (pixel) accumulated during the exposition time. It is convenient what most probable value of signal is equal to the average brightness registered on the light absorption zone. Most probable value of the signal is equal to the average brightness of the illuminated area. The most probable brightness value of illuminated area is associated with the temperature of radiated object. During all exposition time the same detectors is absorbing the light.

2. The object speed is not equal to zero.

   If object is moving, than at different times, different detectors are illuminating by different parts of the object. Thus, same detectors that were used in the case of a stationary emitter, will be irradiated only during the time where particle will take place in the projection sector of the pixel. Therefore, the scheme of moving particle Is equivalent to stationary emitter but exposition time is less and equal to the particle transit time along the same detector witch used for the case 1The particle velocity at all time of track registration is considered constant. Then:

\[ \frac{L - D}{t} = \frac{D - d}{t_i} \]  

(5)
\[ t_1 = t \cdot \frac{D - d}{L - D} \]  

where: \( L \)-track length, \( D \)-particle diameter, \( d \)-pixel size, \( t_1 \)-passage time of pixel projection zone, \( t \)-exposition time.

Thus, it is possible to measure the temperature of a moving emitter by comparing the brightness of pixels corresponding to the image gradation in another exposition time:

1. Measure the average brightness (grayscale) in the selected track, resulting in the frame sequence with exposition time \( t \);
2. Measure the transverse and longitudinal dimensions of the track (in pixels);
3. Accept the diameter of the moving emitter as transverse dimension of its clear picture. We accept that track length contains a minimum \( L = 2D \) pixels;
4. According to the formula 6 providing exposition time calculation, corresponded to the passage time of pixel projection zone;
5. According to calibration curve finding the brightness temperature corresponding to the measured average brightness of the image on the exposition time \( t_1 \).

For example, when the particle diameter \( D = 2d \), and the track length \( L = 4d \) exposition time is reduced by 2 times. So, if the average brightness (Fig. 2) in the track on the exposition time 20 microseconds was 29 shades of gray, this corresponds to a brightness temperature at 2000 C 10 microseconds exposition. If a correction coefficient has not been entered, the additional error amounted 100C, which is 5% of the measured temperature. At lower temperatures, the introduced error about 50 C.

3. Results and conclusion
The introduction of a correction coefficient in the brightness micropyrometry method allows increasing the result accuracy not less than 2.5%. Future developing will allow to create a method the OES using for two-phase flows diagnostics, estimates the intensity of the flows independently from temperature and dispersion composition [11].

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