Aerosol size and shape analyzer "Arfa"

G.A. Kolomiets and S.M. Kolomiets

Institute of Experimental Meteorology, Scientific Research Association "Taifun," Obninsk

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The aerosol size and shape analyzer "Arfa" is described. Its most important characteristic differentiating it from existing analogs is its capability in the presence of only one illumination source to simultaneously record in one plane (in one register) images of each particle corresponding to its projections onto two mutually perpendicular planes, thereby significantly increasing the information content of the measurements. In addition, a considerable simplification of the formation of the count volume is possible.

Among the various methods of determining the size and shape of suspended particles,[1] the most informative are television methods. Their essence is that the particles are illuminated by a light beam and images of these particles are formed by the corresponding optics on the photocathode screen of the video camera (these are usually bright-field images), from which it is possible to judge the size and shape of the particles. In the overwhelming majority of known methods, each particle gives only one image, corresponding to the projection of the particle on only one plane (perpendicular to the axis of the light beam).

However, the information contained in only one image is insufficient for a unique estimate of the shape of arbitrarily oriented nonspherical particles of even the simplest shape, i.e., an ellipsoid of revolution, without even talking about triaxial ellipsoids and more complicated shapes. Besides, in measurements directly in a particle flux (without fixing the specimens onto a substrate), for correct measurements it is necessary to bound the count volume along the axis of the light beam to conform to the acceptable depth of field. The latter is by itself a complicated problem and is solved, for example, by choosing a definite degree of coherence of the light beam and by additional nontrivial processing of the images.[1] That is, the realization of known television methods applied to measurements in particle fluxes is quite complex. In this light, let us consider possible adaptations of television methods that will increase the information content of the measurements and at the same time make it possible in a simple way to bound the count volume.

In the present paper we consider special features of the optical scheme of the television analyzer "Arfa,B developed at the Institute of Experimental Meteorology, Scientific Research Association "Taifun.B

Figure 1*a* shows a diagram of the device,[2] which allows one simultaneously to obtain two images on the photocathode of the video camera corresponding to projections of the particle onto two mutually perpendicular planes. The mirrors *5* and *6* are positioned and oriented so that the light-beam axis at the exit of objective *7* (the OY axis) is perpendicular to the light-beam axis at the exit of objective *2* (the OX axis). Objectives *4* and *7* are positioned so that the front focus of objective *4* coincides with the back focus of objective *7* at some point A (Fig. 1*b*). Objective *8*, coaxial with objective *7*, optically conjugates the above-indicated common focus A of objectives *4* and *7* with some point A' (Fig. 1*c*) in the recording plane of the photocathode of the video camera *9*.

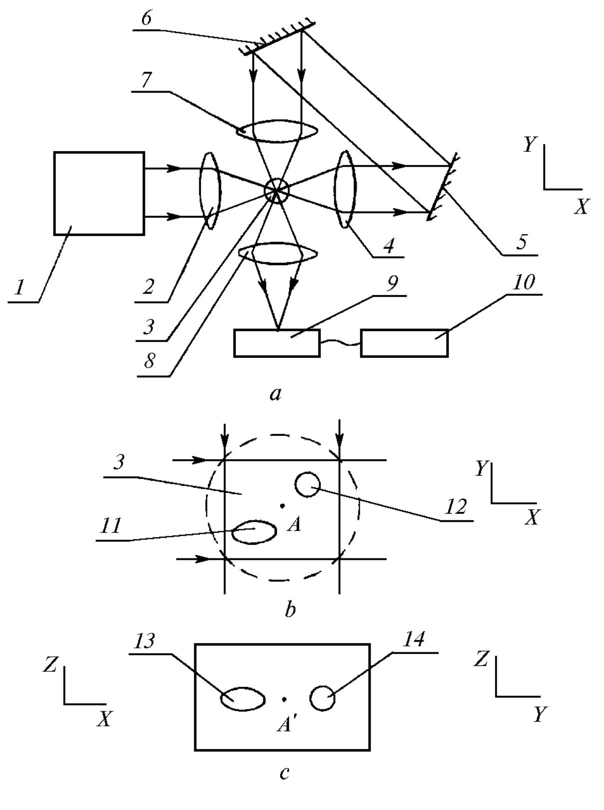

Fig. 1. Formation of projections of a particle onto two mutually perpendicular planes: overall diagram (*a*), view of the beam intersection region (*b*), view of the recording plane (*c*): illuminator *1*; objectives *2*, *4*, *7*, *8*; particle flux *3*; mirrors *5*, *6*; video camera *9;* processing block *10*; particle *11*; first and second images of the particle *12*, *13*; image of the first image *14*.

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The light-beam bending scheme (objectives *4* and *7* and mirrors *5* and *6*) constructs in the region of the particle flux *3*, perpendicular to the plane of the figure, the first real image *12* of the particle *11* (Fig. 1*b*), where this image corresponds to the projection of the particle onto the *YOZ* plane since in the construction of this image the particle is illuminated by the beam from the objective *12* propagating along the *OX* axis. The indicated image *12* (the same as in known methods) is transferred by objective *8* onto the recording plane as an image of the image, *14* (Fig. 1*c*). Simultaneously, objective *8* constructs in this same plane a second image *13* of the same particle *11*; however, the image *13* corresponds to the projection of the particle onto the *XOZ* plane since in the construction of this image the particle is illuminated by the beam from objective *7* propagating along the *OY* axis.

If the particle is found exactly at the common focus of objectives *4* and *7* (at the point *A*), then images *13* and *14* will be superimposed (at the point *A*′). This superposition can be avoided if the indicated foci are separated somewhat (e.g., in the direction of the particle flux) by a magnitude that exceeds the maximum size of the particles.

Thus, two images of each particle are formed simultaneously in the recording plane corresponding to its projections onto two mutually perpendicular planes.

Let us consider some peculiarities of these images.[3] As can be seen from the figures, the distance of images *13* and *14* from the point *A*′ is proportional to the distance of the particle *11* from the axes of objectives *7* and *4*, respectively. That is to say, it turns out to be possible to estimate the spatial position of the particle in the intersection plane of the direct and rotated beams (in the *XOY* plane). In particular, to limit the count volume in this plane it is sufficient to select for subsequent processing from among all the image pairs only the "goodB pairs, namely those for which the indicated distances (or, what is simpler to realize, the distance between the images) are less than some prescribed value. Such a discarding of "poorB images is realized in a way that is quite trivial and significantly simpler than in Ref. 1.

Next, if the particle is found within the limits of the acceptable depth of field, then the maximum size of images *13* and *14* in the *OZ* direction (in the vertical direction in Fig. 1*c*) is none other than the projection of these images (i.e., the projection of the particle) onto the indicated axis. Obviously, this size will be the same for both images *13* and *14* of particles of any shape and orientation. If the particle is not found within the limits of the acceptable depth of field, then the indicated dimensions of these images can differ. Thus, comparison of the indicated sizes gives additional information about the position of the particle in the plane of the figure (*XOY*) and can also be used to bound the count volume.

In the corresponding image processing step, which is especially easy to realize with the help of a PC, it is not hard to find both the area of each image and the length of its projection onto the mutually perpendicular coordinate axes *OX*, *OY*, and *OZ* (Fig. 1*c*). Consequently, from the relations given in Ref. 3 it is possible to calculate both dimensions of an ellipsoid of revolution oriented arbitrarily in space.

The considered device uses type M-42 standard microlenses with 8x magnification as the objectives *2*, *4*, *7*, and *9*. These objectives are mounted at a working distance from the center of the count volume (point *A* in Fig. 1*b*) of 8.6 mm (correspondingly, the diameter of the aerosol channel is roughly 15 mm). In accordance with the usual requirements of the theory of optical devices, we also determined the distance between objectives *4* and *7* along the optical axis. Here, objective *4* constructs an intermediate real image of the point *A* in the plane symmetric relative to mirrors *5* and *6*; it is this image that is transferred by objective *7* into the count volume (point *A*′ in Fig. 1*c*).

For correct measurements, it is necessary that the magnification V of the pair of objectives *4* and *7* be equal to unity and not depend on the position of the particle in space. The first condition is easily satisfied for the corresponding alignment of the optical scheme for some "zeroB position of the particle (whose center coincides with the point *A*). However, if the particle is shifted from this zero position, the magnification V, generally speaking, can vary.

Let the particle be shifted from its "zeroB position along the *OX* axis by some distance Δ. Then, as it is not hard to show, its image in the count volume (constructed by the pair of objectives *4* and *7*) will be shifted along the *OY* axis by some amount Δ^*, and the magnification of the image will take some value V^*, where

$$\Delta^*/\Delta = V^*/V = 1/[1 + 2\Delta/(a_0 - f)], \qquad (1)$$

where f is the focal length of the objectives and a_0 is the distance from the object plane to the front principal plane.

For the case under consideration $a_0 - f \approx 1.5$ mm. Hence it is clear that for $|(\Delta - \Delta^*)/\Delta| = |(V - V^*)/V| \le 0.1$ the permissible shift $\Delta \le 0.08$ mm while the field of view is roughly 0.6 mm so that $\Delta_{max} = 0.3$ mm. That is to say, the scheme[2] represented in the figure is very sensitive to the position of the particles in the count volume.

In light of this, a collective is added to the actual scheme of the device, which is mounted in the plane of the above-indicated intermediate image. This collective fulfills two functions. The first (the usual function of a collective) is conjugation of objectives *4* and *7* in the light flux. The second is "stabilizationB of magnification of the two objectives *4* and *7*. Indeed, in this case

$$\Delta^*/\Delta = V^*/V = 1/[1 + 2\Delta/a_0]. \quad (2)$$

It can be seen that relation (2) differs substantially from relation (1) since $a_0 \gg a_0 - f$. Thus, for $a_0 \approx 15$ mm and $\Delta = 0.3$ mm it turns out that $|(\Delta - \Delta^*)/\Delta| = |(V - V^*)/V| \le 0.04$. But this is completely acceptable for the majority of cases.

In devices of this type very high requirements are placed on the illuminator, which should form in each half-frame quite short light pulses one microsecond in duration (in order that the images of the particles not "smear outB in their direction of motion). Here the energy per pulse should be sufficient for reliable recording of the images.

In the considered device, a PIN-756 video camera with a horizontal resolution of 600 tvl served to record the images. Studies showed that for this video camera it is possible to use a 1–2K LED as the illuminator.[4] For the indicated pulse regime, we obtained an experimental dependence of the peak value of the light flux of the LED on the pump current. This dependence deviates considerably from a linear dependence for currents exceeding 300 mA. In this case, a current of roughly 1 A is probably the limiting value from a practical point of view. Note that in the nominal data[4] the limiting current (100 mA) is indicated only for the continuous-wave regime.

Thus, the considered device can be used to analyze the size and shape of suspended particles in the size range of roughly 2 to 100 μm. The substantially greater information content that can be achieved with this device in comparison with known devices of similar design is complemented by a dramatic simplification of the procedure for bounding the count volume to accommodate the acceptable depth of field.

Acknowledgments

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