Determination of parameters of the compelled capillary disintegration of liquid jets

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Abstract. The technique of the automated precision parameters diagnostics of the compelled capillary disintegration of liquid jets is developed for the solution of heat-physical problems of receiving the stable monodisperse drop streams. The analysis of the images received from two digital cameras, located at the angle ninety degrees to each other is the basic of this procedure. One of cameras fixes the image of a drop flow in plane X, another - in plane Y. The minimum time of storing images is ~0.1 microsecond. By means of specially developed software in the "on line" mode it is possible to process images and to determine the following parameters: jets speed, drops speed, jets length, jets diameter and drops diameter. Testing on objects with the known geometrical sizes confirmed working capacity and efficiency of the technique and the software. The relative error of parameters determination does not exceed 0.5% for jets with length of several millimeters. The developed technique and the software allow to increase the accuracy and reliability of parameters determination of compelled capillary disintegration of liquid jets and drop streams and expand possibilities of parameters control of setups for receiving monodisperse streams.

1. Introduction

The basic trend of modern development of disperse technologies is passes from disperse systems with wide spacing in parameters to the monodisperse systems consisting of spherical particles flows of a different phase status with small dispersion by the sizes and the speed. The small dispersion by the sizes and speed allows not only to improve considerably existing technological processes, but also to create new technologies. Now the monodisperse streams and technologies developed on their base are used in the following fields of science and technology: scientific instrument making, space technologies, power and electronics, biology and medicine, ecology. The detailed description of the technologies using the monodisperse streams is submitted in [1-7].

Structurally and technologically the installations for receiving the monodisperse streams can differ from each other, however, they should have the following necessary elements: the monodisperse drops generator with a nozzle, the working chambers and sluices connecting working chambers. The description of some types of the installations is submitted in [8, 9]. A theoretical basis of receiving stable monodisperse drops stream is the theory of compelled capillary disintegration of Rayleigh-Weber (the theory of CCDJ) [10].

There are many methods of definition of separate characteristics of CCDJ: jets length; jets speed and drops speed; jets diameter and drops diameter; deflection angle of jets from the vertical. However for receiving the stable monodisperse streams it is necessary to know not separate characteristics, but
all characteristics of CCDJ and drop streams at the same time. The technique of the automated definition of CCDJ and drop streams characteristics was developed.

2. Technique of determination of the CCDJ and drops stream parameters
Underlying the technique is processing the image of the streams and drop flows. The full technique consists of the following parts: image acquisition, image processing and definitions of CCDJ and drop streams characteristics.

2.1. Image acquisition technique
Two digital video cameras PCO-PixelFly of Pro.imaging located at an angle ninety degrees to each other and the illumination system consisting of two pulsed light sources are used for the definition of CCDJ characteristics (figure 1). One of cameras fixes characteristics of CCDJ and monodisperse drops in plane $X$ (camera $X$), another — in plane $Y$ (camera $Y$).

There are following elements: CCD matrix, analog-digital converter and fast internal memory in each video camera. Cameras connect to the computer by means of RS-232 interface.

The illumination system consists of two pulsed light sources. Synchronous operation of the cameras and light sources is carried out by means of the external or internal generator which start the video cameras and the illumination system at the same time. The full cycle of cameras operation consists of two parts: mode of picture storage and reading mode.

In the storing mode the image of a jet, drop stream and additional objects is focused on matrixes of video cameras, and are remembered in fast memory in the form of separate frames. Usually additional objects which image is remembered together with the image of jets and drops are: an output nozzle of the drops generator and the sluice through which drops pass between working chambers (figure 1). Storing time of a frame is ~0.1 microsecond. Thanks to short storing time the jet and drops are displaced slightly in space, and the image turns out bright and contrast.

In the reading mode the frames are consistently read out from an internal memory of cameras and sent to memory of the computer. The minimum reading time of a frame is 40 msec.

2.2. Image processing technique
Read frames are located to the respective area of memory $X$ (folder $X$) or $Y$ (folder $Y$) in the computer. For selection of information on the CCDJ parameters, each frame is exposed to special processing which consists of the following stages: contrasting, selection of the closed dark bodies, identification of the selected bodies and scaling.

Contrasting of the image is made at an initial stage. Contrasting consists in the analysis of brightness value of the image and the background in each point of a frame. If point brightness is less than background brightness, then this point is defined as black. Otherwise, the point is defined as white. This operation is necessary for receiving a clear boundary between a background and the studied objects: jets, drops and other support entities.

The search of the closed dark bodies which are in limits of one frame begins after contrasting. The identification of separate bodies: the nozzle, a jet, drops, the sluice is made after their selection.

The nozzle is understood as the body touching the upper bound of the frame and having the relation of depth dimension to lateral dimension smaller 1.

The sluice is understood as the body touching the lower bound of the frame and having the relation of depth dimension to lateral dimension more than 1.

If the lower bound of a nozzle has a sharp reduction of width, then all lower part is recognized as a jet.

Objects in the drop form have no contacts with frame borders, for their selection the additional selection condition – rotundity coefficient is imposed. The rotundity coefficient of a drop indicates proximity of the found body circuit to an ellipse with the same vertical and horizontal size.

The final stage of processing is scaling. As a result of the made experiments the determination of scaling ratio by the known sizes of two bodies (the nozzle and the sluice) and the fixed distance be-
tween them was the most optimum. In this case borders of all bodies are defined steadily and at single
coefficient of increase the error of delimitation makes ±3 microns.

![Figure 1. Arrangement of the optical system elements by definition of CCDJ and monodisperse drops characteristics: 1 – digital video cameras, 2 – pulsed light sources, 3 – the nozzle, 4 – a jet, 5 – drops, 6 – the sluice.](image)

### 2.3. Technique of definition of CCDJ and drop streams characteristics

Definition of CCDJ and drop streams characteristics: jet lengths, deflection angle of jets from the vertical, diameter of a jet and drops, speeds of a jet and drops occurs as follows.

The beginning of a jet is accepted the line with sharp change of image width. At first the right and left borders of a jet is defined for this line, and then – position of the jet center. Jet diameter is equal to the difference of coordinates between the right border and left. The end of a jet is accepted the line in which the right and left borders of the image coincide. Jet length is defined as the difference between the coordinate of the initial center of a jet and the coordinate of a point of borders coincidence.

Definition of deflection angle of jets axis from the vertical for each of the planes comes on the following algorithm. At first the right and left borders of a jet are defined for each line of the image. Then the position of the jet center is defined for every line. The deflection angle from the vertical is defined as a result of approximation of all jet centers coordinates.

The bodies which do not have contacts with image borders are accepted to drops. At first the right and left borders are defined for each such object line by line in each plane. Then boundary points for each plane are approximated by means of the least-squares method by circles. As a result of approximation we receive the following characteristics: diameter of a drop and coordinate of each drop center. Coordinates of next drop centers are used for determination of drop speed in planes X and Y and full speed of a drop.

### 3. Description of the program of definition of CCDJ and drop streams parameters

The technique described above was a basis for creation of the program for image processing and definition of CCDJ and drop streams parameters in "on line" mode [11, 12]. At the same time the program processes the images from two cameras which are conditionally called X and Y. The block – scheme and the working window of the program are submitted in figure 2 and 3.

The block– scheme of the program includes the following stages: task of initial parameters, obtaining the image from the camera, definition of transition point from light to dark for every line, the anal-
ysis of transition points and definition of full border of all dark bodies, definition of bodies type, determination of jet and drops parameters, an output of results.

At each camera it is possible to configure the following settings: permission in horizontal direction, permission in vertical direction, sensitivity, type of start (external or internal), digit capacity, exposure, scale, interval between frames, operation mode (framing or video mode), image recording, image processing parameters. The choice of necessary parameters is made in the corresponding window of the program (figure 3).

In the upper window of the program it is possible to configure the following settings: permission, sensitivity, a type of start, digit capacity in bits and exposure.

The buttons with plus signs (increase) and minus (reduction) are used for change of the image scale in program window.

In the lower right window of the program it is possible to select an operation mode of cameras. “Frame” button allows to receive the single image, “Video” button - the image from cameras through a certain interval. The time interval between frames is specified in the lower part of the window.

The “Processing Parameters” mode is selected in the upper working program window for setup of parameters of image processing. In this mode it is possible to configure the following settings: preprocessing, parameters, work with objects.

Preprocessing allows to cut out the most informative fragment of the image from a full frame and to use only this fragment in the course of further image processing. For convenience of postprocessing this fragment can be transformed in addition. The following opportunities are provided in the program: turn of a fragment on a corner, to multiple 90 degrees, and reflection of this fragment in horizontal or vertical direction.

“Parameters” button allows to select the level of a binding to object border in the contrasting mode.

After contrasting of the image the program carries out search of the closed dark bodies and their identification. For correct algorithms execution it is necessary to specify the following parameters in the section “Work with Objects”: minimum area, squareness coefficient, body width relation to its height, coefficient of change of body width, rotundity coefficient.

The “Calibration” mode is intended for determination of scaling ratios on each plane. In addition it is necessary to specify the liquid density and exciting frequency for determination of weight, volume and speed of drops. The scaling ratio decides by comparison of the known sizes of the nozzle, the sluice and the fixed distance between them in microns on the corresponding sizes in pixels. The sizes of the nozzle, the sluice and the fixed distance between them are entered in the editor located below on a tab. If necessary it is possible to set scale manually, for this purpose it is necessary to put “Specify Manually” checkbox. The received scaling ratios are used for determination of jet length, the diameter of jet and drops, the speed of a jet and drops, deflection of nozzle axis and sluice axis, deflection of jet axis and sluice axis.

A set of tabs in the left lower part of a primary window of the program allows to select the current output mode of results of a program runtime. The type of tabs for some modes is presented in figure 3. “Viewing” tab allows to browse the images received from cameras without their processing. By means of “Disk writing” button it is possible to write the specified number of image files on a disk in the specified folder (the folder is selected by a folder image button). Names of files form from date and time of obtaining the image. The plane in which the camera is located (X or Y) is specified at the end of a name. It is possible to interrupt the sequence of record with “Interrupt” button.

The “Adjustment of Cameras” mode is intended for alignment of images and scales of both cameras. In this mode the following data are programatically defined and output: data on nozzle height in pixels, nozzle thickness in pixels, stream width in pixels, deflection angle of a jet or a nozzle from the vertical. At coincidence of the sizes on images of both cameras and corners equal 0, cameras are considered as aligned.

In “Nozzle Adjustment” mode the values of space shift of nozzle axis from sluice axis are programatically defined and displayed.
In “Jet Adjustment” mode the values of space shift of jet axis from sluice axis are programmatically defined and displayed. Besides, the average length of not broken up part of a jet is defined and displayed.

**Figure 2.** Block scheme of the program for determination of CCDJ and drop streams parameters.
Figure 3. Working window of the program for determination of CCDJ and drop streams parameters.

“Average Parameters of Drops” mode is intended for definition of mean values of drops: volume, weight, speed and diameter. For determination of drops mass it is necessary to specify liquid density in addition. The quantity of drops for averaging is set in the corresponding editor.
“Dispersion of Drops” mode is intended for accumulation of statistics and determination of dispersion on drops diameters. The quantity of drops for averaging is specified in the corresponding editors. Preliminary results are displayed in the right lower part of a primary window of the program (figure 3).

“Draw Circuits of Objects” checkbox in the lower part of a primary window of the program allows to apply circuits and axes of the received bodies on the image.

“Exit” button is intended for completion of work with the program.

4. Testing of the technique and software
For testing of the technique and the software the object with the known sizes was located in focus of a lens of video cameras, and its geometrical sizes experimentally were defined. Knowing the difference between experimentally measured geometrical sizes of the object and its exact sizes, it is possible to define an error of the technique and the software. The glass fibers of different diameter (from 100 μm to 400 μm) and different length (from 0.5 mm to 1 mm) were use as experimental objects. The error of determination of length and diameter made ±0.1 μm. The upper end of the fiber fastened to an output nozzle of the drops generator, and lower end connected to a small load.

By means of the special justified screws installed on the drops generator in “Adjustment of Cameras” mode the maximum coincidence of cameras axes to drops generator axis and to fiber axis was carried out. Then in “Jet Adjustment” mode were defined: average diameter of fiber, length of fiber and measurement error.

As a result of processing of experimental data it was established that the relative error of determination of length for jets over one millimeter long does not exceed ±0.5%. For shorter jets the error increases and for jets 100 μm long reaches ±5%.

Thus, testing confirmed working capacity and efficiency of the developed technique of definition of CCDJ and drop jets characteristics.

5. Conclusion
The technique of the automated precision diagnostics of CCDJ and drop streams parameters is developed for the solution of heat-physical problems of receiving the stable monodisperse drop streams.

The analysis of the images received from digital cameras, located at the angle ninety degrees to each other is the basic of this technique. In the "on line" mode it is possible to define the following characteristics by specially developed software: jet speed, drops speed, jet length, jet diameter, drops diameter, an angular deviation of jet axis from the vertical.

Testing of the technique and the software on objects with the known geometrical sizes confirmed their working capacity and efficiency. For jets of several millimeters the relative error of determination of jet length, drops speed, drops size and jet speed does not exceed 0.5%. The error of definition of an angular deviation of jet axis from the vertical does not exceed 0.003 rad.

The developed technique and the software allow to increase the accuracy and reliability of determination of CCDJ and drop streams parameters and significantly expand possibilities of control of installations parameters for receiving monodisperse streams.

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