Shadow Doppler Particle Analyzer

Koji UEYAMA, Minoru KOMAKI, Kazuaki MATSUURA, and Katsuji HIRONAGA

KANOMAX Japan Inc., Shimizu, Suita, Osaka 565-0805, JAPAN

1. Introduction

Recently, the better understanding on the characteristics and behavior of particles (or droplets) in a multi-phase flow became essential to the development of various kinds of industrial machines. As the measuring techniques of such particles, optical methods have been widely applied for practical uses because of their superiority to the other systems, such as its no-flow-disturbance feature. However, strictly speaking, most of them are not applicable to non-spherical particles or those with unknown refractive indices since they are based on the Mie scattering theory. Therefore, a new technique is demanded, which can measure particles of arbitrary-shape with unknown optical properties.

The present paper provides a brief introduction on a new measuring system, "Shadow Doppler Particle Analyzer (SDPA)". Lately, this new technique suggested by Ref [1] and [2] has been considerably developed as an integrated system to be fitted for industrial processes. The SDPA can realize the simultaneous measurements of shape and velocity of arbitrary-shaped particles, by combining a conventional laser Doppler velocimetry (LDV) with additional receiving optics detecting the shadow image of the particles by a linear fiber-array sensor. The principles, distinguished features, and some experimental results measured by the SDPA are presented to show the high performance of the present system.

2. Principle of SDPA

The SDPA system consists of a conventional LDV, receiving optics, and a signal processor, whose optics is schematically illustrated in Fig.1. The LDV and the receiving optics are shown on the left and right in the figure, respectively.

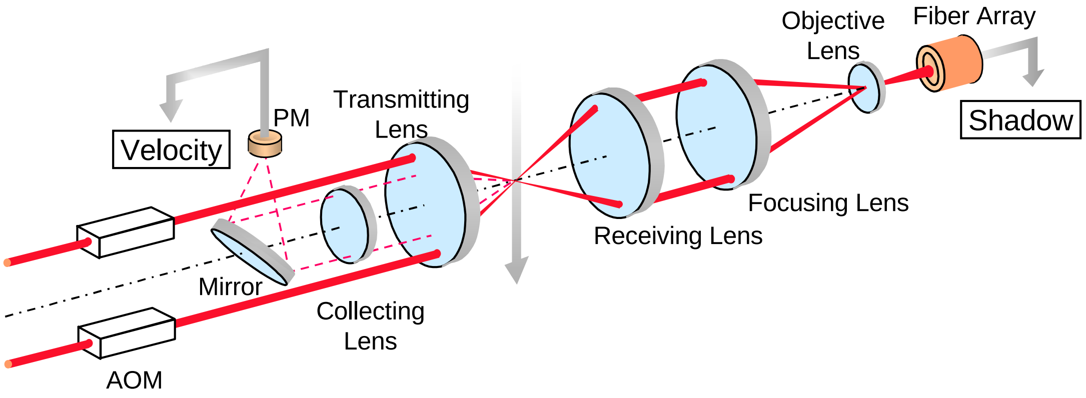

Figure 1: Schematic of SDPA Optical System

The particle velocity is measured by the LDV. In Fig.1, the two laser beams originating from the same laser source coincide each other at the focal point of the transmitting lens, forming the measuring volume of the LDV. The passage of a particle through the measuring volume causes the light scattering, which is collected by the collecting lens onto a photo-multiplier detector (PM). The particle velocity is obtained from this light-scattering signal since it contains the Doppler shift frequency depending on the particle velocity.

On the other hand, the particle shape is measured by means of the receiving optics. The two laser beams of the LDV transmitting optics are focused again, and the image of this secondary focal point is magnified by the objective lens. The image is finally projected onto the linear image detector consisting of 64 optical fiber array in line, each of which is connected to an avalanche photo diode (APD). During the passage of a particle through the measuring volume, its 'sliced' shadow images are stored at each moment of the data-sampling. Hence, the shadow image of the particle can be reconstructed from the temporal series of the sliced images.

The particle shape is obtained from the reconstructed shadow images in the following manner. Depending on the trajectory of a particle, its shadow image can be classified into one of the three categories as illustrated in Fig.2. The figure also presents the corresponding APD output signals.

When the particle trajectory is on the focal plane of the receiving optics (Trajectory A), the two shadows projected by each of the two laser beams coincide precisely. Therefore, the shadow image in Fig.2 exactly represents the particle shape.

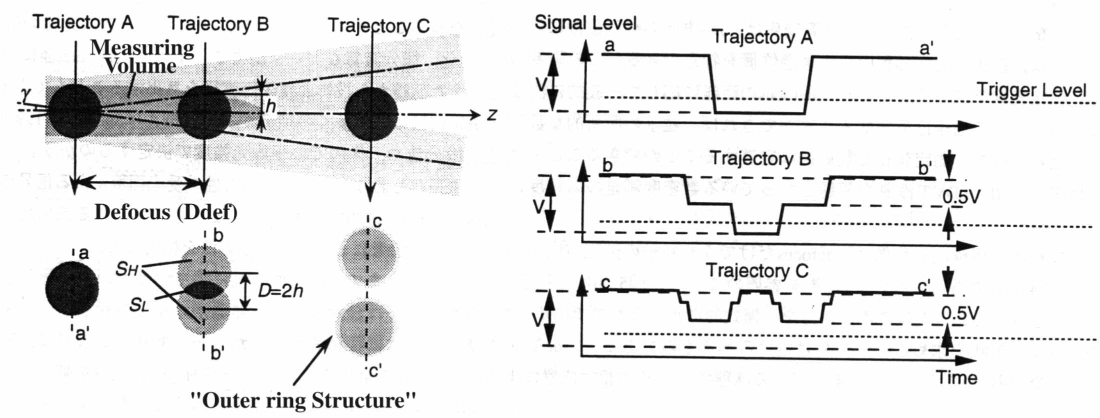

Figure 2: Dependence of Shadow Images and Signals on Trajectories of Particles

As the distance between the particle trajectory and the focal plane ("defocus distance") increases, the overlapped area of the two shadows decreases and the shadow image has two different intensity levels (Trajectory B). In the case, the particle shape is obtained by separating the original shadow image in Fig.2 into the two shadows by each laser beam. Furthermore, the two shadows are utilized to calculate their cross correlation, which provides us useful information, such as the defocus distance and the direction of the trajectory projected onto the focal plane.

If the defocus distance is too far, the two shadows do not overlap any more (Trajectory C). Since such shadow images may derive from particles not passing across the measuring volume, only the particles passing through Trajectory A or B are sampled as valid data.

3. Remarkable features of SDPA

The SDPA has the advantages over the other conventional measurements with the following features:

(1) The SDPA can measure not only particle size but also its shape since the principle is based on its shadow image. This also means that SDPA is applicable to "non-spherical" particles.
(2) The SDPA measurement is free from the optical properties of particles. Therefore, various applications are possible, such as the measurements of particles in a chemical reaction process and of droplets with pigment in a painting spray.
(3) The SDPA provides the information on the direction of the trajectory projected onto the focal plane so that two-dimensional velocity vector can be measured.
(4) The SDPA requires no calibration by means of known-size particles since all the parameters necessary for the measurements are obtained from the geometrical arrangement of the optical system.
(5) The SDPA can accurately estimate particle concentration since it provides the information on the position of particle trajectory, that is, the defocus distance.

A typical specification of the SDPA is summarized in Table.1. The present system has achieved high-speed data-sampling for both Doppler signals (80MHz) and shadow image signals (20MHz), which has realized the measurements of such small and fast-moving particles as shown in the table.

It should be also noted that original shadow images are stored with its intensity resolved into 256(8bit) levels, which enables users to perform various kinds of post-processing.

Table 1: Specification of SDPA

Specifications	
Particle Concentration	10^3 particles /cm^3
Dynamic Size Range	15 to 1
Overall Size Range	5 μm to 1 mm
Size Accuracy	4% (spherical), 10% (non-spherical)
Particle Velocity	～Maximum 100 m/s

4. Application Examples

Some results of SDPA measurements are presented in Fig.3 and Fig.4. In Fig.3, the shapes of aluminum particles are revealed in detail. These shadow images are utilized to calculate such as the length of major and minor axes, aspect ratio, and Feret diameter. Figure 4 shows the results of SDPA measurement for a painting spray. In addition to the histograms of particle velocity and its diameter, the simultaneous measurement of those particle properties enables us to analyze their correlation.

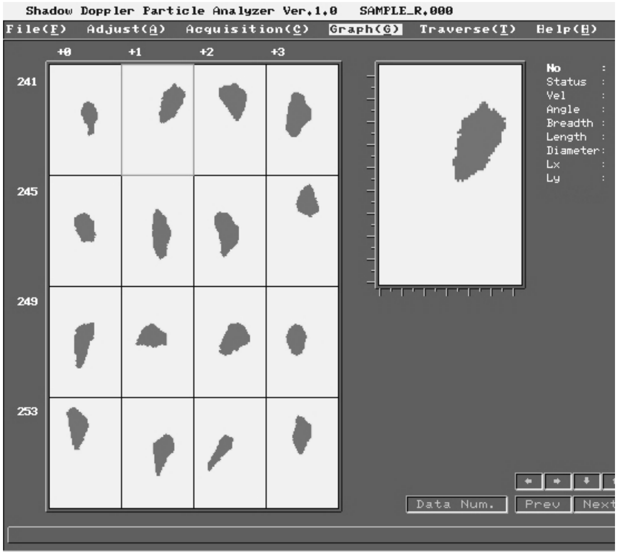
Shadow Doppler Particle Analyzer Ver.1.0   SAMPLE_R.000

Figure 3: Aluminum Particles monitored by
SDPA Particle Shape Display

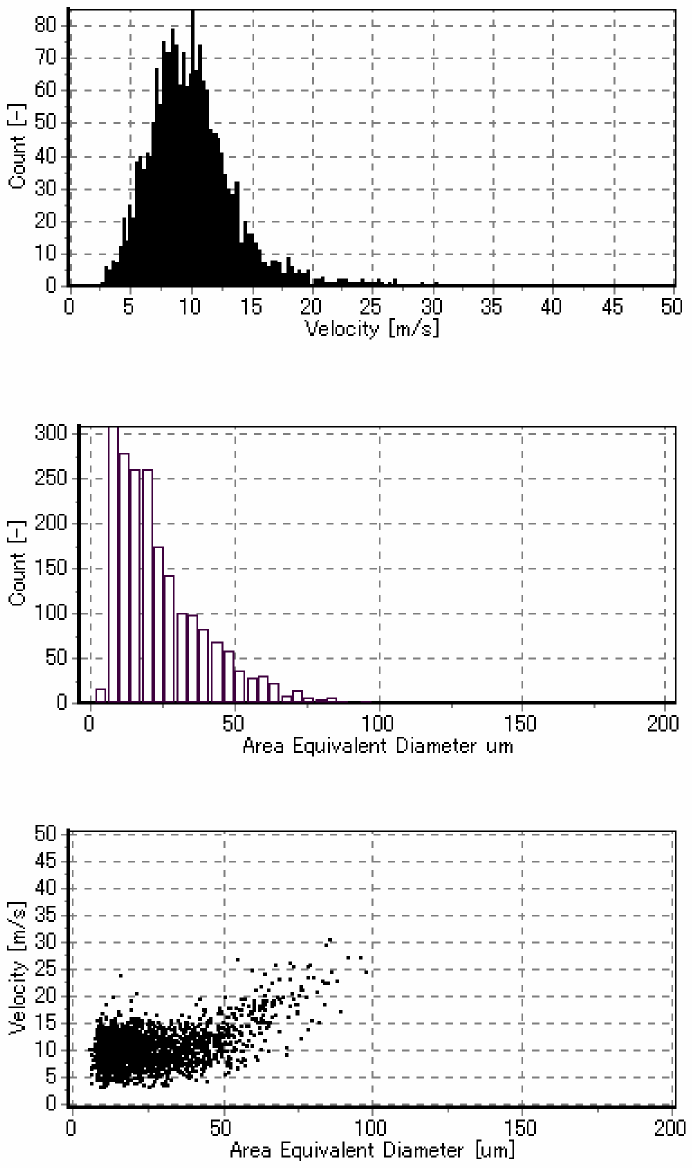

Figure 4: SDPA measurements for Painting Spray;
Velocity Histogram, Diameter Histogram,
and Their Correlation

5. Summary

The present paper reported the "Shadow Doppler Particle Analyzer (SDPA)", which was recently developed for simultaneous measurements of particle velocity and its shape. The SDPA provides various kinds of useful information on particle properties and it is applicable to practical multi-phase flow fields in various industrial processes.

6. References

1. Y. Hardalupas, K. Hishida, M. Maeda, H. Morikita, A. M. K. P. Taylor, and J. H. Whitelaw, “Shadow Doppler Technique for Sizing Particles of Arbitrary Shape,” *Applied Optics*, Vol. 33, No. 36, pp.8417-8426 (1994)

2. H. Morikita, K. Hishida, and M. Maeda, “Measurement of Size and Velocity of Arbitrarily Shaped Particles by LDA Based Shadow Image Technique,” *Developments in Laser Techniques and Applications to Fluid Mechanics*, Springer-Verlag, pp.354-375 (1995)