Influence of user adjustable PDA-parameters on drop size measurements

Ralf Kapulla[*] and Salvador Bravo Najera[**]

[*]Laboratory for Thermal Hydraulics, Paul Scherrer Institut, 5232 Villigen, Switzerland
[**]Chemist´s Faculty. University of Murcia. Campus of Espinardo. 30100 Murcia, Spain

Abstract

The influence of operational parameters of a phase Doppler anemometer (PDA) measuring droplet size distributions has been experimentally determined using water droplets. During the experiments the following PDA parameters have been varied: the beam power (4 to 30 mW), the photomultiplier amplification voltage (700 to 1200 V), the signal gain (4 to 24 dB) and the signal-to-noise ratio (SNR) (-6 to 4 dB). It is found that the apparent count mean droplet diameter $D(1,0)$ decreases then reaches a constant asymptotic value as the beam power, the photomultipliers amplification voltage and the signal gain are increased, respectively. Disregarding the above-mentioned parameters might result in false measurements especially for droplet size distributions which contain fractions below ≈ 15 μm. This behaviour is attributed to the fact, that smaller droplets scatter less light than larger droplets at the same scattering angle for a given set of adjusted parameters. For low beam powers the scattered light from small particles vanishes partly in the noise floor of the system and becomes therefore invisible for further data treatment. Increasing the beam power results in valid signals for the smaller particles until the smallest physical existing particles are resolved. Increasing the beam power further dos not alter the measured distribution anymore; the asymptotic state is reached. For further measurements, the operational parameters have to be chosen in this asymptotic range where the measured quantities do not vary significantly. The SNR has only a small effect on the results.

1 Introduction

In contrast to the care spent in describing the important optical alignment of a PDA by the manufacturer (DANTEC 2003), only little information can be found in the operation manuals regarding the influence of software or hardware adjustable parameters such as laser beam power (BP), amplification level of the photomultipliers (PM) and signal gain (SG). We therefore decided to perform easy to reproduce measurements to obtain a more systematic insight into these mutual dependencies. Beside published work (Albrecht et al. 2003, pp. 651 ff.), (Mulpuru et al. 1996), (McDonell and Samuelson 1990) and (Chao et al. 1990), where only some of the above mentioned operating parameters have been treated, an early investigation on the mean diameter for a non-commercial PDA can be found in (Wriedt 1993).

In (McDonell and Samuelson 1990) and (Chao et al. 1990), for example, the influence of the photomultiplier tube voltage and the frequency shift are examined. It is observed that the PM voltage strongly affects volume flux measurements and number mean diameter, but has a little effect on Sauter mean diameter.

2 Experimental-Setup

To extend the findings of the above-mentioned experiments to smaller droplet sizes (mean diameter $\approx 5\ \mu m$) in order to produce less scattered and easy to reproduce data, and to include also the software adjustable signal gain and the beam power, an intensive program was conducted where mainly the size distribution of water droplets have been measured for different combinations of operational parameters.

The homogeneous water droplets were produced with demineralized water by means of a nebulizer similar to the TSI Model 3075/3076 (TSI 2003, pp. 1-3). The droplets have been measured by means of a three-detector, standard DANTEC PDA, see Fig. 1. The measurement volume was $20\ mm$ above the orifice of the nebulizer. The operation principle of the PDA can be found elsewhere, (Albrecht et al. 2003). The optical parameters of the set-up can be found in Table 1.

Laser	$ArIon$	–
wavelength	514.5	nm
focal length, transmitter	800	mm
intersection angle $\Theta/2$	2.716	$^\circ$
beam expander ratio	1.950	–
probe volume dx	0.122	mm
probe volume dy	0.122	mm
probe volume dz	2.578	mm
focal length, receiver	310	mm
off-axis angle Φ	40	$^\circ$
Dominating scattering order	refraction	–

Table 1: *Optical parameters used for the measurements.*

Under certain circumstances, particle size measurements using a PDA instrument can be erroneous due to the Gaussian beam effect, see (Araneo et al. 2000). A general rule of thumb

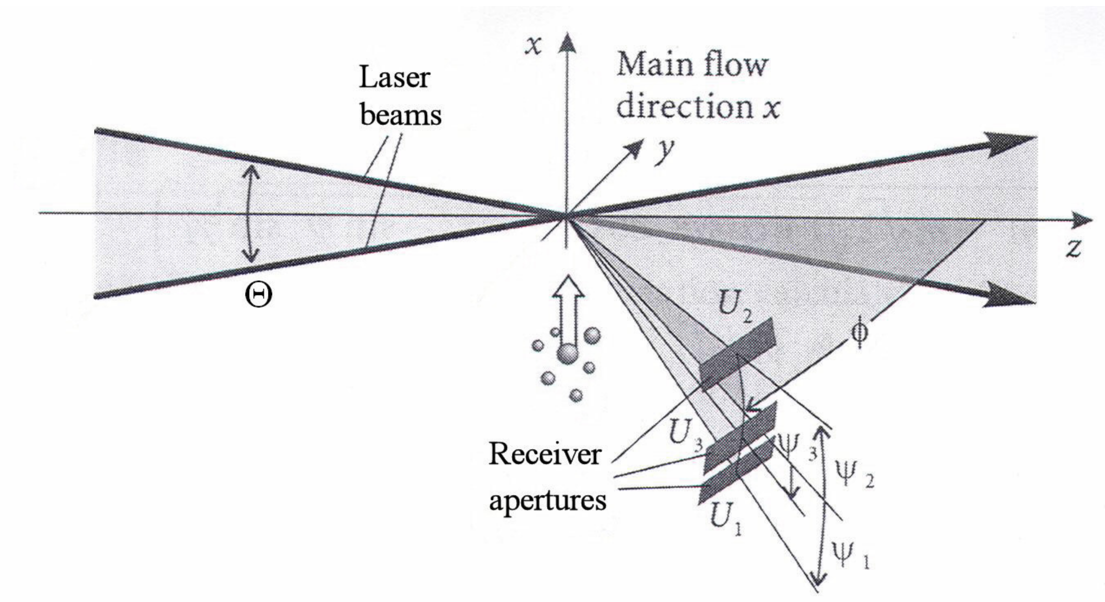

Figure 1: *Optical arrangement of a three-detector, standard PDA. Picture adopted from (Albrecht et al. 2003, pp.: 418).*

recommends applying standard PDA techniques only up to particle diameters which do not exceed $1/3$ to $1/2$ the beam waist diameter. With the probe volume given in Table 1, an approximate upper limit for what particle diameter Gaussian beam effects becoming important is $\approx 50\ \mu m$. This is far above the droplet sizes considered here.

The following parameters have been systematically varied: 1) the *laser beam power* (4 to 30 mW), 2) the *high voltage level* (700 to 1200 V), determining the amplification of the PMs, 3) the *signal gain* (4 to 24 dB) and the 4) *signal-to-noise ratio* (SNR) (-6 to $4\ dB$). During all of the experiments presented below, the optical configuration as well as the operation parameters for the nebulizer were left unchanged, i.e. the physical droplet distribution was the same for all runs..

3 Results

The count mean diameter $D(1,0) = \sum d_i/N$ (with $i = 1, ..., N$) as a function of beam power with the PM amplification voltage (AV) level as parameter can be found in Fig. 2 a).

All other operation parameters were left unchanged (signal-to-noise ratio, $SNR = -2\ dB$ and signal gain $SG = 20\ dB$). Increasing the beam power from 4 to 20 mW causes a decrease in the measured $D(1,0)$ for lower amplification voltages ($AV \leq 850\ V$). Taking the results for $AV = 750\ V$, $D(1,0)$ decreases from $\approx$ 20 to 4 μm. In contrast, for beam powers beyond 20 mW the count mean diameter $D(1,0)$ remains essentially constant. For higher amplification voltages ($AV \geq 900\ V$) the curves collapse nearly indistinguishably onto each other.

In a second series $D(1,0)$ has been determined as a function of the amplification voltage with the beam power as parameter, Fig. 2 b). $D(1,0)$ decreases for increasing AV until an asymptotic level is reached. The results for different BP within the asymptotic range collapse onto each other, indicating that small changes of the BP and the AV have negligible influence on the result. $D(1,0)$ is no more PDA operation parameter sensitive.

The measured size distributions are presented in Fig. 3 a) and b) for a beam power of 7 and 20 mW ($AV = 750\ V$), and a PM voltage of 750 and 1000 V ($BP = 6\ mW$). The corresponding measurements are marked in Fig. 2 with a small arrow.

All distributions show a log-normal profile with the geometric standard deviation (GSD,

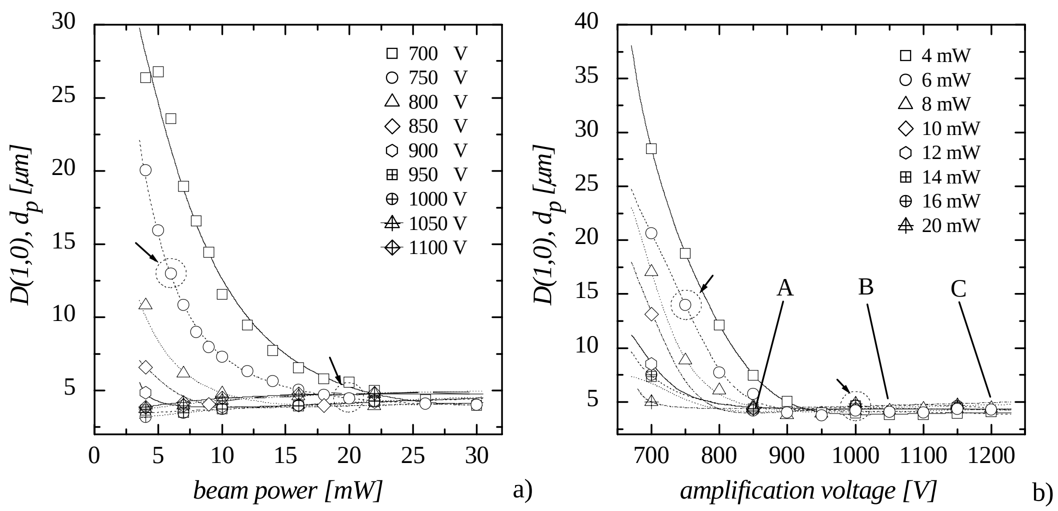

Figure 2: *Dependence of mean droplet size on a) beam power with AV as parameter and b) photomultiplier amplification voltage with BP as parameter.*

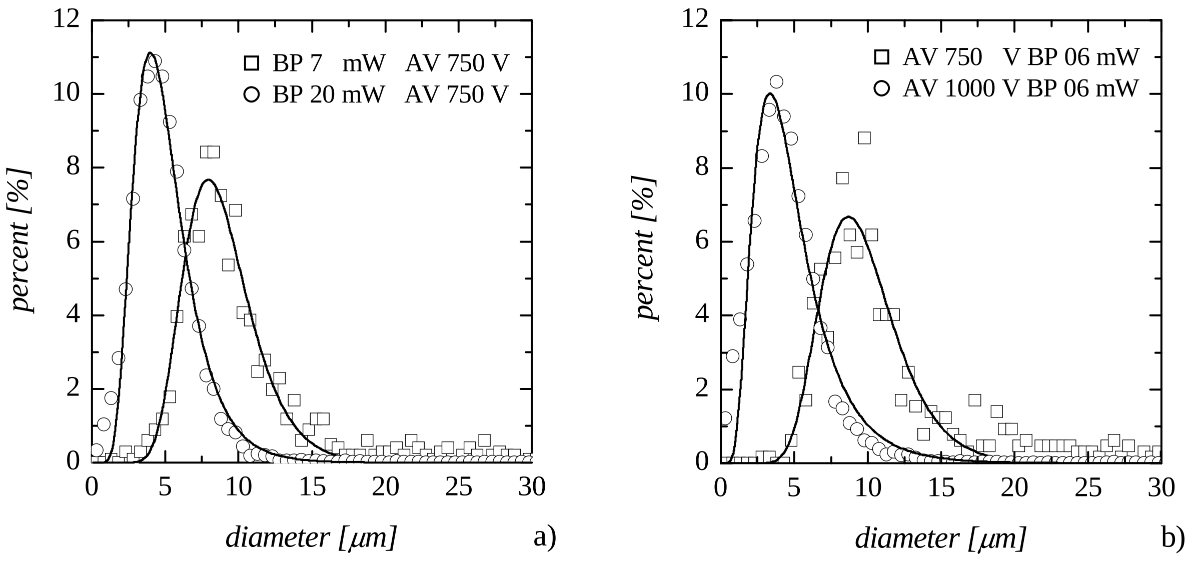

Figure 3: *Dependence of droplet size distribution on a) beam power and b) photomultiplier amplification voltage.*

$\sigma_g = (d_{84\%}/d_{16\%})^{1/2}$) characterizing the spread and with the count median diameter (CMD) characterizing the diameter for which $50\ \%$ of the total number of particles are smaller. The results can be found in Tab. 2.

The most remarkable result is the decrease by a factor of about two in the CMD when either the beam power is increased from 7 to $20\ mW$, or the PM amplification voltage is raised from 750 to $1000\ V$. This indicates the importance of optimizing also the operation parameters.

The reproducibility of the measurements and the influence of the signal gain with the beam power as parameter can be found in Fig. 4. At different days, the same results are obtained from additional measurements (RUN1 to RUN4, $BP = 10\ mW$) as shown in Fig. 4 a). Except for low signal gains, the measurements collapse nearly indistinguishably onto each other.

Also the signal gain (SG) has a pronounced effect on the results, Fig. 4 b). Increasing the signal gain decreases the mean droplet diameter. For $BP = 12\ mW$, the droplet diameter decreases from ≈ 30 to $4\ \mu m$ when the signal gain is increased from 5 to $24\ dB$. In contrast to the results before, no constant $D(1,0)$ region could be achieved for low beam powers. For higher beam powers ($BP \geq 16\ mW$) one obtains an asymptotic range. For example with $BP = 16\ mW$ the asymptotic range covers $18\ dB \leq SG \leq 28\ dB$ whereas for $BP = 24\ mW$ the asymptotic range covers $12\ dB \leq SG \leq 28\ dB$.

Finally, several measurements have been performed to determine the influence of the signal-to-noise ratio (SNR), but the effect of the SNR was negligible.

	σ_g $[\mu m]$	CMD $[\mu m]$
beam power: $7\ mW$ ($AV = 750\ V$)	1.32	8.55
beam power: $20\ mW$ ($AV = 750\ V$)	1.50	4.70
PM voltage: $750\ V$ ($BP = 6\ mW$)	1.32	9.39
PM voltage: $1000\ V$ ($BP = 6\ mW$)	1.67	4.36

Table 2: *Parameters of the size distributions in Fig. 3.*

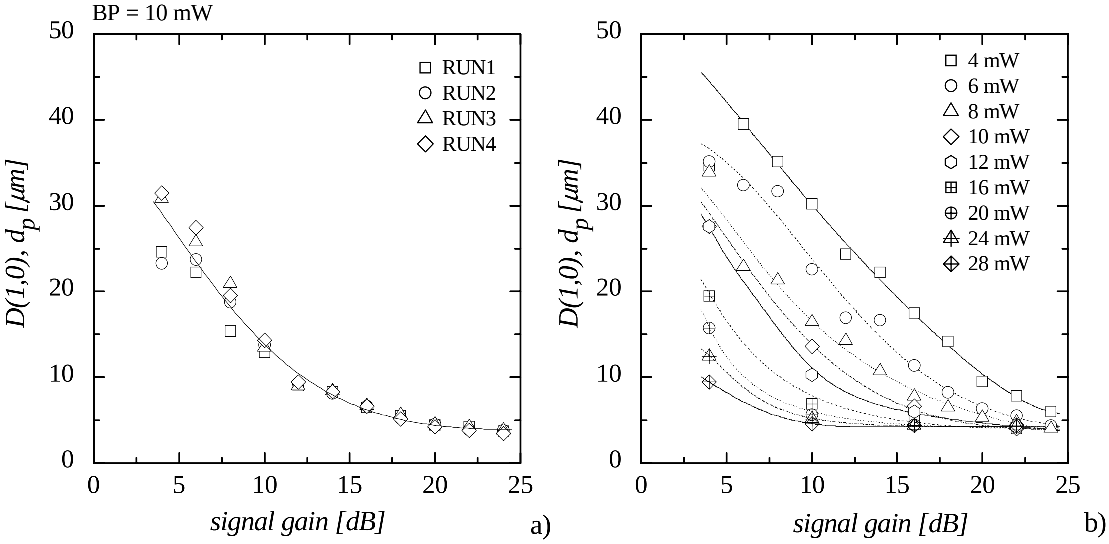

Figure 4: *Dependence of mean droplet size on signal gain a) reproducibility of the results and b) with beam power as parameter.*

4 Discussion

All the observations presented are based on the fact that smaller droplets scatter less light than larger droplets at the same scattering angle for a given set of adjusted parameters. For low beam powers, for example, the detected scattering-light-signal from small particles vanishes partly in the noise floor of the system and becomes therefore invisible for further data treatment. Larger particles, on the other hand, result in valid Doppler burst. The resulting size distribution is biased towards larger sizes, since the smaller particles – although physically present – are not measured. Increasing the beam power also increases the light intensity scattered and therefore the amplitude of the doppler burst. This results in valid signals also for the smaller particles until the smallest physical existing particles are resolved. Increasing the beam power further does not alter the measured distribution anymore; the asymptotic state is reached. The same explanation applies for the amplification voltage and the signal gain. The parameters used for final measurements should be chosen from these ranges. For the present experiments these ranges are: beam power $> 20\ mW$, PM amplification voltage $> 850\ V$, signal gain $> 16\ dB$ and arbitrary SNR. Using these recommendations results in $D(1,0) = 4.4\ \mu m$ for the droplets produced by the nebulizer. Assuming a normal distribution for the scatter of the estimates for $D(1,0)$, the probability of being within $\pm 1.96 \cdot \sigma_{\overline{d}}$ of the true value would be $95\ \%$. With a variance of $\sigma_d^2 \approx 8\ \mu m^2$ and a number of samples of $N \approx 10000$ (note that only $1/4$ th of the samples are statistically independent) this results in $\sigma_{\overline{d}}^2 = 0.032\ \mu m^2$ or $\sigma_{\overline{d}} = 0.056\ \mu m$. Using the recommended operation parameters this results finally in $D(1,0) = 4.4 \pm 0.11\ \mu m$ for the measurement uncertainty.

It should be however noted that: comparing these recommendations with the values reported in (Albrecht et al. 2003, pp. 651 ff.) and (Mulpuru et al. 1996) leads to the conclusion that these parameters are entirely case sensitive, i.e. they highly depend on the measurement problem and have to be determined individually for a given experimental setup.

5 Summary

The results can be summarized as follows:

- The adjustable parameters i.e. 1. *the laser beam power*, 2. *the amplification level of the PM* and 3. the *signal gain* can significantly influence the results. In the present experiments, the resulting mean diameter was altered for example by a factor of two.
- It was found that for higher laser beam power, higher PM amplification level and higher signal gain, the apparent mean droplet size decreases and finally reaches a stable value. These values in the asymptotic range should be used for further measurements. These values are case sensitive and have to be determined in advance for every measurement configuration.
- For the *signal-to-noise ratio* only a negligible influence could be determined.
- Although attributed as "calibration-free", the PDA requires considerable efforts not only to choose an appropriate optical configuration and properly align the system but also to ensure that the result is not biased by the choice of the adjustable parameters described above.

References

Albrecht, H.-E. and Borys, M. and Damaschke, N. and Tropea, C. (2003). Laser doppler and phase doppler measurement techniques. Wiley-Interscience.

Araneo, L., Damaschke, N., Tropea, C.(2000), *Measurement and Prediction of the Gaussian Beam Effect in the Phase Doppler Technique*, In Proc. 10th Int. Symp on Appl. of Laser Techn. to Fluid Mechanics, Lisbon, Portugal, Paper 20.6.

Bendat, J.S. and Piersol A.G.(1986), *Random Data: Analysis and Measurement Procedures,* A Wiley-Interscience Publication, New York, Chichester, Toronto, Singapore.

Chao, J., Hwang, K. and Lee, T. (1990), Sensitivity of user parameter settings of phase Doppler particle analyzer in combusting spray, AIAA 21st Fluid Dynamics, Plasma Dynamics and Laser Conference (Seattle, WA), paper AIAA-90-1553.

DANTEC, (2003). *BSA Flow Software V. 2.1*, Installation and Users´s guide. Publication no.: 9040U5718, Dantec Dynamics A/S, P.O. Box 121, Tonsbacken18, DK-2740 Skovlunde, Denmark.

McDonell, V. G. and Samuelson, S. (1990), Sensitivity Assessment of a Phase-Doppler Interferometer to User-Controlled Settings, in: Liquid Particle Size Measurement Techniques: 2nd Volume, ASTM STP 1083, E. Dan Hirleman, W. D. Bachalo and Philip G. Felton, Eds., American Society for Testing and Materials, Philadelphia, pp. 170-189.

Menn, P. (2005), Charakterisierung von Sprays, experimentelle PDA-Meßergebnisse und ihre mathematische Nachbearbeitung, Shaker Verlag.

Mulpuru, S. R., Balachandar, R., and Ungurian, M. H. (1996). Phase Doppler anemometer: commissioning tests for measurement of water aerosol sizes and velocities in flushing jets. Nuclear Engineering and Design 166, 443-452.

Ofner, B. (2001), Phase Doppler Anemometry, in: Optical Measurements, Techniques and Applications, F. Mayinger and O. Feldmann, Eds., Springer Verlag, pp. 135-148.

TSI, (2003). Model 3075/376 Constant Output Atomizer, Instruction Manual, P/N 1933076, Revision I

Wriedt, T. (1993). Einfluß der Parameter eines Phasen-Doppler-Anemometrie-Prozessors auf die gemessenen Größenverteilungen. Technisches Messen 60, vol. 7/8, 278-282.