Dynamic Image Analysis extended to Fine and Coarse Particles

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ABSTRACT

During the last decade Dynamic Image Analysis has become a widely-used method for particle size and shape analysis. Since its introduction this technique has been extended into various fields of application. A unique combination of a pulsed light source, telecentric imaging and a high-speed mega-pixel camera allows for the simultaneous characterisation of particle size and shape at unrivalled particle numbers. Sophisticated evaluation software in combination with a modern database storing the image data creates results of high statistical relevance.

Particles are characterised within cycle times down to below a few seconds per measurement using a family of instruments combining representative sampling as well as dry or wet dispersion. Wet dispersing systems, telecentric illumination and imaging create high contrast images of even highly transparent gel particles in water.

Recently a lens module has been developed to lower the minimum particle size for wet dispersion down to 1 µm. Although there are physical restrictions concerning the depth-of-field, high-quality results are obtained by precise particle positioning. Even fine materials like silicon carbide F1200 can now be analysed. Another lens module has been developed to cover the coarse regime requiring even optical demagnification. Mainly dry dispersers are used then to characterise fibres or other significantly elongated particles as well as materials with wide particle size distributions like soil without any loss of statistical relevance.

Keywords: Dynamic Image Analysis, Fine and Coarse Particles, Statistics, Resolution

1 INTRODUCTION

Dynamic image analysis with light pulses shorter than 1 ns, telecentric optics and high-speed camera in combination with powerful dry dispersion has been introduced at PARTEC 2004 (Witt 2004). Acquisition rates up to 450 frames per second have made the characterisation of particle size and shape possible at unrivalled particle numbers. Sophisticated software algorithms and a high-performance database storing image data, measuring conditions and evaluated results allow for the creation results of formerly unimaginable statistical relevance.

Within the following decade this technique has been extended into various fields of application. The modular QICPIC design provides the opportunity to use completely different dry and wet dispersing techniques like RODOS, GRADIS or LIXELL. Later on even GMP solutions for the process environment have been developed as well.

The technology has been improved continuously. Nowadays particle numbers of more than 100 million particles per measurement can be acquired, stored and evaluated. The maximum acquisition time for a single measurement has been extended to more than 1.5 hours at maximum frame rate. Since all particle images are stored, this allows e.g. for searching the proverbial "pin in a haystack". As the evaluation software fully supports multi-core processors, the calculation speed is increased to more than hundred thousand particles per second when the equivalent area diameter is determined.

A wide portfolio of measuring ranges provides the optimum magnification for each application. The family of available lenses has been extended to image very fine or coarse particles.

2 DISPERSION

Particle dispersion is one of the crucial requirements of particle analysis. The modular design of the dynamic image analysis sensor, QICPIC, is the basis for the application of dry as well as wet dispersing systems. Flexible set-ups allow for an optimum adaptation to the requirements of the application and sample respectively.

2.1 Dry Dispersion

In combination with the dry dispersing system RODOS the QICPIC analyses particle size and shape of even sticky materials in a dispersed aerosol beam. Additionally, for coarse or fragile samples the gravity dispersing system GRADIS is a remarkable supplement.

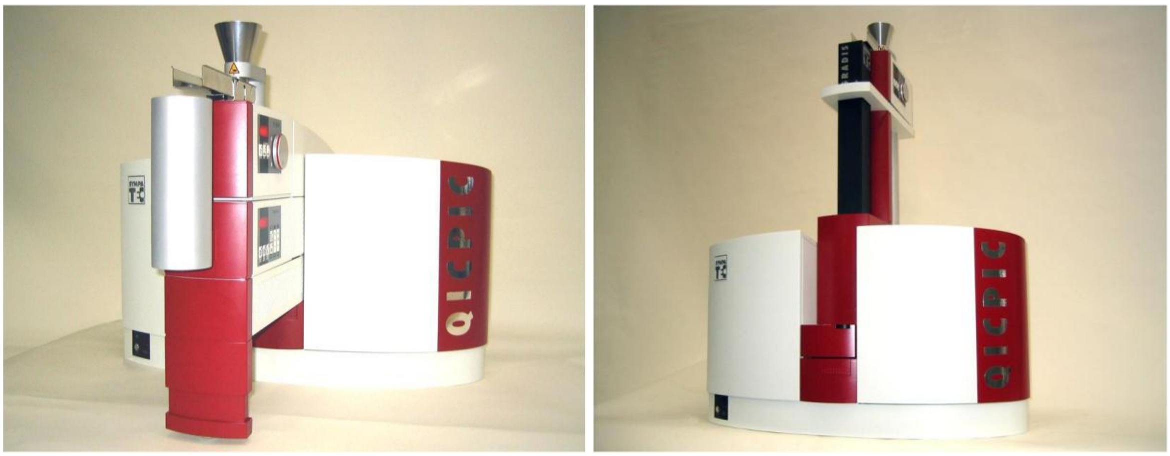


Fig. 1: QICPIC+RODOS and QICPIC+GRADIS

2.2 Wet Dispersion

For image analysis applications, wet dispersion in addition to dry dispersion has been introduced in 2006 (Witt 2008). The OASIS combines the principles of dry (RODOS) and wet dispersion (SUCELL) in one automated system (fig. 3), whereas LIXELL offers most flexible setups for all kinds of applications (fig. 4).

Fig. 2: QICPIC+OASIS and LIXELL

Both systems offer an automatic alignment of the flow cell in order to image the moving particles within the depth of field and hence to achieve particle images of maximum sharpness.

3 DEPTH OF FIELD

In optics the depth of field (DOF) is the interval of positions with respect to the lens where all objects appear acceptably sharp in the image. From the theoretical point of view a lens can precisely focus at only one distance. However, the loss of sharpness is gradual on both sides of the focused distance. In other words, the DOF is the interval of positions where blur remains invisible in the image.

Invisible in terms of digital image analysis means a blur of less than one pixel. The depth of image field Δz_{image} with acceptable image blur depends on the maximum aperture angle θ' in image space (fig. 5) and the pixel size a. The aperture angle θ required in object space is given by the angle of the first zero of the Airy diffraction pattern of the smallest particles with an image size of one pixel. The relation between θ and θ' (or Δz_{object} and Δz_{image}) depends on the transversal magnification *M* (Hecht 2001):

$$\Delta z_{object} = \Delta z_{image} / M^2 \quad (1)$$

Δz_{image} is given by the setup and hence fixed. The remaining relation shows a reciprocal dependence of the DOF (Δz_{object}) on the square of the magnification.

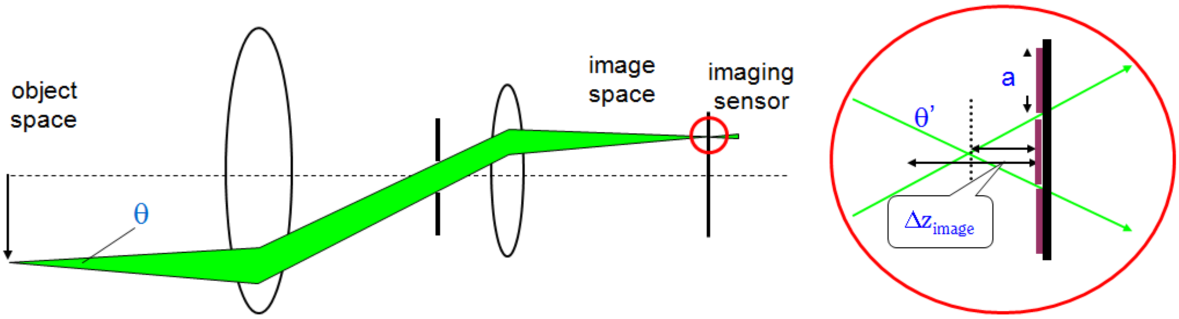


Fig. 3: Relation of magnification, depth of field and maximum blur

From the microscope it is well-known that keeping the particles in the DOF gets more and more important with increasing magnification due to this strong dependence.

4 EXTENSION OF MEASURING RANGES: M3 AND M9

Two new members have been added to the QICPIC measuring range family: M3 and M9. Whereas the first one is used for comparatively fine particles, the latter covers the coarse end up to centimetre particles like fibres, food, beans or even smaller pebbles.

Fig. 4: Measuring ranges M3 and M9 (left, front) and USAF resolution target imaged by M3 (right)

The optical resolution of the measuring ranges is usually checked via a USAF standard target. As shown in fig. 4, line pairs (one black + one transparent line) of approximately 2 µm width and hence particles of 1 µm are imaged with good resolution.

4.1 Measuring Range M3 for Particles Sizes Down to 1 µm

As the short theoretical consideration in the preceding section 3 shows, increasing the number of pixels as well as the usage of smaller pixels does not overcome physical laws. Instead the blur would cover more than one pixel then, i.e. high-resolution blurs instead of high-resolution particle edges are the consequences.

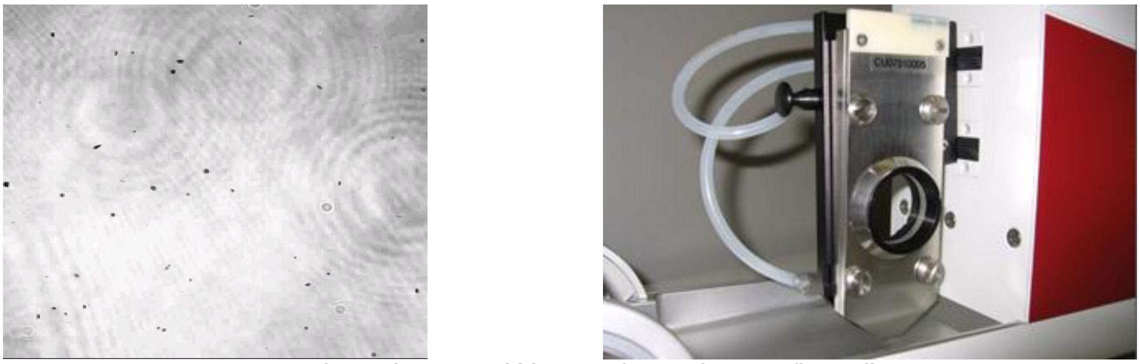


Fig. 5: SiC-F1200 within DOF of M3 and LIXELL flow cell

Fig. 5 shows a snapshot of F1200 silicon carbide reference particles ($x_{50} \approx 5$ µm) used to characterise particle size and shape simultaneously as well as the LIXELL and its optimised flow cell allowing for proper particle focussing of even fine material (List 2010).

Although, in image analysis fine particles naturally consist of only a few pixels, it is possible to obtain sharp particle edges and even meaningful shape information, e.g. the aspect ratio.

Obviously the combination of proper particle position within the DOF via suitable flow cells, precise positioning and M3 lens successfully meets the challenges of proper focussing and creates high-contrast images of even fine particles. Some results of those measurements providing size and shape information of F1200 are presented in fig. 6. The shape diagram on the right-hand side confirms the expected irregular shape of a typical abrasive.

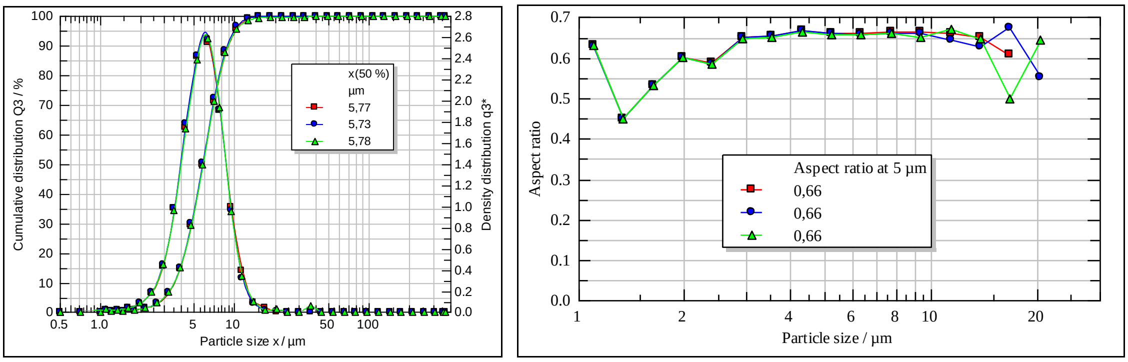
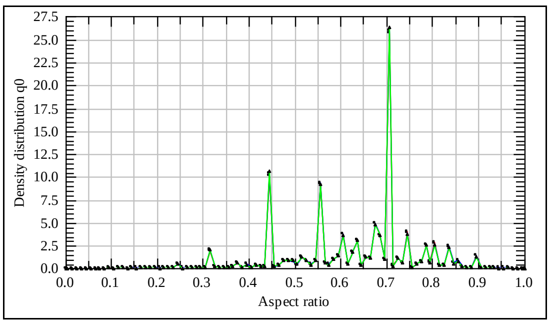
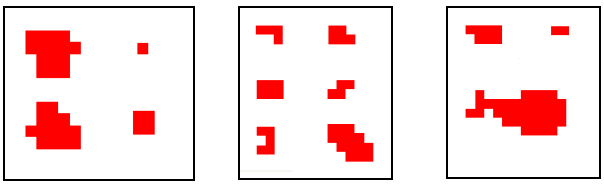


Fig. 6: Particle size and shape distributions of SiC-F1200 within DOF of M3

In contrast to coarse particles, fine particles consist of a comparably low number of pixels. Since the number of pixel arrangements is limited for low pixel numbers the correlating aspect ratios are emphasized peaks in the shape distribution (fig. 7).





$1/\sqrt{2} \approx 0.707$ $\quad 2/\sqrt{3^2+2^2} \approx 0.555$ $\quad 1/\sqrt{1^2+2^2} \approx 0.447$

Fig. 7: Particle shape distributions of SiC-F1200 (left) showing typical low pixel number artefacts (right)

4.2 Measuring Range M9 for Coarse Particles

In contrast to M3 the measuring range M9 is designed for coarse particle applications, e.g. soil or fibres as shown in fig. 8. Whereas positioning within the depth-of-field is the crucial challenge for fine particles, these applications require large samples in order to obtain statistically meaningful results.

Fig. 8: Sample of wood fibres and a typical image created by QICPIC with measuring range M9

A typical result for wood fibres using different evaluation modes as fibre length and diameter is shown in fig. 9 (left).

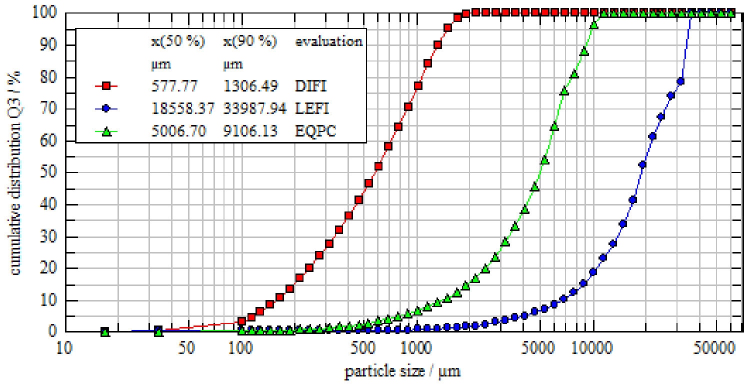


Fig. 9: Results for wood fibres

Very often these samples are collected for further investigations. Hence, the QICPIC now offers an optional drawer for coarse particle collection.

5 CONCLUSIONS

The additional measuring ranges M3 and M9 allow for measuring even demanding samples like fine abrasives, wooden fibres and soil respectively. The quality of the results is high as long as for finer particles the physical restrictions regarding the depth-of-field are taken into account.

6 REFERENCES

HECHT, E., (2001), Optik, 3. vollständig überarbeitete Auflage, Oldenbourg 2001, München.

LIST, J., KÖHLER, U., WITT, W., (2010), Innovations in Dynamic Image Analysis: Down to 1 µm, PARTEC 2010, Nuremberg, Germany

WITT, W., KÖHLER, U., LIST, J., (2004), Direct Imaging of very fast Particles Opens the Application of Powerful (Dry) Dispersion for Size and Shape Characterisation, PARTEC 2004, Nuremberg, Germany

WITT, W., LIST, J., KÖHLER, U., (2008), Possibilities of Dynamic Image Analysis in the Laboratory and Process Environment, Particulate Systems Analysis, Stratford-upon-Avon, UK